The Marine Life Information Network® for Britain and Ireland (*MarLIN*)

Description, temporal variation, sensitivity and monitoring of important marine biotopes in Wales.

Volume 2. Littoral biotopes

Report to Cyngor Cefn Gwlad Cymru / Countryside Council for Wales

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Contents

Fucus distichus and *Fucus spiralis* f. *nana* on extremely exposed upper shore rock (ELR.Fdis)

Key information authored by: Jacqueline Hill

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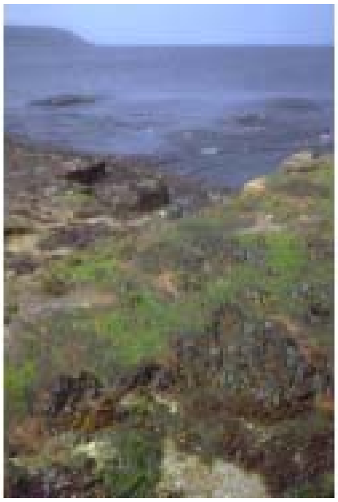
This information is not refereed.



View down shore showing upper shore bedrock with *Fucus disticus* and green algae.
Image width ca XX cm.
Image: Sue Scott / Joint Nature Conservation Committee

Recorded and expected ELR.Fdis distribution for Britain and Ireland

Description of biotope

Extremely exposed gently or steeply sloping upper shore bedrock may support a mixture of *Fucus distichus* and *Fucus spiralis* f. *nana*, the latter often at the top of the zone. This biotope is rare and restricted to the far north and west coasts. This mixed band is generally found between the *Verrucaria maura* and *Porphyra* zone (LR.Ver.Por) above, and the *Mytilus edulis* and barnacle zone below (ELR.MytB). Although it may occur above a red algal zone (MLR.Mas), as recorded on Barra or above a *Porphyra* and sparse barnacle zone (LR.Ver.Por) as on St Kilda. (Information taken from the Marine Biotope Classification for Britain and Ireland, Version 97.06: Connor *et al.*, 1997a, b).

Welsh variation

Although the Welsh examples of many of the biotopes in this report follow the British and Irish classification description closely, some regional variation may exist. Reference should be made to Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

No text entered

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Habitat complex	ELR	Exposed littoral rock (mussel/barnacle shores)
Biotope complex	ELR.FR	Robust fucoids or red seaweeds
Biotope	ELR.Fdis	*Fucus distichus* and *Fucus spiralis* f. *nana* on extremely exposed upper shore rock

Other biotope classification schemes

European Union Nature Information System (EUNIS) code: A1.1/B-ELR.FR Robust fucoids or red seaweeds on very exposed rock.

Ecology

Ecological and functional relationships

- In general exposed conditions favour the growth of barnacles, limpets and mussels rather than fucoid algae. However, the ELR.Fdis biotope includes seaweeds that are able to tolerate the extreme conditions of wave exposed rocky shores, primarily the physical stresses caused by wave action. The strong holdfast and short tufted structure of *Fucus distichus* and *Fucus spiralis* f. *nana* allow these fucoids to survive on extremely exposed shores in the north and north-west. Other seaweeds able to tolerate the wave-wash are the red encrusting algae *Hildenbrandia rubra* and seasonally occurring *Porphyra* spp.
- In Britain and Ireland, *Fucus distichus* has only been recorded attached to bedrock in the mid to upper eulittoral zone on exposed rocky shores in northern Scotland and Ireland. It is thought to be prevented from growing further south due to its poor tolerance of desiccation and inability to compete with plants growing further down the shore. However, on the east coast of North America, *Fucus distichus* is only found in rock pools and is incapable of growing on emergent rock surfaces in the mid to upper eulittoral. The isolated and dispersed occurrence of *Fucus distichus* together with a greater abundance on more northerly shores of the North Atlantic suggest that it may be a relic form surviving only in habitats which are unsuitable for the main fucoids found at these latitudes (Lewis, 1964). A critical factor in the distribution of *Fucus distichus* is probably day length. Short day lengths stimulate the onset of receptacle formation (Bird & McLachlan, 1976).
- Grazing on rocky shores can exert significant controlling influences on the algal vegetation, particularly by patellid limpets and littorinid snails which are usually the most prominent grazers. There may also be effects caused by 'mesograzers' - amphipods such as *Hyale prevostii* and isopods, which are much smaller but can occur in high densities.
- The surf-swept conditions under which both *Fucus distichus* and *Fucus spiralis* f. *nana* occur are not always conducive to the formation of well-defined zones. Scattered plants or thick ankle-deep carpets can often lie somewhat randomly placed (Lewis, 1964).
- The presence of a fucoid canopy inhibits the settlement of barnacles by blocking larval recruitment mainly by 'sweeping' the rock of colonizers. However, the canopy offers protection against desiccation which promotes the clumping of adults and the recruitment of young in several species of mobile animals. The number of limpets increases with maturing fucoid clumps.

Seasonal and longer term change

Rocky shore communities are often highly variable in time, due to the combined influences of physical disturbance, competition, grazing, predation and variation in recruitment. However, the communities on wave exposed shores tend to be less variable than on moderately exposed shores and are therefore more stable. The wave exposed conditions in this biotope seems to favour the development of a relatively stable covering of wave tolerant fucoids plus a patchy covering of barnacles and limpets. However, seasonal changes are apparent on rocky shores with seasonal variation in growth and recruitment. For example, *Fucus distichus* plants lose fronds in the autumn after reproducing and are then removed from the rock by wave action during their third winter.

Habitat structure and complexity

The ELR.Fdis biotope provides a variety of habitats and refugia for other species. Macroalgae increases the structural complexity of the habitat providing a variety of resources that are not available on bare rock. Algal fronds provide space for attachment of encrusting or sessile epifauna and epiphytic algae and give shelter from wave action, desiccation and heat for invertebrates. Empty barnacle shells can shelter small littorinids such as *Littorina neglecta* and *Littorina saxatilis*. If present mussels can increase habitat complexity and species diversity because the gaps between interconnected mussels form numerous interstices for a variety of organisms. The barnacles may be covered by *Porphyra* sp. on the upper shore although few other species can attach to them.

Dominant trophic groups	Photoautotrophs

Productivity

Rocky shore communities are highly productive and are an important source of food and nutrients for members of neighbouring terrestrial and marine ecosystems (Hill *et al*., 1998). Macroalgae exude considerable amounts of dissolved organic carbon which are taken up readily by bacteria and may even be taken up directly by some larger invertebrates. Only about 10% of the primary production is directly cropped by herbivores (Raffaelli & Hawkins, 1999). Dissolved organic carbon, algal fragments and microbial film organisms are continually removed by the sea. This may enter the food chain of local, subtidal ecosystems, or be exported further offshore. Rocky shores make a contribution to the food of many marine species through the production of planktonic larvae and propagules which contribute to pelagic food chains.

Major sources of organic carbon	Photosynthesis (macroalgae and/or halophytic plants)

Recruitment processes

Many rocky shore species, plant and animal, possess a planktonic stage: gamete, spore or larvae which float in the plankton before settling and metamorphosing into adult form. This strategy allows species to rapidly colonize new areas that become available such as in the gaps often created by storms. For these organisms it has long been evident that recruitment from the pelagic phase is important in governing the density of populations on the shore (Little & Kitching, 1996). Both the demographic structure of populations and the composition of assemblages may be profoundly affected by variation in recruitment rates.

- Receptacles of *Fucus distichus* are initiated in December, they become ripe in April and gametes are released from April to August. The species produces gametes of both sexes within each conceptacle. When released, ova can survive and disperse for several days. Antherozoids can only live for several hours. Self-fertilization is thought to be high in the species and once a zygote is formed it can only be dispersed over limited distances (Rice *et al*., 1985).
- *Fucus spiralis* is also hermaphroditic. Receptacles are initiated during late January to February, gametes discharged during July and August, and the receptacles shed by November, although exact timing of reproduction depends on location and the form of the plant.
- Among sessile organisms, patterns fixed at settlement, though potentially altered by post settlement mortality, obviously cannot be influenced by dispersal of juveniles or adults. Some of the species that may be found living in the biotope, such as amphipods, do not have pelagic larvae, but instead have direct development of larvae producing their offspring as 'miniature adults'.

Time for community to reach maturity

The time for the biotope to reach maturity should be relatively rapid because recruitment of key species is good. For example, *Fucus distichus* and *Fucus spiralis* have been observed to readily recruit to cleared areas (Ang, 1991) and have fast growth rates, so recovery rates are expected to be high. *Fucus distichus* has a lifespan of about 3 years. Colonization by other species found in the biotope, such as *Littorina neglecta* and *Melarhaphe neritoides*, is also likely to be quite rapid. Therefore, it seems likely that the biotope should reach maturity within a few years.

Additional information

No text entered

Habitat preference and distribution

Distribution in Britain and Ireland

This biotope is rare and is only found on the coasts of the far north and west of Scotland including Shetland, Orkney, the Outer Hebrides and St. Kilda.

Habitat preferences

Temperature range preferences	No information found
Water clarity preferences	High clarity / Low turbidity
Limiting nutrients	Nitrogen (nitrates) Phosphorus (phosphates)
Other preferences	No information found

Additional information

No text entered

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	Species name	Common Name
Key structural	*Fucus distichus*	A brown seaweed
Key structural	*Fucus spiralis*	Spiral wrack

Explanation

The biotope is a fucoid dominated community characterized by *Fucus distichus* and *Fucus spiralis* f. *nana*. Although several other species are present in the biotope it is the sensitivity of the fucoids that are important in determining the sensitivity of the biotope.

Species found especially in biotope

None

Additional information

No text entered

Biotope sensitivity

Physical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	High	Moderate	Major Decline	Moderate
Smothering	Low	Very high	Very Low	No Change	Moderate
Increase in suspended sediment	Low	Very high	Very Low	No Change	Moderate
Decrease in suspended sediment	Low	Very high	Very Low	No Change	Moderate
Desiccation	Intermediate	High	Low	Major Decline	Moderate
Increase in emergence regime	Low	Very high	Very Low	No Change	Moderate
Decrease in emergence regime	Low	Very high	Very Low	No Change	Moderate
Increase in water flow rate	Low	Very high	Very Low	No Change	Moderate

Decrease in water flow rate	Low	Very high	Very Low	No Change	Low
Increase in temperature	Low	High	Low	No Change	Low
Decrease in temperature	Low	Very high	Very Low	No Change	High
Increase in turbidity	Low	Very high	Very Low	No Change	Moderate
Decrease in turbidity	Low	Very high	Very Low	No Change	Moderate
Increase in wave exposure	High	High	Moderate	Major Decline	Moderate
Decrease in wave exposure	High	High	Moderate	No Change	Moderate
Noise	Tolerant	Not Relevant	Tolerant	No Change	High
Visual Presence	Tolerant	Not Relevant	Tolerant	No Change	High
Abrasion & physical disturbance	High	High	Moderate	Minor Decline	Moderate
Displacement	High	High	Moderate	Decline	Moderate
Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	High	High	Moderate	Decline	Low
Heavy metal contamination	Low	Very high	Very Low	No Change	Moderate
Hydrocarbon contamination	Low	High	Low	Minor Decline	Low
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	NR	Not Relevant
Changes in nutrient levels	Low	Very high	Very Low	No Change	Moderate
Increase in salinity	High	High	Moderate	Major Decline	Low
Decrease in salinity	Low	High	Low	Minor Decline	Moderate
Changes in oxygenation	Low	Immediate	Not sensitive	No Change	Moderate
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Low	High	Low	Minor Decline	Low
Introduction of non-native species	Not Relevant	Not Relevant	Not relevant	No Change	Moderate
Extraction of key or important characterizing species	Intermediate	High	Low	Decline	Moderate
Extraction of important species	Low	High	Low	No Change	Moderate

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	All key and important species in the biotope are highly intolerant of substratum loss. The algae and barnacles are permanently attached to the substratum so populations would be lost. Epifaunal grazers like *Patella vulgata* and littorinid snails are epifaunal and most will be removed along with substratum loss. Those that do remain have an increased risk of desiccation and predation and so populations are unlikely to survive. Mobile species like the amphipod *Hyale prevostii* will be indirectly affected by the loss of fucoid plants as protection from desiccation is removed, as will sessile epiphytic flora and fauna. See additional information for recovery.
Smothering (see benchmark)	Smothering by 5 cm of sediment, although unlikely to occur in this biotope, is likely to completely cover the species in the biotope, preventing photosynthesis and respiration. The individual key species have high intolerance to smothering. Algae may rot under smothering material and sessile and slow moving fauna may suffocate. Barnacle feeding is likely to be affected and limpet locomotion and grazing will probably be impaired. Sediment will have an especially adverse effect on young germling algae and on the settlement of larvae and spat. Suspension feeders such as mussels may be killed by smothering. However, since the biotope occurs in extremely exposed locations wave action will mobilize sediment alleviating the effect of smothering and so intolerance has been assessed as low. As sediment is removed photosynthesis, locomotion and feeding will return to normal so recovery will be rapid.
Increase in suspended sediment (see benchmark)	Increased suspended sediment may reduce growth rate in barnacles due to the energetic costs of cleaning sediment particles from feeding apparatus although if the organic content is high suspension feeders will benefit. *Patella vulgata* and *Mytilus edulis* also have low intolerance to an increase in suspended sediment because they are found in turbid estuaries where suspended sediment levels are high. Intertidal algae (which continue to photosynthesize when the tide is out) are not sensitive to levels of suspended sediment. Therefore, at the level of the benchmark, the biotope is considered to have low intolerance. On return to normal conditions feeding rates will return to pre-impact levels almost immediately and growth within a short time. Recovery is therefore reported to be very high.
Decrease in suspended sediment (see benchmark)	A decrease in suspended sediment, especially organic particulates, could potentially reduce the food available to suspension feeders such as the barnacles and *Mytilus edulis* and hence growth rates. For a period of a month however, the effect is not likely to be significant. None of the other species in the biotope require a supply of suspended sediment particles for feeding or for activities such as tube building. Therefore, an intolerance of low has been recorded.
Desiccation (see benchmark)	The fucoid species *Fucus distichus* and the more widespread form of *Fucus spiralis* both have high intolerance to desiccation stress. *Fucus distichus* is thought to be prevented from growing further south due to its poor tolerance of desiccation and inability to compete with plants growing further down the shore. The southern distribution of the species is also thought to be limited by day length as shorter day lengths are thought to stimulate the onset of receptacle formation (Bird & McLachlan, 1976). *Fucus spiralis* can tolerate desiccation until the water content has been reduced to 10-20 % (Lüning, 1990). However if water is lost beyond this critical level irreversible damage occurs. As *Fucus spiralis* lives close to the upper limit of its physiological tolerance the species probably cannot tolerate increased desiccation. However, care is needed in extrapolating information on the physiological tolerances of the widespread form of *Fucus spiralis* to *Fucus spiralis* f. *nana*. Increased desiccation equivalent to a change in position of one vertical biological zone on the shore, e.g., from the littoral fringe to the upper

	littoral fringe or supralittoral would cause the upper limit of both fucoid species distribution, and hence the biotope to become depressed. At the top of its range the biotope will probably become replaced by another biotope such as a lichen dominated one. However, the lower limit of the biotope may also move down the shore. Intolerance is therefore, reported to be intermediate. For recovery see additional information.
Increase in emergence regime (see benchmark)	A change in the level of emergence on the shore will affect the upper or lower distribution limit of all the key species. An increase in the period of emersion would subject the species in the biotope to greater desiccation and nutrient stress, leading to reduced growth and a depression in the upper distribution limit. Changes in the numbers of important species are likely to have profound effects on community structure and may result in loss of the biotope at the extremes of its range. For example, at the upper limit the biotope may lose fucoid cover and so change to one dominated by barnacles and limpets or lichens. However, the more widespread form of *Fucus spiralis* can tolerate an emersion period of 1-2 days so an increase in time spent in air of 1 hour in per day may limit growth and fecundity rather than survival. Although care is needed in extrapolating information on the physiological tolerances of the widespread form of *Fucus spiralis* to *Fucus spiralis* f. *nana* it seems likely that only those species at the extremes of their physiological limits would die. Limpets are able to move down the shore although the loss of a home scar can increase the species vulnerability to predation. Thus, the biotope is likely to be lost only at the very upper limit of its range and so a rank of low is reported. A change in the level of emergence on the shore may also affect the lower distribution limit of all the key species as competition increases lower down the shore. Growth, condition and fecundity are likely to return within several months if pre-impact emersion levels return.
Decrease in emergence regime (see benchmark)	A decrease in the period of emersion will immerse animals at the bottom of the biotope in seawater for longer which may increase growth rates as the supply of oxygenated water and nutrients increase. However, competition from other species may increase and the biotope could change to another more species rich biotope. The overall effect could simply be a moving of the biotope up the shore so intolerance is assessed as low.
Increase in water flow rate (see benchmark)	The water flow rates in which the biotope occurs are not known. However, *Fucus distichus* and *Fucus spiralis* f. *nana* appear to attach very strongly to the substratum because they live in areas exposed to very high wave action. Barnacles can tolerate very high flow rates as they are unlikely to be washed off the substratum although feeding in very strong water flows may be impaired resulting in reduced growth and fecundity. The mollusc *Patella vulgata* is also able to attach very strongly to rock and populations can adapt to changing water currents through the development of different shell shape and profile. Thus, strong water flow may impair feeding of some fauna but it seems likely that the biotope will survive and so an intolerance of low is reported. Recovery will be immediate on return to normal conditions.
Decrease in water flow rate (see benchmark)	A decrease in water flow rates may affect the supply of particulate matter, nutrients and oxygenated water to the biotope. However, since wave exposure in this biotope is high wave action is also likely to bring fresh water supplies and so intolerance to a decrease in water flow rate is likely to be low.
Increase in temperature (see benchmark)	Schonbeck & Norton (1979) demonstrated that fucoids can increase tolerance in response to gradual change in a process known as 'drought hardening'. However, fucoids are intolerant of sudden changes in temperature and relative humidity with field observations of bleaching and death of plants during periods of hot weather (Hawkins & Hartnoll, 1985). Also, *Fucus distichus* reaches the southern limit of its distribution in the British Isles, so may be very intolerant of increases in temperature. However, day length is thought to be responsible for the southern

	limit of the species, which requires short day lengths to stimulate the onset of receptacle formation. However, a short-term increase of 5°C may result in the death of some algal plants, especially at the upper limit of the biotope. However, many plants are likely to survive this temperature increase for a period of only 3 days. The more widespread form of *Fucus spiralis* has low intolerance to temperature changes and so is not likely to be affected by an increase. Increased temperature is likely to favour chthamalid barnacles rather than *Semibalanus balanoides* (Southward *et al*. 1995). *Chthamalus* spp. are warm water species, with a northern limit of distribution in Britain so are likely to be tolerant of or favourably affected by long term increases in temperature. However, a change in the species of barnacle will not change the nature of the biotope. *Patella vulgata* is a hardy intertidal species that tolerates long periods of exposure to the air and consequently wide variations in temperature. Therefore, the impact on the biotope of temperature increases at the benchmark level is likely to be the loss of some fucoid plants and sub-lethal effects on growth and fecundity of other plants and species. Thus, the biotope is reported as having low intolerance to the benchmark increases in temperature. On return to normal temperatures original metabolic activity will rapidly resume and new plants will soon recruit so recoverability is set to high.
Decrease in temperature (see benchmark)	*Fucus distichus* reaches the southern limit of its distribution in the British Isles so decreases in temperature would probably have little effect and also because the species distribution appears to be determined primarily by day length rather than temperature. And may allow the species to colonize further south. The species has been found to tolerate freezing in small rock pools in Maine (Pearson & Davison, 1994). *Fucus spiralis* also has low intolerance to temperature changes. A decrease in temperature will favour *Semibalanus balanoides* rather than Chthamalid barnacles which will not change the nature of the biotope. *Patella vulgata* is largely unaffected by short periods of extreme cold. Ekaratne & Crisp (1984) found adult limpets continuing to grow over winter when temperatures fell to -6 °C, and stopped only by still more severe weather. Therefore, a benchmark decrease in temperature is likely to have only minimal sub-lethal effects on growth and fecundity only. The biotope is therefore of low intolerance to a decrease in temperature. On return to normal temperatures original metabolic activity will rapidly resume so recoverability is set to very high.
Increase in turbidity (see benchmark)	An increase in turbidity would reduce the light available for photosynthesis during immersion which could result in reduced biomass of the algae in the biotope. However, the biotope is found at the upper and mid-tide levels and so is subject to periods of emersion during which time macroalgae can continue to photosynthesize as long as plants have a sufficiently high water content. Therefore, photosynthesis and consequently growth will be unaffected during this period. The overall effects on the overall community dynamics of the biotope are likely to be negligible so intolerance is considered to be low. Upon return to previous turbidity levels the photosynthesis rate would return immediately to normal and growth rates would be restored within a few months. Recovery is therefore, set to very high. The impacts on suspension feeding organisms are addressed under 'suspended sediment' above.
Decrease in turbidity (see benchmark)	A decrease in turbidity would increase light availability for photosynthesis during immersion which may result in increased growth rates of the algal species. However, this is not likely to affect the overall community dynamics so the intolerance of the biotope is considered to be low. Upon return to previous turbidity levels the photosynthesis rate would return immediately to normal and growth rates within a few months.
Increase in wave exposure	The ELR.Fdis biotope occurs on some of the most exposed coasts in Britain and so is very tolerant of extreme wave exposure. The short tufted form of the fucoids *Fucus distichus* and *Fucus spiralis* f. *nana* enable them to remain attached to the

(see benchmark)	rock even when exposed to severe wave action. However, if wave exposure were to increase further it is likely that most algae and fauna would be lost leaving bare rock so intolerance is high. The biotope extends into some of the severest wave conditions existing around the British and Irish coasts so in reality wave exposure is not likely to increase. See additional information for recovery.
Decrease in wave exposure (see benchmark)	A shift to more sheltered conditions may allow other fucoid species to inhabit the shore which are faster growing and would out-compete *Fucus distichus*. The normal form of *Fucus spiralis* would predominate over the diminutive form. Barnacle and limpet abundance may increase and lead to the development of a different biotope such as MLR.BF barnacle and fucoid biotope commonly found on moderately exposed rocky shores. Thus intolerance is reported to be high as ELR.Fdis would be lost. See additional information for recovery.
Noise (see benchmark)	None of the selected key or important species in the biotope are recorded as sensitive to noise although limpets do respond to vibration. However, the biotope as a whole is not likely to be sensitive to changes in noise levels at the benchmark level.
Visual Presence (see benchmark)	Algae have no visual perception. Most macroinvertebrates have poor or short range perception and are unlikely to be affected by visual disturbance such as by boats or humans. Although limpets have eyes, visual perception is probably quite limited and as such the species is unlikely to be sensitive to the visual presence of humans on the shore, for example. The biotope is therefore, considered to be not sensitive to the factor.
Abrasion & physical disturbance (see benchmark)	The rocky intertidal is not at risk from boating or fishing activity except strandings but is susceptible to physical disturbance and abrasion from trampling. Even very light trampling on shores in the north east of England was sufficient to reduce the abundance of fucoids (Fletcher & Frid, 1996), which in turn reduced the microhabitat available for epiphytic species. Light trampling pressure, of 250 steps in a 20x20 cm plot, one day a month for a period of a year, has been shown to damage and remove barnacles (Brosnan & Crumrine, 1994). Trampling pressure can thus result in an increase in the area of bare rock on the shore (Hill *et al.*, 1998). Chronic trampling can affect community structure with shores becoming dominated by algal turf or crusts. Therefore, an intolerance of high has been recorded. However, if trampling stops recovery should be good. In Oregon for example, the algal-barnacle community recovered within a year after trampling stopped (Brosnan & Crumrine, 1994).
Displacement (see benchmark)	Intolerance to displacement is high because many of the key species in the biotope, including the fucoids and barnacles are permanently attached to the substratum and cannot re-establish themselves if detached. Epifaunal species such as limpets can re-attach to the substratum if displaced although removal from the home scar is likely to increase the likelihood of predation. Loss of the key species results in loss of the biotope. Recovery should be possible within a few years - see additional information.
Chemical Factors	
Synthetic compound contamination (see benchmark)	There is no information available on the effects of chemicals on the biotope as a whole. However, there is some information on the effects of several chemicals on the species that make up the biotope. Fucoids in general, for example, are reported to exhibit high intolerance to chlorate and pulp mill effluents containing chlorate (Kautsky, 1992). *Patella vulgata* is extremely intolerant of aromatic solvent based dispersants such as those used in the *Torrey Canyon* oil spill clean-up (Smith, 1968). However, on rocky coasts of Amlwch in areas close to acidified halogenated effluent from a bromine plant the shore consisted almost entirely of bare rock but there was a fucoid-barnacle mosaic nearby (Hoare & Hiscock, 1974). Therefore, effects depend on the chemical under consideration and there is

	obviously tolerance to some chemicals. However, intolerance is assessed as high because some chemicals could lead to the loss of the biotope. See additional information for recovery.
Heavy metal contamination (see benchmark)	Intolerance of the biotope is low because the key species are fairly robust in terms of heavy metal pollution. Adult fucoid plants appear to be fairly tolerant of heavy metal pollution although earlier life stages may be more sensitive (Holt *et al*., 1997). Barnacles are able to concentrate heavy metals in their tissues and *Patella vulgata* is found living in conditions of fairly high metal contamination in the Fal estuary in Cornwall (Bryan & Gibbs, 1983). Recovery from sub-lethal effects will be very high as metabolism and growth return to normal.
Hydrocarbon contamination (see benchmark)	The loss of key herbivores, such as limpets and littorinids, and the subsequent prolific growth of ephemeral algal mats appear to be a fairly consistent feature of coastal oil spills (Hawkins & Southward, 1992). Species richness, diversity and evenness were all much lower in fucoid-barnacle communities at sites close to the *Braer* oil spill (Newey & Seed, 1995). In the absence of tarry masses of oil which cause physical smothering of sessile animals and mechanical damage to algae, adult fucoids and barnacles occupying primary space in the community are relatively resistant to damage from chemical properties of the oil itself, although some damage will inevitably occur. The most serious effects tend to occur among juvenile and newly settling recruits to the community. However, this biotope is subject to very strong wave action and therefore, oil is likely to be rapidly removed and not cause smothering effects. Intolerance of the biotope is considered to be low. See additional information for recovery.
Radionuclide contamination (see benchmark)	Insufficient information.
Changes in nutrient levels (see benchmark)	A reduction in the level of nutrients could reduce growth rates of algal species in the biotope. Nutrient availability is the most important factor controlling germling growth. A slight increase in nutrients may enhance growth rates but high nutrient concentrations could lead to the overgrowth of the algae by ephemeral green algae and an increase in the number of grazers. The effect of sewage discharge on an extremely exposed rocky shore is likely to be low because water movements should limit the build up of particulates and prevent eutrophication. Fucoids appear to be relatively resistant to the input of sewage, and grow apparently healthily to within 20 metres of an outfall discharging untreated sewage in the Isle of Man (Holt *et al*., 1997). Intolerance of the biotope is therefore assessed as low. Recovery will be rapid as growth responds to changing nutrient levels.
Increase in salinity (see benchmark)	The biotope occurs in areas of full salinity although will be subject to some variability because of rainfall in the intertidal. However, there are no reports of the biotope occurring in hypersaline areas such as rockpools where evaporation in the summer causes salinity to increase. Therefore, it seems likely that the biotope will be highly intolerant of a long term increase in salinity and a rank of high is reported. See additional information for recovery.
Decrease in salinity (see benchmark)	Barnacle and fucoid shores are able to tolerate short term variations in salinity because the littoral zone is regularly exposed to precipitation. *Fucus distichus* extends into estuaries on the coast of North America so the biotope may tolerate long term reductions in salinity within its normal tolerance range although growth rates and fecundity are likely to be impaired. Intolerance is therefore, reported to be low. However, the biotope is only found on open exposed coasts.
Changes in oxygenation (see benchmark)	Cole *et al*. (1999) suggest possible adverse effects on marine species below 4 mg/l and probable adverse effects below 2 mg/l. There is no information about key algae species tolerance to changes in oxygenation although Kinne (1972) reports that reduced oxygen concentrations inhibit both algal photosynthesis and

	respiration. However, since the biotope occurs in the upper eulittoral a proportion of time will be spent in air where oxygen is not limited so the metabolic processes of photosynthesis and respiration can take place. Therefore, for a period of a week reduced oxygenation in the water is likely to have minimal sub-lethal effects and so an intolerance rank of low is reported.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	The cryptoniscid isopod *Hemioniscus balani* is a widespread parasite of barnacles, found around the British Isles. Heavy infestation inhibits or destroys the gonads resulting in castration of the barnacle. High levels of infestation may reduce barnacle abundance and distribution which would impact on patch dominance although no reported cases of this were found. There were no reported occurrences found of the fucoid algae or the biotope being affected by these or any other infestations so intolerance is reported to be low. However, there is always the potential for this to occur so intolerance may change.
Introduction of non-native species (see benchmark)	There are no non-native species at present in Britain likely to occur in this biotope.
Extraction of key or important characterizing species (see benchmark)	The biotope has no commercial importance so is not likely to be exploited. However, if 50% of the fucoids were removed recovery should be high because all key species have a dispersive larval stage and reproduce every year.
Extraction of important species (see benchmark)	The amount of fucoid plants on moderately exposed shores has been shown to be greatly affected by perturbations in grazer, particularly *Patella vulgata*, populations (Hartnoll & Hawkins, 1985) and this may also be true of more exposed shores. Interactions with barnacles may also be involved. Adults of *Fucus distichus* are very tolerant of grazing due to a high content of phlorotannin, but germlings do not have any protection and are susceptible to grazing. Therefore, removal of grazers such as *Patella vulgata* and littorinids may increase fucoid cover.

Additional information

Recoverability

Recovery of the biotope is high because recruitment of key species is fairly rapid and the biotope will look much as before within five years. For example, *Fucus distichus* (Ang, 1991) and *Fucus spiralis* have been observed to readily recruit to cleared areas (Hartnoll & Hawkins, 1985; Hawkins & Hartnoll, 1985) and have fast growth rates, so recovery rates are expected to be high. Bennell (1981) observed that barnacle populations removed when the surface rock was scraped off in a barge accident at Amlwch, North Wales returned to pre-accident levels within 3 years. However, barnacle recruitment can be very variable because it is dependent on a suite of environmental and biological factors, such as wind direction, so populations may take longer to recruit to suitable areas. Recolonization of *Patella vulgata* on rocky shores is rapid as seen by the appearance of limpet spat 6 months after the *Torrey Canyon* oil spill reaching peak numbers 4-5 years after the spill. Therefore, it seems likely that the biotope should recover within five years.

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors		
	Fucus distichus	***Fucus spiralis***
Community Importance	Key structural	Key structural
Substratum Loss	High	High
Smothering	High	High
Increase in suspended sediment	Low	Low
Decrease in suspended sediment	See explanation	See explanation
Desiccation	High	High
Increase in emergence regime	High	High
Decrease in emergence regime	See explanation	See explanation
Increase in water flow rate	Low	Intermediate
Decrease in water flow rate	See explanation	See explanation
Increase in temperature	High	Low
Decrease in temperature	See explanation	See explanation
Increase in turbidity	Low	Low
Decrease in turbidity	See explanation	See explanation
Increase in wave exposure	Intermediate	High
Decrease in wave exposure	See explanation	See explanation
Noise	Not Sensitive	Not Sensitive
Visual Presence	Not Sensitive	Not Sensitive
Abrasion & physical disturbance	Intermediate	Intermediate
Displacement	High	High
Chemical factors		
	Fucus distichus	***Fucus spiralis***
Community Importance	Key structural	Key structural
Synthetic compound contamination	Insufficient information	Insufficient information
Heavy metal contamination	Low	Intermediate
Hydrocarbon contamination	Insufficient information	High
Radionuclide contamination	Insufficient information	Insufficient information
Changes in nutrient levels	Insufficient information	Intermediate
Increase in salinity	Low	Intermediate
Decrease in salinity	See explanation	See explanation
Changes in oxygenation	Insufficient information	Insufficient information
Biological factors		
	Fucus distichus	***Fucus spiralis***
Community Importance	Key structural	Key structural
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information
Introduction of non-native species	Insufficient information	Insufficient information
Extraction of this species	Intermediate	Intermediate
Extraction of other species	Insufficient information	Insufficient information

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors		
	Fucus distichus	***Fucus spiralis***
Community Importance	Key structural	Key structural
Substratum Loss	High	High
Smothering	High	High
Increase in suspended sediment	Very high	Very high
Decrease in suspended sediment	See explanation	See explanation
Desiccation	High	High
Increase in emergence regime	High	High
Decrease in emergence regime	See explanation	See explanation
Increase in water flow rate	High	High
Decrease in water flow rate	See explanation	See explanation
Increase in temperature	High	Not Relevant
Decrease in temperature	See explanation	See explanation
Increase in turbidity	Very high	High
Decrease in turbidity	See explanation	See explanation
Increase in wave exposure	High	High
Decrease in wave exposure	See explanation	See explanation
Noise	Not Relevant	Not Relevant
Visual Presence	Not Relevant	Not Relevant
Abrasion & physical disturbance	High	High
Displacement	High	High
Chemical factors		
	Fucus distichus	***Fucus spiralis***
Community Importance	Key structural	Key structural
Synthetic compound contamination	Not Relevant	Not Relevant
Heavy metal contamination	Very high	High
Hydrocarbon contamination	Not Relevant	High
Radionuclide contamination	Not Relevant	Not Relevant
Changes in nutrient levels	Not Relevant	High
Increase in salinity	High	Very high
Decrease in salinity	See explanation	See explanation
Changes in oxygenation	Not Relevant	Not Relevant
Biological factors		
	Fucus distichus	***Fucus spiralis***
Community Importance	Key structural	Key structural
Introduction of microbial pathogens/parasites	Not Relevant	Not Relevant
Introduction of non-native species	Not Relevant	Not Relevant
Extraction of this species	High	High
Extraction of other species	Not Relevant	Not Relevant

Importance

Marine natural heritage importance

Listed under:	**UK Biodiversity Action Plan** **EC Habitats Directive**
National importance	Rare
Habitat Directive feature (Annex 1)	Reefs
UK Biodiversity Action Plan habitat	Littoral rock (broad habitat statement)

Biotope importance

Shore birds feed on rocky shores on species such as limpets. Rich pickings are also available under macroalgae canopies. Fish and crustaceans, migrating into the intertidal zone to feed as the tide rises, are important predators of rocky shore species.

Exploitation

It is unlikely that species in this biotope will be exploited. The biotope occurs on remote and dangerously wave exposed shores.

Additional information

No text entered

This Biology and Sensitivity Key Information review can be cited as follows:

Hill, J.M., 2001. *Fucus distichus* and *Fucus spiralis* f. *nana* on extremely exposed upper shore rock. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 19/01/2005]. Available from: <http://www.marlin.ac.uk>

Underboulder communities (MLR.Fser.Fser.Bo)

Key information authored by: Dr Keith Hiscock

Last updated 14/04/2000

Refereed by: Dr Bob Foster-Smith

Underboulder community dominated by sponges from a rock pool habitat. Wembury, South Devon. Image width ca 1 m.
Image: Keith Hiscock

Recorded and expected MLR.Fser.Fser.Bo distribution for Britain and Ireland

Description of biotope

Underboulder communities are found from midshore downwards on moderately exposed to sheltered boulder shores. The community present under boulders is of the character described here where the boulders are clear of sediment, in pools and/or on open rock from the lower midshore downwards. Characteristic species include the hairy porcelain crab *Porcellana platycheles*, the long-clawed porcelain crab *Pisidia longicornis* and juvenile edible crabs *Cancer pagurus*. Also present beneath the boulders are often high densities of the barnacle *Balanus crenatus*, the keel worm *Pomatoceros* spp., spirorbid worms, gammarid amphipods and a few small gastropods and mussels. The encrusting bryozoans *Umbonula littoralis* and *Schizoporella unicornis* and encrusting colonies of the sponges *Hymeniacidon perleve* and *Halichondria panicea* and the star ascidian *Botryllus schlosseri* are also typical of this habitat. The richest examples also contain a variety of brittlestars, ascidians and small hydroids. (Information taken from the Marine Biotope Classification for Britain and Ireland, Version 97.06: Connor *et al.*, 1997a, b).

Welsh variation

MLR.Fser.Fser.Bo recorded in Wales compares well with the general biotope description except that a number of additional species are shown in Welsh data. These additional species are mainly generalists that re-occur in this zone on hard substrata (Holt, 2003). See Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

MLR.Fser.Fser.Bo is also representative of MIR.Ldig.Ldig.Bo where the underboulder fauna is very similar. Underboulder communities are entirely different from the communities present on the tops and sides of boulders in this biotope and will have been included in relevant open rocky shore reviews.

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Habitat complex	MLR	Moderately exposed littoral rock (barnacle/fucoid shores)
Biotope complex	MLR.BF	Barnacles and fucoids (moderately exposed shores)
Biotope	MLR.Fser.Fser.Bo	Underboulder communities
Similar biotopes:	MIR.Ldig.Ldig.Bo	

Underboulder communities in the sub-biotopes MLR.Fser.Fser.Bo and MIR.Ldig.Ldig.Bo are essentially the same. The species present on the tops of boulders are not considered here as they are relevant only to the upper surface biotope.

Biotopes represented by this Key Information review:

MIR.Ldig.Ldig.Bo	*Laminaria digitata* and under-boulder fauna on sublittoral fringe boulders

Other biotope classification schemes

European Union Nature Information System (EUNIS) Habitat classification code: A1.22321 **-** *Fucus serratus* and underboulder fauna on lower eulittoral boulders (Davies & Moss, 1998).

Ecology

Ecological and functional relationships

- The fauna are dominated by a variety of active and passive suspension feeders such as encrusting sponges (e.g. *Halichondria panicea*), solitary ascidians (e.g. *Dendrodoa grossularia*), barnacles (e.g. *Balanus crenatus*), spirorbid worms (e.g. *Spirorbis spirorbis*), hydroids (e.g. *Dynamena pumila*), bryozoans (e.g. the sea mat *Electra pilosa* and the encrusting bryozoan *Umbonula littoralis*) and colonial ascidians (e.g. *Botryllus schlosseri*). There is likely to be competition for space between many of the encrusting species. Gordon (1972) noted that competition between bryozoans and ascidians always favoured ascidians. He also noted that *Halichondria* sponges, even after they had died, prevented the spreading and survival of bryozoans trying to overgrow them. Herbivores include the common periwinkle *Littorina littorea*, the grey top shell *Gibbula cineraria*, the green sea urchin *Psammechinus milaris* and, less frequently, the common limpet *Patella vulgata*. Herbivorous grazers most likely use the underboulder habitat for shelter but emerge from under the boulders to feed.
- There are few species that prey on other members of the community but, for instance, dog whelks *Nucella lapillus* may feed on barnacles and the European cowrie *Trivia monacha* feeds on the star ascidian *Botryllus schlosseri*. The common shore crab *Carcinus maenas* is probably the largest mobile predator associated with MLR.Fser.Fser.Bo. It will move between the boulders and pebbles feeding primarily on small molluscs, especially *Littorina* spp., annelids and other crustacea. It will also consume algal material. Non-mobile carnivores include the beadlet anemone *Actinia equina* which feeds passively.
- Some resident mobile species are detritivores such as the hairy porcelain crab *Porcellana platycheles* and some brittle stars.
- Several species that occur under boulders gain shelter from insolation and predators when the tide is out but are not an integral part of the community; for instance, blennies, crabs and shrimps e.g. the common prawn *Palaemon serratus*.

Species diversity and disturbance

Boulder communities are subject to frequent wave-induced disturbance, especially during the winter months as storm and wave energy increases. Due to the varying size of boulders likely to be found in MLR.Fser.Fser.Bo, some boulders will be moved around and turned-over more frequently than others. Larger boulders remain undisturbed for longer periods of time and, consequently, the community on them is likely to be dominated by a few late successional species. In MLR.Fser.Fser.Bo, large stable boulders may be dominated by a few prolific species such as *Dendrodoa* and *Halichondria* (Foster-Smith, pers. comm.). In contrast, small boulders are tossed around regularly and are unlikely to reach a 'climax' community as disturbance is too frequent. The frequency of disturbance determines the interval of time over which recolonization can occur (Sousa, 1985) and small boulders sample the available pool of spores and larvae more often (Sousa, 1979a) and they are likely to be characterized by hardy species capable of rapidly colonizing bare space e.g. barnacles, spirorbid worms and bryozoans. Sousa (1979a) noted that, in an algal dominated boulder field in California, boulders subjected to intermediate disturbance frequencies were usually less dominated than those which are frequently disturbed, and always less dominated than boulders which were seldom disturbed. Furthermore, intermediate boulders remained undisturbed for long enough that several species had become dominant but not so long that species had been competitively displaced, resulting in dominance. In other words, intermediate size boulders are likely to be more diverse in terms of species diversity. For this reason, the species composition under boulders within the MLR.Fser.Fser.Bo classification can vary considerably which can be problematic when assessing sensitivity (see Species Composition).

Seasonal and longer term change

Some species of bryozoans and hydroids demonstrate seasonal cycles of growth in spring/summer and regression (die back) in late autumn/winter, over wintering as dormant stages or juvenile stages (see Ryland, 1976; Gili & Hughes, 1995; Hayward & Ryland, 1998). Many of the bryozoans and hydroid species are opportunists adapted to rapid growth and reproduction (r-selected), taking advantage of the spring/summer phytoplankton bloom and more favourable (less stormy) conditions (Dyrynda & Ryland, 1982; Gili & Hughes, 1995). Henry (2002) reported a drastic decline in *Dynamena pumila* over the winter months in the Bay of Fundy. Foster-Smith (1989) recorded that many encrusting ascidians increased in abundance by late summer under boulders on the Northumbrian coast.

On the boulder shores with which MLR.Fser.Fser.Bo is associated, the increased storm and wave energy over the winter months are likely to significantly influence both the flora and faunal components of MLR.Fser.Fser.Bo. Many boulders and cobbles will be thrown around creating bare patches in encrusting species, ripping seaweed off the boulders and overturning boulders to the detriment of species previously on top of the boulders which may suffer from anoxia and crushing etc. These species are likely to perish if left under the boulder which will mean that the proportion of 'bare' rock will increase. Over the winter months therefore they may be an increase in opportunistic species such as *Pomatoceros triqueter*. However, the winter months also giver the late successional species a chance to colonize the rocks as other e.g. algae such as *Ulva* die back. Sousa (1979b) found that *Ulva* sp. inhibited the colonization of mid-successional species such as *Fucus serratus* and that these mid-successional species, in turn, inhibited the recruitment of late-successional species such as *Gigartina canaliculata*. Therefore, these winter months are important for the development and diversity of the biotope as a whole.

Habitat structure and complexity

- The epilithic community usually occurs as a single layer although competition between encrusting species may result in overgrowth and smothering.
- Habitat complexity increases where soft rocks are bored by bivalve molluscs creating holes for other species to nestle.
- Variation occurs especially in relation to the degree of influence of underlying sediments. Physical complexity is increased where boulders lie on top of other loosely-packed boulder creating interstices whilst siltation under the boulders means that deeper silty layers may support detritus-feeding polychaetes (Foster-Smith, pers. comm.). Faunal diversity on the boulder surface will be decreased where the boulders are embedded or partly in sediment. In contrast, there may be flowing water under some boulders (for instance, overflows from pools or lagoonal habitats draining at low water) which creates rich communities.

Dominant trophic groups	Suspension feeders

Productivity

Insufficient information

Major sources of organic carbon	Detritus Plankton

Recruitment processes

The majority of important and characteristic species associated with MLR.Fser.Fser.Bo have planktonic larvae which recruit frequently. Recruitment in the important species is summarized below.

- The breadcrumb sponge *Halichondria panicea* is likely to have a short, annual season of sexual reproduction. Most sponges are hermaphroditic but cross-fertilization normally occurs. The process may be oviparous, where there is a mass spawning of gametes through the osculum which enter a neighbouring individual in the inhalant current. Fertilized eggs are discharged into the sea where they develop into a planula larva. However, in the majority, development is viviparous, whereby the larva develops within the sponge and is then released. Larvae have a short planktonic life of a few hours to a few weeks, so that dispersal is probably limited.
- In *Botryllus schlosseri*, up to eight eggs are produced per zooid. After fertilization and development to a tadpole stage, the tadpole is released and is free swimming for up to 36 hours (Berril 1950; Berril, 1975). This short planktonic stage therefore limits recruitment to nearby colonies.
- Ingle (1997) indicated that the eggs of *Pisidia longicornis* were present from March to August in southern England and from February to September in the Mediterranean. The planktonic larvae and highly mobile nature of this crab mean that this species does not necessarily rely on recruitment from ,local sources. Underboulder areas may be important refuges for young crabs, especially *Cancer pagurus*.
- The dispersal phase of *Umbonula littoralis* is probably brief and larvae probably do not travel far therefore recruitment is dependant on local sources. Embryos were recorded as present in the Plymouth area in June and August (Marine Biological Association, 1957), from October and November on the north-east coast of England (Hastings, 1944) and from September to February in Manx waters (Eggleston, 1969).
- *Balanus crenatus* releases planktotrophic nauplii larvae between February and September, with peaks in April and late summer when phytoplankton levels are highest. They pass through six nauplii stages before eventually developing into a cyprid larva which is are specialized for settlement. Peak settlement occurs in April and declines until October. The larvae may not settle for a month after release and therefore, dispersal potential is relatively high as is recruitment from distant sources. Metamorphosis usually takes place within 24 hours of settlement.
- Although asexual reproduction occurs in many ascidians, reproduction in the baked bean ascidian *Dendrodoa grossularia* is entirely sexual (Millar, 1954). Millar studied reproduction in *Dendrodoa grossularia* in two locations (the River Crouch in Essex and the Isle of Cumbrae in the Firth of Clyde) and found that reproduction was bi-polar in nature with one peak in spring and another in late autumn, the spring episode being more intense. The average number of eggs produced per individual (over 7 mm in length) was only ca 25-100 eggs in the Clyde and River Crouch respectively. Furthermore, the eggs are brooded internally until the larval stage is reached thereby compressing the free swimming stage.

Time for community to reach maturity

Settlement panels, which attract similar communities to underboulder habitats, may be fully colonized within about 18 months of being placed into the environment (extrapolated from Sutherland & Karlson 1977; Todd 1994). Development of 'mature' communities under boulders is likely to occur within two years and there will be dynamic stability, i.e. composition of the community will remain much the same although individual organisms and colonies will die and be replaced by the same species.

Additional information

No text entered

Habitat preference and distribution

Distribution in Britain and Ireland

All around Britain but known to be particularly well developed along the coast of Northumberland, in the Plymouth area, in the Isles of Scilly, in the Menai Strait (North Wales) and in tidal rapids at the entrances of sea lochs, obs and (in Ireland) loughs.

Habitat preferences

Temperature range preferences	No preferences noted.
Water clarity preferences	No preference
Limiting nutrients	No preference
Other preferences	Flowing water

Additional information

The richest underboulder communities develop in wave sheltered locations on stable boulders where the downward facing surfaces are clear of sediment and there is flowing water present e.g. Strangford Lough, Menai Strait and Linne Mhuirich.

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (see Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	Species name	Common Name
Important characterizing	*Pisidia longicornis*	Long-clawed porcelain crab
Important characterizing	*Umbonula littoralis*	An encrusting bryozoan
Important characterizing	*Botryllus schlosseri*	Star ascidian
Important other	*Dendrodoa grossularia*	Baked bean ascidian
Important structural	*Halichondria panicea*	Breadcrumb sponge
Important other	*Balanus crenatus*	An acorn barnacle

Explanation

The structure of MLR.Fser.Fser.Bo communities is likely to vary greatly between boulders. As a result many of the species chosen as indicative to sensitivity have been listed as 'important other', since other designations suggest the species plays a permanent central role in the biotope. A representative of the groups of organisms most likely to be found in the biotope at a given time has been selected, bearing in mind the difference between frequently disturbed and seldom disturbed boulder communities (see Ecological and Functional Relationships).

The breadcrumb sponge *Halichondria panicea* and star ascidian *Botryllus schlosseri* have both been listed as important structural species since they are competitively superior to many encrusting bryozoan species likely to occur in underboulder communities. A solitary ascidian, *Dendrodoa grossularia*, has also been included since its represents a species that is likely to be found in larger boulders that have undergone considerable succession in terms of community development. *Umbonula littoralis* has been included as a representative of the various encrusting bryozoans likely to be found in MLR.Fser.Fser.Bo. The acorn barnacle *Balanus crenatus*, along with bryozoans and colonial ascidians, will be an important early colonizer of the rock surface and is likely to be one of the pioneer species on smaller frequently disturbed boulders. Apart from filter feeders, the dominant trophic group, the long-clawed porcelain crab, *Pisidia longicornis* scavenger has been listed as important other since it is likely to be found in and around the sediment that under the boulder. The broad-clawed porcelain crab *Porcellana platycheles* may be more commonly associated with MLR.Fser.Fser.Bo than *Pisidia longicornis* although more information was available for the long-clawed porcelain crab.

In undertaking this assessment of sensitivity, account is taken of knowledge of the biology of all characterizing species in the biotope. However, 'indicative species' are particularly important in undertaking the assessment because they have been subject to detailed research.

Species found especially in biotope

Turbicellepora magnicostata A sea mat

Rare or scarce species associated with this biotope

Nationally rare	*Turbicellepora magnicostata*

Additional information

Underboulder communities are especially described in Foster-Smith (1989, 1991), Foster-Smith & Foster-Smith (1987), and Hiscock (1984) and in various reports produced during the MNCR survey of Scottish sea lochs.

Biotope sensitivity

Physical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	High	Moderate	Major Decline	Low
Smothering	High	High	Moderate	Decline	Low
Increase in suspended sediment	Intermediate	High	Low	Minor Decline	Low
Decrease in suspended sediment	Tolerant*	Not Relevant	Not Sensitive*	No Change	Low
Desiccation	High	High	Moderate	Major Decline	Low
Increase in emergence regime	Intermediate	High	Low	Decline	Low
Decrease in emergence regime	Tolerant	Not Relevant	Not Sensitive	No Change	Very Low
Increase in water flow rate	Tolerant*	Not Relevant	Not Sensitive*	No Change	Low
Decrease in water flow rate	Intermediate	High	Low	Decline	Low
Increase in temperature	Low	High	Low	Minor Decline	Low
Decrease in temperature	Low	High	Low	Minor Decline	Low
Increase in turbidity	Tolerant	Not Relevant	Not Sensitive	No Change	Moderate
Decrease in turbidity	Tolerant	Not Relevant	Not Sensitive	No Change	Moderate
Increase in wave exposure	Intermediate	High	Low	Decline	Low
Decrease in wave exposure	Intermediate	High	Low	Decline	Low
Noise	Tolerant	Not Relevant	Tolerant	NR	Moderate
Visual Presence	Tolerant	Not Relevant	Tolerant	NR	Moderate
Abrasion & physical disturbance	High	High	Moderate	Decline	Moderate
Displacement	High	High	Moderate	Major Decline	Moderate
Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	Intermediate	High	Low	Decline	Low
Heavy metal contamination	Insufficient information	Not Relevant	Insufficient information	Insufficient Information	Not Relevant

Hydrocarbon contamination	Intermediate	High	Low	Decline	Moderate
Radionuclide contamination	Insufficient information	Not Relevant	Insufficient information	Insufficient Information	Not Relevant
Changes in nutrient levels	Tolerant	Not Relevant	Tolerant	No Change	Low
Increase in salinity	Tolerant	Not Relevant	Not Sensitive	No Change	Low
Decrease in salinity	Intermediate	High	Low	Decline	Low
Changes in oxygenation	Intermediate	High	Low	Minor Decline	Very low
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Insufficient information	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Introduction of non-native species	Insufficient information	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Extraction of key or important characterizing species	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Extraction of important species	Low	High	Low	Minor Decline	Low

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	If boulders are removed or covered, the associated community is also removed. With suitable substratum available for recolonization, the community will recover.
Smothering (see benchmark)	Many of the underboulder species are low-lying encrusting forms that cannot escape smothering and are, therefore, especially vulnerable. Over the course of one month, feeding in suspension feeders is likely to be inhibited as a result of the clogging of the feeding apparatus. In addition, deoxygenation will occur due to the decomposition of smothered matter under the boulder. *Balanus crenatus* can withstand covering by silt provided that the cirri can extend above the silt layer but smothering by 5 cm of sediment would prevent feeding and could cause death. It is likely that many of the important species including the bryozoans and colonial ascidians will experience mortality and accordingly, intolerance has been assessed as high. However, smothering by sand is part of the natural dynamics of some boulders (Foster-Smith, pers. comm.) and the fact that the majority of underboulder communities are downward facing means that the effects of smothering are likely to be relatively short lived. Recoverability is expected to be high (see additional information). (This assessment is for smothering by sediment - some typical underboulder species can survive overgrowth by other species (c.f. Turner, 1988)).
Increase in suspended sediment (see benchmark)	Underboulder communities face downwards so that silt is unlikely to settle but may clog the feeding structures of some species such as hydroids, bryozoans and ascidians thereby reducing total ingestion over the benchmark period. *Umbonula littoralis* for example, is expected to have a limited ability to clear itself of silt. Rich underboulder communities are known to occur in turbid waters, for instance, the Menai Strait. However, increased suspended sediment, in combination with areas of low wave energy or water movement may lead to siltation (see water flow rate) and therefore, intolerance has been assessed as intermediate. Recoverability is likely to be high (see additional information).
Decrease in suspended sediment	A decrease in suspended sediment is likely to be beneficial to most of the underboulder community. The suspension feeders may become more efficient as

(see benchmark)	there would be fewer inorganic particles to clog and interfere with feeding apparatus. Assuming that the decrease in suspended sediment refers to inorganic particles, a reduction in total ingestion in the suspension feeding community is not expected. Therefore, tolerant* has been assessed.
Desiccation (see benchmark)	Underboulder communities are generally damp due to the fact that they are mostly unaffected by the drying influences of wind and insolation. Furthermore, many underboulder communities are in contact with flowing water. Underboulder species on boulders which are turned so that the undersurface community ceases to be shaded and damp are likely to be killed. The number and diversity of species likely to be killed be dependent on the size of the boulder since larger boulders are less likely to be turned over and so will have more developed community (see Ecology). Small rocks frequently turned over (either through natural energy, e.g. by wave energy, or humans) will have fewer species and species that, nevertheless, are opportunistic species characteristic of disturbed environments. *Balanus crenatus*, for example, were reported to have a mean survival time of 14.4 hours in dry air (Barnes *et al.*, 1963). The community will eventually re-develop on the new underside and therefore, recoverability is expected to be high (see additional information).
Increase in emergence regime (see benchmark)	A one hour change in the time not covered by the sea for a period of one year is unlikely to adversely affect the majority of the MLR.Fser.Fser.Bo community since the habitat is likely to remain shaded and damp. Mobile species such as *Pisidia longicornis* and *Carcinus maenas*, because of their mobility, may be able to escape the effects of increased emergence by crawling to damper areas further down the shore. On balance, however, MLR.Fser.Fser.Bo has been assessed as being of intermediate intolerance to changes in emergence to reflect the likelihood that species at the limits of their tolerance to emergence might be killed. Recoverability is likely to be high (see additional information).
Decrease in emergence regime (see benchmark)	A decrease in emergence would reduce the influence of desiccation on the community which would be beneficial to the biotope. However, this benefit may be counteracted by the fact that the more submerged boulders may be subject to increased disturbance through wave energy. Larger boulders previously undisturbed may move around more, potentially leading to an increased species diversity (see Ecology). On balance, MLR.Fser.Fser.Bo has been assessed as tolerant to a decrease in emergence.
Increase in water flow rate (see benchmark)	The richest underboulder communities develop in areas subject to strong tidal flows and, therefore, at the benchmark level, MLR.Fser.Fser.Bo is likely to be tolerant*.
Decrease in water flow rate (see benchmark)	A decrease in strength of tidal flow will lead to loss or reduction in abundance of some species and this would most likely be a result of increased siltation. Species including *Pisidia longicornis* and *Umbonula littoralis* thrive in habitats that are in areas of moderate to strong water movement. A decrease in water flow rates where wave action is also weak would be likely to result in mortality in, for example, some bryozoans, colonial ascidians and sponges. This is most likely as a secondary effect from siltation but possibly also due to a reduction in food source. Barnes & Bagenal (1951) found that the growth rate of *Balanus crenatus* epizoic on *Nephrops norvegicus* was considerably slower than animals on raft exposed panels and this was attributed to reduced currents and increased silt loading of water in the immediate vicinity of *Nephrops norvegicus*. Intolerance is, therefore, assessed as intermediate. However, recoverability will be high (see additional information).
Increase in temperature	The shaded and damp conditions found in underboulder communities may serve to protect the MLR.Fser.Fser.Bo community from extremes of temperature.

(see benchmark)	Nevertheless, the important species found in this biotope have varying levels of tolerance to changes in temperature at the benchmark level and some species living under boulders are normally subtidal species and may be unable to withstand large changes in temperature. • *Pisidia longicornis* occurs in a wide range of temperature regimes from Norway to Angola and it is unlikely that they would be adversely affected by an increase in temperature at the level of the benchmark. • The British Isles are at the centre of geographical range for *Umbonula littoralis*, *Botryllus schlosseri* and *Halichondria panicea* suggesting that colonies are likely to be tolerant of both an increase and decrease in temperature at the benchmark level. • *Balanus crenatus* is a boreal species that is likely to be intolerant of increases in water temperature. In Queens Dock, Swansea, where the water temperature was on average 10 °C higher than average due to the effects of a condenser effluent, *Balanus crenatus* was replaced by the subtropical barnacle *Balanus amphitrite*. After the water temperature cooled *Balanus crenatus* returned (Naylor, 1965). *Balanus crenatus* was unaffected during the severe winter of 1962-63, when average temperatures were 5 to 6 °C below normal (Crisp, 1964a). • Gamete release in *Dendrodoa grossularia* decreases at 15 degrees and is suppressed at 20 degrees and below about 8-11 degrees (Millar, 1954). It is likely to be sensitive to an increase and decrease in temperature at the benchmark level. On balance, it is likely that overall intolerance to an increase in temperature will be low.
Decrease in temperature (see benchmark)	The shaded and damp conditions found in underboulder communities may serve to protect the MLR.Fser.Fser.Bo community from extremes of temperature. Nevertheless, the important species found in this biotope have varying levels of tolerance to changes in temperature at the benchmark level and some species living under boulders are normally subtidal species and may be unable to withstand large changes in temperature. • *Pisidia longicornis* were adversely affected by the 1962-63 winter in Britain. Crisp (1964a) records that many hundreds were found dead on the strandline at Oxwich, south Wales. In other locations, they were not found on the shore (although could have migrated offshore). • The British Isles are at the centre of geographical range for *Umbonula littoralis*, *Botryllus schlosseri* and *Halichondria panicea* suggesting that colonies are likely to be tolerant of both an increase and decrease in temperature at the benchmark level. • Gamete release in *Dendrodoa grossularia* decreases at 15 degrees and is suppressed at 20 degrees and below about 8-11 degrees (Millar, 1954). It is likely to be sensitive to an increase and decrease in temperature at the benchmark level. On balance, it is likely that overall intolerance to a decrease in temperature will be low.
Increase in turbidity (see benchmark)	Rich underboulder communities are known to occur in turbid waters, for instance, the Menai Strait. Therefore, it has been suggested that MLR.Fser.Fser.Bo is tolerant to an increase in turbidity at the benchmark level.
Decrease in turbidity (see benchmark)	A decrease in turbidity may stimulate phytoplankton production which would be beneficial to the suspension feeding community associated with MLR.Fser.Fser.Bo. Therefore, it has been suggested that MLR.Fser.Fser.Bo is tolerant to an increase in turbidity at the benchmark level.
Increase in wave	Many of the species likely to be found in MLR.Fser.Fser.Bo communities are

exposure (see benchmark)	probably tolerant of very wave exposed conditions. However, increases in wave exposure may cause more boulders to become mobile and abrade underboulder communities. Increased mobilization of boulders may result in patches of sponges, bryozoans and barnacles being crushed on impact with other boulders. For example, *Umbonula littoralis* has a hard calcareous skeleton which is likely to be broken through contact with hard surfaces such as cobbles moving around during storms. Crabs and other fragile mobile species are also at risk from being crushed. Furthermore, many of the stable boulders are fused together by algal growth (especially corallines) and breaking up this matrix would adversely affect the community (Foster-Smith, pers. comm.). The release of sediment between boulders may serve to interrupt suspension feeding (see Suspended Sediment above). MLR.Fser.Fser.Bo is found on shores ranging from wave sheltered to moderately wave exposed and as a result the communities in the biotope between each of these locations will vary anyway and. Therefore, different sites are likely to have varying tolerances with respect to changes in wave exposure. On balance, MLR.Fser.Fser.Bo has been assessed as being of intermediate intolerance to a change I wave exposure since some species may experience mortality although even frequently disturbed boulders with a few pioneer species may still represent MLR.Fser.Fser.Bo. Recovery is expected to be rapid (see additional information).
Decrease in wave exposure (see benchmark)	A decrease in wave exposure may facilitate sedimentation which will smother underboulder species resulting in mortality (see Smothering above). MLR.Fser.Fser.Bo is found on shores ranging from wave sheltered to moderately wave exposed and as a result the communities in the biotope between each of these locations will vary anyway and. Therefore, different sites are likely to have varying tolerances with respect to changes in wave exposure. On balance, MLR.Fser.Fser.Bo has been assessed as being of intermediate intolerance to a change in wave exposure since some species may experience mortality although even frequently disturbed boulders with a few pioneer species may still represent MLR.Fser.Fser.Bo. Recovery is expected to be rapid (see additional information).
Noise (see benchmark)	The characteristic and permanent members of the fauna are invertebrates unlikely to detect or be affected by noise.
Visual Presence (see benchmark)	The characteristic and permanent members of the fauna are invertebrates unlikely to detect or be affected by visual presence.
Abrasion & physical disturbance (see benchmark)	In addition to disturbance caused by wave energy, intertidal boulder communities are often disturbed by, for example, bait collectors, inquisitive school groups and field researchers. Boulders left overturned place the organisms on the now upward facing part of the boulder at great risk of desiccation (see Desiccation above). Furthermore, many stable boulders are fused together by algal growth (especially corallines) and breaking this matrix would be very harmful (Foster-Smith, pers. comm.). Furthermore, this disturbance and habitat degradation could change a stable boulder field to an unstable field on a long-term basis (Foster-Smith, pers. comm.). Movement of the boulder surface against other hard surfaces (for instance, during extreme storm events) is likely to cause significant damage to encrusting fauna that is characteristic of the community. Recoverability is expected to be high (see additional information).
Displacement (see benchmark)	Due to the fact that the majority of species likely to be found in the MLR.Fser.Fser.Bo community are permanently attached to the substratum, displacement will have the same effect as substratum removal and, therefore, intolerance has been assessed as high.
Chemical Factors	
Synthetic compound	Some members of the community, particularly crustaceans and molluscs, may be

contamination (see benchmark)	intolerant of chemicals that may have an adverse effect on reproduction. Chemicals developed as anti-fouling paints have been developed to counter fouling communities which are similar to underboulder communities. Barnacles have a low resilience to chemicals such as dispersants, dependant on the concentration and type of chemical involved (Holt *et al.*, 1995). Hoare & Hiscock (1974) found that *Balanus crenatus* survived near an acidified halogenated effluent discharge where many other species were killed, suggesting a high tolerance to chemical contamination. Little information is available on the impact of endocrine disrupters on adult barnacles or on the effects of synthetic chemicals on the other important species. However, intolerance has been suggested as intermediate to reflect the likely effects of antifouling chemicals. Component species generally have planktonic larvae and reproduce frequently so that re-colonization will be rapid, providing the environment is clean of any chemicals that were having an adverse effect ob the community.
Heavy metal contamination (see benchmark)	Barnacles accumulate heavy metals and store them as insoluble granules (Rainbow, 1987). Pyefinch & Mott (1948) recorded a median lethal concentration of 0.19 mg/l copper and 1.35 mg/l mercury, for *Balanus crenatus* over 24 hours. Barnacles may tolerate fairly high level of heavy metals in nature, for example they are found in Dulas Bay, Anglesey, where copper reaches concentrations of 24.5 µg/l, due to acid mine waste (Foster *et al.*, 1978). However, insufficient information was available on the remaining important species in MLR.Fser.Fser.Bo and sensitivity has not been assessed.
Hydrocarbon contamination (see benchmark)	Little evidence was found. Ryland & de Putron (1998) found no detectable damage to underboulder faunas during oil pollution in Watwick Bay, Pembrokeshire. However, fresh oil is likely to narcotize and kill Decapoda and some Gastropoda. Component species generally have planktonic larvae and reproduce frequently so that re-colonization will be rapid, providing the environment is clean of any chemicals that were having an adverse effect on the community.
Radionuclide contamination (see benchmark)	Insufficient information.
Changes in nutrient levels (see benchmark)	Underboulder communities occur where nutrient concentrations are high in enclosed coastal areas, for instance, the Menai Strait. The underboulder area is shaded and therefore any risks of thereby reducing the likelihood of smothering by ephemeral green algal species that are likely to flourish in the event of nutrient influx. Tolerant has been suggested.
Increase in salinity (see benchmark)	Underboulder communities occur in full to variable salinity habitats although it might be that higher salinity occurs at the outflow of some basins. At the levels expected, MLR.Fser.Fser.Bo is likely to be tolerant to an increase in salinity.
Decrease in salinity (see benchmark)	Rich underboulder communities occur in outflows from areas of variable salinity (for instance, in the Menai Strait, North Wales and in sea lochs). The communities therefore have some tolerance to at least short-term reduced salinity. However, some of the component species may be intolerant of reduced salinity. *Pisidia longicornis* and *Umbonula littoralis* both occur in full salinity and are likely to be intolerant of an acute reduction in salinity. Other species would be very tolerant. *Balanus crenatus*, for example, can tolerate salinities down to 14 psu if given time to acclimate (Foster, 1970). On balance, an intolerance of intermediate has been suggested to reflect the possibility that some species may experience some mortality. Component species generally have planktonic larvae and reproduce frequently so that re-colonization will be rapid.
Changes in oxygenation (see benchmark)	Underboulder habitats may be subject to lowered oxygen levels due to restricted water flow in calm periods. Also, organic debris that becomes trapped under the

	boulders may rot and cause de-oxygenated conditions. Some tolerance of low oxygen levels is therefore expected in some situations. However, the richest underboulder communities occur where water flow is strong and almost continuous and might suffer in de-oxygenated conditions. Component species generally have planktonic larvae and reproduce frequently so that re-colonization will be rapid.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	No text entered
Introduction of non-native species (see benchmark)	No text entered
Extraction of key or important characterizing species (see benchmark)	No text entered
Extraction of important species (see benchmark)	Species that are extracted from underboulder communities include edible crustaceans which, as scavengers, are not of key importance in the functioning of the community. None of the important species are likely to be targeted for extraction although the collection of other creatures including crabs and shrimps may result in increased physical disturbance, to the detriment of the community (see Physical Disturbance).

Additional information

Recoverability

The community associated with MLR.Fser.Fser.Bo will very greatly depending on various factors including the size of boulder, wave exposure and the presence or absence of flowing water under the boulder. In addition, it is difficult to identify a ‘climax’ community *per se* because the extent of community succession will vary greatly between boulders of different sizes etc. Furthermore, because there are no key functional, structural or characterizing species, any combination of the important species could, theoretically, determine the biotope community. Nevertheless, the recolonization of fauna typically associated with MLR.Fser.Fser.Bo will occur within a year or two and recoverability is expected to be high. However, the development of a mature community characteristic of seldom disturbed boulders dominated by e.g. *Halichondria panicea* and *Dendrodoa grossularia* may take longer although many boulders will never mature to this stage.

In the study of recolonization of vertical rock wall in Maine (Sebens, 1986), epifaunal and algal crust species were shown to re-colonize cleared areas quickly. For example encrusting bryozoans, tubeworms, tubicolous amphipods and worms, erect hydroids and bryozoans were reported to cover cleared areas within 1-4 months in spring, summer and autumn (Sebens, 1986). Sebens (1985) reported that *Halichondria panicea* had reached previous cover within two or more years. It was slow to recolonize the cleared areas, only appearing after about a year, although it is relatively fast growing. *Balanus crenatus* is another important early colonizer of sublittoral rock surfaces (Kitching, 1937) and it heavily colonized a site that was dredged for gravel within 7 months (Kenny & Rees, 1994).

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors			
	Pisidia longicornis	***Umbonula littoralis***	***Botryllus schlosseri***
Community Importance	Important characterizing	Important characterizing	Important characterizing
Substratum Loss	Intermediate	High	High
Smothering	Low	Intermediate	High
Increase in suspended sediment	Not Sensitive	Intermediate	High
Decrease in suspended sediment	Not Sensitive	See explanation	See explanation
Desiccation	High	Intermediate	Intermediate
Increase in emergence regime	Low	Intermediate	Intermediate
Decrease in emergence regime	Not Sensitive*	See explanation	See explanation
Increase in water flow rate	Low	Intermediate	Intermediate
Decrease in water flow rate	Intermediate	See explanation	See explanation
Increase in temperature	Not Sensitive	Low	Low
Decrease in temperature	Intermediate	See explanation	See explanation
Increase in turbidity	Low	Low	Low
Decrease in turbidity	Not Sensitive	See explanation	See explanation
Increase in wave exposure	Intermediate	Intermediate	Intermediate
Decrease in wave exposure	Intermediate	See explanation	See explanation
Noise	Not Sensitive	Not Sensitive	Not Sensitive
Visual Presence	Low	Not Sensitive	Not Sensitive
Abrasion & physical disturbance	High	Intermediate	Intermediate
Displacement	Low	High	High
Chemical factors			
	Pisidia longicornis	***Umbonula littoralis***	***Botryllus schlosseri***
Community Importance	Important characterizing	Important characterizing	Important characterizing
Synthetic compound contamination	Intermediate	Insufficient information	Insufficient information
Heavy metal contamination	Intermediate	Insufficient information	Insufficient information
Hydrocarbon contamination	Intermediate	Intermediate	Insufficient information
Radionuclide contamination	Not Sensitive	Insufficient information	Insufficient information
Changes in nutrient levels	Not Sensitive	Insufficient information	Low
Increase in salinity	Intermediate	High	Intermediate
Decrease in salinity	High	See explanation	See explanation
Changes in oxygenation	Intermediate	Low	Intermediate
Biological factors			
	Pisidia longicornis	***Umbonula littoralis***	***Botryllus schlosseri***
Community Importance	Important characterizing	Important characterizing	Important characterizing
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information
Introduction of non-native species	Insufficient information	Insufficient information	Not Sensitive*
Extraction of this species	High	Not Relevant	Not Relevant
Extraction of other species	Insufficient information	High	High

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors			
	Pisidia longicornis	***Umbonula littoralis***	***Botryllus schlosseri***
Community Importance	Important characterizing	Important characterizing	Important characterizing
Substratum Loss	High	High	High
Smothering	High	High	High
Increase in suspended sediment	Not Relevant	High	High
Decrease in suspended sediment	Not Relevant	See explanation	See explanation
Desiccation	High	High	High
Increase in emergence regime	Very high	High	High
Decrease in emergence regime	Not Relevant	See explanation	See explanation
Increase in water flow rate	High	High	High
Decrease in water flow rate	High	See explanation	See explanation
Increase in temperature	Not Relevant	High	Very high
Decrease in temperature	High	See explanation	See explanation
Increase in turbidity	High	High	Immediate
Decrease in turbidity	Not Relevant	See explanation	See explanation
Increase in wave exposure	High	High	Moderate
Decrease in wave exposure	High	See explanation	See explanation
Noise	Not Relevant	Not Relevant	Not Relevant
Visual Presence	Immediate	Not Relevant	Not Relevant
Abrasion & physical disturbance	High	High	High
Displacement	Very high	High	Moderate
Chemical factors			
	Pisidia longicornis	***Umbonula littoralis***	***Botryllus schlosseri***
Community Importance	Important characterizing	Important characterizing	Important characterizing
Synthetic compound contamination	High	Not Relevant	Not Relevant
Heavy metal contamination	High	Not Relevant	Not Relevant
Hydrocarbon contamination	High	High	Not Relevant
Radionuclide contamination	Not Relevant	Not Relevant	Not Relevant
Changes in nutrient levels	Not Relevant	Not Relevant	High
Increase in salinity	High	High	High
Decrease in salinity	High	See explanation	See explanation
Changes in oxygenation	High	High	High
Biological factors			
	Pisidia longicornis	***Umbonula littoralis***	***Botryllus schlosseri***
Community Importance	Important characterizing	Important characterizing	Important characterizing
Introduction of microbial pathogens/parasites	Insufficient information	Not Relevant	High
Introduction of non-native species	Not Relevant	Not Relevant	Not Relevant
Extraction of this species	High	Not Relevant	Not Relevant
Extraction of other species	Not Relevant	High	Moderate

Importance

Marine natural heritage importance

Listed under:	**UK Biodiversity Action Plan** **EC Habitats Directive**
National importance	Common
Habitat Directive feature (Annex 1)	Reefs Large shallow inlets and bays Estuaries
UK Biodiversity Action Plan habitat	Littoral rock (broad habitat statement)

Biotope importance

Important as a shelter for mobile species not usually considered a part of the community. Underboulder communities may be especially important for juvenile lobsters (Foster-Smith, pers. comm.).

Exploitation

Lobsters and winkles are collected from underboulder habitats for human consumption and crabs and shrimps are also collected, primarily for bait (Foster-Smith, pers. comm.). Both activities are very common in some areas e.g. Northumberland (Foster-Smith, pers. comm.). There is incidental damage to communities by crushing when boulders are returned and much greater damage if boulders are left upturned (see Sensitivity).

Additional information

Boulder habitats are a part of "Reefs" in Annex 1 of the Habitats Directive and also occur in "Large shallow inlets and bays" and in "Estuaries".

This Biology and Sensitivity Key Information review can be cited as follows:
Hiscock, K., 2000. Underboulder communities. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 20/01/2005]. Available from: <http://www.marlin.ac.uk>

Mytilus edulis and piddocks on eulittoral firm clay (MLR.MytPid)

Key information authored by: Charlotte Marshall

Last updated 10/11/2004

This information is not refereed.

No image available.

If you would be willing to supply *MarLIN* with an image of this species/habitat please contact marlin@mba.ac.uk

Recorded and expected MLR.MytPid distribution for Britain and Ireland

Description of biotope

Clay outcrops in the mid to lower eulittoral that are bored by a variety of piddocks including *Pholas dactylus*, *Barnea candida* and *Petricola pholadiformis*. The surface of the clay is characterized by small clumps of the mussel *Mytilus edulis*, the barnacle *Elminius modestus* and the winkle *Littorina littorea*. Seaweeds are generally sparse on the clay, although small patches of the red seaweeds *Mastocarpus stellatus*, *Halurus flosculosus* and *Ceramium* spp. can occur, usually attached to loose-lying cobbles or mussel shells. Also the green seaweeds *Ulva* spp. including *Ulva lactuca* may be present. The polychaete *Lanice conchilega* can sometimes be present in the clay, while the crustacean *Carcinus maenas* is present as well. More data required to validate this biotope. (Information taken from the revised Marine Habitat Classification, Version 04.05: Connor *et al*., 2004.).

Welsh variation

In Wales, MLR.MytPid does not fit the standard biotope description and there are many sites where piddocks are found in bare clay without the associated clumps of mussels, for example, Salisbury Middle and Salisbury Bank (*Pholas dactylus*, no *Mytilus edulis*) and Traeth Afon Wen (*Barnea candida*, no *Mytilus edulis*). See Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

No text entered

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Habitat complex	MLR	Moderately exposed littoral rock (barnacle/fucoid shores)
Biotope complex	MLR.MF	*Mytilus* (mussels) and fucoids (moderately exposed shores)
Biotope	MLR.MytPid	*Mytilus edulis* and piddocks on eulittoral firm clay

Other biotope classification schemes

European Union Nature Information System (EUNIS) habitat classification: A1.253/B-MLR.MF.MytPid *Mytilus edulis* beds and piddocks on eulittoral firm clay (Davies & Moss, 1998).

Ecology

Ecological and functional relationships

- Filter / suspension feeding organisms such as the piddocks *Barnea candida*, *Petricola pholadiformis* and *Pholas dactylus*, the mussel *Mytilus edulis* and the sand mason worm *Lanice conchilega*, are the dominant trophic group in the biotope. They feed on phytoplankton and detritus but also small zooplankton and dissolved organic material. Other associated suspension feeders may include the barnacles *Semibalanus balanoides* and *Elminius modestus*, mud shrimps *Corophium* spp. and the slipper limpet *Crepidula fornicata*. Inter and intra-specific competition for food may exist between the key structural species (see Species Composition) and other filter feeders within the biotope.
- The common shore crab *Carcinus maenas* is the predominant mobile species in the biotope, travelling through as it scavenges for food. It is a significant predator on both adult mussels and their spat.
- The algae that occur in small loose lying patches or attached to cobbles on the surface of the clay may provide shelter and possibly a source of food for the grazing prosobranchs *Littorina littorea*, which frequently occurs in the biotope. *Littorina littorea* feed within and around the mussel bed, grazing on benthic microalgae and macroalgae (sporeling and adult plants), and bulldozing newly settled invertebrate larvae (Hawkins & Hartnoll, 1983).

Predation

- Predation is the single most important source of mortality in *Mytilus edulis* populations (Seed & Suchanek, 1992; Holt *et al.*, 1998). Many predators target specific sizes of mussels and, therefore influence population size structure. For example, *Carcinus maenas* was unable to consume mussels of ca. 70 mm in length and mussels >45 mm long were probably safe from attack (Davies *et al.*, 1980; Holt *et al.*, 1998).The lower limit of intertidal mussel populations may be limited by predation by *Carcinus maenas*.
- Birds are important predators of mussels. Oystercatchers, herring gulls, eider ducks and knot have been reported to be major sources of *Mytilus edulis* mortality. For example, in the Ythan estuary bird predation consumed 72% of mussel production, with oystercatchers and herring gulls being each responsible for 15%. Mussels are regarded as a staple food of oystercatchers (Dare, 1976; Holt *et al.*, 1998). It is not known if birds are significant predators of the piddock species but the areas in which this biotope is found are often important sites for thousands of wildfowl and wading birds.

Seasonal and longer term change

- It is unlikely that piddock populations will be subject to significant seasonal changes in abundance. *Petricola pholadiformis*, for example, has a longevity of up to 10 years (Duval, 1963a) and its established populations may not exhibit significant seasonal changes, besides spawning in the summer.
- *Mytilus edulis* spawns in spring and summer and in some areas again in August and September, with settlement occurring 1-4 weeks later. However, while recruitment can be annual, it is often sporadic and unpredictable. The species richness of the macro-invertebrate fauna associated with mussel patches was shown to fluctuate seasonally, probably reflecting random fluctuations in settlement and mortality typical of marine species with planktonic larvae (see Seed, 1996 for discussion). Winter storms can remove clumps of mussels, especially where the mussels are fouling by macroalgae or epifauna, due to wave action and drag, or direct impact by wave driven debris, e.g. logs (Seed & Suchanek, 1992).
- The *Carcinus maenas* population may migrate offshore in the winter, therefore reducing predation pressure on the mussels.
- Macroalgae populations are also likely to exhibit some seasonal differences with a general decline in abundance / biomass over the winter months.

Habitat structure and complexity

Clay platforms can support rich and diverse communities. Piddock burrowing creates a generally uneven surface on a small scale (5-15 cm) providing habitats for other animals that inhabit vacant burrows and crevices in the clay. Resident piddock populations can result in extensively burrowed clay and empty piddock burrows can influence the abundance of other species by providing additional habitats and refuges. Wallace & Wallace (1983) reported densities of 30-60 *Barnea candida* siphon holes per square foot in Merseyside and burrows up to 6 inches deep. Duval (1977) found that the depth of the boring depended on the size of the animal. For example, an animal with a shell length of 1.2 cm could bore a 2.7 cm burrow whereas animals 4.8 cm long could bore burrows of 12 cm. Eunice Pinn (pers. comm.) found a statistically significant increase in species diversity in areas where old piddock burrows were present compared to where they were absent. Empty shells protruding from the eroded surface are also an important settlement surface within this habitat. Due to the impervious nature of the clay, small depressions on the surface can retain water as the tide goes out. In the Swale, Kent, these areas of shallow water have been colonized by the suspension feeders *Crepidula fornicata* and *Hydrallmania falcata* and the red algae *Halurus flosculosus* (as *Griffithsia* flosculosus) and *Dictyota dichotoma* (Hill *et al*., 1996).

Mussel beds can be divided into three distinct habitat components: the interstices within the mussel matrix; the biodeposits beneath the bed; and the substratum afforded by the mussel shells themselves (Suchanek, 1985; Seed & Suchanek, 1992). The sediments, shell fragments and byssal threads that form important components of the mussel patches are important for increasing the heterogeneity of the environments (Tsuchiya & Nishihira, 1986). After the settlement of mussel larvae, a monolayer is formed in the early stages of patch growth (Tsuchiya & Nishihira, 1986). As the patch grows, and the mussels require more space, mussels on the outside may be pushed outwards whilst those on the inside may be pushed up, resulting in the formation of a multi-layered mussel bed (Tsuchiya & Nishihira, 1986). If surface space is limited, as is likely if the sediment surface is extensively bored by the piddocks, mussels may be forced upwards rather than outwards in their patches. This will result in further increases to the heterogeneity of the substratum. Recent evidence suggests that the *Mytilus edulis* communities studied by Suchanek (1985) and Tsuchiya & Nishihira (1985, 1986) were probably *Mytilus trossulus* and *Mytilus galloprovincialis* respectively (Seed, 1992), although their community structure is probably similar to that of *Mytilus edulis*.

- The interstices between the mussels provide refuge from predation, and a humid environment protected from wave action, desiccation, and extremes of temperature.
- In the intertidal, *Mytilus* sp. beds the species richness and diversity increases with the age and size of the bed (Suchanek, 1985; Tsuchiya & Nishihira, 1985, 1986; Seed & Suchanek, 1992). However, the biotope is characterized by small clumps of mussels.
- Mussel faeces and pseudo-faeces, together with silt, build up organic biodeposits under the patches. In mussel beds the silt supports infauna such as sediment dwelling sipunculids, polychaetes and ophiuroids (Suchanek, 1978; Tsuchiya & Nishihira, 1985, 1986; Seed & Suchanek, 1992).
- *Mytilus edulis* can use its prehensile foot to clean fouling organisms from its shell (Theisen, 1972). Therefore, the epizoan flora and fauna is probably less developed or diverse than found in beds of other mussel species but may include barnacles (e.g. *Elminius modestus*) and tubeworms (e.g. *Pomatoceros* species)
- Mobile epifauna including *Littorina littorea* can obtain refuge from predators, especially birds, within the mussel matrix and emerge at high tide to forage (Suchanek, 1985; Seed & Suchanek, 1992).
- The mussels provide a substratum for the attachment of foliose and filamentous algae e.g. *Ceramium* species, *Mastocarpus stellatus* and *Ulva lactuca*. These algae in turn can provide a habitat for cryptic fauna such as amphipods.

Dominant trophic groups Suspension feeders

Productivity

Dense beds of bivalve suspension feeders increase turnover of nutrients and organic carbon in estuarine (and presumably coastal) environments by effectively transferring pelagic phytoplanktonic primary production to secondary production (pelagic-benthic coupling) (Dame, 1996).

- Specific information about the productivity of the key structural species was not found. However, the piddocks together with the mussels mean that detritus will contribute the most to the productivity of the biotope.

- *Mytilus* spp. communities are highly productive secondary producers (Seed & Suchanek, 1992; Holt *et al.*, 1998). Low shore mussels were reported to grow 3.5-4 cm in 30 weeks and up to 6-8 cm in length in 2 years under favourable conditions, although high shore mussels may only reach 2-3 cm in length after 15-20 years (Seed, 1976). Seed & Suchanek (1992) suggested that in populations of older mussels, productivity may be in the region of 2000-14,500 kJ/m²/yr. However, this biotope is characterized by patches of mussels, as opposed to mussel beds, and although mussel productivity is nevertheless important, it will not be as high as productivity from mussel beds. In Killary Harbour, western Ireland, the shore population of mussels contributed significantly to the larval population of the inlet. Kautsky (1981) reported that the release of mussel eggs and larvae from subtidal beds in the Baltic Sea contributed an annual input of 600 tons of organic carbon/yr. to the pelagic system. The eggs and larvae were probably an important food source for herring larvae and other zooplankton. The *Mytilus edulis* beds probably also provide secondary productivity in the form of tissue, faeces and pseudofaeces (Seed & Suchanek, 1992; Holt *et al.*, 1998).
- The small amount of macroalgae associated with this biotope including *Mastocarpus stellatus*, *Ceramium* species and *Ulva intestinalis* will contribute some dissolved organic carbon to the biotope. This is taken up readily by bacteria and may even be taken up directly by some larger invertebrates. Only about 10% of the primary production is directly cropped by herbivores (Raffaelli & Hawkins, 1999). Dissolved organic carbon, algal fragments and microbial film organisms are continually removed by the sea. This may enter the food chain of local, subtidal ecosystems, or be exported further offshore. Measurements of the productivity of benthic algae are relatively few, particularly for the Rhodophyta (Dixon, 1973). Blinks (1955) estimated the net production of red algae to be in the order of 11 to 54 g dry weight per m² per day.

Major sources of organic carbon	Detritus Dissolved organic matter

Recruitment processes

Most of the characterizing species in the biotope are sessile or sedentary suspension feeders. Recruitment of adults of these species to the biotope by immigration is therefore unlikely. Consequently, recruitment occurs primarily through dispersive larval stages. However, recruitment in many bivalve species is sporadic with unpredictable recruitment episodes.

- The three piddock species *Pholas dactylus*, *Petricola pholadiformis* and *Barnea candida* spawn in the summer months of July, August and September respectively. El-Maghraby (1955) showed that in southern England *Barnea candida* was unusual in that it started to spawn when the temperature fell at the beginning of the autumn (September).
- The fecundity of female *Petricola pholadiformis* is estimated to be between 3 - 3.5 million eggs per year (Duval, 1963a).
- *Mytilus edulis* recruitment is dependant on larval supply and settlement, together with larval and post-settlement mortality. Jørgensen (1981) estimated that larvae suffered a daily mortality of 13% in the Isefjord, Denmark but Lutz & Kennish (1992) suggested that larval mortality was approximately 99%. Larval mortality is probably due to adverse environmental conditions, especially temperature, inadequate food supply (fluctuations in phytoplankton populations), inhalation by suspension feeding adult mytilids, difficulty in finding suitable substrata and predation (Lutz & Kennish, 1992). Widdows (1991) suggested that any environmental factor that increased development time, or the time between fertilization and settlement would increase larval mortality.
- Recruitment in many *Mytilus* sp. populations is sporadic, with unpredictable pulses of recruitment (Seed & Suchanek, 1992). *Mytilus* sp. is highly gregarious and final settlement often occurs around or in-between individual mussels of established populations. Persistent mussels beds can be maintained by relatively low levels of recruitment e.g. McGrorty *et al.* (1990) reported that adult populations were largely unaffected by large variations in spat fall between 1976 and 1983 in the Exe estuary.
- The *Mytilus edulis* patch may act as a refuge for larvae or juveniles; however, the intense suspension feeding activity of the mussels is likely to consume large numbers of pelagic larvae.
- *Littorina littorea* can breed all through the year although the length and timing of the breeding period is dependent on climatic conditions. Large females can produce up to 100, 000 eggs during

this time. The pelagic phase of the larvae can be as long as six weeks providing potential for dispersal.

- The breeding season in *Carcinus maenas* depends on geographic location and in general, the length of the breeding period increases further south in England with year round breeding possible on the south coast. Fecundity in females can exceed 100, 000 eggs.

Time for community to reach maturity

Little information was found concerning community development. However, piddocks, *Barnea candida*, *Pholas dactylus* and *Petricola pholadiformis* are likely to settle readily. These piddocks breed annually and produce a large number of gametes. Once established individuals may live for a considerable length of time; *Petricola pholadiformis* of length 5-6 cm are likely to be between 6-10 years old (Duval, 1963a). Duval (1977) proposed that it was as a result of the extensive borings of *Barnea candida* that facilitated the colonization of an area in the Thames Estuary by the introduced American piddock, *Petricola pholadiformis*. This suggests that *Barnea candida* is a more competitive colonizing species in clay environments than the American piddock and it is possible that this species will appear first on cleared substrates.

Mytilus spp. populations are considered to have a strong ability to recover from environmental disturbance (Seed & Suchanek, 1992; Holt *et al.*, 1998). Larval supply and settlement could potentially occur annually; however, settlement is sporadic with unpredictable pulses of recruitment (Lutz & Kennish, 1992; Seed & Suchanek, 1992). The presence of macroalgae in disturbance gaps in *Mytilus califorianus* populations, where grazers were excluded, inhibited recovery by the mussels. In New England, U.S.A, prior barnacle cover was found to enhance recovery by *Mytilus edulis* (Seed & Suchanek, 1992). While good annual recruitment is possible, recovery of the mussel population may take up to 5 years. However, recovery of the mussel population may be delayed by 1-7 years for the initial macroalgal cover to reduce and barnacle cover to increase. Therefore, the biotope may take between 5 -10 years to recover depending on local conditions. Once the patches of mussels have returned, colonization of the associated community is dependant on the development of a mussel matrix, younger beds exhibiting lower species richness and species diversity than older beds, and hence growth rates and local environmental conditions. Tsuchiya & Nishihira (1986) examined young and older patches of *Mytilus* (probably *Mytilus galloprovincialis*) in Japan. They noted that as the patches of mussels grew older, individuals increased in size, and other layers were added, increasing the space within the matrix for colonization, which also accumulated biogenic sediment. Increased space and organic sediment was then colonized by infauna and epiphytes and as the patches and mussels became older, eventually epizoic species colonized the mussel shells. Macroalgae could colonize at any time in the succession. Unfortunately, Tsuchiya & Nishihira (1986) did not suggest a timescale.

Additional information

No text entered

Habitat preference and distribution

Distribution in Britain and Ireland

The biotope is recorded in the River Blackwater in Essex, the Swale in Kent and in Morecambe Bay, Lancashire.

Habitat preferences

Temperature range preferences	Data deficient
Water clarity preferences	Medium clarity / Medium turbidity Low clarity / High turbidity
Limiting nutrients	Data deficient
Other preferences	Clay

Additional information

This biotope occurs in predominantly turbid waters which are vital for the suspension feeders, the dominant trophic group. The three piddock species are likely to be fairly specific with regard to sediment preferences. *Petricola pholadiformis*, for example, requires a fairly soft but firm and stable sediment in which to live and in Britain, its upper limit is usually determined by a change in substratum (Duval, 1963a), namely a lack of appropriate substrata. Richter & Sarnthein (1976) looked at the re-colonization of different sediments by various molluscs on suspended platforms in Kiel Bay, Germany. They found that *Barnea candida* was restricted to clay, and occasionally fine sand, and that substrate type was certainly the most important factor for this species, in contrast to depth that was the primary factor for all other species. No information was found concerning the factors influencing the lower limits of their distribution.

The upper limit of mussel beds is often clear cut (see Lewis, 1964) and determined by physical factors such as temperature and desiccation, which may be synergistic, i.e. sudden mass mortalities at the upper limit of intertidal mussel beds are often associated with prolonged periods of unusually high temperatures and desiccation stress (Seed & Suchanek, 1992).

The lower limit of distribution is strongly influenced by predation, primarily from starfish but also dog whelks and crabs. Tsuchiya & Nishihira (1985, 1986) noted that increase sediment or silt build up within the mussel bed matrix, reduced the available space within the matrix, changing species composition, presumably in favour of infaunal invertebrates, and reduced species richness.

The high silt deposition environment is also favourable for deposit feeders which may include the ragworm *Hediste diversicolor* and mud shrimps *Corophium* spp.

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	Species name	Common Name
Key Structuring	*Barnea candida*	White piddock
Key Structuring	*Pholas dactylus*	Common piddock
Key Structuring	*Petricola pholadiformis*	American piddock
Key Structuring	*Mytilus edulis*	Common mussel

Explanation

The piddocks *Barnea candida*, *Pholas dactylus* and *Petricola pholadiformis* and the mussel *Mytilus edulis* are the key structuring species. The piddocks create an uneven surface, and empty burrow holes in clay platforms that provide habitats for other animals, greatly increasing species diversity of the biotope. The *Mytilus edulis* patches between the burrows also provide some heterogeneity to the substratum and additional surface area for attachment for epibionts including algal species. Within the mussel matrix, associated fauna may find refuge. In *Mytilus edulis* islands, biological activities such as suspension feeding and the production of biodeposits affect the process of community organization of the associated fauna (Tsuchiya & Nishihira, 1986). The periwinkle *Littorina littorea* is a grazer commonly associated with this biotope. However, it is unlikely to affect the community structure.

Species found especially in biotope

No text entered

Additional information

The MNCR reported 42 species from this biotope, although not all species occur in all examples of the biotope (JNCC, 1999). Tsuchiya & Nishihira (1986) found more than 40 different species associated with mussel patches approximately 500 cm² in size.

Biotope sensitivity

Physical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	Moderate	Moderate	Major Decline	High
Smothering	Intermediate	Moderate	Moderate	Major Decline	Moderate
Increase in suspended sediment	Low	Very high	Very Low	Decline	Moderate
Decrease in suspended sediment	Low	Very high	Very Low	Minor Decline	Low
Desiccation	Intermediate	High	Low	Minor Decline	Moderate
Increase in emergence regime	Intermediate	High	Low	Minor Decline	Low
Decrease in emergence regime	Intermediate	High	Low	Minor Decline	Low
Increase in water flow rate	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Decrease in water flow rate	Low	Very high	Very Low	No Change	Very low
Increase in temperature	Tolerant	Very high	Not sensitive	Rise	Very low
Decrease in temperature	Intermediate	Moderate	Moderate	Major Decline	High
Increase in turbidity	Low	Very high	Very Low	Minor Decline	Low
Decrease in turbidity	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Increase in wave exposure	High	Moderate	Moderate	Major Decline	Moderate
Decrease in wave exposure	Low	High	Low	Minor Decline	
Noise	Tolerant*	Not Relevant	Not sensitive*	Not Relevant	Low
Visual Presence	Tolerant*	Not Relevant	Not sensitive*	Not Relevant	Low
Abrasion & physical disturbance	Intermediate	Moderate	Moderate	Major Decline	Moderate
Displacement	High	Moderate	Moderate	Major Decline	Moderate
Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	Intermediate	High	Low	Decline	Low
Heavy metal contamination	Intermediate	High	Low	Decline	Very low
Hydrocarbon contamination	High	Moderate	Moderate	Major Decline	Moderate
Radionuclide contamination	Insufficient information	Not Relevant	Insufficient information	Insufficient Information	Not Relevant
Changes in nutrient levels	Intermediate	High	Low	Decline	Low
Increase in salinity	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Decrease in salinity	Low	High	Low	Minor Decline	Low
Changes in oxygenation	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant

Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Intermediate	High	Low	Minor Decline	Low
Introduction of non-native species	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Extraction of key or important characterizing species	Intermediate	High	Low	Minor Decline	Low
Extraction of important species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	Piddocks live permanently in burrows excavated into the substratum. Loss of the substratum will result in loss of the piddocks and loss of the biotope. Mussels will be similarly affected by the loss of substratum and an intolerance of high has been recorded. Recolonization by pelagic larvae is likely within five years although under certain conditions this may take significantly longer (see additional information below). A recoverability of moderate has been recorded assuming that clay remains after the removal event.
Smothering (see benchmark)	*Pholas dactylus* have been found living under layers of sand in Aberystwyth, Wales, (Knight, 1984) and in Eastbourne, with their siphons protruding at the surface (E. Pinn, pers. comm.). *Barnea candida* has also been found to survive being covered by shallow layers of sand in Merseyside (Wallace & Wallace, 1983). Wallace & Wallace (1983) were unsure as to how long the *Barnea candida* could survive smothering but noted that, on the coast of the Wirral, the piddocks have survived smothering after periods of rough weather. In contrast, the redistribution of loose material following storms off Whitstable Street, in the Thames Estuary, is thought to be responsible for the suffocation of many *Petricola pholadiformis* and it is possible that this species may be the most intolerant of the three piddock species associated with this biotope. However, it was not known how deep the layer of 'loose material' was, nor how long it lasted for or what type of material it was made up of. Intertidal *Mytilus edulis* beds have been reported to suffer mortalities as a result on smothering by large scale movements of sand or sand scour (Daly & Mathieson, 1977; Holt *et al.*, 1998). Similarly, biodeposition within a mussel bed results in suffocation or starvation of individuals that cannot re-surface. Young mussels have been shown to move up through a bed, avoiding smothering, while many others were suffocated (Dare, 1976; Holt *et al.*, 1998). Some gastropods including *Littorina littorea* have been recorded as being highly intolerant of smothering and may be suffocated by the sediment. A decrease in the number of *Littorina littorea* individuals, a prey species for *Carcinus maenas*, may increase predation pressure on the mussels. Smothering may also adversely affect interstitial fauna and epifauna, resulting in a decrease in species richness and an increase of infaunal species (Tsuchiya & Nishihira, 1985, 1986). However, on moderately wave exposed to wave exposed coasts sediment is unlikely to remain in place resulting in scour which may remove a proportion of the mussels and possible adversely affect the stability of the sediment surrounding piddock burrows in extensively bored clay. Scouring may be more detrimental to patches of mussels, as opposed to beds, since the patches will have a greater total

	patch edge:area ratio. Consequently, there will be relatively fewer mussels protected by the inside of the patch / bed. Overall it is suggested that a proportion of the *Mytilus edulis* population and of the piddock populations may be able to survive smothering. Therefore, an intolerance of intermediate has been recorded. Smothering by impermeable or immobile materials, e.g. oil, is likely to result in a higher intolerance (see hydrocarbons). Recoverability has been recorded as moderate (see additional information below).
Increase in suspended sediment (see benchmark)	This biotope (MLR.MytPid) occurs in areas associated with turbid water and the associated fauna are likely to be adapted to a certain degree of suspended sediment. An increase in the organic content of suspended sediment is likely to be beneficial to both suspension feeders and deposit feeders. Piddocks must function in burrows into which sediment is continuously deposited from the both particle-laden water above the burrow to the by-products of the piddock's own mechanical boring (Fankboner, 1971). The piddocks have efficient mechanisms to remove sediment via pseudofaeces. Experimental work on *Pholas dactylus* showed that large particles can either be rejected immediately in the pseudofaeces or passed very quickly through the gut (Knight, 1984). *Petricola pholadiformis* is able to cope in water laden with much suspended material by binding the material in mucus and using the palps to reject it (Purchon, 1955). *Mytilus edulis* has been reported to be relatively tolerant of suspended sediment and siltation and survived over 25 days at 440 mg/l and on average 13 days at 1200 mg/l (Purchon, 1937; Moore, 1977). *Mytilus edulis* also has efficient pseudofaeces discharge mechanisms (Moore, 1977; de Vooys, 1987), although increased suspended sediment may reduce feeding efficiency (Widdows *et al.*, 1998). In addition, super-abundant accumulation of sediments prevents the *Mytilus* larvae from settling to patches (Field, 1982, in Tsuchiya & Nishihira, 1986). Increased siltation may also interfere with larval recruitment in some macroalgae species. Increased siltation may fill the mussel matrix, resulting in increased abundance of infauna but loss of more mobile species and species richness (Tsuchiya & Nishihira, 1985, 1986). Certainly, the space for mussel spat and other small invertebrates to shelter between mussels will be reduced. Overall, the biotope will be little affected but species richness will probably decline and an intolerance of low has been recorded.
Decrease in suspended sediment (see benchmark)	A decrease in the volume of suspended sediment, especially organic particles, may reduce the amount of available food to *Pholas dactylus*, *Petricola pholadiformis*, *Barnea candida*, *Mytilus edulis* and other suspension feeders. A decrease in food consumption may have a temporary deleterious effect on growth rate and fecundity however, on resumption of normal levels of suspended sediment, the suspension feeders are likely to recover rapidly. The sediments within mussel patches are an important component that contributes to the heterogeneity of the environment and therefore to its diversity (Tsuchiya & Nishihira, 1986). A reduction in suspended sediment may therefore temporarily decrease the diversity of infaunal invertebrates within the mussel matrix. Overall, the biotope will be little affected and accordingly, an intolerance of low has been recorded.
Desiccation (see benchmark)	*Pholas dactylus* inhabits the shallow sub-tidal and lower shore and is therefore likely to have some tolerance to desiccation due to periodic immersion and emersion. *Barnea candida* and *Petricola pholadiformis* live slightly higher up the shore than *Pholas dactylus* (Duval, 1977) and are also likely to have a degree of tolerance. The fact that the piddocks live in burrows that are likely to retain some water when the tide falls will offer them further protection from desiccation. However, the shells of the piddocks are unable to close completely and this renders them susceptible to desiccation to a certain degree. An increase in

	desiccation at the level of the benchmark, equivalent to a change in position of one vertical biological zone is likely to result in the death of many individuals particularly at the upper shore extent of the population. The upper limit of *Mytilus edulis* population is primarily controlled by the synergistic effects of temperature and desiccation (Suchanek, 1978; Seed & Suchanek, 1992; Holt *et al.*, 1998). For example, on extremely hot days in the summers of 1974 -1976 on Strawberry Island, Washington State, Suchanek (1978) reported mass mortality of mussels at the upper edge of the mussel bed. Mortality decreased down the shore. The upper limit of mussels fluctuated, increasing up the shore in winter and decreasing again in summer (Suchanek, 1978). Therefore, an increase in desiccation at the benchmark level is likely to result in mortality of mussels at the upper limit of the bed, and loss of their associated organisms, with patches of mussels restricted to depressions and rocks pools at their upper limit. Similarly the upper limit of most intertidal species is partly determined by desiccation. *Ceramium virgatum*, for example, has been recorded as being highly intolerant to desiccation. Small invertebrates using small patches of this species for shelter may therefore be displaced or lost altogether. The entire biotope is likely to become 'squeezed' between a reduced upper limit and its lower limit. The biotope is likely to be more vulnerable to desiccation in moderately wave exposed conditions than in wave exposed conditions, since the latter tend to exhibit a greater humidity due to wash, spray and wave crash. Overall, the extent of the biotope is likely to be reduced and an intolerance of intermediate has been recorded. Recoverability is probably high (see additional information below).
Increase in emergence regime (see benchmark)	Piddocks are fixed in position in their burrows and are therefore unable to escape any changes in emergence through migration. The burrows are likely to retain some water when the tide falls and this will offer them some protection from desiccation. However, the shells of the piddocks are unable to close completely. During extended periods of exposure, *Pholas dactylus* squirt some water from their inhalant siphon and extend their gaping siphons into the air (Knight, 1984). This may result in increased predation by birds. An increase in emergence, equivalent to a one hour change in the time not covered by the sea for one year, is likely to result in the death of many individuals, particularly at the upper shore extent of the population. *Mytilus edulis* can only feed when immersed, therefore, changes in emergence regime will affect individuals ability to feed and their energy metabolism. Growth rates decrease with increasing shore height and tidal exposure, due to reduced time available for feeding and reduced food availability, although longevity increases (Seed & Suchanek, 1992; Holt *et al.*, 1998). Concomitant with the cessation of feeding during periods of exposure is the cessation of biodeposit production (Tsuchiya, 1980). Consequently, the amount of available food for deposit feeders such as *Hediste diversicolor* will be decreased. Increased emergence will expose mussel populations to increased risk of desiccation (see above) and increased vulnerability to extreme temperatures, potentially reducing their upper limit on the shore, and reducing their extent in the intertidal. Predation from birds such as the oyster catcher can reduce the number of mussel eggs released into the plankton and decrease the amount of byssal settlement space for the protection of the spat (McGrorty *et al.*, 1990). The result is likely to be a fall in recruitment to the mussel patches. Overall, the upper limit of the biotope and its associated community will probably decrease and an intolerance of intermediate has been recorded. Recoverability will probably be high (see additional information below).

Decrease in emergence regime (see benchmark)	A decrease in exposure to air will reduce exposure to desiccation and extremes of temperature and allow the resident *Pholas dactylus*, *Barnea candida*, *Petricola pholadiformis* and *Mytilus edulis* to feed for longer periods and hence grow faster. Piddocks and mussels are therefore likely to be tolerant of a decrease in emergence and as a result, the biotope may be able to colonize further up the shore, providing a suitable substrate was available. No information was found on factors controlling the lower limit of piddock populations and it is possible, for example, that predation may increase at the lower edge of the biotope. The lower limit of the mussel in the biotope may become susceptible to greater predation pressure from crabs resulting in greater turnover of individuals and a reduced number of size classes, and reduced age of mussels. Therefore, in the short term, a decrease in emergence is likely to change the population structure of the mussel bed and, possibly, the piddock populations at their lower limits, probably reducing the species richness of the biotope. Although the mussel patches and piddock populations will effectively survive, the lower limit of the biotope as described may be lost and an intolerance of intermediate has been recorded. This biotope will probably colonize further up the shore and recovery is likely to be high (see additional information below).
Increase in water flow rate (see benchmark)	This biotope occurs in moderately wave exposed and wave exposed habitats where water movement from wave action will probably exceed the strength of any water flow rate. At any rate, piddocks live fixed permanently in burrows and are therefore unlikely to be washed away or adversely affected by an increase in water flow rate. Mussels are firmly attached to the substratum but can be dislodged by storms and strong surges (see *MarLIN* review of *Mytilus edulis*). Overall, the biotope is considered to be tolerant of an increase in water flow rate.
Decrease in water flow rate (see benchmark)	This biotope occurs in moderately wave exposed and wave exposed habitats where water movement from wave action will probably exceed the strength of any water flow rate. If the biotope occurred in areas where water flow was more important to provide an adequate supply of food and prevent siltation some adverse effects on feeding and reproduction may occur. An intolerance of low has been recorded.
Increase in temperature (see benchmark)	Little information was found about the specific effects of increasing temperature on any of the three species of piddocks. However, the occurrence of *Pholas dactylus* in Britain is known to represent the northern limit of its distribution and an increase in temperature may therefore facilitate the extension of this species' presence further north. Temperature has also been implicated in the timing of reproduction in *Pholas dactylus*, which usually spawns at the end of August. Increased summer temperatures in 1982 induced spawning in July on the south coast of England (Knight, 1984). Spawning of the piddock *Petricola pholadiformis* is initiated by increasing water temperature (> 18 °C) (Duval, 1963a), so elevated temperatures outside of usual seasons may disrupt normal spawning periods. The spawning of *Barnea candida* was also reported to be disrupted by changes in temperature. *Barnea candida* normally spawns in September when temperatures are dropping (El-Maghraby, 1955). However, a rise in temperature in late June of 1956 induced spawning in some specimens of *Barnea candida* (Duval, 1963b). Disruption from established spawning periods, caused by temperature changes, may be detrimental to the survival of recruits as other factors influencing their survival may not be optimal, and some mortality may result. Established populations may otherwise remain unaffected by elevated temperatures. In laboratory studies, the majority of *Petricola pholadiformis* larvae did not survive beyond the veliger stage at 22 °C. However, it is unlikely that the species will experience these temperatures in British waters at the level of the benchmark.

	In the British Isles, an upper, sustained thermal tolerance limit of about 29 °C was reported in *Mytilus edulis* (Read & Cumming, 1967; Almada-Villela *et al.*, 1982). However, Seed & Suchanek (1992) noted that European populations were unlikely to experience temperatures greater than about 25 °C. *Mytilus edulis* is generally considered to be eurythermal. Temperature has been found to affect the amount of biodeposit produced by this animal. The optimum temperature for maximum biodeposit production was found to be approximately 20 °C (Tsuchiya, 1980). An increased amount of biodeposit produced by the mussels, associated with an increase in temperature, could increase the amount of potential habitat for infaunal species and increase the amount of available food for deposit feeders. Overall, the dominant characterizing species will probably survive an increase in temperature at the benchmark level and it is possible that the diversity of associated fauna may even increase slightly. In balance, tolerant has been recorded.
Decrease in temperature (see benchmark)	Little information concerning the effects of a decrease in temperature on piddock species was found. In *Pholas dactylus*, the siphon activity and oxygen consumption was considerably reduced at a temperature of 7 °C when compared to behaviour at 15 and 18 °C where the animals were observed to be siphoning actively (Knight, 1984). Crisp (1964) reported that no living individuals of *Pholas dactylus* could be found above low-water mark in Lyme Regis on the south coast of England during the extreme winter of 1962-3. In the same winter, J. Taylor (pers. comm. to Knight, 1984) mentioned a number of *Pholas dactylus* were found frozen in the chalk at Margate in Kent. Eunice Pinn (pers. comm. to *MarLIN*) said that cold certainly kills individuals. Overall, *Mytilus edulis* is considered to be eurythermal. *Mytilus edulis* can withstand extreme cold and freezing, surviving when its tissue temperature drops to -10 °C (Williams, 1970; Seed & Suchanek, 1992) or exposed to -30 °C for as long as six hours twice a day (Loomis, 1995). Bourget (1983) also reported that cyclic exposure to otherwise sublethal temperatures, e.g. -8 °C every 12.4 hrs resulted in significant damage and death after 3-4 cycles. This suggests that *Mytilus edulis* can survive occasional, sharp frost events but may succumb to consistent very low temperatures over a few days. *Mytilus edulis* was relatively little affected by the severe winter of 1962/63, with 30% mortality reported from south-east coasts of England (Whitstable area) and ca. 2% from Rhosilli in south Wales (Crisp, 1964) mainly due to predation on individuals weakened or moribund due to the low temperatures rather than the temperature itself. Overall, the dominant key structural species, namely the piddocks, are likely to experience some mortality. A long term, chronic change in temperature similar to that of the benchmark could ultimately result in the loss of a significant proportion of the biotope. Accordingly, an intolerance of intermediate has been recorded. Recolonization by pelagic larvae is likely within five years although under certain conditions this may take significantly longer (see additional information below). A recoverability of moderate has been recorded.
Increase in turbidity (see benchmark)	Increased turbidity may reduce phytoplankton primary productivity, therefore reducing the food available to *Pholas dactylus*, *Petricola pholadiformis*, *Barnea candida*, *Mytilus edulis* and other suspension feeders. However, mussels use a variety of food sources and the effects are likely to be minimal, and this species is probably not sensitive to changes in turbidity. No information concerning the effects of an increase in turbidity on piddocks was found. Increased turbidity will decrease photosynthesis and primary productivity in seaweeds when immersed but they will probably be able to compensate when emersed. In any case, the seaweeds in this biotope only represent a small part of the total flora and fauna. An intolerance of low has been recorded.

Decrease in turbidity (see benchmark)	Decreased turbidity may increase phytoplankton primary productivity, therefore potentially increasing the food available to *Pholas dactylus*, *Petricola pholadiformis*, *Barnea candida*, *Mytilus edulis* and other suspension feeders. Macroalgae may benefit from decreased turbidity resulting in rapid growth, especially of ephemeral green algae. This will, in turn, increase the available food for grazers including *Littorina littorea*. Therefore, tolerant has been recorded.
Increase in wave exposure (see benchmark)	This biotope occurs in moderately wave exposed to wave exposed locations. *Pholas dactylus*, *Petricola pholadiformis* and *Barnea candida* are protected to a certain degree due to their fixed position within the burrow. However, Wallace & Wallace (1983) reported that the clay crumbled easily around the piddocks where there were dense aggregations of the animals, as would certainly be the case in this biotope. Wallace & Wallace (1983) reported densities of 30-60 *Barnea candida* siphon holes per square foot in Merseyside and burrows up to 6 inches deep. Duval (1977) found that the depth of the boring depended on the size of the animal. For example, an animal with a shell length of 1.2 cm could bore a 2.7 cm burrow whereas animals 4.8 cm long could bore burrows of 12 cm. An increase from, for example, wave exposed to extremely wave exposed may threaten the viability of the sediment in which the piddocks dwell. If the clay then started to erode it may result in loss of the piddock burrows, especially those of smaller animals, and ultimately the loss of the biotope. Duval (1963a) found that displaced piddocks made no attempt at a second boring when placed on a consolidated substratum. Mussels are tolerant of wave exposure and increase their byssus thread production (and hence attachment) with increased by water agitation (Young, 1985). However, Young (1985) concluded that mussels would be susceptible to sudden squalls and surges. Fouling organisms, e.g. barnacles and seaweeds, may also increase mussel mortality by increasing weight and drag, resulting in an increased risk of removal by wave action and tidal scour (Suchanek, 1985; Seed & Suchanek, 1992). Winter storms and increased wave exposure are likely to result in removal of patches of mussels. Loss of patches may lead to further sediment instability and piddock loss. In *Mytilus californianus* gaps were enlarged during winter, while recolonization and recovery rates increased in summer (Seed & Suchanek, 1992). Sediment and decaying matter may be 'flushed' from remaining mussel patches which will lead to a reduction in numbers of infauna and scavengers such as the common ragworm *Hediste diversicolor*. Mussel spat, that use the byssal threads of the adults in the patches as refuge from the common shore crabs, *Carcinus maenas*, may also be dislodged leaving them more susceptible to predation. A reduction in macroalgae will result in loss of associated mesoherbivores. Similarly, mobile gastropods such as littorinids are likely to be lost. Overall, an increase in wave exposure is likely to result in major decline in key structural species and an intolerance of high has been recorded. Recoverability will probably be moderate (see additional information below).
Decrease in wave exposure (see benchmark)	*Mytilus edulis* is tolerant of sheltered conditions and a reduced wave exposure may leave to a build-up of sediment and biodeposits within the mussel patches. This could result in increased scavenger and infauna diversity. Alternatively, the reduced wave exposure may lead to dominance by certain invertebrate species and therefore a decrease in species diversity. It is unlikely that piddocks will be adversely affected by a decrease in wave exposure. However, the supply of particulate matter for suspension feeding may be reduced and therefore an intolerance of low has been recorded.
Noise (see benchmark)	Most of the invertebrates within the community are probably not sensitive to noise at the benchmark level. *Pholas dactylus* can probably detect the vibration caused by predators and will withdraw its siphons, ejecting water from the burrow as it

	does so. *Mytilus edulis* can probably detect slight vibrations in its immediate vicinity, however, it probably detects predators by touch (on the shell) or by scent. Therefore, it is probably insensitive to noise disturbance at the levels of the benchmark. Birds are major predators of mussels and piddocks, and several species are highly intolerant of noise. Therefore, noise at the level of the benchmark may disturb predatory birds, so that the mussel and piddock populations may benefit indirectly.
Visual Presence (see benchmark)	*Pholas dactylus* reacts quickly to changes in light intensity, after a couple of seconds, by withdrawing its siphon (Knight, 1984). This reaction is ultimately an adaptation to reduce the risk of predation by, for example, approaching birds (Knight, 1984). *Mytilus edulis* can probably detect changes in light commensurate with shading by predators as well. However, its visual acuity is probably very limited and it is unlikely to be sensitive to visual disturbance. Birds are highly intolerant of visual presence and are likely to be scared away by increased human activity, therefore reducing the predation pressure on the mussels and piddocks. Therefore, visual disturbance may be of indirect benefit to mussel and piddock populations.
Abrasion & physical disturbance (see benchmark)	The shell of *Pholas dactylus* is thin and brittle so a force equivalent to a 5-10 kg anchor and its chain being dropped or a passing scallop dredge is likely to result in death. Although the piddocks are afforded some protection by living in their burrows, the clay is soft which leaves many individuals, especially those near the surface of the clay, vulnerable to damage and death. Duval (1977) found that the depth of the boring depended on the size of the animal. For example, an animal with a shell length of 1.2 cm could bore a 2.7 cm burrow whereas animals 4.8 cm long could bore burrows of 12 cm. Daly & Mathieson (1977) reported that the lower limit of *Mytilus edulis* populations at Bound Rock, USA, was determined by burial or abrasion by shifting sands. Wave driven logs have been reported to influence *Mytilus edulis* populations causing the removal of patches. It is likely that abrasion or impact at the level of the benchmark would also damage or remove patches of the population. The effects of trampling on *Mytilus californianus* beds in Australia were studied by Brosnan & Cumrine (1994). They concluded that mussel beds were intolerant of trampling, depending on bed thickness, and noted that in heavily tramped site mussels were uncommon and restricted to crevices. Trampling also inhibited subsequent recovery. Trampling pressure was most intense in spring and summer, so that gaps and patches created by storms in winter were not repaired but exacerbated. Patches are likely to be even more susceptible to damage than the beds mentioned in the above study. Therefore, it is likely that abrasion and physical disturbance at the benchmark level will result in loss of a proportion of the piddocks populations and mussel patches and their associated species and an intolerance of intermediate has been recorded. Recoverability is likely to be moderate (see additional information below). The effects of large scale abrasion e.g. due to a vessel grounding, is likely to be similar to substratum loss.
Displacement (see benchmark)	The key structural species in this biotope are sessile. Duval (1963a) reported that neither juvenile nor adult *Petricola pholadiformis* attempted to re-bore after being left on the surface of consolidated substrata. *Pholas dactylus* has also been reported to be incapable of excavating a new chamber (Barnes, 1980). The piddocks, therefore, are likely to be highly intolerant to displacement due to increased risk of predation and desiccation. Dare (1976) reported that individual mussels swept or displaced from mussel beds rarely survived, since they either became buried in sand or mud, or were scattered

	and eaten by oystercatchers. However, mussels can attach to a wide range of substrata and, should a mussel be displaced to a suitable substratum, it is likely to be able to attach itself using byssus threads quickly. Mobile gastropods may be washed to deeper water, only to return, while mobile crustaceans are unlikely to be adversely affected. However, displacement would result in removal of the mussel patches and piddocks, and loss of their associated community, and hence the biotope. Intolerance has, therefore, been recorded as high. Recoverability is likely to be moderate (see additional information below).
Chemical Factors	
Synthetic compound contamination (see benchmark)	Although no information on the specific effects of chemicals on the three piddock species was found, tributyl tin (TBT) has been found to be toxic to many bivalves. See, for example, Beaumont *et al.*, 1989. Michelson (1978, cited in Knight, 1984) suggested that the dispersants used to clean up oil spills may have been responsible for the disappearance of the French colonies of *Pholas dactylus*. *Mytilus edulis* species were extensively reviewed by Widdows & Donkin, (1992) and Livingstone & Pipe (1992), and summarized in the *MarLIN* review and Holt *et al.* (1998). A variety of chemical contaminants have been shown to produce sublethal effects and reduce scope for growth (e.g. PCBs, and organo-chlorides) (Widdows *et al.*, 1995), while others (e.g. the detergent BP1002, the herbicide trifluralin and TBT) cause mortalities. Similarly, most pesticides and herbicides were suggested to be very toxic for invertebrates, especially crustaceans (amphipods, isopods, mysids, shrimp and crabs) (Cole *et al.*, 1999). The pesticide Ivermectin is very toxic to crustaceans, and has been found to be toxic towards some benthic infauna (Cole *et al.*, 1999). The common shore crabs *Carcinus maenas* are susceptible to various synthetic compounds including cypermethrin, a chemical used to treat salmon for fish lice, and DDT (see *MarLIN* review of *Carcinus maenas*). Laboratory studies of the effects of oil and dispersants on several red algae species (Grandy, 1984, cited in Holt *et al.*, 1995) concluded that they were all sensitive to oil/ dispersant mixtures, with little differences between adults, sporelings, diploid or haploid life stages. O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination. *Ceramium virgatum*, for example, has been recorded as being highly intolerant to synthetic chemicals (see *MarLIN* review). Loss of intolerant epifaunal and epifloral grazers such as gastropods may result in an increase in fouling of the mussels themselves by algae. Overall, a number of chemical contaminants are likely to result in reduced growth and condition and loss of a proportion of the mussel and piddock populations while the species richness may show a marked decline. Therefore an intolerance of intermediate has been recorded. Recoverability is probably high (see additional information below).
Heavy metal contamination (see benchmark)	Heavy metal contamination affects different taxonomic groups and species to varying degrees. • The effects of contaminants on *Mytilus edulis* were extensively reviewed by Widdows & Donkin, (1992) and Livingstone & Pipe (1992), and summarized in the *MarLIN* review. Heavy metals were reported to cause sublethal effects and occasionally mortalities in mixed effluents. • Bryan (1984) suggested that adult gastropod molluscs (e.g. *Littorina littorea*) were relatively tolerant of heavy metal pollution. • Crustaceans are generally regarded to be intolerant of cadmium (McLusky

	et al., 1986). • Bryan (1984) suggested that the general order for heavy metal toxicity in seaweeds is: Organic Hg > inorganic Hg > Cu > Ag > Zn > Cd > Pb. Cole *et al.* (1999) reported that Hg was very toxic to macrophytes. No information concerning the effects of heavy metals on piddocks was found. However, Bryan (1984) stated that Hg is the most toxic metal to bivalve molluscs and that mortalities occurred above 0.1-1 µg/l after 4-14 days of exposure (Crompton, 1997). *Scrobicularia plana*, another burrowing bivalve, was absent from large areas of metal polluted intertidal mud in the Fal estuary, Cornwall, where under normal conditions it would account for a large amount of the biomass (Bryan & Gibbs, 1983). This was thought to be a consequence of the mussels spending so much time avoiding contact with the metals, via valve closure, that they died of anoxia and starvation. Overall, a proportion of the mussel bed and piddock population is likely to be lost. A loss of mesoherbivores, crabs and red algal species will lead to a decline in species richness. Therefore, an intolerance of intermediate has been recorded but with very low confidence. Recoverability will probably be high (see additional information below).
Hydrocarbon contamination (see benchmark)	Hydrocarbon contamination, e.g. from spills of fresh crude oil or petroleum products, may cause significant loss of component species in the biotope, through impacts on individual species viability or mortality, and resultant effects on the structure of the community. • Michelson (1978) suggested that oil pollution, and the dispersants used to clean it up, may have been responsible for the disappearance of populations of *Pholas dactylus* in Brittany, France. However, no other information concerning the specific effects of hydrocarbon was found. • The effects of contaminants on *Mytilus edulis* species were extensively reviewed by Widdows & Donkin, (1992) and Livingstone & Pipe (1992), and summarized in the *MarLIN* review and Holt *et al.* (1998). Overall, hydrocarbon tissue burden results in decreased scope for growth and in some circumstances may result in mortalities, reduced abundance or extent of *Mytilus edulis* (see *MarLIN* Web site). • *Littorina littorea* has been recorded as being highly intolerant to hydrocarbon contamination (see Suchanek, 1993). The abundance of *Littorina littorea* and other littorinids were reduced after the *Esso Bernica* oil spill in Sullom Voe in December 1978 but had returned to pre-spill levels by May 1979 (Moore *et al.*, 1995). In heavily impacted sites, subjected to clean-up where communities were destroyed in the process, *Littorina littorea* took ca 7 years to recover prior abundance (Moore *et al.*, 1995). Widdows *et al.* (1981) found *Littorina littorea* surviving in a rockpool, exposed to chronic hydrocarbon contamination due to the presence of oil from the *Esso Bernica* oil spill. A decrease in abundance of *Littorina littorea*, a prey species for *Carcinus maenas*, may increase predation pressure on the mussels. • *Ulva intestinalis* and *Ceramium virgatum* have also recorded as being highly intolerant to hydrocarbon contamination. Laboratory studies of the effects of oil and dispersants on several red algae species (Grandy, 1984, cited in Holt *et al.* 1995) concluded that they were all intolerant of oil/ dispersant mixtures, with little differences between adults, sporelings, diploid or haploid life stages. O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination. The loss of these species may reduce the abundance of cryptic fauna and herbivores. • The common shore crab *Carcinus maenas* has been recorded as having a high intolerance to hydrocarbon contamination (see *MarLIN* review of this species).

	The mussels may succumb directly to smothering by oil which is likely to be retained within the mussel matrix resulting is additional mortality to interstitial and infauna species. Although a proportion of the mussel population may survive hydrocarbon contamination, the additional effects on the community and potential for smothering suggest that the biotope will be lost. Similarly, oil on the shore is likely to collect in the vertical burrows of the piddocks which may lead to suffocation and increased mortality. Therefore, an intolerance of high has been recorded. On wave exposed rocky coasts oil will be removed relatively quickly. Recovery of rocky shore populations was intensively studied after the *Torrey Canyon* oil spill in March 1967. On shores that were not subject to clean-up procedures, the community recovered within ca 3 years, however, in shores treated with dispersants recovery took 5-8 years but was estimated to take up to 15 years on the worst affected shores (Southward & Southward, 1978; Hawkins & Southward, 1992; Raffaelli & Hawkins, 1999). Therefore, a recoverability of moderate has been recorded (see additional information below).
Radionuclide contamination (see benchmark)	Insufficient information
Changes in nutrient levels (see benchmark)	*Pholas dactylus, Petricola pholadiformis, Barnea candida* and *Mytilus edulis* may benefit from moderate nutrient enrichment, especially in the form of organic particulates and dissolved organic matter. The resultant increased food availability may increase growth rates and reproductive potential, and reduce vulnerability to predators. However, filter feeders are likely to accumulate toxins from toxic algae which may be associated with areas of nutrient enrichment and algal blooms. The accumulation of such toxins in mussels has resulted in the closure of shellfish beds (Shumway, 1992). The toxic algal blooms themselves (or deoxygenation resulting from their death) have been shown to cause tumours, sublethal effects, and reproductive failure and to be highly toxic to *Mytilus edulis* (Pieters *et al*., 1980; Shumway, 1990; Landsberg, 1996). Nutrient enrichment may lead to an increase in algal growth but also lead to eutrophication and associated increases in turbidity and suspended sediments (see above), deoxygenation (see below) and the risk of algal blooms. Increased nutrients may increase growth in fast growing species (e.g. *Ulva* spp.) to the detriment of slower growing species of macroalgae. An increase in ephemeral algae may be detrimental to the mussel bed due to smothering of the mussels and increased drag which will render the mussels more susceptible to dislodgement during increased wave exposure (see above). Therefore, algal blooms may result in loss of a proportion of the biotope and its associated species and an intolerance of intermediate has been recorded. Recoverability is probably high (see additional information).
Increase in salinity (see benchmark)	This biotope occurs in intertidal areas and will therefore be exposed to some changes in salinity due to precipitation and evaporation. It is possible that piddock burrows may act as a buffer to protect them against large changes in salinity although when the water eventually evaporates from burrows exposed to air at low tide, hypersaline conditions may occur in the burrow. However, the piddocks experience this change on a cyclical basis. *Mytilus edulis* is considered tolerant of a wide range of salinities (Holt *et al*., 1998). Therefore tolerant has been suggested.
Decrease in salinity (see benchmark)	This biotope occurs in intertidal areas and will therefore be exposed to some changes in salinity due to precipitation and evaporation. Only limited information was found on the effects of a decrease in salinity on piddock populations. It is possible that their burrows may act as a buffer to protect them against large

	changes in salinity. Fish & Fish (1996) stated that *Barnea candida* can live in water with a salinity as low as 20 ppt in estuaries. *Petricola pholadiformis* is particularly common off the Essex and Thames estuary, e.g. the River Medway (Bamber, 1985) suggesting tolerance of brackish waters. Hyposaline conditions (20% of normal seawater) adversely affected the uptake of glycine in *Pholas dactylus* (Knight, 1984). It is possible that if fresh water collects in the vertical burrows after, for example, an extended period of rain at low tide, hyposaline conditions may occur temporarily. However, given the short amount of time in which the piddocks could be affected, i.e. low tide, it is unlikely that the piddocks will suffer an enduring adverse effect. *Mytilus edulis* is considered to be tolerant of a wide range of salinity (see *MarLIN* Web site for details). The intertidal interstitial invertebrates and epifauna probably experience short term fluctuating salinities, with increased salinity due to evaporation or reduced salinities due to rainfall and freshwater runoff when emersed. Prolonged reduction in salinity, e.g. from full to reduced may reduce species richness of the biotope. However, the dominant species will probably survive and accordingly, an intolerance of low has been suggested, together with a decline in species richness. Recoverability is likely to be high (see additional information below).
Changes in oxygenation (see benchmark)	Duval (1963a) observed that conditions within the burrows of *Petricola pholadiformis* were anaerobic and lined with a loose blue/black sludge, suggesting that the species may be relatively tolerant to conditions of reduced oxygen. Knight (1984) reported that *Pholas dactylus* could survive for 17 hours at 5% oxygen saturation of seawater (approximately 0.33 ml/l dissolved oxygen) and, on return to 90% oxygen saturated seawater, functioned entirely as normal. However, decreasing oxygen levels could also result in water being squirted from the inhalant siphon in this species and the siphon may also be extended into the air during periods of low oxygen (Knight, 1984). This could ultimately lead to an increase in predation. However, in moderately wave exposed to exposed habitats the resultant water movement and turbulence probably provides adequate oxygenation so that deoxygenation at the benchmark is unlikely to occur except under extreme circumstances. Accordingly, tolerant has been suggested.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	A ciliated protozoan, *Syncilancistrumina elegantissima*, has been found associated with *Pholas dactylus* and may be specific to this host (Knight & Thorne, 1982). However, the effects of this parasite are unknown. Information concerning the effects of diseases or parasites on the other two piddock species was not available. *Mytilus* spp. host a wide variety of disease organisms and parasites from many animal and plant groups including bacteria, blue green algae, protozoa, boring sponges, boring polychaetes, boring lichen, the intermediary life stages of several trematodes, the copepod *Mytilicola intestinalis* (red worm disease) and decapods e.g. the pea crab *Pinnotheres pisum* (Bower, 1992; Bower & McGladdery, 1996). Bower (1992) noted that mortality from parasitic infestation in *Mytilus* sp. was lower than in other shellfish in which the same parasites or diseases occurred. Mortality may result from the shell boring species such as the polychaete *Polydora ciliata* or sponge *Cliona celata*, which weaken the shell increasing the mussels vulnerability to predation (see *MarLIN* review for details). Overall, the occurrence of diseases and parasites are probably highly variable but significant infestations may result in loss of a proportion of the mussel population, either through mortality or reproductive failure. Therefore, an intolerance of intermediate has been recorded. Recovery is likely to be high (see additional information below).

Introduction of non-native species (see benchmark)	The American piddock, *Petricola pholadiformis* is a non-native, boring piddock that was unintentionally introduced from America with the American oyster, *Crassostrea virginica*, not later than 1890 (Naylor, 1957). Rosenthal (1980) suggested that, from the British Isles, the species has colonized several northern European countries by means of its pelagic larva and may also spread via driftwood, although it usually bores into clay, peat or soft rock shores. In Belgium and The Netherlands *Petricola pholadiformis* has almost completely displaced the native piddock, *Barnea candida* (ICES, 1972). However, there is no documentary evidence to suggest that *Barnea candida* has been displaced in the British Isles (J. Light & I. Kileen, pers. comm. to Eno *et al.*, 1997). The Australian barnacle *Elminius modestus* may also occur in this biotope. Overall, there is little evidence of this biotope being adversely affected by non-native species. *Petricola pholadiformis* and *Barnea candida* co-occur in this biotope; therefore an assessment of tolerant has been made.
Extraction of key or important characterizing species (see benchmark)	The only regularly harvested key species to occur in this biotope is *Mytilus edulis*. *Pholas dactylus* is also known to be harvested in Britain but not to the same extent. In Italy, harvesting of piddocks has had a destructive impact on habitats and has now been banned (E. Pinn, pers. comm. to *MarLIN*). In Britain, collection of piddocks is thought to have a similarly destructive effect. People have been known to go out onto the shore and, with the use of a hammer and chisel, excavate the piddocks from the soft rock (K. Hiscock, pers. comm.). This would be catastrophic for the biotope. The stability of the soft rock would be reduced and potentially lead to the loss of the vast majority of piddocks that inhabit the top few centimetres of the substratum. Farming methods are being investigated as an alternative and it is therefore possible that further targeted extraction could be a future possibility. Holt *et al.* (1998) suggest that when collected by hand at moderate levels using traditional skills mussel beds will probably retain most of their biodiversity. They also cite incidences of over-exploitation of easily accessible small beds by anglers for bait. Holt *et al*. (1998) suggest that in particular embayments over-exploitation may reduce subsequent recruitment leading to long term reduction in the population or stock. Due to the position of this biotope within the eulittoral and the fact that the mussel patches are likely to be small, removal of a significant proportion of the *Mytilus edulis* is unlikely. However, even a small amount of piddock exploitation would lead to the loss of a proportion of the biotope and accordingly, intolerance has been assessed as intermediate.
Extraction of important species (see benchmark)	Few other species in the biotope are likely to be subject to extraction. Collection of *Littorina littorea* is likely to reduce its abundance. However, the effects on the biotope as a whole are likely to be slight. Not relevant is suggested.

Additional information

Richter & Sarnthein (1976) looked at the re-colonization of different sediments by various molluscs on suspended platforms in Kiel Bay, Germany. The platforms were suspended at 11, 15 and 19 m water depth, each containing three round containers filled with clay, sand, or gravel. Substratum type was found to be the most important factor for the piddock *Barnea candida*, although for all other species it was depth. This highlights the significance of the availability of a suitable substratum to the recovery of piddock species. Richter & Sarnthein (1976) found that within the two year study period the piddocks grew to represent up to 98% of molluscan fauna on clay platforms. Piddock species have also shown very high growth rates of up to 54 mm in 30 months in the laboratory (Arntz & Rumohr, 1973). However, the process of colonization on clay at 15 and 19 m was found to be highly discontinuous, as reflected by the repeated growth and decrease of specimen numbers. In addition, *Mytilus edulis* showed temporary dominance on clay, linked to heavy settlement by *Mytilus edulis* larvae. Duval (1977) proposed that it was as a result of the extensive borings of *Barnea candida* that facilitated the colonization of an area in the Thames Estuary by the introduced American piddock, *Petricola pholadiformis*. This suggests that *Barnea candida* is a more competitive colonizing species in clay environments than the American piddock and it is possible that this species will appear first on cleared substrates. Recolonization of the piddock component by pelagic larvae is likely to occur within five years, although possibly not to its original abundance. The sporadic colonization seen in the Kiel Bay experiment above should also be noted.

Mytilus edulis is highly fecund but larval mortality is high. Indeed this is probably true of most bivalves. Larval development occurs within the plankton over ca 1 month (or more), with high dispersal potential. Recruitment within the population is possible when larvae may be entrained within enclosed coasts but it is likely that larval produced in open coast examples of the biotope are swept away from the biotope to settle elsewhere. Larval supply and settlement could potentially occur annually. However, settlement is sporadic with unpredictable pulses of recruitment (Lutz & Kennish, 1992; Seed & Suchanek, 1992). Once settled, *Mytilus edulis* can reproduce within its first year if growth conditions allow. High intertidal and less exposed sites recovered slower than low shore, more exposed sites. *Mytilus* spp. populations were considered to have a strong ability to recover from environmental disturbance (Seed & Suchanek, 1992; Holt *et al.*, 1998). While good annual recruitment is possible, recovery of gaps in the mussel population may take up to 5 years. However, where the biotope is significantly damaged, recovery of the mussel population may be delayed by 1-7 years.

Therefore, a recognizable biotope may take between 5 -10 years to recover depending on local conditions. However, it should be noted that in certain circumstances and under some environmental conditions recovery may take significantly longer.

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (see Appendix 3).

Physical factors		
	Pholas dactylus	***Mytilus edulis***
Community Importance	Key Structuring	Key Structuring
Substratum Loss	High	High
Smothering	Low	Intermediate
Increase in suspended sediment	Low	Low
Decrease in suspended sediment	See explanation	Low
Desiccation	Intermediate	Low
Increase in emergence regime	Intermediate	Low
Decrease in emergence regime	See explanation	Low
Increase in water flow rate	Low	Low
Decrease in water flow rate	See explanation	Low
Increase in temperature	Intermediate	Low
Decrease in temperature	See explanation	Low
Increase in turbidity	Low	Not Sensitive
Decrease in turbidity	See explanation	Not Sensitive
Increase in wave exposure	Low	Intermediate
Decrease in wave exposure	See explanation	Intermediate
Noise	Low	Not Sensitive*
Visual Presence	Low	Not Sensitive*
Abrasion & physical disturbance	Intermediate	Intermediate
Displacement	High	Intermediate
Chemical factors		
	Pholas dactylus	***Mytilus edulis***
Community Importance	Key Structuring	Key Structuring
Synthetic compound contamination	High	Intermediate

Heavy metal contamination	Intermediate	Intermediate
Hydrocarbon contamination	Insufficient information	Intermediate
Radionuclide contamination	Insufficient information	Insufficient information
Changes in nutrient levels	Insufficient information	Intermediate
Increase in salinity	Intermediate	Low
Decrease in salinity	See explanation	Low
Changes in oxygenation	Low	Low
Biological factors		
	Pholas dactylus	***Mytilus edulis***
Community Importance	Key Structuring	Key Structuring
Introduction of microbial pathogens/parasites	Insufficient information	Intermediate
Introduction of non-native species	Not Sensitive	Insufficient information
Extraction of this species	Intermediate	Intermediate
Extraction of other species	Not Sensitive	Low

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors		
	Pholas dactylus	***Mytilus edulis***
Community Importance	Key Structuring	Key Structuring
Substratum Loss	High	High
Smothering	High	High
Increase in suspended sediment	High	Immediate
Decrease in suspended sediment	See explanation	Immediate
Desiccation	High	Immediate
Increase in emergence regime	High	Very high
Decrease in emergence regime	See explanation	Very high
Increase in water flow rate	Very high	Very high
Decrease in water flow rate	See explanation	Very high
Increase in temperature	High	Very high
Decrease in temperature	See explanation	Very high
Increase in turbidity	Immediate	Not Relevant
Decrease in turbidity	See explanation	Not Relevant
Increase in wave exposure	High	High
Decrease in wave exposure	See explanation	High
Noise	Immediate	Not Relevant
Visual Presence	Immediate	Not Relevant
Abrasion & physical disturbance	High	High
Displacement	High	High
Chemical factors		
	Pholas dactylus	***Mytilus edulis***
Community Importance	Key Structuring	Key Structuring
Synthetic compound contamination	High	High
Heavy metal contamination	High	High
Hydrocarbon contamination	Insufficient information	High
Radionuclide contamination	Insufficient information	Not Relevant
Changes in nutrient levels	Insufficient information	High
Increase in salinity	High	Very high

Decrease in salinity	See explanation	Very high
Changes in oxygenation	High	Very high
Biological factors		
	Pholas dactylus	***Mytilus edulis***
Community Importance	Key Structuring	Key Structuring
Introduction of microbial pathogens/parasites	Not Relevant	High
Introduction of non-native species	Not Relevant	Not Relevant
Extraction of this species	High	High
Extraction of other species	Insufficient information	Very high

Importance

Marine natural heritage importance

Listed under:	**EC Habitats Directive**
National importance	Rare
Habitat Directive feature (Annex 1)	Reefs Large shallow inlets and bays Estuaries

Biotope importance

Dense beds of bivalve suspension feeders increase turnover of nutrients and organic carbon in estuarine (and presumably coastal) environments by effectively transferring pelagic phytoplanktonic primary production to secondary production (pelagic-benthic coupling) (Dame, 1996). Suspension feeding *Mytilus* beds can deplete the seston (organic particulates) available downstream of them and are probably important in energy flow within the wider ecosystem (Holt *et al.*, 1998). Mussel eggs and larvae from mussel beds (including subtidal beds) are probably an important food source for herring larvae and other zooplankton (Kautsky 1981; Seed & Suchanek, 1992).

The *Mytilus edulis* beds provide an important food source for *Carcinus maenas* and may provide refuge for other fauna (see habitat complexity above). *Mytilus edulis* are important food sources for wildfowl, and *Mytilus* is a staple food for oystercatchers and eider ducks. For example, unprecedented low stocks of *Mytilus edulis* in the Dutch Wadden Sea resulted in eider ducks either dying or leaving the area, while oystercatchers sought alternative food, depleting stocks of *Mya arenaria* and *Cerastoderma edule* (Holt *et al*, 1998). The piddocks may also represent an important food source for wildfowl and wading birds. In addition, their empty burrows provide habitat for associated fauna (see habitat complexity above).

Exploitation

Large *Mytilus edulis* reefs and beds have been the subject of fisheries for at least the past 100 years, and *Mytilus edulis* is also the subject of cultivation (Holt *et al*., 1998). However, small, eulittoral patches are highly unlikely to be subject to large scale exploitation. See sensitivity section for further detail.

Pholas dactylus is also known to be harvested in Britain but not to the same extent. In Italy, harvesting of piddocks has had a destructive impact on habitats and has now been banned (E. Pinn, pers. comm. to *MarLIN*). In Britain, collection of piddocks is thought to have a similarly destructive effect. People have been known to go out onto the shore and, with the use of a hammer and chisel, excavate the piddocks from the soft rock (K. Hiscock, pers. comm.). Farming methods are being investigated as an alternative and it is therefore possible that further targeted extraction could be a future possibility.

Additional information

The mussels and piddocks in this intertidal biotope may represent an important food source for wildfowl and wading birds.

This Biology and Sensitivity Key Information review can be cited as follows:
Marshall, C.E., 2004. *Mytilus edulis* and piddocks on eulittoral firm clay. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 19/01/2005]. Available from: <http://www.marlin.ac.uk>

Ceramium sp. and piddocks on eulittoral fossilized peat (MLR.RPid)

Key information authored by: Georgina Budd

Last updated 28/11/2002

This information is not refereed.

Piddock bored rock with red algae. Image width ca 1 m (foreground).
Image: Rohan Holt / Joint Nature Conservation Committee

Recorded and expected MLR.RPid distribution for Britain and Ireland

Description of biotope

Outcrops of fossilized peat in the eulittoral are soft enough to allow a variety of piddocks (such as *Barnea candida* and *Petricola pholadiformis*) to bore into them. The surface of the peat is characterized by a dense algal mat, predominantly *Ceramium* spp. but also with *Ulva* spp. and *Polysiphonia* spp. Damp areas amongst the algal mat are covered by aggregations of the sand mason worm *Lanice conchilega* and the fan worm *Sabella pavonina*. The anemone *Sagartia troglodytes* and the crabs *Carcinus maenas* and *Cancer pagurus* occur in crevices in the peat. Small pools on the peat may contain hydroids, such as *Obelia longissima* and *Kirchenpaueria pinnata*, the brown alga *Dictyota dichotoma* and the prawn *Crangon crangon*. [Description derived largely from sites in north Norfolk. Further records of this biotope required]. (Information taken from the Marine Biotope Classification for Britain and Ireland, Version 97.06: Connor *et al.*, 1997a, b).

Welsh Variation

Red algae are not always found in Welsh examples of this biotope. Welsh examples are generally less species rich and often only *Barnea candida* are found on the peat e.g. in Swansea Bay. See Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

No text entered

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Habitat complex	MLR	Moderately exposed littoral rock (barnacle/fucoid shores)
Biotope complex	MLR.R	Red seaweeds (moderately exposed shores)
Biotope	MLR.RPid	*Ceramium* sp. and piddocks on eulittoral fossilized peat
Similar biotopes:	MLR.FserPid	

The biotope MLR.FserPid **-** *Fucus serratus* and piddocks on lower eulittoral soft rock, occurs in similar physical conditions, but the rocky substratum favours colonization by *Fucus serratus* rather than ephemeral seaweeds, such as *Ulva* and *Enteromorpha* spp.

Other biotope classification schemes

European Nature Information System (EUNIS) habitat classification code: A1.235/B-MLR.RPid **-** *Ceramium* sp. and piddocks on eulittoral fossilized peat (Davies & Moss, 1998).

Ecology

Ecological and functional relationships

- Little information was found concerning the community of this biotope.
- All boring piddocks begin excavation following settling of the larva and slowly enlarge and deepen the burrow with growth. They are forever locked within their burrows, and only the siphons project to the surface opening (Barnes, 1980). A relationship exists between the distribution of piddock species and substratum type. Duval (1963a) examined the penetrability of a variety of substrata by *Petricola pholadiformis*. It may bore into London Clay, Thanet Sandstone, softer chalk and peaty substrata. It was unable to bore into abnormally hard clays, soft loose mud, shifting sand, gritty and Lower Greensand Gault clay, hard chalk and Blue Lower Lias. Thus its distribution is determined by changes in the substratum of the shore rather than by tidal level (the piddock may flourish from extreme low water to mid-tide level).
- Hydroids living in pools in the peat are opportunistic carnivores mainly catching suspended plankton as food.
- Filter / suspension feeding organisms such as the piddocks, *Barnea candida* and *Petricola pholadiformis*; the peacock worm, *Sabella pavonina* and sand mason worm, *Lanice conchilega*, are the dominant trophic group in the biotope, indicating the importance of planktonic inputs to the community. Piddocks probably contribute to the creation of a relatively high silt environment through burrowing activities.
- Crabs, such as *Carcinus maenas* and *Cancer pagurus*, are the predominant mobile species in the biotope, traveling through as they scavenge for food.
- The anemone, *Sagartia troglodytes*, which may occur in crevices of the peat, uses 'catch’ tentacles to prey upon small shrimps and crabs. In turn, *Sagartia troglodytes* is preyed upon by the grey sea slug, *Aeolidia papillosa*, and attacked by the tompot blenny, *Parablennius gattorugine* (BMLSS, 2002) that may frequent the biotope
- Algae that grow on the surface of the peat may provide shelter for small crustaceans and possibly a source of food for grazing prosobranchs, such as *Littorina littorea*, which may occasionally occur in the biotope but is not characteristic.
- Species of isopod and amphipod may also feed on detrital matter within the dense algal mat and prey upon each other.

Seasonal and longer term change

- One of the characteristic species of this biotope, *Petricola pholadiformis*, has a longevity of up to 10 years (Duval, 1963a) and whose established populations may not exhibit significant seasonal changes, besides spawning in the summer. Variations in the abundance and seaweed species present would be expected to vary between and within locations according to the season. For instance, following storms, the peat may be covered by a layer of sand which could adversely affect the surface of algal species, especially propagules.

Habitat structure and complexity

Outcrops of fossilized peat in the eulittoral may project above sand level by > 15 cm and form extensive platforms up to 100 m in length across the shore. Fossilized peat tends to be firm and relatively erosion resistant (Murphy, 1981), and occur in localities backed by extensive beach and dune systems, so that the patches of peat exposed varies according to sand movement. The peat is likely to have pits, crevices and undulations in surface level in addition to vacant piddock burrows. Empty piddock burrows can influence the abundance of other species by providing additional habitats and refuges. For instance, Eunice Pinn (pers. comm. to *MarLIN*) found a statistically significant increase in species diversity in areas where old piddock burrows were present compared to where they were absent. Pools of water may accumulate in surface depressions which favour hydroids (e.g. *Obelia longissima* and prawns such as *Crangon crangon*). The covering of red and ephemeral green algae probably provide cover for cryptic fauna.

Dominant trophic groups	Photoautotrophs Suspension feeders

Productivity

Algal species, *Ceramium*, *Ulva*, form a characteristic mat over the surface of the peat substratum so primary production is a component of productivity. Many of the characterizing species that are present in the biotope are suspension/filter feeders, so productivity of the biotope would probably be largely dependent on detrital input. However, specific information about the productivity of characterizing species or about the biotope in general was not found.

Major sources of organic carbon	Photosynthesis (macroalgae and/or halophytic plants) Detritus

Recruitment processes

Most of the characterizing species in the biotope are sessile or sedentary. Consequently, recruitment must occur primarily through dispersive larval or spore stages. Examples of characterizing species are given below.

- Duval (1963a) reviewed the biology of *Petricola pholadiformis*. The sexes of *Petricola pholadiformis* are separate. Females are estimated to produce between 3,000,000 and 3,500,000 eggs annually. Gametogenesis takes place between April and early June and a waiting period ensues before spawning occurs towards late July and during August, lasting just over six weeks in total. The juvenile trochophore stage is reached within 28 hours, and the veliger stage in 44 hours. Length of planktonic life was estimated to be in the region of only one and a half to two weeks in duration, after which the young *Petricola pholadiformis* assume a benthic lifestyle, but remain extremely active. Juveniles of 0.4 cm length possess a very strongly ciliated and mobile foot and large amounts of mucus aid adherence to the substratum. Shell growth may begin in April or during May and continues until after June. Thereafter, growth rings are laid down annually, and annual growth in younger specimens is in the region of 0.7 - 0.9 cm.
  Similarly, the white piddock, *Barnea candida*, has separate sexes and fertilization occurs externally (Duval, 1963b). Many bivalves spawn during the part of the year when sea temperatures are rising. No information was found concerning length of planktonic life in *Barnea candida* but El-Maghraby (1955) showed that in southern England *Barnea candida* spawned in September, being unusual that it started to spawn when the temperature fell at the beginning of the autumn.
- Edwards (1973) reported that the red seaweed, *Ceramium virgatum* (as *Ceramium nodulosum*), has a triphasic life history consisting of a sequence of gametophytic, carposporophytic and tetrasporophytic phases in which the first and the third are morphologically similar. Maggs & Hommersand (1993) reported spermatangia in January, March-April, June and August-September; cystocarps in January-February and April-September; tetrasporangia in February-September. Although no information on dispersal has been found directly for *Ceramium virgatum*, Norton (1992) concluded that dispersal potential is highly variable in seaweeds, but recruitment probably occurs on a local scale, typically within 10m of the parent plant.
- The green seaweed, *Ulva* is considered to be opportunistic in its colonization of available substrata, its rapid recruitment made feasible by its life cycle, which consists of both sexual and asexual generations. Reproduction can occur throughout the year, but is maximal in summer. The haploid gametophytes (arising from sexual reproduction) of *Ulva* produce enormous numbers of motile gametes that fuse and germinate to produce sporophytes. Sporophytes also produce large numbers of motile spores that are released in such great numbers that the water can become green (Little & Kitching, 1996). The dispersal potential of such spores is great (> 10 km) so that the species may recruit from distant populations.
- Hydroids, such as *Obelia longissima*, are often the first organisms to colonize available space in settlement experiments (Gili & Hughes, 1995). The hydroid phase of *Obelia longissima* releases dioecious sexual medusae that swim for up to 21 days (Sommer, 1992) and release sperm or eggs

into the sea (fertilization is external). The resultant embryos then develop into planulae larvae that swim for 2-20 days (Sommer, 1992). Therefore, their potential dispersal is much greater than those species that only produce planulae. In addition, few species of hydroids have specific substratum requirements and many are generalists, for example *Obelia longissima* has been reported from a variety of rock and mud substrata.

Time for community to reach maturity

Little information was found concerning community development. However, piddocks, *Barnea candida* and *Petricola pholadiformis* are likely to settle readily. These piddocks breed annually and produce a large number of gametes. Once established individuals may live for a considerable length of time; *Petricola pholadiformis* of length 5-6 cm are likely to be between 6-10 years old (Duval, 1963a). Another characteristic component of the biotope is the algal mat of *Ceramium* and *Ulva* that caps the peat and development of this algal mat would be expected to be rapid. For instance, panels were colonized by *Ceramium virgatum* (as *Ceramium nodulosum*) within a month of being placed in Langstone Harbour (Brown *et al.*, 2001), whilst *Ulva* spp. are known to colonize available substrata rapidly.

Additional information

No text entered.

Habitat preference and distribution

Distribution in Britain and Ireland

Few records of the biotope exist; its description is derived from sites in north Norfolk (Tichwell Marsh, Brancaster) and Cardigan Bay (Borth, north of Aberystwyth).

Habitat preferences

Temperature range preferences	No information found
Water clarity preferences	No text entered
Limiting nutrients	No information found
Other preferences	Fossilized peat.

Additional information

Further records of this biotope are required.

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	**Species name**	**Common Name**
Important characterizing	*Barnea candida*	White piddock
Important characterizing	*Petricola pholadiformis*	American piddock
Important structural	*Ceramium virgatum*	A red seaweed
Important structural	*Ulva intestinalis*	Gut weed

Explanation

The most significant feature for identification of this biotope is the fossilized peat substratum. In the absence of peat the biotope would not be recognized. All species of the community can occur elsewhere, on and in other substrata. The most faithful species to the MLR.RPid biotope are the piddocks, *Barnea candida* and *Petricola pholadiformis*, and these species have been assessed to be important characterizing species. The surface of the peat is covered by a mat of predominantly red seaweed, *Ceramium* sp., but also ephemeral green seaweeds such as *Ulva* and *Ulva*. These species are included as important structural species as they provide a habitat for small invertebrates.

Species found especially in biotope

Barnea candida White Piddock
Petricola pholadiformis American piddock

Additional information

No text entered.

Biotope sensitivity

Physical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	None	Very High	Major Decline	High
Smothering	Intermediate	Very high	Low	Decline	Moderate
Increase in suspended sediment	Tolerant*	Not Relevant	Not sensitive*	No Change	Low
Decrease in suspended sediment	Low	Immediate	Not sensitive	No Change	Low
Desiccation	Intermediate	Very high	Low	Decline	Moderate
Increase in emergence regime	Low	Very high	Very Low	Minor Decline	Low
Decrease in emergence regime	Tolerant	Not Relevant	Tolerant	No Change	Low
Increase in water flow rate	Intermediate	Very high	Low	Decline	Moderate
Decrease in water flow rate	Low	High	Low	No Change	Low
Increase in temperature	Tolerant	Not Relevant	Tolerant	Not Relevant	Low
Decrease in temperature	High	Moderate	Moderate	Major Decline	Moderate
Increase in turbidity	Tolerant	Not Relevant	Tolerant	No Change	Moderate
Decrease in turbidity	Tolerant	Not Relevant	Tolerant	No Change	Moderate
Increase in wave exposure	Intermediate	Very high	Low	Decline	Moderate
Decrease in wave exposure	Tolerant	Not Relevant	Tolerant	No Change	Low
Noise	Tolerant	Not Relevant	Tolerant	Not Relevant	Low
Visual Presence	Tolerant	Not Relevant	Tolerant	Not Relevant	Low
Abrasion & physical disturbance	Intermediate	Very high	Low	Decline	Moderate
Displacement	High	High	Moderate	Major Decline	Moderate

Chemical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound	High	High	Moderate	Major	Low

contamination				Decline	
Heavy metal contamination	Insufficient information	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Hydrocarbon contamination	High	Moderate	Moderate	Major Decline	Moderate
Radionuclide contamination	Insufficient information	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Changes in nutrient levels	Tolerant*	Not Relevant	Not sensitive*	No Change	Low
Increase in salinity	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Decrease in salinity	Low	Very high	Very Low	Minor Decline	Low
Changes in oxygenation	Insufficient information	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Insufficient information	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Introduction of non-native species	Tolerant	Not Relevant	Tolerant	Not Relevant	Low
Extraction of key or important characterizing species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Extraction of important species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	The biotope is characterized by a substratum of fossilized peat. Removal of the fossilized peat would therefore mean that the biotope no longer existed. Intolerance has been assessed to be high and recoverability none, as the formation of peat and its fossilization takes many thousands of years and is dependent on appropriate conditions for formation. However, if only a layer of the peat is removed, recolonization of the remaining peat may be fairly rapid and a recovery of moderate likely.
Smothering (see benchmark)	Sometimes the substratum in which piddocks reside is covered by a thin layer of loose sandy material, through which the piddocks maintain contact with the surface via their siphons. It is likely that the piddocks would be able to extend their siphons through loose material. Species comprising, and living within the dense algal mat are likely to be more intolerant of smothering. Over the period of one month, seaweeds may begin to decompose owing to frond damage and inhibition of photosynthesis. Sporelings would certainly be adversely affected as Vadas *et al.* (1992) stated that algal spores and propagules are adversely affected by a layer of sediment, which can exclude up to 98% of light. Intolerance has been assessed to be intermediate, as impoverishment of the community would result as a consequence of smothering by an additional covering of 5 cm of sediment. Seaweeds such as *Ceramium virgatum* are known to recruit rapidly to cleared surfaces. For instance, experimental panels were colonized by *Ceramium*

	virgatum (as *Ceramium nodulosum*) within a month of being placed in Langstone Harbour (Brown *et al.*, 2001). Recoverability has been assessed to be very high. A higher intolerance would be expected if the biotope were smothered by materials that were impermeable or of a viscous nature.
Increase in suspended sediment (see benchmark)	Although increased levels of suspended sediment may require additional clearance of feeding structures, increased levels of suspended sediment may in fact be beneficial to the community. Suspension / filter feeders are the dominant trophic group within the MLR.RPid biotope, and particles in suspension represent a food resource. An assessment of not sensitive* has been made.
Decrease in suspended sediment (see benchmark)	A significant decrease in suspended sediment may reduce food input to the biotope resulting in reduced growth and fecundity of suspension feeding animals, e.g. piddocks. Intolerance has been assessed to be low. Normal feeding would resume on return to prior conditions and recovery has been assessed to be immediate.
Desiccation (see benchmark)	The adult piddocks are offered significant protection from desiccation by their environmental position within the peat substratum. However, the dense algal mat covering the substratum, predominantly of the red seaweed *Ceramium virgatum*, may be more intolerant of an increase in desiccation. *Ceramium virgatum* occurs profusely in rockpools, on the lower shore and in the subtidal but not on the open shore away from damp places suggesting that it is intolerant of desiccation. As a consequence of a change in this factor, the algal cover may become diminished. Intolerance has been assessed to be intermediate to reflect impoverishment of the community. Recovery is expected to be very high as settlement and growth appears to be rapid at least at appropriate times of year. For example, Brown *et al.* (2001) found that the red seaweed had settled onto panels within four weeks of their placement in Langstone Harbour.
Increase in emergence regime (see benchmark)	The biotope occurs in the eulittoral zone, where it experiences regular immersion and emersion. Species present are therefore tolerant of periods of emergence to some extent. A one hour increase in the period of emergence for one year, may impact on the viability of suspension feeding species, as they have less time for feeding. Furthermore, physiological stresses on both surface flora and fauna are likely to increase as they cope with effects of desiccation. Intolerance to increased emergence has been assessed to be low. On return to prior conditions, recoverability has been assessed to be very high as normal feeding resumes, and species recover form effects of desiccation (see above).
Decrease in emergence regime (see benchmark)	The biotope occurs in the eulittoral zone, where it experiences regular immersion and emersion. All species within the biotope are also found in the subtidal, so a decrease in emergence is not likely to be detrimental to the biotope. An assessment of not sensitive has been made.
Increase in water flow rate (see benchmark)	Established adult piddocks are, to a large extent, protected from effects, direct and indirect, of increased water flow, owing to their environmental position within the substratum. However, increased water flow rate may be responsible for a reduction in the recruitment of juvenile piddock species. Duval (1963b) reported that the reduced density of *Barnea candida* on the 'street' Whitstable (south coast of England) was attributable to the redistribution and deposition of loose material during storms causing smothering, and increased scour during periods of elevated water flow. Similarly, increased scour, as a consequence of increased water flow, would also inhibit settlement of seaweed spores. The fronds of adults and germlings may also be damaged. Furthermore, feeding by suspension feeders within the biotope may be impaired, as delicate structures are withdrawn for protection. Intolerance has been assessed to be intermediate. On return to prior conditions, recoverability has been assessed to be very high. Adult populations capable of reproducing are likely to remain in the vicinity. Piddocks recruit annually and produce many gametes, and the red seaweed, *Ceramium* recruits

	rapidly to cleared surfaces. For instance, experimental panels were colonized by *Ceramium virgatum* (as *Ceramium nodulosum*) within a month of being placed in Langstone Harbour (Brown *et al.*, 2001).
Decrease in water flow rate (see benchmark)	Changes in water flow rate affect siltation levels and also probably the feeding of suspension feeders. A decrease in water flow rate may reduce the suspended particulate material carried in the water column important for the feeding of the faunal components of the community. This may result in reduced viability of the population. Intolerance has been assessed to be low. On return to prior conditions, recovery is likely to be rapid as normal feeding would resume.
Increase in temperature (see benchmark)	The piddocks, *Barnea candida* and *Petricola pholadiformis* both occur to the south of the British Isles, so are likely to be tolerant of a chronic decrease in temperature of 2 °C. Lüning (1990) reported that *Ceramium virgatum* (as *Ceramium rubrum*) survived temperatures from 0 to 25 °C with optimal growth at about 15 °C. The species is therefore likely to be tolerant of higher temperatures than it experiences in the seas around Britain and Ireland. *Ulva intestinalis* is considered to be tolerant of elevated temperatures. It is characteristic of upper shore rock pools, where water and air temperatures are greatly elevated on hot days, whilst (Vadas *et al.*, 1976) observed *Ulva intestinalis* to significantly increase in abundance near a heated effluent outfall. Spawning of the piddock, *Petricola pholadiformis*, is initiated by increasing water temperature (> 18 °C) (Duval, 1963a), so elevated temperatures outside of usual seasons may disrupt normal spawning periods. The spawning of *Barnea candida* was also reported to be disrupted by changes in temperature. The species normally spawns in September when temperatures are dropping (El-Maghraby, 1955), however, a rise in temperature in late June of 1956, induced spawning in some specimens of *Barnea candida* (Duval, 1963b). Disruption from established spawning periods, caused by temperature changes, may be detrimental to the survival of recruits as other factors influencing their survival may not be optimal, and some mortality may result. Established populations may otherwise remain unaffected by elevated temperatures. On balance, an assessment of not sensitive has been suggested.
Decrease in temperature (see benchmark)	The piddocks, *Barnea candida* and *Petricola pholadiformis* both occur to the north of the British Isles, so are likely to be tolerant of a chronic decrease in temperature of 2 °C. Lüning (1990) reported that *Ceramium virgatum* (as *Ceramium rubrum*) survived temperatures from 0 to 25 °C with optimal growth at about 15 °C. The species is therefore likely to be tolerant of lower temperatures than it experiences in the seas around Britain and Ireland. Sub-optimal temperatures may delay or slow reproduction. During the exceptionally cold winter of 1962-1963, the population of *Barnea candida* was entirely wiped out in the Whitstable area of the south-east coast of England (Crisp, 1964). Intolerance has therefore been assessed to be high since acute decreases in temperature may be responsible for the decimation of piddock populations. Recovery would be expected, assuming that a breeding adult population remains in a refuge locally, as the piddocks recruit annually and produce many gametes. However, the occurrence of suitable substrata for piddock species is localized and patchy. Following complete loss of a population, recovery would be reliant on larval recruitment over considerable distances. Evidence suggests that such recolonization is possible for *Petricola pholadiformis*, as the non-native species has successfully invaded continental Europe from sites in Britain via its pelagic larva. Information concerning length of time in the plankton was not found for *Barnea candida* and recoverability has been assessed to be moderate.
Increase in turbidity (see benchmark)	Faunal species are unlikely to be affected by the light attenuating effects of an increase in turbidity. Hily *et al.* (1992) found that, in conditions of high turbidity, *Ceramium virgatum* (as *Ceramium rubrum*) (and *Ulva* sp.) dominated sediments

	in the Bay of Brest, France. It is most likely that *Ceramium virgatum* thrived because other species of algae could not. Whilst the field observations in the Bay of Brest suggested that an increase in abundance of *Ceramium virgatum* might be expected in conditions of increased turbidity, populations where light becomes limiting will be adversely affected. However, in shallow depths, such as in the MLR.RPid biotope, *Ceramium virgatum* may benefit from increased turbidity. An assessment of not sensitive has been made.
Decrease in turbidity (see benchmark)	Faunal species are unlikely to be affected by the increased light penetration of the water column following a decrease in turbidity. A decrease in turbidity would result in greater light availability for algae and potentially potential benefit from the factor. Although, the work of Hiley *et al.* (1992) suggested that other species of algae might out-compete *Ceramium virgatum* (as *Ceramium rubrum*) in lower turbidity situations, the situation is unlikely in this biotope, owing to the nature of the fossilized peat substratum. An assessment of not sensitive has been made.
Increase in wave exposure (see benchmark)	The biotope typically occurs in moderately wave exposed locations. The piddocks are unlikely to be affected by changes in wave exposure, owing to their environmental position within the peat substratum, which protects them. The surface of the fossilized peat is covered by a dense mat of predominantly red algae *Ceramium virgatum* is reported to thrive in wave sheltered environments (see full *MarLIN* review). Strong wave action is likely to cause some damage to fronds resulting in reduced photosynthesis and compromised growth. Furthermore, individuals may be damaged or dislodged by scouring from sand and gravel mobilized by increased wave action (Hiscock, 1983). Damage to at least a part of the seaweed stand is likely due to increased wave exposure and intolerance has been assessed to be intermediate. Recovery of the red seaweed *Ceramium virgatum* would be expected to be expected to be very high. For instance, experimental panels were colonized by *Ceramium virgatum* (as *Ceramium nodulosum*) within a month of being placed in Langstone Harbour (Brown *et al.*, 2001).
Decrease in wave exposure (see benchmark)	The biotope typically occurs in moderately wave exposed locations. The piddocks are unlikely to be affected by changes in wave exposure, owing to their environmental position within the peat substratum. *Ceramium virgatum* is reported to thrive in wave sheltered locations (see *MarLIN* Web site). For instance, it is recorded in some of the most sheltered parts of Hardangerfjord in Norway (Jorde & Klavestad, 1963). A decrease in wave exposure is therefore unlikely to be an adverse factor for this biotope and assessment of not sensitive has been made.
Noise (see benchmark)	Piddocks probably have limited facility for detection of noise. However, piddocks can probably detect the vibration caused by predators and will withdraw siphons, ejecting water from their cavities as they do so. Humans walking over piddock grounds often get squirted as the animals pull down into their burrows in response to human movement. On removal of noise or vibration disturbance normal behaviour will resume. The community is unlikely to be affected by noise at the benchmark level and an assessment of not sensitive has been made.
Visual Presence (see benchmark)	Piddocks may react to changes in light intensity. For instance, the common piddock *Pholas dactylus* reacts to changes in light intensity by withdrawing its siphon which may be an adaptive response to avoid predation by shore birds and fish (Knight, 1983). Such responses are not documented in either *Barnea candida* or *Petricola pholadiformis*, but the behaviour of other piddocks suggests that the visual presence of boats or humans is not likely to be detrimental to the MLR.RPid community. On removal of visual disturbance normal behaviour will resume.
Abrasion & physical disturbance	Piddocks are the most important characterizing species of the MLR.RPid biotope and owing to their position within the fossilized peat, they are protected from

(see benchmark)	physical disturbance and abrasion. However, the biotope is also characterized by a dense algal mat of red and green seaweed that would be susceptible to physical disturbance Some species protruding from the surface, e.g. *Lanice conchilega*, *Sabella pavonina* may also be removed. Intolerance has been assessed to be intermediate. Recovery of the algal mat would be expected to be rapid. For instance, experimental panels were colonized by *Ceramium virgatum* (as *Ceramium nodulosum*) within a month of being placed in Langstone Harbour (Brown *et al.*, 2001). Recoverability has been assessed to be very high.
Displacement (see benchmark)	Adult piddocks are confined to their cavities for life. If removed from the substratum death of adults is likely as no displaced specimens of *Petricola pholadiformis* were ever observed to make a second boring in a consolidated substratum (Duval, 1963a). Intolerance has been assessed to be high. Recovery would be expected, assuming that a breeding adult population remains in a refuge locally, as the species recruit annually and produce many gametes. However, the occurrence of suitable substrata for piddock species is localized and patchy. Following complete loss of a population, recovery would be reliant on larval recruitment over considerable distances. Evidence suggests that such recolonization is possible for *Petricola pholadiformis* as the non-native species has successfully invaded continental Europe from sites in Britain via its pelagic larva. *Barnea candida* also bores into wood, so the beaching of driftwood is also a route of recolonization for the species (e.g. adults arrive and spawn). Recoverability has therefore been assessed to be high.
Chemical Factors	
Synthetic compound contamination (see benchmark)	No information on the specific effects of chemicals on the piddocks, *Barnea candida* and *Petricola pholadiformis* was found. However the toxicity of some synthetic chemicals, e.g. TBT, to bivalves has been widely reported. For instance, reports of reductions in the numbers of bivalves in estuaries with high pleasure craft activity have provided evidence of the high toxicity of TBT to bivalves (Beaumont *et al.*, 1989). *Ceramium virgatum* seems to be intolerant of at least some synthetic chemicals. In studies of the effect of chromated copper arsenate wood preservative, Brown *et al.* (2001) found that a significantly higher coverage of *Ceramium virgatum* (as *nodulosum*) occurred on untreated wood after four weeks. Hardy (1993) observed that *Ceramium virgatum* (as *Ceramium rubrum*) was lost between 1923 and 1991 from the mouth of the (polluted) Tees Estuary. Inferences may also be drawn from the sensitivities of red algal species generally. O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination, possibly due to the susceptibility of phycoerythrins to destruction. They also reported that red algae are effective indicators of detergent damage since they undergo colour changes when exposed to relatively low concentration of detergent. Smith (1968) reported that 10 ppm of the detergent BP 1002 killed the majority of specimens of *Ceramium virgatum* (as *Ceramium rubrum*) in 24 hour toxicity tests. Evidence suggests that this community would probably have a high intolerance to synthetic chemical contamination. Recovery would be expected assuming deterioration of contaminants. Piddock species recruit annually and produce many gametes. However, the occurrence of suitable substrata for piddock species is localized and patchy. Following complete loss of a population, recovery would be reliant on larval recruitment over considerable distances. Evidence suggests that such recolonization is possible for *Petricola pholadiformis* as the non-native species has successfully invaded continental Europe from sites in Britain via its pelagic larva. *Barnea candida* also bores into wood, so the beaching of driftwood is also a route of recolonization for the species (e.g. adults arrive and spawn). Recovery of the algal mat would be expected to be rapid. For instance, experimental panels were colonized by *Ceramium virgatum* (as *Ceramium nodulosum*) within a month of being placed in

	Langstone Harbour (Brown *et al.*, 2001). Overall, recoverability has therefore been assessed to be high.
Heavy metal contamination (see benchmark)	Specific information concerning heavy metal pollution and this piddock community was not found. Bryan (1984) stated that Hg was the most toxic metal to bivalve molluscs while Cu, Cd and Zn seem to be most problematic in the field. In bivalve molluscs Hg was reported to have the highest toxicity, mortalities occurring above 0.1-1 µg/l after 4-14 days exposure (Crompton, 1997), toxicity decreasing from Hg> Cu and Cd > Zn > Pb and As > Cr (in bivalve larvae, Hg and Cu > Zn> Cd, Pb, As, and Ni > Cr). Bryan (1984) suggested that the general order for heavy metal toxicity in seaweeds to be: Organic Hg > inorganic Hg > Cu > Ag > Zn > Cd > Pb. In the absence of evidence from which to derive an intolerance assessment for this community, insufficient information has been recorded.
Hydrocarbon contamination (see benchmark)	Specific information concerning effects of hydrocarbon contamination on piddocks was not found. However, should oil be washed ashore and coat the peat substratum in which piddocks reside, smothering and suffocation may occur as siphons in contact with the surface are coated and withdrawn in to the cavity for a prolonged period of time. Mortalities may also in the longer term be attributable to toxic effects of oil. Smith (1968) reported that *Ceramium virgatum* (as *Ceramium rubrum*) was killed during the *Torrey Canyon* oil spill. O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination, possibly due to the susceptibility of phycoerythrins to destruction. Laboratory studies of the effects of oil and dispersants on several red algal species concluded that they were all sensitive to oil/ dispersant mixtures, with little difference between adults, sporelings, diploid or haploid life stages (Grandy, 1984). Intolerance has been assessed to be high. Until oil that had covered the substratum becomes sufficiently weathered, it may serve to deter the settlement of planktonic larvae and spores, otherwise recovery of the community would be expected, although not to previous levels of abundance for some time. Piddock species recruit annually and produce many gametes. However, the occurrence of suitable substrata for piddock species is localized and patchy. Following complete loss of a population, recovery would be reliant on larval recruitment over considerable distances. Evidence suggests that such recolonization is possible for *Petricola pholadiformis* as the non-native species has successfully invaded continental Europe from sites in Britain via its pelagic larva but the potential for *Barnea candida* to recolonize over considerable distances is not known. Recovery of the algal mat would be expected to be rapid. For instance, experimental panels were colonized by *Ceramium virgatum* (as *Ceramium nodulosum*) within a month of being placed in Langstone Harbour (Brown *et al.*, 2001). Overall recoverability has therefore been assessed to be moderate.
Radionuclide contamination (see benchmark)	Insufficient information.
Changes in nutrient levels (see benchmark)	Specific information concerning effects of nutrient enrichment on the community was not found. Hily *et al.* (1992) found that, in conditions of high nutrients, *Ceramium virgatum* (as *Ceramium rubrum*) and *Ulva* sp. dominated substrata in the Bay of Brest, France. *Ceramium* spp. are also mentioned by Holt *et al.* (1995) as likely to smother other species of macroalgae in nutrient enriched waters. Fletcher (1996) quoted *Ceramium virgatum* (as *Ceramium rubrum*) to be associated with nutrient enriched waters. It therefore seems that algal stands of *Ceramium virgatum* are likely to benefit from elevated levels of nutrients. Furthermore, nutrient enrichment that enhances productivity of phytoplankton may indirectly benefit the faunal community. The dominant trophic group are

	filter/suspension feeders and abundant phytoplankton represent a food resource. An assessment of not sensitive* has been made.
Increase in salinity (see benchmark)	The salinity tolerances of the piddocks, *Barnea candida* and *Petricola pholadiformis*, and other important characterizing species of the biotope are not known. However, the biotope occurs in the eulittoral zone under conditions of full salinity and where conditions of hyper salinity are not likely to be encountered. An assessment of not relevant has been made.
Decrease in salinity (see benchmark)	The biotope will experience periods of reduced salinity, for example when the tide is out and rain occurs. *Barnea candida* is reported to extend in to estuarine environments in salinities down to 20 psu (Fish & Fish, 1996). *Petricola pholadiformis* is particularly common off the Essex and Thames estuary, e.g. the River Medway (Bamber, 1985) suggesting tolerance of brackish waters. *Ceramium virgatum* occurs over a very wide range of salinities. The species penetrates almost to the innermost part of Hardanger Fjord in Norway where it experiences very low salinity values and large salinity fluctuations due to the influence of snowmelt in spring (Jorde & Klavestad, 1963). It is likely therefore that the benchmark decrease in salinity would not result in mortality. Seaweed photosynthesis by seaweed may be impaired and also growth and reproduction of both fauna and flora may be compromised. Intolerance has been assessed to be low. Physiological processes should quickly return to normal when salinity returns to original levels, so recoverability is recorded as very high.
Changes in oxygenation (see benchmark)	Specific information concerning oxygen consumption and reduced oxygen tolerances were not found for important characterizing species within the biotope. Cole *et al.* (1999) suggested possible adverse effects on marine species below 4 mg O_2/l and probable adverse effects below 2mg O_2/l. Duval (1963a) observed that conditions within the borings of *Petricola pholadiformis* were anaerobic and lined with a loose blue/black sludge, suggesting that the species may be relatively tolerant to conditions of reduced oxygen. However, insufficient information has been recorded.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	More than 20 viruses have been described for marine bivalves (Sinderman, 1990). Bacterial diseases are more significant in the larval stages and protozoans are the most common cause of epizootic outbreaks that may result in mass mortalities of bivalve populations. Parasitic worms, trematodes, cestodes and nematodes can reduce growth and fecundity within bivalves and may in some instances cause death (Dame, 1996). However, no information concerning the effects of microbial pathogens upon the community of this biotope was found and insufficient information has been recorded.
Introduction of non-native species (see benchmark)	The American piddock, *Petricola pholadiformis* is a non-native, boring piddock that was unintentionally introduced from America with the American oyster, *Crassostrea virginica*, not later than 1890 (Naylor, 1957). Rosenthal (1980) suggested that from the British Isles, the species has colonized several northern European countries by means of its pelagic larva and may also spread via driftwood, although it usually bores into clay, peat or soft rock shores. In Belgium and The Netherlands *Petricola pholadiformis* has almost completely displaced the native piddock, *Barnea candida* (ICES, 1972). However, there is no documentary evidence to suggest that *Barnea candida* has been displaced in the British Isles (J. Light & I. Kileen pers. comm. to Eno *et al.*, 1997). The two species co-occur in this biotope and an assessment of not sensitive has been made.
Extraction of key or important characterizing species (see benchmark)	Species within the biotope are not targeted for extraction. An assessment of not relevant has been made.

Extraction of important species (see benchmark)	Species within the biotope are not targeted for extraction. An assessment of not relevant has been made.

Additional information

No text entered.

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (see Appendix 3).

Physical factors		
	Ceramium virgatum	***Ulva intestinalis***
Community Importance	Important structural	Important structural
Substratum Loss	High	High
Smothering	Intermediate	High
Increase in suspended sediment	Intermediate	Intermediate
Decrease in suspended sediment	Not Sensitive*	Not Sensitive
Desiccation	High	Low
Increase in emergence regime	Intermediate	Not Sensitive*
Decrease in emergence regime	Not Sensitive	Low
Increase in water flow rate	Intermediate	Intermediate
Decrease in water flow rate	Not Sensitive	Not Sensitive
Increase in temperature	Low	Not Sensitive*
Decrease in temperature	Low	Not Sensitive
Increase in turbidity	Not Sensitive	Low
Decrease in turbidity	Not Sensitive	Not Sensitive*
Increase in wave exposure	Intermediate	Low
Decrease in wave exposure	Not Sensitive	Not Sensitive
Noise	Not Sensitive	Not Relevant
Visual Presence	Not Sensitive	Not Relevant
Abrasion & physical disturbance	High	High
Displacement	High	Not Sensitive
Chemical factors		
	Ceramium virgatum	***Ulva intestinalis***
Community Importance	Important structural	Important structural
Synthetic compound contamination	High	Intermediate
Heavy metal contamination	Insufficient information	Low
Hydrocarbon contamination	High	High
Radionuclide contamination	Insufficient information	Insufficient information
Changes in nutrient levels	Not Sensitive*	Not Sensitive*
Increase in salinity	Not Relevant	Not Sensitive
Decrease in salinity	Low	Not Sensitive
Changes in oxygenation	Insufficient information	Insufficient information

Biological factors		
	Ceramium virgatum	***Ulva intestinalis***
Community Importance	Important structural	Important structural
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information
Introduction of non-native species	Not Sensitive*	Not Relevant
Extraction of this species	Not Relevant	Intermediate
Extraction of other species	Not Relevant	Not Relevant

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors		
	Ceramium virgatum	***Ulva intestinalis***
Community Importance	Important structural	Important structural
Substratum Loss	Very high	Very high
Smothering	Very high	Very high
Increase in suspended sediment	Very high	Very high
Decrease in suspended sediment	Not Relevant	Not Relevant
Desiccation	Very high	Very high
Increase in emergence regime	Very high	Not Relevant
Decrease in emergence regime	Not Relevant	Very high
Increase in water flow rate	Very high	Very high
Decrease in water flow rate	Not Relevant	Not Relevant
Increase in temperature	Very high	Not Relevant
Decrease in temperature	Very high	Not Relevant
Increase in turbidity	Not Relevant	Very high
Decrease in turbidity	Not Relevant	Not Relevant
Increase in wave exposure	Very high	Very high
Decrease in wave exposure	Not Relevant	Not Relevant
Noise	Not Relevant	Not Relevant
Visual Presence	Not Relevant	Not Relevant
Abrasion & physical disturbance	Very high	Very high
Displacement	Very high	Not Relevant
Chemical factors		
	Ceramium virgatum	***Ulva intestinalis***
Community Importance	Important structural	Important structural
Synthetic compound contamination	Very high	High
Heavy metal contamination	Not Relevant	Very high
Hydrocarbon contamination	Very high	Very high
Radionuclide contamination	Not Relevant	Not Relevant
Changes in nutrient levels	Not Relevant	Not Relevant
Increase in salinity	Not Relevant	Not Relevant
Decrease in salinity	Very high	Not Relevant
Changes in oxygenation	Not Relevant	Not Relevant
Biological factors		
	Ceramium virgatum	***Ulva intestinalis***
Community Importance	Important structural	Important structural
Introduction of microbial pathogens/parasites	Not Relevant	Not Relevant
Introduction of non-native species	Very high	Not Relevant

Extraction of this species	Not Relevant	Very high
Extraction of other species	Not Relevant	Not Relevant

Importance

Marine natural heritage importance

Listed under:	**UK Biodiversity Action Plan** **EC Habitats Directive**
National importance	Rare
Habitat Directive feature (Annex 1)	Reefs Large shallow inlets and bays Estuaries
UK Biodiversity Action Plan habitat	Littoral rock (broad habitat statement)

Biotope importance

No information found.

Exploitation

Piddocks may be consumed and there has been concern about collection (that involves habitat destruction) in chalk areas of Kent (K. Hiscock, pers. comm.).

Additional information

No text entered

This Biology and Sensitivity Key Information review can be cited as follows:
Budd, G.C., 2002. *Ceramium* sp. and piddocks on eulittoral fossilized peat. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 19/01/2005]. Available from: <http://www.marlin.ac.uk>

Sabellaria alveolata reefs on sand-abraded eulittoral rock (MLR.Salv)

Key information authored by: Angus Jackson

Last updated 24/11/2004

Refereed by: Dr Terry Holt

Sabellaria alveolata reefs on sand abraded eulittoral rocks. Image width ca 150 cm.
Image: Rohan Holt / Joint Nature Conservation Committee

Recorded and expected MLR.Salv distribution for Britain and Ireland

Description of biotope

Many wave-exposed boulder scar grounds in the eastern basin of the Irish Sea (and as far south as Cornwall), are characterized by reefs of *Sabellaria alveolata* which build tubes from the mobile sand surrounding the boulders and cobbles. The tubes formed by *Sabellaria alveolata* form large reef-like hummocks, which serve to further stabilize the boulders. Other species in this biotope include the barnacles *Semibalanus balanoides*, *Balanus crenatus* and *Elminius modestus* and the molluscs *Patella vulgata*, *Littorina littorea*, *Nucella lapillus* and *Mytilus edulis*. Low abundances of algae tend to occur in areas of eroded reef. The main algal species include *Porphyra* spp., *Mastocarpus stellatus*, *Ceramium* spp., *Fucus vesiculosus*, *Fucus serratus*, *Ulva* spp. and *Ulva* spp. On exposed surf beaches in the south-west *Sabellaria* forms a crust on the rocks, rather than the classic honeycomb reef, and may be accompanied by the barnacle *Balanus perforatus* (typically common to abundant). On wave-exposed shores in Ireland, the brown alga *Himanthalia elongata* can also occur. (Information taken from the Marine Biotope Classification for Britain and Ireland, Version 97.06: Connor *et al.*, 1997a, b).

Welsh variation

Although the Welsh examples of many of the biotopes in this report follow the British and Irish classification description closely, some regional variation may exist. Reference should be made to Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

Sabellaria alveolata can perform important stabilization of habitat, particularly when forming raised structures and reefs (see Ecology).

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Habitat complex	MLR	Moderately exposed littoral rock (barnacle/fucoid shores)
Biotope complex	MLR.Sab	Littoral *Sabellaria* (honeycomb worm) reefs

Biotope	MLR.Salv	*Sabellaria alveolata* reefs on sand-abraded eulittoral rock
Similar biotopes:	MLR.Sab	

Other biotope classification schemes

- European Union Nature Information System code: A1.2 /B-MLR.Sab.Salv (Davies & Moss, 1998)
- France (ZNIEFF-MER) classification code: II.5.6 Recifs d'Hermelles a *Sabellaria alveolata* (Dauvin *et al.*, 1995).

Ecology

Ecological and functional relationships

- Ecological relationships within MLR.Salv are not especially complex. Nevertheless, diversity of associated fauna may be high. Collins (2001) found 59 faunal taxa and 18 floral taxa associated with *Sabellaria alveolata* reefs at Criccieth in North Wales, dominated by annelids, molluscs, nematodes and hexapods. Dias & Paula (2001) recorded a total of 137 taxa in *Sabellaria alveolata* colonies on two shores on the central coast of Portugal. Sheets of *Sabellaria alveolata* can form ridges on flat shores which can trap water and create small pools (Cunningham *et al.*, 1984) (see Habitat Complexity). This may also result in an increased species diversity, as might the stabilization of mobile sand, shingles, pebbles and cobbles (Holt *et al.*, 1998) often attributed to the presence of extensive *Sabellaria alveolata* sheets.
- Algae use older reefs as substratum. Some of these are perennials such as *Fucus serratus* and others annual ephemerals such as *Ulva* sp. The attached community may themselves have epifaunal species (Collins, 2001). In addition, the space between the epiphytic algae and the reef provide shelter for mobile organisms.
- Several grazing molluscs, including *Patella vulgata* and *Littorina littorea*, feed directly on these algae as well as on epiphytic microalgae.

Seasonal and longer term change

Some temporal changes may be apparent in *Sabellaria alveolata* reefs with a cycle of decay and settlement over several years. Recruitment is very sporadic so cycles are not very predictable. Decay is primarily through the effects of storms and wave action. There will also be changes with season in the amount of algae growing in the biotope. Annual species will come and go and perennial species such as *Fucus serratus* exhibit changes in the level of surface cover they provide. Epiflora such as *Fucus serratus*, particularly if dense, may act as nursery grounds for various species including *Nucella lapillus*.

Habitat structure and complexity

Habitat complexity varies temporally with the cycles of development and break up of the reefs. When growing actively as sheets or hummocks the entire sea shore can be covered. Ridges can be formed on flat shores which may trap water leading to the formation of pools (Cunningham *et al.*, 1984). These extensive sheets ('placages'), can stabilize otherwise mobile sand, shingle, cobbles and pebbles (Holt *et al.*, 1998). However, increased habitat diversity, and therefore increased species diversity, are found as the reef begins to break up, cracks, crevices and a greater variety of available surfaces develops, creating a more diverse and complex habitat. Collins (2001) found that reefs in poor condition had a significantly higher diversity of associated infauna than intermediate condition reefs at Criccieth in North Wales. Porras *et al.* (1996) reported similar findings, in addition to the observation that eroded reefs have higher structural complexity. Collins (2001) also reported that, within reefs in poor condition, the sediment size was significantly larger than in other reefs. In contrast, the levels of organic content were found to be significantly higher in reefs in condition. *Sabellaria alveolata* reefs, due to their structure, maintain a high level of relative humidity during low tide, thereby protecting some associated flora and fauna from desiccation, which may permit some species to occur at higher levels on the shore than normal.

Dominant trophic groups	Photoautotrophs Suspension feeders Herbivores

Productivity

Sabellaria alveolata reefs can support diverse communities (see Ecological Relationships). For example, colonies may support several species of annual and perennial algae, particularly if the reefs are older and beginning to break up. This algal growth can support several species of grazing mollusc (including *Littorina littorea* and *Patella vulgata*). Where hummocks or reefs form, the density of *Sabellaria alveolata* can be very high, causing high secondary productivity.

Major sources of organic carbon	Photosynthesis (macroalgae and/or halophytic plants)

Recruitment processes

Sabellaria alveolata recruits from pelagic larvae that spend from 6 weeks to 6 months in the plankton. Although reproduction occurs each year, recruitment is very sporadic and unpredictable. Larval settlement appears to favour areas with existing *Sabellaria alveolata* colonies, or their dead remains (e.g. Wilson, 1971; Cunningham *et al.*, 1984). *Fucus serratus* also recruits from tiny pelagic plants.

Time for community to reach maturity

Sabellaria alveolata has been recorded as living for up to 9 years but most worms survive for four years or so. The growth of *Sabellaria alveolata* appears to slow after its first year after settle. Wilson (1971) reported that the growth in the second and third years after settlement in some colonies was about half that of growth in the first year. Such active growth effectively prevents any other species from colonizing the reef. When growth is less active then algae can begin to colonize, as the reef begins to break up the available substratum becomes more heterogeneous permitting establishment of more species. If further recruitment does not then occur, allowing new growth, the reef will disintegrate. There is no real 'mature stage' as such, rather a cycle of growth and decay. Although settlement of *Sabellaria alveolata* is sporadic, areas that are good for *Sabellaria alveolata* tend to remain so because larval settlement appears to favour areas with existing *Sabellaria alveolata* colonies, or their dead remains (e.g. Wilson, 1971; Cunningham *et al.*, 1984).

Additional information

Cunningham *et al*. (1994) noted the presence of large numbers of *Mytilus edulis* on the remains of *Sabellaria alveolata* colonies in several locations including Llwyngwril in Wales and at Dubmill Point in West Cumbria. In some circumstances therefore, the mussels could potentially interrupt the usual cycle of growth and decay of the reef.

Habitat preference and distribution

Distribution in Britain and Ireland

In Britain, *Sabellaria alveolata* distribution is restricted to south and west coasts with the eastern limit in Lyme Bay. The northern limit is the outer Solway Firth. It is also found on south, west and north coasts of Ireland. To date, MLR.Salv has only been recorded in the Solway Firth and along the Cumbrian coast, western Wales, and the Severn Estuary. In Northern Ireland reefs have been recorded from the Down coast (Rossglass and Glassdrummand) although surveys are incomplete. It has also been recorded at two sites in Ireland, Ballycotton Bay (south) and Killala Bay, (north-west).

Habitat preferences

Temperature range preferences	See additional information.
Water clarity preferences	Very high clarity / Very low turbidity High clarity / Low turbidity Medium clarity / Medium turbidity
Limiting nutrients	No information found
Other preferences	Availability of sand grains.

Additional information

Although identified in the Severn Estuary, the habitat is rather different and the assemblage present is not likely to be the same as in occurrences of the biotope more typically found on open coasts. At Glasdrummand (Northern Ireland), the *Sabellaria alveolata* reefs extend into the subtidal. Optimal temperatures are probably higher than those typically found in the waters of the British Isles. There needs to be an adequate supply of suspended coarse sand grains in order for *Sabellaria alveolata* to be able to build their tubes.

Temperature preferences

The growth of *Sabellaria alveolata* is severely restricted below 5 °C (Gruet, 1982, cited in Holt *et al*., 1998). Cunningham *et al.* (1984) reported increasing growth rates with temperatures up to 20 °C.

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	Species name	Common Name
Key structural	*Sabellaria alveolata*	Honeycomb worm
Important structural	*Fucus serratus*	Toothed wrack
Important functional	*Littorina littorea*	Common periwinkle

Explanation

Sabellaria alveolata is the key structural species, giving the name to the biotope. *Fucus serratus* has been included as the most frequent and abundant of the characterizing species in the biotope. It contributes to biotope sensitivity when attached to *Sabellaria alveolata* by creating extra surface area exposed to wave action or water flow. *Littorina littorea* is the most frequent algal grazer in the biotope and can contribute to the regulation of levels of epiflora.

Species found especially in biotope

No text entered

Additional information

No text entered

Biotope sensitivity

Physical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	Moderate	Moderate	Major Decline	Low
Smothering	Intermediate	High	Low	Major Decline	High
Change in suspended sediment	Intermediate	High	Low	Decline	Moderate
Desiccation	High	Moderate	Moderate	Major Decline	Moderate
Change in emergence regime	High	Moderate	Moderate	Major Decline	Moderate
Change in water flow rate	Intermediate	High	Low	Minor Decline	Moderate
Change in temperature	Intermediate	High	Low	Decline	Moderate

Change in turbidity	Low	Very high	Very Low	No Change	Moderate
Change in wave exposure	High	High	Moderate	Major Decline	Moderate
Noise	Tolerant	Not Relevant	Tolerant	No Change	High
Visual Presence	Tolerant	Not Relevant	Tolerant	No Change	High
Abrasion & physical disturbance	Intermediate	High	Low	Decline	Moderate
Displacement	High	Moderate	Moderate	Major Decline	High
Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	Low	Very high	Very Low	Minor Decline	Low
Heavy metal contamination	Intermediate	High	Low	Decline	Moderate
Hydrocarbon contamination	Intermediate	High	Low	Decline	Moderate
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Changes in nutrient levels	Low	Very high	Very Low	No Change	Moderate
Change in salinity	Intermediate	High	Low	Decline	Low
Changes in oxygenation	Intermediate	High	Low	Decline	Low
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Introduction of non-native species	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Extraction of key or important characterizing species	Intermediate	High	Low	Decline	Moderate
Extraction of important species	Intermediate	High	Low	Decline	Moderate

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	All the key and important species in the biotope exhibit high intolerance to substratum loss. *Sabellaria alveolata*, the key structural species has moderate recoverability.
Smothering (see benchmark)	*Sabellaria alveolata*, the key structural species has only low intolerance to smothering. Wilson (1971) reported *Sabellaria* reefs surviving burial for a few days or even weeks. However, the important structural (*Fucus serratus*) and functional species (*Littorina littorea*) are both highly intolerant. Both *Sabellaria alveolata* and *Fucus serratus* are likely to recover from smothering within a few years.
Change in suspended sediment (see benchmark)	The intermediate intolerance of the functional grazing species *Littorina littorea* means that siltation may indirectly cause increased growth of algae on *Sabellaria alveolata* reefs, contributing to their more rapid breakdown through water action. Variability in recruitment of *Sabellaria alveolata* (dependent on suitable

	environmental conditions) means that recovery could take a few years. The presence of some remaining adult worms will assist in *Sabellaria alveolata* larval settlement as this is the preferred substratum (Wilson, 1929).
Desiccation (see benchmark)	The key structural species *Sabellaria alveolata* is intermediately intolerant of increases in desiccation. *Fucus serratus* occurs in a fairly specific zone on the lower shore. Increases in desiccation will probably result in high intolerance of this seaweed. Lower densities of algae growing on *Sabellaria alveolata* reefs may increase the time that the reef remains intact before being broken up through wave action. Loss of the seaweed will have consequential effects such as the loss of other species using the weed as substratum, including *Littorina littorea*. *Sabellaria alveolata*, the key structural species has moderate recoverability.
Change in emergence regime (see benchmark)	The key structural species *Sabellaria alveolata* is intermediately intolerant of increases in emergence. *Fucus serratus* occurs in a fairly specific zone on the lower shore. Increases in emergence will probably result in high intolerance of this seaweed. Lower densities of algae growing on *Sabellaria alveolata* reefs may increase the time that the reef remains intact before being broken up through wave action. Loss of the seaweed will have consequential effects such as the loss of other species using the weed as substratum, including *Littorina littorea*. *Sabellaria alveolata*, the key structural species has moderate recoverability.
Change in water flow rate (see benchmark)	Decreases in water flow rate will result in lower levels of suspended sediment and intermediate intolerance for *Sabellaria alveolata* but will have no effect on *Fucus serratus* or *Littorina littorea*. Increases in water flow may benefit *Sabellaria alveolata* but be detrimental for the other important species.
Change in temperature (see benchmark)	*Sabellaria alveolata*, the key structural species is intermediately intolerant of short term acute decreases in temperature. Variability in recruitment of *Sabellaria alveolata* (dependent on suitable environmental conditions) means that recovery could take a few years. The presence of some remaining adult worms will assist in *Sabellaria alveolata* larval settlement as this is the preferred substratum (Wilson 1929).
Change in turbidity (see benchmark)	*Fucus serratus* and *Littorina littorea* have low intolerance to increases in turbidity. Recoverability and restoration of condition should occur in less than six months.
Change in wave exposure (see benchmark)	Increases in wave exposure cause high intolerance in *Fucus serratus* and intermediate intolerance in *Littorina littorea* and *Sabellaria alveolata*. Variability in recruitment of *Sabellaria alveolata* (dependent on suitable environmental conditions) means that recovery could take a few years. The presence of some remaining adult worms will assist in *Sabellaria alveolata* larval settlement as this is the preferred substratum (Wilson, 1929). Recoverability of both the seaweed and the snail is high.
Noise (see benchmark)	None of the selected important or characterizing species in the biotope are recorded as sensitive to noise.
Visual Presence (see benchmark)	None of the selected important or characterizing species in the biotope are recorded as sensitive to visual presence.
Abrasion & physical disturbance (see benchmark)	Cunningham *et al.* (1984) examined the effects of trampling on *Sabellaria alveolata* reefs. The reef recovered within 23 days from the effects of trampling, (i.e. treading, walking or stamping on the reef structures) repairing minor damage to the worm tube porches. However, severe damage, estimated by kicking and jumping on the reef structure, resulted in large cracks between the tubes, and removal of sections (ca 15x15x10 cm) of the structure (Cunningham *et al.*, 1984). Subsequent wave action enlarged the holes or cracks. However, after 23 days, at one site, one side of the hole had begun to repair, and tubes had begun to extend into the eroded area. At another site, a smaller section (10x10x10 cm) was lost but

	after 23 days the space was already smaller due to rapid growth. Cunningham *et al.* (1984) reported that *Sabellaria alveolata* reefs were more tolerant of trampling than expected but noted that cracks could leave the reef susceptible to erosion and lead to large sections of the reef being washed away. However, eroded sections can survive and may lead to colonization of previously unsettled areas. The strange sculpturing of colonies in some areas is probably due to a combination of erosion and recovery (Cunningham *et al.*, 1984). Continuous trampling may be more detrimental. For example, Holt *et al.* (1998) reported that, in Brittany, damage to reefs on popular beaches was limited to gaps created by trampling through the reef. Once gaps are formed, they may be enlarged by wave action. The main cause of colony destruction is through wave action. Cunningham *et al.* (1984) also noted that collection of *Sabellaria alveolata*, although a rare occurrence, may be particularly damaged as it will involve removal of sections of the reef.
Displacement (see benchmark)	*Sabellaria alveolata*, the key structural species of the biotope has high intolerance to and moderate recoverability from displacement.
Chemical Factors	
Synthetic compound contamination (see benchmark)	*Littorina littorea* has low intolerance to Tri-butyl tin. There is insufficient information to make an assessment for the other two selected species. The biotope intolerance and recoverability is therefore represented by the periwinkle.
Heavy metal contamination (see benchmark)	Because there is insufficient information on *Sabellaria alveolata* (key species) intolerance to heavy metal contamination, biotope intolerance is represented by the intolerance of the important species, *Littorina littorea* to mercury chloride contamination.
Hydrocarbon contamination (see benchmark)	Because there is insufficient information on *Sabellaria alveolata* (key species) intolerance to hydrocarbon contamination, biotope intolerance is represented by the intolerance of the important species, *Littorina littorea* and *Fucus serratus*. Gastropods have been noted to recover quite quickly (by the next year) from oil spill events such as Amoco Cadiz.
Radionuclide contamination (see benchmark)	There is insufficient information available on all three selected species to be able to make an intolerance assessment for the biotope.
Changes in nutrient levels (see benchmark)	Nutrient availability is a very important factor in regulating *Fucus serratus* growth. Increases in nutrient levels may favour growth of the seaweed and decreases may limit growth. Following resumption of normal nutrient conditions, the seaweed will probably recover within a few months.
Change in salinity (see benchmark)	*Sabellaria alveolata* inhabits fully marine environments and has intermediate intolerance to decreases in salinity. The species must though be able to tolerate some variation in salinity due to exposure to precipitation in the intertidal.
Changes in oxygenation (see benchmark)	*Sabellaria alveolata* has intermediate intolerance to decreases in oxygenation. Cole *et al*. (1999) suggest possible adverse effects on marine species below 4 mg/l and probable adverse effects below 2mg/l. There is no information about *Sabellaria alveolata* tolerance to increases in oxygenation.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	Insufficient information
Introduction of non-native species	Insufficient information

(see benchmark)	
Extraction of key or important characterizing species (see benchmark)	Extraction of *Sabellaria alveolata* by bait digging is a possibility. *Fucus serratus* and *Littorina littorea* are also subject to extraction. Recoverability for all three species is high.
Extraction of important species (see benchmark)	Bait digging for other species, such as crabs, that live within crevices and cracks of *Sabellaria alveolata* reefs (as has been noted to occur in Portugal) may cause damage to other species in the biotope.

Additional information

No text entered

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors			
	Sabellaria alveolata	***Fucus serratus***	***Littorina littorea***
Community Importance	Key structural	Important structural	Important functional
Substratum Loss	High	High	High
Smothering	Low	High	High
Increase in suspended sediment	Low	Low	Intermediate
Decrease in suspended sediment	See explanation	See explanation	See explanation
Desiccation	Intermediate	Intermediate	Low
Increase in emergence regime	Intermediate	Intermediate	Low
Decrease in emergence regime	See explanation	See explanation	See explanation
Increase in water flow rate	Intermediate	Intermediate	Intermediate
Decrease in water flow rate	See explanation	See explanation	See explanation
Increase in temperature	Intermediate	Not Sensitive	Low
Decrease in temperature	See explanation	See explanation	See explanation
Increase in turbidity	Not Sensitive	Low	Low
Decrease in turbidity	See explanation	See explanation	See explanation
Increase in wave exposure	Intermediate	High	Intermediate
Decrease in wave exposure	See explanation	See explanation	See explanation
Noise	Not Sensitive	Not Sensitive	Not Sensitive
Visual Presence	Not Sensitive	Not Sensitive	Not Sensitive
Abrasion & physical disturbance	Intermediate	Intermediate	Intermediate
Displacement	High	High	Not Sensitive
Chemical factors			
	Sabellaria alveolata	***Fucus serratus***	***Littorina littorea***
Community Importance	Key structural	Important structural	Important functional
Synthetic compound contamination	Insufficient information	High	Low
Heavy metal contamination	Insufficient information	Low	Intermediate
Hydrocarbon contamination	Insufficient information	Intermediate	High
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	Insufficient information	Intermediate	Not Sensitive
Increase in salinity	Intermediate	Low	Not Sensitive

Decrease in salinity	See explanation	See explanation	See explanation
Changes in oxygenation	Intermediate	Low	Low
Biological factors			
	Sabellaria alveolata	***Fucus serratus***	***Littorina littorea***
Community Importance	Key structural	Important structural	Important functional
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information
Introduction of non-native species	Insufficient information	Insufficient information	Insufficient information
Extraction of this species	Intermediate	Intermediate	Intermediate
Extraction of other species	Intermediate	Not Sensitive	Not Sensitive

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors			
	Sabellaria alveolata	***Fucus serratus***	***Littorina littorea***
Community Importance	Key structural	Important structural	Important functional
Substratum Loss	Moderate	High	High
Smothering	Immediate	High	High
Increase in suspended sediment	Very high	Very high	High
Decrease in suspended sediment	See explanation	See explanation	See explanation
Desiccation	High	High	Immediate
Increase in emergence regime	High	High	Immediate
Decrease in emergence regime	See explanation	See explanation	See explanation
Increase in water flow rate	High	High	High
Decrease in water flow rate	See explanation	See explanation	See explanation
Increase in temperature	High	Not Relevant	Immediate
Decrease in temperature	See explanation	See explanation	See explanation
Increase in turbidity	Not Relevant	Very high	Very high
Decrease in turbidity	See explanation	See explanation	See explanation
Increase in wave exposure	High	High	High
Decrease in wave exposure	See explanation	See explanation	See explanation
Noise	Not Relevant	Not Relevant	Not Relevant
Visual Presence	Not Relevant	Not Relevant	Not Relevant
Abrasion & physical disturbance	High	High	High
Displacement	Moderate	High	Not Relevant
Chemical factors			
	Sabellaria alveolata	***Fucus serratus***	***Littorina littorea***
Community Importance	Key structural	Important structural	Important functional
Synthetic compound contamination	Insufficient information	High	Very high
Heavy metal contamination	Insufficient information	High	High
Hydrocarbon contamination	Insufficient information	High	High
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	Insufficient information	High	Not Relevant
Increase in salinity	High	Very high	Not Relevant
Decrease in salinity	See explanation	See explanation	See explanation
Changes in oxygenation	High	Very high	Very high
Biological factors			
	Sabellaria alveolata	***Fucus serratus***	***Littorina littorea***
Community Importance	Key structural	Important structural	Important functional

Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information
Introduction of non-native species	Insufficient information	Insufficient information	Insufficient information
Extraction of this species	High	High	High
Extraction of other species	High	Not Relevant	Not Relevant

Importance

Marine natural heritage importance

Listed under:	**UK Biodiversity Action Plan** **EC Habitats Directive**
National importance	Scarce
Habitat Directive feature (Annex 1)	Reefs Large shallow inlets and bays Estuaries
UK Biodiversity Action Plan habitat	*Sabellaria alveolata* reefs Littoral rock (broad habitat statement)

Biotope importance

MLR.Salv can support a highly diverse associated fauna. Dias & Paula (2001), for example, recorded a total of 137 taxa associated with *Sabellaria alveolata* colonies in two areas on the Portuguese coast. In addition to the direct role of providing a habitat or substratum for a variety of flora and fauna, *Sabellaria alveolata* reefs may indirectly enhance species richness by stabilizing otherwise mobile shingle, pebbles and cobbles, for example, on cobble shores. Holt *et al.* (1998) reported that within the Lleyn Peninsula and the Sarnau SAC, sheets of *Sabellaria alveolata* "cement boulders and cobbles". These extensive sheets can form ridges on flat shores which trap water to create pools (Cunningham *et al.*, 1984).

The biotope will vary in importance slightly with time as species come and go depending on the state of the reefs (Porras *et al*., 1996). If dense *Fucus serratus* is present then this may form a nursery ground for species such as *Nucella lapillus*. Such algae also provide substrata for species such as *Spirorbis spirorbis* as well as a feeding location for grazing molluscs including *Patella vulgata* and *Littorina littorea*. The surface of *Sabellaria alveolata* has been noted to possibly provide a barrier to limpets. No species are noted for feeding on *Sabellaria alveolata* itself.

Exploitation

Sabellaria alveolata reefs are sometimes exploited by fishermen as a source of bait although this is only carried out on a very small scale.

Additional information

No text entered

This Biology and Sensitivity Key Information review can be cited as follows:
Jackson, A., 2004. *Sabellaria alveolata* reefs on sand-abraded eulittoral rock. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 19/01/2005]. Available from: <http://www.marlin.ac.uk>

Ascophyllum nodosum ecad *mackaii* beds on extremely sheltered mid eulittoral mixed substrata (SLR.AscX.mac)

Key information authored by: Jacqueline Hill

Last updated 20/06/2001

This information is not refereed.

A dense mat of *Ascophyllum nodosum mackaii*. Image width ca 40 cm.
Image: Sue Scott

Recorded and expected SLR.AscX.mac distribution for Britain and Ireland

Description of biotope

Extremely sheltered mid shore mixed substrata, usually subject to variable salinity due to freshwater runoff, may support beds of the free-living *Ascophyllum nodosum* ecad *mackaii*. Cobbles and other hard substrata are often characterized by the normal form of *Ascophyllum nodosum* and other fucoids such as *Fucus serratus* and *Fucus vesiculosus*. The loose mats of *A. nodosum* ecad *mackaii* provide a cryptic and humid habitat for mobile species such as gammarids, the shore crab *Carcinus maenas*, littorinid molluscs (especially *Littorina littorea*) and eels *Anguilla anguilla*. *Semibalanus balanoides* and *Mytilus edulis* are commonly attached to pebbles and cobbles on the sediment, while the infauna may contain *Arenicola marina*, *Lanice conchilega* and other polychaetes. (Information taken from the Marine Biotope Classification for Britain and Ireland, Version 97.06: Connor *et al.*, 1997a, b).

Welsh variation

Although the Welsh examples of many of the biotopes in this report follow the British and Irish classification description closely, some regional variation may exist. Reference should be made to Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

No text entered

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Habitat complex	SLR	Sheltered littoral rock (fucoid shores)
Biotope complex	SLR.FX	Fucoids, barnacles or ephemeral seaweeds (mixed substrata)
Biotope	SLR.AscX.mac	*Ascophyllum nodosum* ecad *mackaii* beds on extremely sheltered mid eulittoral mixed substrata

Other biotope classification schemes

European Union Nature Information System (EUNIS) code: A1.3/B-SLR.FX Fucoids, barnacles or ephemeral seaweeds on sheltered mixed substrata (Davies & Moss, 1998).

Ecology

Ecological and functional relationships

- An ecad is a distinctive form of a species which develops in response to environmental conditions rather than genotypic differences. *Ascophyllum nodosum* ecad *mackaii* arises when detached fragments of the species are deposited onto sheltered shores where they continue to multiply and branch independently of the original fragment (Chock & Mathieson, 1976). The frond has extensive dichotomous branching and bears few air bladders. The plants drift in large, spherical masses in sheltered waters.
- Extensive beds sometimes develop in appropriate conditions. However, more often beds are very local, often only a few metres across, and typically in small bays between rock outcrops (Anon., 1999a).
- The presence of the *Ascophyllum nodosum* ecad *mackaii* in any particular situation depends on the combination of a number of conditions applying at a tide level between high and low water neaps:
    - frequent alternation of high and low salinities. Very sheltered sea loch shores where freshwater runs or seeps across the shore can provide suitable conditions. The freshwater forms a brackish layer at the loch surface over the saline waters beneath, which moves up and down with the tides and subjects the shores to regularly fluctuating salinities. Therefore, a supply of freshwater is of primary importance
    - good shelter from wave action because of the unattached state of the ecad
    - absence of fast moving water, whether caused by freshwater streams or tidal conditions
    - flat, undulating or slightly sloping shore profile where stability is high
    - substratum type, the porosity of which affects the conditions of salinity also influences, to some extent, the development of the ecad.
- Chock & Mathieson (1979) demonstrated the physiological responses of *Ascophyllum nodosum* and its detached ecad *scorpioides* were similar under varying conditions of light intensity, temperature and salinity.
- The loose mats of *Ascophyllum nodosum* ecad *mackaii* provide a sheltered and humid habitat for many mobile mid-shore animals which would otherwise be unable to live on open sediments or shingle. Gammarid amphipods, shore crabs and littorinid snails hide and feed amongst the weed, while barnacles and mussels are often attached to stones beneath. Fish such as young common eels *Anguilla anguilla* and viviparous blennies *Zoarces viviparus* may also shelter in the weed.

Seasonal and longer term change

In Strangford Lough in Northern Ireland, Stengel & Dring (1997) observed the growth of the attached form of *Ascophyllum nodosum* to be highly seasonal with low growth rates during November and December, and highest growth rates in late spring and early summer. A decline in growth in mid-summer was observed at all shore levels. Chock & Mathieson (1979) demonstrated the physiological responses of *Ascophyllum nodosum* and its ecad *scorpioides* were similar under varying conditions of light intensity and temperature. Therefore, it seems likely that growth rate patterns of the *mackaii* ecad will be similar to the attached plant under the same conditions and the ecad will show clear seasonal changes in growth rate. Gibb (1957) found growth of the ecad to be very slow during the winter. There was no other information found on seasonal or temporal changes in the biotope.

Habitat structure and complexity

The unattached *mackaii* ecad is generally found on flat, undulating or slightly sloping shores of mud, muddy sand or small stones with high stability so there is low habitat complexity. However, the presence of plants of the free living ecad itself add complexity to the habitat because plant masses provide shelter for other species that would otherwise be unable to live on open sediments or shingle.

Dominant trophic groups Photoautotrophs

Productivity

Most productivity in the biotope will be primary due to the photosynthetic activity of *Ascophyllum nodosum*. However, there will also be secondary productivity in the biotope. For example, macroalgae exude considerable amounts of dissolved organic carbon which are taken up readily by bacteria and may even be taken up directly by some larger invertebrates. Detrital input may also be important for the deposit and suspension feeders, such as *Arenicola marina* and *Lanice conchilega*, which may also be present in the biotope.

Major sources of organic carbon	Photosynthesis (macroalgae and/or halophytic plants)

Recruitment processes

Formation of the *mackaii* ecad of *Ascophyllum nodosum* is dependant on a supply of fragments from the attached form of the species. Once formed, the ecad can proliferate itself vegetatively from its own broken fragments which continue to divide forming new plants. *Ascophyllum nodosum* is recruited from pelagic sporelings, but recruitment is generally poor with few germlings found on the shore so recruitment of the ecad will also probably be poor. A supply of pelagic larvae is likely to be important in the recruitment of many of the macrofaunal species in the biotope. Some species, such as amphipods, have direct development and so recruitment will be mainly from local populations although some 'rafting in' of individuals does occur.

Time for community to reach maturity

Ascophyllum nodosum is a slow growing species. If growth rate of the unattached *mackaii* ecad is also low then the time for the community to reach maturity is likely to be several years.

Additional information

No text entered

Habitat preference and distribution

Distribution in Britain and Ireland

The distribution of *Ascophyllum nodosum* ecad *mackaii* is limited to Scottish sea lochs, Strangford Lough in Northern Ireland and a few sites in the Irish Republic.

Habitat preferences

Temperature range preferences	No information found
Water clarity preferences	High clarity / Low turbidity Medium clarity / Medium turbidity
Limiting nutrients	Nitrogen (nitrates) Phosphorus (phosphates)
Other preferences	No information found

Additional information

Detached forms of *Ascophyllum nodosum* are known from several habitats. *Ascophyllum nodosum* var. *mackaii* is found on very sheltered shores, in sea lochs and is sometimes common on the west coasts of Ireland and Scotland and in these situations the ecad is sometimes present in great abundance. Sheltered or land-locked bays or situations in the lee of small islands are other favourable positions (Gibb, 1957).

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	**Species name**	**Common Name**
Key structural	*Ascophyllum nodosum*	Egg wrack
Important characterizing	*Hyale prevostii*	An amphipod
Important characterizing	*Littorina littorea*	Common periwinkle

Explanation

The biotope often consists of both the free-living *Ascophyllum nodosum* ecad *mackaii* and on cobbles and other hard substrata the normal form of *Ascophyllum nodosum*. The beds often provide a habitat for other species such as gammarid amphipods like *Hyale prevostii* and the periwinkle *Littorina littorea*.

Species found especially in biotope

Ascophyllum nodosum ecad *mackaii*

Additional information

No text entered

Biotope sensitivity

Physical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	Low	High	Major Decline	Moderate
Smothering	High	Low	High	Major Decline	Moderate
Increase in suspended sediment	Low	Immediate	Not sensitive	No Change	High
Decrease in suspended sediment	Low	Immediate	Not sensitive	No Change	High
Desiccation	Intermediate	Moderate	Moderate	Minor Decline	Moderate
Increase in emergence regime	Intermediate	Moderate	Moderate	No Change	Moderate
Decrease in emergence regime	Low	High	Low	No Change	Moderate
Increase in water flow rate	High	Low	High	Decline	Moderate
Decrease in water flow rate	Not Relevant	Not Relevant	Not relevant	No Change	Moderate
Increase in temperature	Low	Very high	Very Low	Minor Decline	Moderate
Decrease in temperature	Low	Very high	Very Low	Minor Decline	High
Increase in turbidity	Low	Immediate	Not sensitive	No Change	High
Decrease in turbidity	Tolerant*	Very high	Not sensitive*	No Change	High

Increase in wave exposure	High	Low	High	Decline	Moderate
Decrease in wave exposure	Not Relevant	Not Relevant	Not relevant	NR	High
Noise	Tolerant	Not Relevant	Tolerant	NR	High
Visual Presence	Tolerant	Not Relevant	Tolerant	NR	High
Abrasion & physical disturbance	Intermediate	Moderate	Moderate	Minor Decline	High
Displacement	Tolerant	Not Relevant	Tolerant	NR	High

Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	Intermediate	High	Low	Minor Decline	Low
Heavy metal contamination	Intermediate	High	Low	Minor Decline	Low
Hydrocarbon contamination	Intermediate	Moderate	Moderate	Decline	Moderate
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Changes in nutrient levels	Intermediate	Low	High	Minor Decline	Low
Increase in salinity	High	Low	High	Minor Decline	Low
Decrease in salinity	High	Low	High	Minor Decline	Moderate
Changes in oxygenation	Insufficient information	Not Relevant	Insufficient information	Insufficient Information	Not Relevant
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Low	High	Low	No Change	Low
Introduction of non-native species	Tolerant	Not Relevant	Tolerant	NR	Moderate
Extraction of key or important characterizing species	Intermediate	Moderate	Moderate	No Change	Low
Extraction of important species	Tolerant	Not Relevant	Not sensitive	NR	Moderate

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	Although the *mackaii* ecad of *Ascophyllum nodosum* is unattached the species is likely to be removed along with substratum removal. Other key or characterizing species in the biotope will also be removed and so intolerance is considered to be high. For recoverability see additional information.
Smothering (see benchmark)	The key species, *Ascophyllum nodosum* ecad *mackaii*, is likely to be intolerant of smothering by 5 cm of sediment because photosynthesis would not be possible and plants would also be likely to rot underneath the smothering material. The habitats in which the ecad is found are very sheltered from wave exposure and tidal streams so sediment is unlikely to be removed by water movement.

	However, some component species such as amphipods and snails may excavate out of the sediment. Thus, because the key characterizing species is lost the biotope will also be lost if smothered and so is considered to be highly intolerant. The small embayments and inlets, often enclosed by rocky headlands, the typical habitat for *Ascophyllum nodosum* ecad *mackaii*, are vulnerable to infilling for land-based deposits for marine industries such as fish and shellfish farms, slipways, car parks and other developments (Anon., 1999a). For recoverability see additional information.
Increase in suspended sediment (see benchmark)	*Ascophyllum nodosum* ecad *mackaii* is not likely to be directly intolerant of an increase in suspended sediment because although turbidity will increase, photosynthesis can still occur when the tide is out (see turbidity). However, settlement out of the sediment may cover some surfaces of the plant, reducing photosynthesis rates which may reduce growth. Other species in the biotope, in particular the suspension feeders, such as *Lanice conchilega,* are likely to be more intolerant because an increase in suspended sediment may interfere with feeding, increase cleaning costs and result in lower growth rates. However, the impact on the biotope as a whole will be negligible so intolerance has been assessed as low. On return to pre-impact suspended sediment levels feeding rates of affected species and photosynthetic rates will return to normal very rapidly.
Decrease in suspended sediment (see benchmark)	*Ascophyllum nodosum* ecad *mackaii* is not likely to be directly intolerant of a decrease in suspended sediment because the species is a primary producer. Other species in the biotope, in particular the suspension feeders, such as *Lanice conchilega*, are likely to be more intolerant because a decrease in suspended sediment may also result in a decrease in food supplies so growth may be affected. However, the impact on the biotope as a whole will be negligible so intolerance has been assessed as low. On return to pre-impact suspended sediment levels feeding of affected species and photosynthetic rates will return to normal very rapidly.
Desiccation (see benchmark)	*Ascophyllum nodosum* ecad *mackaii* is found at upper or mid-tide levels where it regularly becomes exposed to air during tidal cycles and so is tolerant of some desiccation. An increase in desiccation at the level of the benchmark, equivalent to a change in position of one vertical biological zone on the shore, will kill a large proportion of plants at the upper end of the populations range depressing the upper limit and so intolerance is assessed as intermediate. Macrofauna, such as the gammarid amphipod *Hyale prevostii*, that use the algae as a sheltered and humid habitat are also intolerant of increased desiccation and will be likely to move down the shore to avoid the factor. Other species such as the periwinkle *Littorina littorea* are able to tolerate some increase in desiccation and will be little affected. Where present, the ecad can proliferate itself vegetatively from its own broken fragments which continue to divide forming new plants. Therefore, recovery should be possible within five years although it may take longer for plants to return to original density and biomass so a rank of moderate of reported.
Increase in emergence regime (see benchmark)	*Ascophyllum nodosum* is normally exposed to air for no more than a few hours (Lüning, 1990). An increase in the period of emersion would subject the species to greater desiccation and nutrient stress, leading to a depression in the upper limit of the species distribution on the shore. Other species are also likely to be affected in a similar way so intolerance of the biotope is considered to be intermediate. Where present the ecad can proliferate itself vegetatively from its own broken fragments which continue to divide forming new plants. Therefore, recovery should be possible within five years although it may take longer for plants to return to original density and biomass so a rank of moderate of reported.
Decrease in emergence regime (see benchmark)	*Ascophyllum nodosum* ecad *mackaii* and its component species are all likely to survive increased or full immersion. However, a reduction in the period of emersion may result in the species being competitively displaced by faster

	growing species and may allow the upper limit of the population of *Ascophyllum nodosum* to extend up the shore.
Increase in water flow rate (see benchmark)	The biotope occurs in very sheltered locations with weak or very weak tidal streams because the *mackaii* ecad is unattached. Therefore, the biotope is likely to be highly intolerant of an increase in water flow rate because plants of the characterizing species will be washed away. The attached form and the other fucoid algal species in the biotope are able to tolerate higher water flow rates than the unattached ecad. For recovery see additional information.
Decrease in water flow rate (see benchmark)	The biotope occurs in very sheltered locations where water flow rates may be negligible so a decrease is not relevant.
Increase in temperature (see benchmark)	Chock & Mathieson (1979) found no major physiological difference between the attached form of *Ascophyllum nodosum* and its ecad *scorpioides* so it seems likely that the *mackaii* ecad will also be physiologically similar to the attached form. *Ascophyllum nodosum* and the *mackaii* ecad are intertidal and so are regularly exposed to rapid and short-term variations in temperature. Both exposure at low tide or rising tide on a sun-heated shore may involve considerable temperature increases. Growth has been measured between 2.5 and 35 °C with an optimum between 10 and 17 °C (Strömgren, 1977). In the North Sea *Ascophyllum nodosum* can tolerate a maximum temperature of 28 °C and the optimum growth rate is at 15 °C (Lüning, 1990). Laboratory experiments in New Hampshire showed that *Ascophyllum nodosum* exhibits a eurythermal response to temperature with a more pronounced optimum occurring during the summer than the winter (Chock & Mathieson, 1979). Overall, summer plants showed a higher rate of net photosynthesis than winter specimens. Therefore, the species is likely to be quite tolerant of a long term change in temperature of 2 °C. The species is unlikely to be affected by a short term change of 5 °C, as it was not damaged during the unusually hot summer of 1983 when the average temperature was 8.3 °C higher than normal (Hawkins & Hartnoll, 1985). Although some of the associated macrofauna may be more intolerant of increases in temperature they are not key to the structure and function of the biotope. Therefore, the biotope is considered to have low intolerance to increases in temperature. However, the species has been found to be damaged by thermal pollution if the water temperature is above 24 °C for several weeks (Lobban & Harrison, 1997) and the southern limit of the species distribution is controlled by the maximum summer temperature of about 22 °C (Baardseth, 1970).
Decrease in temperature (see benchmark)	In Newfoundland populations of *Ascophyllum nodosum* ecad *mackaii* are subjected to low temperatures and ice conditions probably seldom encountered in the Scottish and Irish habitats studied by Gibb (1957). In January 1970, some populations were encased in ice, a phenomenon enhanced by the "layering" effect of fresh and salt water in these habitats (South & Hill, 1970). Judging from the age of some of the globular tufts at some of these sites, the authors suggest the plants can presumably withstand a number of successive winters of ice encasement without undue harm. Such conditions during the particularly stormy months of the year could possibly ensure the survival of *mackaii* in these localities. The extreme sheltered conditions occupied by the ecad, and its free-living habit would preclude it, however, from the severest action of pack ice frequently occurring on the open coast in Newfoundland. Although some other species, such as the gammarid amphipod *Hyale prevostii*, will be more intolerant of long and short term changes in temperature the key species, the ecad, is likely to tolerate such changes and so intolerance is assessed as low. Metabolic and reproductive processes which may be affected by a drop in temperature are likely to return to normal very quickly.

Increase in turbidity (see benchmark)	An increase in turbidity would reduce the light available for photosynthesis during immersion. However, the species is found at the upper and mid-tide levels and so is subject to long periods of emersion during which time it can continue to photosynthesize as long as the plant has a sufficiently high water content. Therefore, photosynthesis and consequently growth will be unaffected during this period and so intolerance of the species, and hence the biotope, is considered to be low. Upon return to previous turbidity levels the photosynthesis rate would return immediately to normal.
Decrease in turbidity (see benchmark)	A decrease in turbidity would increase the light available for photosynthesis during immersion which may increase growth rates of all the algae in the biotope. Upon return to previous turbidity levels the photosynthesis rate would return immediately to normal.
Increase in wave exposure (see benchmark)	The biotope is likely to be highly intolerant of increases in wave exposure because the free living *mackaii* ecad of *Ascophyllum nodosum* only develops in locations of extreme shelter. Increased wave action could also result in the displacement of plants from ideal conditions. In addition the fauna that shelter in plants are also likely to be displaced if wave action increases. Therefore, the intolerance of the biotope is considered to be high. Recoverability is assessed as low because it is not known if lost beds can recover - see additional information.
Decrease in wave exposure (see benchmark)	*Ascophyllum nodosum* ecad *mackaii* only develops in areas of extreme shelter where wave exposure in negligible so a decrease in wave exposure at the level of the benchmark is not relevant.
Noise (see benchmark)	Macroalgae have no known sound or vibration sensors so the biotope will not be intolerant of noise disturbance such as boat traffic. The response of macroinvertebrates is not known.
Visual Presence (see benchmark)	Macrophytes have no known visual sensors. Most macroinvertebrates have poor or short range perception and are unlikely to be affected by visual disturbance such as boat traffic or walkers on the shore.
Abrasion & physical disturbance (see benchmark)	Frond injury in the *mackaii* ecad is common and often severe and plays an important part in the life of plants (Gibb, 1957). Injury influences the branching of the plant by acting as a stimulus for the development of lateral branches. Therefore, the plants are likely to have low intolerance to abrasion. However, a passing scallop dredge, or similar impact, is likely to physically remove a number of the plants themselves, similar to but not as extensive as substratum loss above. Therefore, an intolerance of intermediate has been recorded. Where present, the ecad can proliferate itself vegetatively from its own broken fragments which continue to divide forming new plants. Therefore, recovery should be possible within five years although it may take longer for plants to return to original density and biomass so a score of moderate of reported.
Displacement (see benchmark)	*Ascophyllum nodosum* ecad *mackaii* is unattached and so should not be intolerant of displacement to another suitable location.
Chemical Factors	
Synthetic compound contamination (see benchmark)	The disappearance of *Ascophyllum nodosum* from Oslofjord has been attributed to the reduced ability of germlings to recruit at highly polluted sites (Sjoetun & Lein, 1993). Hoare & Hiscock (1974) observed that *Ascophyllum nodosum* was absent from within 100m of an acidified, halogenated effluent discharge, and that plants nearby had abnormal and retarded growth. Most *Ascophyllum nodosum* ecad *mackaii* beds are found in unpolluted sites so the ecad may be intolerant of synthetic chemicals.
Heavy metal contamination	Copper at concentrations of 1039 nM (66 µg/L) have been found to inhibit the growth of *Ascophyllum nodosum* (Strömgren, 1979). However, adult plants

(see benchmark)	appear to be fairly robust in the face of heavy metal pollution (Holt *et al*., 1997).
Hydrocarbon contamination (see benchmark)	Experimental studies have found that long-term exposure to low levels of diesel reduces the growth rate in *Ascophyllum nodosum*. A limited amount of oil pollution need not be detrimental to a population of the characterizing species with good recruitment (Sjoetun & Lein, 1993). However, other components of the biotope are known to be intolerant of hydrocarbon pollution, especially amphipods.
Radionuclide contamination (see benchmark)	Insufficient information.
Changes in nutrient levels (see benchmark)	There are reports of a decline in populations of *Ascophyllum nodosum* in the North Atlantic as a result of increased eutrophication (Fletcher, 1996). Most *A. nodosum* ecad *mackaii* beds are in unpolluted sites and may be adversely affected by eutrophication of sea lochs which can be caused by fish farm activities.
Increase in salinity (see benchmark)	The development and maintenance of the ecad depends on the frequent alternation of high and low salinity. These conditions occur between high and low water neaps, in places where freshwater streams have an influence but where there is full marine salinity for a period during the tidal cycle. Therefore, it is expected that a long term increase in salinity would be detrimental to the species and hence the biotope and a rank of high is recorded. Information on recovery can be found in 'additional information' below.
Decrease in salinity (see benchmark)	The development and maintenance of the ecad depends on the frequent alternation of high and low salinity. These conditions occur between high and low water neap tide levels, in places where freshwater streams have an influence but where there is full marine salinity for a period during the tidal cycle. Therefore, the ecad can tolerate very short periods of low salinity. However, the longest exposure will only be about 10 hours and so *A. nodosum* ecad *mackaii* is not likely to be able to tolerate the benchmark decreases in salinity. When the ecad and the attached plant are frequently submerged for long periods in running fresh water they develop 'freshwater decay' where plants begin to break up. Although this breaking up of plants is important to the life of plants (it influences the branching habit) a long term decrease in salinity would probably cause the death of plants and so the biotope is considered to have high intolerance to decreased salinity. For recovery see additional information.
Changes in oxygenation (see benchmark)	There is insufficient information on the response of the key and other organisms in the biotope to changes in oxygenation to make an assessment. However, an oxygen concentration of 2 mg/l is thought likely to cause effects in marine organisms (Cole *et al*., 1999) and if experienced for a period of one week is likely to result in the death of some intolerant species.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	Although bacteria and fungi are associated with the attached form of *Ascophyllum nodosum* no information could be found on any disease causing microbes in the biotope and so intolerance is assessed as low. However, there is always the potential for this to change.
Introduction of non-native species (see benchmark)	There are no records of any non-native species invading the biotope that may compete with or graze upon *Ascophyllum nodosum* ecad *mackaii* and so the biotope is assessed as not sensitive. However, as several species have become established in British waters there is always the potential for an adverse effect to occur.
Extraction of key or important characterizing	The attached form of *Ascophyllum nodosum* is still collected on a small scale in western Scotland for the extraction of alginate. The unattached *mackaii* ecad is

species (see benchmark)	very easy to collect as it does not need cutting from the rock and it has been collected along with the attached form in the past. For example, *Ascophyllum nodosum* ecad *mackaii* beds and associated communities in the Uists in the Outer Hebrides have been decimated by removal of plants. It is not known if it is possible, or how long it takes for beds to recover from harvesting. For example, there was no sign of recovery of a bed two years after its removal at Kyle of Lochalsh (Anon., 1999a). However, once present the ecad can proliferate itself vegetatively from its own broken fragments which continue to divide forming new plants. Therefore, recovery should be possible within five years although it may take longer for plants to return to original density and biomass so a rank of moderate of reported.
Extraction of important species (see benchmark)	With the exception of *Ascophyllum nodosum* the other species in the biotope do not have an important functional or structural influence. For example, although some species may graze on plants the nature of the biotope will not altered if they are extracted and so the biotope is considered to be not sensitive.

Additional information

Recoverability

On return to normal conditions after a perturbation the sheltered conditions of the biotope should enable fragments of the attached *Ascophyllum nodosum* to grow and develop into the ecad. However, recovery depends on the supply of *Ascophyllum nodosum* fragments which may be from distant sources and may therefore take several years to return. For example, during the construction of the Skye Bridge a dense bed at Kyle of Lochalsh was accidentally removed and more than two years later there was still no sign of recovery of this bed so recovery may be unpredictable. The key characterizing species *Ascophyllum nodosum* ecad *mackaii* is also very slow growing so recovery to original sized plants and beds could take many years. Recoverability is assessed as low because it is not known if lost beds can recover.

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors			
	Ascophyllum nodosum	***Hyale prevostii***	***Littorina littorea***
Community Importance	Key structural	Important characterizing	Important characterizing
Substratum Loss	High	High	High
Smothering	High	Low	High
Increase in suspended sediment	Low	Low	Intermediate
Decrease in suspended sediment	See explanation	See explanation	See explanation
Desiccation	Intermediate	Intermediate	Low
Increase in emergence regime	High	Low	Low
Decrease in emergence regime	See explanation	See explanation	See explanation
Increase in water flow rate	Intermediate	Low	Intermediate
Decrease in water flow rate	See explanation	See explanation	See explanation
Increase in temperature	Low	Intermediate	Low
Decrease in temperature	See explanation	See explanation	See explanation
Increase in turbidity	Low	Low	Low
Decrease in turbidity	See explanation	See explanation	See explanation
Increase in wave exposure	High	Intermediate	Intermediate
Decrease in wave exposure	See explanation	See explanation	See explanation

Noise	Not Sensitive	Low	Not Sensitive
Visual Presence	Not Sensitive	Low	Not Sensitive
Abrasion & physical disturbance	High	Intermediate	Intermediate
Displacement	High	Low	Not Sensitive
Chemical factors			
	Ascophyllum nodosum	***Hyale prevostii***	***Littorina littorea***
Community Importance	Key structural	Important characterizing	Important characterizing
Synthetic compound contamination	Intermediate	Intermediate	Low
Heavy metal contamination	Low	Intermediate	Intermediate
Hydrocarbon contamination	Low	High	High
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	Intermediate	Intermediate	Not Sensitive
Increase in salinity	Low	Low	Not Sensitive
Decrease in salinity	See explanation	See explanation	See explanation
Changes in oxygenation	Insufficient information	High	Low
Biological factors			
	Ascophyllum nodosum	***Hyale prevostii***	***Littorina littorea***
Community Importance	Key structural	Important characterizing	Important characterizing
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information
Introduction of non-native species	Insufficient information	Not Relevant	Insufficient information
Extraction of this species	Intermediate	Intermediate	Intermediate
Extraction of other species	Not Sensitive	Low	Not Sensitive

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors			
	Ascophyllum nodosum	***Hyale prevostii***	***Littorina littorea***
Community Importance	Key structural	Important characterizing	Important characterizing
Substratum Loss	Low	Moderate	High
Smothering	Low	High	High
Increase in suspended sediment	Immediate	High	High
Decrease in suspended sediment	See explanation	See explanation	See explanation
Desiccation	Moderate	High	Immediate
Increase in emergence regime	Low	High	Immediate
Decrease in emergence regime	See explanation	See explanation	See explanation
Increase in water flow rate	Low	High	High
Decrease in water flow rate	See explanation	See explanation	See explanation
Increase in temperature	Moderate	High	Immediate
Decrease in temperature	See explanation	See explanation	See explanation
Increase in turbidity	Immediate	High	Very high
Decrease in turbidity	See explanation	See explanation	See explanation
Increase in wave exposure	Low	High	High
Decrease in wave exposure	See explanation	See explanation	See explanation
Noise	Not Relevant	High	Not Relevant
Visual Presence	Not Relevant	High	Not Relevant

Abrasion & physical disturbance	Low	High	High
Displacement	Low	High	Not Relevant
Chemical factors			
	Ascophyllum nodosum	***Hyale prevostii***	***Littorina littorea***
Community Importance	Key structural	Important characterizing	Important characterizing
Synthetic compound contamination	Low	High	Very high
Heavy metal contamination	High	High	High
Hydrocarbon contamination	Moderate	Moderate	High
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	High	High	Not Relevant
Increase in salinity	High	High	Not Relevant
Decrease in salinity	See explanation	See explanation	See explanation
Changes in oxygenation	Insufficient information	High	Very high
Biological factors			
	Ascophyllum nodosum	***Hyale prevostii***	***Littorina littorea***
Community Importance	Key structural	Important characterizing	Important characterizing
Introduction of microbial pathogens/parasites	Not Relevant	Insufficient information	Insufficient information
Introduction of non-native species	Not Relevant	Not Relevant	Insufficient information
Extraction of this species	Low	High	High
Extraction of other species	Not Relevant	High	Not Relevant

Importance

Marine natural heritage importance

Listed under:	**UK Biodiversity Action Plan** **EC Habitats Directive**
National importance	Scarce
Habitat Directive feature (Annex 1)	Reefs Large shallow inlets and bays Lagoons
UK Biodiversity Action Plan habitat	*Ascophyllum nodosum* ecad *mackaii* beds Saline lagoons Littoral rock (broad habitat statement)

Biotope importance

Fish such as young common eels *Anguilla anguilla* and viviparous blennies *Zoarces viviparous* may shelter in the weed.

Exploitation

- The attached form of *Ascophyllum nodosum* is harvested in most areas of its distribution. The unattached *mackaii* ecad is easy to collect, as it needs no cutting from the rocks, and it has been collected along with the attached form in the past.
- In the west Highlands many roads run alongside loch shores where the biotope is present. Road improvements or construction or new roads, often involve 'straightening' the shoreline or building causeways across small embayments. In this way the biotope can be destroyed or cut off from the sea.
- Most *Ascophyllum nodosum* ecad *mackaii* beds are in remote, unpolluted sites, and in a natural condition. The rarity of the habitat, the small size of many of the beds, and the importance of the UK populations in an international context, has resulted in a Biodiversity Action Plan for this species (Anon., 1999a).

Additional information

No text entered

This Biology and Sensitivity Key Information review can be cited as follows:

Hill, J.M., 2001. *Ascophyllum nodosum* ecad *mackaii* beds on extremely sheltered mid eulittoral mixed substrata. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 19/01/2005]. Available from: <http://www.marlin.ac.uk>

Ascophyllum nodosum, sponges and ascidians on tide-swept mid eulittoral rock (SLR.Asc.T)

Key information authored by: Charlotte Marshall

Last updated 10/01/2005

This information is not refereed.

Recorded and expected SLR.Asc.T distribution for Britain and Ireland

If you would be willing to supply *MarLIN* with an image of this species/habitat please contact marlin@mba.ac.uk

Description of biotope

Very sheltered to extremely sheltered areas of mid eulittoral rock that are subject to strong to moderate tidal streams, such as the narrows in sea lochs, and characterized by the wrack *Ascophyllum nodosum*. The wracks *Fucus vesiculosus* and *Fucus serratus* are occasionally present. The increased water movement encourages a rich associated fauna including several filter-feeding groups. These include the sponges *Leucosolenia* spp., *Grantia compressa*, *Halichondria panicea* and *Hymeniacidon perleve* which frequently occur on steep and overhanging faces of boulders and bedrock. It also includes the sea squirts *Dendrodoa grossularia* and *Ascidiella scabra*, which occur on steep surfaces and beneath boulders. Hydroids such as the pink *Clava multicornis* can form colonies on *Ascophyllum nodosum* while *Dynamena pumila* is more often found on *Fucus vesiculosus* or *Fucus serratus*. Underneath the canopy formed by the brown seaweeds is a diverse community of the red seaweeds *Gelidium pusillum*, *Chondrus crispus*, *Lomentaria articulata*, *Membranoptera alata* and coralline crusts, but the green seaweeds *Enteromorpha intestinalis*, *Ulva lactuca* and *Cladophora rupestris* can be present. The filamentous red seaweed *Polysiphonia lanosa* can usually be found growing on *Ascophyllum nodosum*. On the rock beneath are the limpet *Patella vulgata* and the barnacle *Semibalanus balanoides*, while the crab *Carcinus maenas* and a variety of winkles including *Littorina littorea*, *Littorina mariae* and *Littorina obtusata* can be found on or among the boulders. The whelk *Nucella lapillus* can either be found in cracks and crevices or preying on the barnacles. (Information taken from the revised Marine Biotope Classification, Version 04.06, Connor *et al.*, 2004).

Welsh variation

Although the Welsh examples of many of the biotopes in this report follow the British and Irish classification description closely, some regional variation may exist. Reference should be made to Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

No text entered

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Habitat complex	SLR	Sheltered littoral rock (fucoid shores)
Biotope complex	SLR.F	Dense fucoids (stable rock)
Biotope	SLR.Asc.T	*Ascophyllum nodosum*, sponges and ascidians on tide-swept mid eulittoral rock

Other biotope classification schemes

European Nature Classification Information System (EUNIS) habitat classification: A1.3142 - *Ascophyllum nodosum*, sponges and ascidians on tide-swept mid eulittoral rock (Davies & Moss, 1998).

Ecology

Ecological and functional relationships

The moderately strong to very strong tidal streams associated with this biotope support a rich and varied marine life, of which the suspension feeders and autotrophs are the dominant trophic groups. *Ascophyllum nodosum*, the knotted wrack, forms a canopy in this biotope. The serrated wrack *Fucus serratus* and bladder wrack *Fucus vesiculosus* may also form part of this canopy but the long lived *Ascophyllum nodosum* tends to dominate in terms of abundance and standing biomass. The canopy layer limits light penetration and the understory is dominated by shade tolerant foliose and red seaweeds including *Chondrus crispus*, *Corallina officinalis*, *Mastocarpus stellatus* and encrusting calcareous algae. The filamentous red seaweed *Polysiphonia lanosa* is possibly the most commonly occurring red algal species in this biotope. It has root like fibres which penetrate the tissue of *Ascophyllum nodosum* and, less frequently, *Fucus* sp. (Fish & Fish, 1996). Green algae, especially *Ulva* sp. and *Cladophora rupestris* may also be found.

Suspension feeders representing several phyla are commonly associated with this biotope. Representatives of the sponge and ascidian communities, that give the biotope its name, are varied and diverse. Both encrusting sponges, including the breadcrumb sponge *Halichondria panicea* and *Hymeniacidon perleve*, and solitary forms such as the purse sponge *Grantia compressa* are found. Similarly, both colonial and solitary ascidians are found although the baked bean ascidian *Dendrodoa grossularia*, for example, is far more abundant and frequently associated with this biotope than the colonial star ascidian *Botrylloides leachi*. Large stands of hydroids may be found on the fucoids including *Dynamena pumila* and the pink hydroid *Clava multicornis*. In general, *Ascophyllum nodosum* is remarkably free of epiphytes even when adjacent plants of other species of fucoid algae are heavily infested (Filion-Myclebust & Norton, 1981). This is due to the fact that *Ascophyllum nodosum* repeatedly sloughs its entire outer epidermis, and potential epiphytes, including spores and germlings of other algae that had settled on the surface are, therefore, discarded with it (Filion-Myclebust & Norton, 1981).

A variety of winkles, most commonly the common periwinkle *Littorina littorea* and flat periwinkle *Littorina obtusata* graze on microorganisms, detritus and algae in this biotope. Whilst the common periwinkle grazes on rock in the biotope, *Ascophyllum nodosum* is the preferred food for the flat periwinkle (Fish & Fish, 1996). The flat periwinkle lays its eggs on *Ascophyllum nodosum*, *Fucus vesiculosus* and *Fucus serratus* and, occasionally, on the rock surface (Fish & Fish, 1996). The common limpet *Patella vulgata* can be abundant and grazes on tough plants including *Fucus* sp. and encrusting red algae. Grazing by *Patella vulgata* can be an important structuring feature on rocky shores and it is often considered to be a keystone species on north-east Atlantic rocky shores. Reductions in limpet density have been observed to have a significant impact on rocky shore community composition, particularly of fucoid algae and barnacles (Hawkins & Hartnoll, 1985; Raffaelli & Hawkins, 1999).

The common shore crab *Carcinus maenas* is the largest mobile predator frequently associated with this biotope and is likely to move between the boulders and pebbles feeding primarily on small molluscs, especially *Littorina* sp. and the common mussel *Mytilus edulis*, annelids and other crustacea. It is an omnivore and will also consume algal material. The predatory mollusc *Nucella lapillus* also feeds primarily on the common mussel, in addition to acorn barnacles (Fish & Fish, 1996) such as *Semibalanus balanoides* which can also be abundant in the biotope.

Seasonal and longer term change

Ascophyllum nodosum can reach an age of 25 years and the community associated with this biotope is usually very stable (Connor *et al.*, 2004). There are unlikely to be large visible changes in the biotope throughout the year, especially since the biotope occurs in very sheltered / extremely sheltered habitats where winter storms are unlikely to have as significant an effect on the algal standing biomass as wave exposed shores. However, an increase in ephemeral algae such as *Cladophora rupestris* may be observed over the summer months.

Habitat structure and complexity

Owing to the tidally swept habitat with which this biotope is associated, a diverse marine life is supported. The fast currents provide a continual supply of food for both active and passive suspension feeders that dominate the attached fauna. Fine sediment is removed by the current and the settlement of material, that could otherwise be detrimental to the suspension feeders, is prevented. Almost every possible substratum, including the bedrock, boulders, cobbles and overhanging faces, is covered with various flora and fauna. In addition to the luxuriant conditions for suspension feeders, Hiscock (1983) lists some the benefits of strong water movement to include the potential for a greater photosynthetic efficiency, thereby possibly increasing the depth penetration of the algae. Increased water movement has been associated with an increase in photosynthesis in several algal species including *Fucus serratus* and *Ascophyllum nodosum* (Robins, 1968, cited in Hiscock, 1983).

The algae themselves provide a substratum for epiphytic species including hydroid, sponge and ascidian communities. *Leucosolenia* sp., for example, are often found on red seaweeds. The hydroid *Dynamena pumila* may grow on several *Fucus* species whereas the spirorbid worm *Spirorbis spirorbis* grows preferentially on *Fucus serratus*. The fronds of *Ascophyllum nodosum*, however, are narrow, flexible and slimy, offering a poor support for most encrusting animals. The species is unattractive to most intertidal species with the exception of the pink hydroid *Clava multicornis*, the bryozoan *Bowerbankia imbricata* and, on sheltered shores, the tube worm *Spirorbis spirorbis*. *Ascophyllum nodosum* also supports the red algae *Polysiphonia lanosa*, which penetrates its fronds with root-like fibres.

Rock surfaces may, depending on their geology, be broken and include shaded overhangs and damp crevices which, together with the shelter of the algal canopy, allow many animal species to thrive in the damp conditions.

Dominant trophic groups	Photoautotrophs Suspension feeders

Productivity

Rocky shore communities are highly productive and are an important source of food and nutrients for members of neighbouring terrestrial and marine ecosystems (Hill *et al.*, 1998). Rocky shores make a contribution to the food of many marine species through the production of planktonic larvae and propagules which contribute to pelagic food chains. Production rates of *Ascophyllum nodosum* in Nova Scotia were estimated to be between 0.61 and 2.82 kg/m² (Cousens, 1984). Raffaelli & Hawkins (1999) reported an estimate of the productivity of intertidal fucoids as 160 gC/m²/year, although this figure was an estimate for moderately wave exposed habitats. The fucoids and other macroalgae associated with this biotope can exude dissolved organic carbon, which is taken-up readily by bacteria and may even be taken-up directly by some larger invertebrates. Dissolved organic carbon, algal fragments and microbial film organisms are continually removed by the sea. This may enter the food chain of local subtidal ecosystems, or be exported further offshore. Many of the species associated with this biotope make a contribution to the food of many marine species through the production of planktonic larvae and propagules, which contribute to pelagic food chains.

Major sources of organic carbon	Photosynthesis (macroalgae and/or halophytic plants) Plankton

Recruitment processes

- *Ascophyllum nodosum* is dioecious and, like all other fucoids, has only a sexual generation. Receptacles are initiated in April, are present on the plant for 12-14 months and ripen in April to June of the following year. Gametes are released from April onwards. In the laboratory, the release of gametes can be triggered by exposing ripe receptacles to air overnight. Fertilization takes place externally and zygotes settle and form a rhizoid within ten days. Recruitment in *Ascophyllum nodosum* is very poor with few germlings found on the shore. The reason for this poor recruitment is unclear, because the species invests the same high level of energy in reproduction as other fucoids and is extremely fertile every year (Printz, 1959). However, the reproductive period lasts about two months, much shorter than for other fucoids. Printz (1959) suggests that it must be assumed that some special combination of climatic or environmental conditions is needed for effective colonization by *Ascophyllum nodosum*. The slow growth rate of germlings, which increases the chance of their being covered by diatoms or grazed by gastropods, may also help to explain the scarcity of germlings (Baardseth, 1970).

- Reproduction in *Fucus serratus* commences in late spring and continues until November, with a peak in August and October. Eggs and sperm are produced separately and fertilized externally to form a planktonic zygote. Recruitment is therefore possible from sources outside the biotope. *Fucus vesiculosus* is highly fecund often bearing more than 1000 receptacles on each plant, which may produce in excess of one million eggs. In England, the species has a protracted reproduction period of about six months. Gametes may be produced from mid winter until late summer with a peak of fertility in May and June. Like *Fucus serratus*, the eggs are fertilized externally to produce a zygote. Zygotes start to develop whenever they settle, even if the substratum is entirely unsuitable. Mortality is extremely high in the early stages of germination up to a time when plants are 3 cm in length and this is due mostly to mollusc predation (Knight & Parke, 1950).
- *Chondrus crispus* has an extended reproductive period (e.g. Pybus, 1977; Fernandez & Menendez, 1991; Scrosati *et al.*, 1994) and produces large numbers of spores (Fernandez & Menendez, 1991). The spores of red algae are non-motile (Norton, 1992) and therefore entirely reliant on the hydrographic regime for dispersal. Hence, it is expected that *Chondrus crispus* would normally only recruit from local populations and that recovery of remote populations would be much more protracted.
- The breadcrumb sponge *Halichondria panicea* is likely to have a short, annual season of sexual reproduction (see *MarLIN* Web site).
- *Patella vulgata* become sexually mature as males aged about nine months. Reproduction is an annual process with peaks within a defined spawning season (October - January) depending on location. Planktonic trophic larvae are produced although the larvae are only planktonic for a few days.
- *Ascidiella scabra* has a high fecundity and settles readily, probably for an extended period from spring to autumn. Eggs and larvae are free-living for only a few hours and so recolonization would have to be from existing individuals no more than a few km away. It is also likely that *Ascidiella scabra* larvae are attracted by existing populations and settle near to adults (Svane *et al.*, 1987).
- The flat periwinkle *Littorina obtusata* are capable of reproducing through out the year (Graham, 1988). Eggs are laid in a jelly mass, usually on the fronds of *Fucus* species and hatch three or four weeks later (Goodwin, 1978, cited in Graham, 1988). Recruitment from external sources would therefore rely on the movement of adults into the area.

Time for community to reach maturity

Ascophyllum nodosum is a long lived, slow growing algae with poor recruitment rates that limit recovery (Holt *et al.*, 1997). The lack of recovery of *Ascophyllum nodosum* from harvesting is well documented. For example, in their work on fucoid recolonization of cleared areas at Port Erin, Knight and Parke (1950) observed that even eight years after the original clearance there was still no sign of the establishment of an *Ascophyllum nodosum* population. In terms of community maturation however, recoverability is likely to take significantly longer. Jenkins *et al.* (2004) studied the long term effects of *Ascophyllum nodosum* canopy removal on the whole understory community structure on a sheltered rocky shore on the Isle of Man. They reported that, even after twelve years, major effects of the canopy removal were still apparent. At the culmination of the study, the emerging canopy was a mixture of *Ascophyllum* and *Fucus serratus* with occasional patches of *Fucus vesiculosus*. Despite some recovery, mean cover of *Ascophyllum nodosum* was still only about 50% of its original level compared with control plots. However, the most alarming changes were evident in the understory community. Previously, this community was characterized by a balance between patches of red algal turf and patches grazed by *Patella vulgata*. Removal of the canopy layer broke down the balance between these two 'functional units' to the extent that the community showed no signs of reverting to its pre-disturbance state. In a cascade of events, the red algal turf deteriorated from the lack of canopy protection which in turn increased the available area for limpet grazing, thereby increasing the limpet population.

The time for this biotope to reach maturity is therefore likely to depend on the circumstance under which the community changed in the first place. For example, it would depend on what species had been lost or reduced in abundance. Starting from bare substratum, the time taken for this biotope to reach maturity is likely to be at least fifteen years and under certain circumstances may take significantly longer.

Additional information

No text entered

Habitat preference and distribution

Distribution in Britain and Ireland

This biotope is not recorded from the east coasts of Britain and Ireland. In England and Wales, the only recorded sites were on the Isles of Scilly and in the Menai Strait respectively. In Scotland, the biotope is found in Shapinsay Sound, Orkney and in various locations in the Inner and Outer Hebrides and on the north west coast of the Scottish mainland. Irish survey data has not been analyzed to identify biotopes although it seems likely that the biotope will occur in tidal sounds and rapids such as occur in Strangford Lough.

Habitat preferences

Temperature range preferences	Data deficient
Water clarity preferences	Data deficient
Limiting nutrients	Data deficient
Other preferences	Moderately strong to very strong tidal streams.

Additional information

This biotope is found exclusively in tide-swept areas with a moderately strong to strong water flow. In the Menai Strait, for instance, water flow rates can reach 8 knots (Brazier *et al.*, 1999).

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	Species name	Common Name
Key Structuring	*Ascophyllum nodosum*	Knotted wrack
Important characterizing	*Halichondria panicea*	Breadcrumb sponge
Important characterizing	*Ascidiella scabra*	A sea squirt
Important other	*Littorina obtusata*	Common flat periwinkle
Important other	*Fucus serratus*	Toothed wrack
Important other	*Fucus vesiculosus*	Bladder wrack
Important other	*Patella vulgata*	Common limpet
Important other	*Chondrus crispus*	Carrageen

Explanation

Ascophyllum nodosum characterizes this biotope and its dense canopy provides a substratum for a variety of epiphytes in addition to protecting the underlying flora and fauna from desiccation and insolation. It has been listed the key structural species since its removal would destroy the biotope. Sponges and ascidians also characterize this biotope and *Halichondria panicea* and *Ascidiella scabra* have been included as representatives of these two groups, although there is a diverse suspension feeding community. *Ascidiella scabra* is not as frequent in occurrence as *Dendrodoa grossularia*; however, more information was available for the former in terms of sensitivity assessment. Given the longevity of the knotted wrack and the sheltered nature of the habitat, the grazing activity of the flat periwinkle *Littorina obtusata* is likely to be the only significant factor affecting the structure of the plant's population. Similarly, *Patella vulgata* is likely to maintain a steady state in terms of the ratio of bare rock, encrusting algae and red foliose seaweeds. For these reasons, the two grazers have been included as 'other' important species. The fucoids *Fucus serratus* and *Fucus vesiculosus* may also be present as part of the canopy layer. Although they are not characterizing species, they provide substratum for various epiphytes, especially the hydroids *Dynamena pumila* and *Clava multicornis* and, accordingly, have been included as other important species. The red algae *Chondrus crispus*, although not the most abundant red algae or most frequently associated with this biotope, has been included to represent the diverse range of red seaweeds that occur in this biotope. Insufficient information on the most abundant red algal species, *Polysiphonia lanosa*, meant that this species was not suitable for assessing the sensitivity of other red algae.

Species found especially in biotope

No text entered

Additional information

Although *Ascidiella scabra* has been listed as an important characterizing species, it has not been recorded in the Menai Strait record of SLR.Asc.T in Wales.

Biotope sensitivity

Physical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	Low	High	Major Decline	High
Smothering	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Increase in suspended sediment	Low	Very high	Very Low	Minor Decline	Moderate
Decrease in suspended sediment	Tolerant	Not Relevant	Not sensitive	Not Relevant	Moderate
Desiccation	Intermediate	Moderate	Moderate	Decline	Moderate
Increase in emergence regime	Intermediate	High	Low	Decline	Moderate
Decrease in emergence regime	Tolerant	Not Relevant	Not sensitive	Not Relevant	Moderate
Increase in water flow rate	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Decrease in water flow rate	Intermediate	High	Low	Decline	Moderate
Increase in temperature	Low	Very high	Very Low	Minor Decline	Low
Decrease in temperature	Low	Very high	Very Low	Decline	Low
Increase in turbidity	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Decrease in turbidity	Tolerant*	Not Relevant	Not sensitive*	Rise	Low
Increase in wave exposure	High	Low	High	Major Decline	Moderate
Decrease in wave exposure	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Noise	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Visual Presence	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant

Abrasion & physical disturbance	Intermediate	High	Low	Decline	Low
Displacement	High	Low	High	Major Decline	Moderate
Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	Intermediate	High	Low	Decline	Low
Heavy metal contamination	Intermediate	High	Low	Decline	Moderate
Hydrocarbon contamination	Intermediate	High	Low	Decline	Moderate
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Changes in nutrient levels	Low	Very high	Very Low	Minor Decline	Low
Increase in salinity	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Decrease in salinity	Low	Very high	Very Low	Minor Decline	Moderate
Changes in oxygenation	Low	Very high	Very Low	Minor Decline	Low
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Introduction of non-native species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Extraction of key or important characterizing species	High	Low	High	Major Decline	Moderate
Extraction of important species	Low	Very High	Very Low	Decline	Low

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	Substratum loss would result in the loss of the entire biotope and, accordingly, intolerance has been assessed as high. *Ascophyllum nodosum* has poor recruitment rates and is slow growing, therefore limiting recovery (Holt *et al.*, 1997). Due to the fact that the *Ascophyllum nodosum* canopy is central to the survival and characterization of the biotope, recoverability is likely to be low (see additional information).
Smothering (see benchmark)	At the benchmark level, smothering is unlikely to adversely affect this biotope. Due to the fact that the biotope is associated with areas of moderately strong to very strong water flow, the sediment layer will be washed away and 'normal' conditions will resume rapidly. The suspension feeders may experience some short-lived interference with feeding but this is not likely to adversely affect their viability. Accordingly, SLR.Asc.T has been assessed as being tolerant to smothering at the benchmark level.
Increase in suspended sediment (see benchmark)	An increase in suspended sediment, in combination with the tide-swept nature of this biotope, could be of detriment to the associated community. The photoautotrophic component may experience a reduction in light available for

	photosynthesis (see turbidity). Furthermore, depending on the nature of the sediment, the fronds of the plants may suffer from a scouring effect. This may also serve to scour delicate species such as hydroids off the fronds and stipes. The feeding apparatus of suspension feeders may become bombarded with particles. Although some of the suspension feeders may be able to clear their feeding apparatus of the sediment, this is energetically expensive and will most probably result in a reduced scope for growth over the benchmark period. If they are unable to effectively clean their feeding apparatus, they will simply experience a reduced ingestion over the course of one month. For example, Robbins (1985) undertook experiments to establish the possible effects of high inorganic particulate concentrations on the sea squirt *Ascidiella scabra*. He concluded that growth rate was likely to be reduced and mortality was possible in high levels of suspended sediment. For the characteristic species this is unlikely to prove fatal although short lived species such as the star ascidian *Botryllus schlosseri* may experience some mortality. Conversely, an increase in suspended sediment could increase food availability for the suspension feeders, especially if the proportion of organic particulate matter were to increase. On balance, an intolerance of low has been assessed. Recoverability is likely to be very high.
Decrease in suspended sediment (see benchmark)	A decrease in the amount of suspended sediment could reduce the scour effect these particles may have on the flora and fauna. Furthermore, the suspension feeding community may become more efficient as there would be fewer inorganic particles to clog and interfere with feeding apparatus. An increase in light availability may occur as a result of a decrease in suspended sediment (see turbidity). Assuming that the decrease in suspended sediment refers to inorganic particles, a reduction in total ingestion in the suspension feeding community is not expected. Therefore, tolerant has been assessed.
Desiccation (see benchmark)	SLR.Asc.T is an intertidal biotope and, at the benchmark level, desiccation is equivalent to a change in position of one biological vertical zone on the shore for one year. In this case, that would mean a transition from the mid eulittoral to the upper eulittoral. The most obvious effect of such a transition would be the risk of desiccation. *Ascophyllum nodosum* regularly becomes exposed to air during tidal cycles and so is tolerant of some desiccation (see *MarLIN* Web site). However, in transplantation experiments, Stengel & Dring (1997) found that 80% of plants moved from the lower shore to the upper shore died within 3 months, whereas all transplants from the upper to the lower shore and all controls survived. Those plants that did survive on the upper shore had acclimated to the new conditions, but whether the plants survived or not seemed to be determined by thallus morphology which may be genetically fixed. In terms of the other important algal species, the critical water content of *Fucus vesiculosus* and *Fucus serratus* are 30% and 40% respectively. If desiccation exceeds these levels, irreversible damage occurs. For *Fucus serratus*, only two hours of sunshine are required before this level is exceeded. Mathieson & Burns (1971) measured the photosynthetic rate of *Chondrus crispus* at varying degrees of desiccation and found that after loss of 65% of its water content, the rate of photosynthesis was only 55% of the control rate (see *MarLIN* Web site). It is likely that an increase in desiccation will kill some of these four species of plants at the upper end of the biotope thereby depressing the upper limit. Species more characteristic of the upper eulittoral may competitively displace these algae. However, some plants are likely to be able to acclimate to the new conditions and survive. In terms of characterizing fauna, the tissue of the breadcrumb sponge *Halichondria panicea* holds some water and is tolerant of a certain degree of desiccation.

	However, at the benchmark level, bleaching and tissue death in colonies at the upper shore extent of the population is likely to occur. The soft body of the sea squirt *Ascidiella scabra* makes it vulnerable to desiccation. It is afforded some protection to desiccation by its location under seaweed and in damp crevices. However, some individuals at the highest point on the shore may dry out and die. Grazing gastropods such as *Patella vulgata* and *Littorina obtusata* occur higher up the shore than *Ascophyllum nodosum* and will therefore most likely to be tolerant to desiccation at the benchmark level. Overall it is likely that much of the associated community will experience some mortality and intolerance has, therefore, been assessed as intermediate. Recoverability will depend on the extent to which *Ascophyllum nodosum* was lost and due to the fact that a proportion of this species is likely to remain, recoverability has been assessed as moderate.
Increase in emergence regime (see benchmark)	Intertidal biotopes such as SLR.Asc.T are adapted to a certain degree of cyclical immersion and emersion and the associated changes in salinity, desiccation and temperature etc. At the benchmark level, the algal canopy is unlikely to experience significant mortality, especially since the density of the canopy is likely to delay water loss. However, some plants at the upper shore extent of the biotope may be lost. In contrast, the suspension feeding community is likely to be adversely affected by an increase in emergence. Feeding time will be reduced and over the course of one year, a reduction in total growth and reproduction is expected. Annual species are likely to be lost and a large decline in suspension feeding diversity is likely to occur. Intolerance has been assessed as high. Recoverability has been assessed as high because *Ascophyllum nodosum* (that has a low recoverability from factors to which it is highly intolerant) is not likely to experience significant changes in abundance and most of the intolerant species produce planktonic larvae and are therefore likely to be able to recolonize quickly from surrounding areas.
Decrease in emergence regime (see benchmark)	In contrast to an increase in emergence, a decrease in emergence will be highly beneficial to the suspension feeding community which will experience greater feeding opportunities. The stresses associated with aerial exposure such as desiccation and extremes of temperature will be reduced for the whole biotope. In consequence, the biotope may extend further up the shore although this extension is likely to be counteracted by a reduction in the lower shore extent of the biotope. Therefore, even though the biotope may just shift its position on the shore, the area it covers is not likely to change and therefore SLR.Asc.T has been assessed as being tolerant of this factor.
Increase in water flow rate (see benchmark)	This biotope is associated with areas of moderately strong to very strong water flow rates (>6 knots, the highest flow rate in the benchmark) and, therefore, an increase in water flow rate is not considered to be relevant.
Decrease in water flow rate (see benchmark)	The diverse and species rich suspension feeding community associated with this biotope is as a result of the strong tidal flows that provide these creatures with a continual supply of food and remove sediment that may otherwise clog their feeding apparatus. A decrease in water flow at the level of the benchmark could result in negligible flow rates. This would lead to siltation which is ultimately detrimental to suspension feeders. Although some filter feeders have the ability to cope with siltation by, for example, clearing their feeding apparatus, this is energetically expensive and could result in reduced scope for growth and reproductive capacity. The sea squirt *Ascidiella scabra* can extend its siphons, to a small extent, above silt and can also most likely maintain a passage through the silt to the siphons. It also attaches to other erect biota and, in such situations, may escape smothering effects. The breadcrumb sponge *Halichondria panicea* has a mechanism for sloughing off their complete outer tissue layer together with any debris (Barthel & Wolfrath, 1989). The algae may also suffer from siltation since the reduction in light penetration would lead to reduced photosynthetic capabilities. Over the course of

	one year, this is likely to result in reduced total growth and reproduction may be adversely affected, especially if algal spores are sensitive to the nature of the substratum on which they settle. An increase in deposit feeders may be observed although these species would most probably be rapidly lost on resumption of previous water flow rates. Recoverability has been assessed as high because *Ascophyllum nodosum* (that has a low recoverability from factors to which it is highly intolerant) is not likely to experience significant changes in abundance and most of the intolerant species produce planktonic larvae and are therefore likely to be able to recolonize quickly from surrounding areas.
Increase in temperature (see benchmark)	Intertidal algae, such as *Ascophyllum nodosum*, are regularly exposed to rapid and short-term variations in temperature. In the North Sea *Ascophyllum nodosum* can tolerate a maximum temperature of 28°C and the optimum growth rate is at 15°C (Lüning, 1990). Therefore, the species is likely to be quite tolerant of a long term change in temperature of 2°C. The species is unlikely to be affected by a short term change of 5°C, as it was not damaged during the unusually hot summer of 1983 when the average temperature was 8.3°C higher than normal (Hawkins & Hartnoll, 1985). This is also true of *Fucus vesiculosus* which can withstand temperatures as high as 30°C (Lüning, 1990). In fact, the distribution of most of the important, key and characterizing species within this biotope is such that a chronic increase in temperature of 2°C is unlikely to adversely affect them. An acute rise in temperature may have a deleterious affect on some species. For example, the soft bodied *Ascidiella scabra* may be more prone to desiccation. However, this is not thought to cause mass mortalities among these populations and, accordingly, an intolerance of low has been recorded. Recoverability is expected to be very high.
Decrease in temperature (see benchmark)	Intertidal algae, such as *Ascophyllum nodosum*, are regularly exposed to rapid and short-term variations in temperature. This species can tolerate freezing temperatures as it has been observed to survive in a block of ice for several days. *Fucus vesiculosus* have been found to tolerate -30°C in Maine for several weeks (Lüning, 1990). However, at these temperatures, intercellular and extracellular ice crystals form which would cause some damage to the plant (S. Kraan, pers. comm.). All of the dominant and characterizing algae and the important and characterizing fauna, are well within their temperature range in Britain and Ireland so would not be affected by a change of 2°C. However, evidence from Crisp (1964) suggests that, during the very cold 1962-63 winter, at least part of the populations of *Halichondria panicea* and *Patella vulgata* were killed in some locations and the fronds of *Ascophyllum nodosum*, where they has become frozen to the bedrock, snapped off and floated away with the tide. However, at the benchmark level of three days, a decrease in temperature of 5 °C is unlikely to cause mortality in *Ascophyllum nodosum*. On balance, it has been suggested that the intolerance of this biotope to a reduction in temperature is low, with a very high recovery.
Increase in turbidity (see benchmark)	The suspension feeding community associated with this biotope would be unaffected by an increase in turbidity and may actually benefit from it if the increase was associated with an increase in the concentration of organic particulate matter. However, an increase in turbidity would alter the light available for photosynthesis during immersion. Over the benchmark period, two of the canopy species, *Fucus serratus* and *Fucus vesiculosus*, may experience negative growth rates. *Ascophyllum nodosum*, on the other hand, can continue to photosynthesize at low tide when the plants are emersed, as long as the plant has a sufficiently high water content and so will be unaffected during this period. Furthermore, the red algae / turf species, that are more tolerant of reduced light levels, may increase in abundance at the expense of small green and brown algal species, although such a change would not affect the recognizable biotope. SLR.Asc.T is considered to be tolerant of an increase in turbidity at the benchmark level.
Decrease in turbidity	This biotope has been recorded in areas of very high turbidity, such as the Menai Strait, and the algal component of this biotope are likely to benefit from a decrease

(see benchmark)	in turbidity. Over the benchmark period the algae may experience enhanced photosynthesis and increased total growth. An increase in the proportion of green algae may be observed which would increase species diversity in the biotope.
Increase in wave exposure (see benchmark)	This biotope occurs in very sheltered to extremely sheltered habitats. Accordingly, an increase in exposure at the benchmark level would be catastrophic for this biotope. The local distribution of *Ascophyllum nodosum* is largely determined by wave exposure. As exposure to wave action increases, the number of plants becomes progressively less and they consist increasingly of short and stumpy shoots (Baardseth, 1970) and with a higher percentage of injured tissue (Levin & Mathieson, 1991). This loss of the main canopy species would lead to the degeneration of the recognizable biotope. As Jenkins *et al.* (2004) observed, in *Ascophyllum nodosum* canopy clearance experiments, the turf species would become bleached and die and the substratum would become progressively dominated by limpet grazed areas. Species more tolerant of wave exposed areas, such as *Fucus vesiculosus*, may replace the *Ascophyllum nodosum* to some degree but the biotope, at this stage, will have been lost. Recoverability is likely to be low (see additional information) since Vadas *et al.* (1990) found that a single wave on a wave exposed shore was sufficient to remove 90% of newly settled *Ascophyllum nodosum* zygotes.
Decrease in wave exposure (see benchmark)	This biotope occurs in very sheltered and extremely sheltered habitats and therefore a decrease in wave exposure is not considered to be relevant.
Noise (see benchmark)	The key structural and important characterizing species are unlikely to have mechanisms for detecting noise. *Patella vulgata* may respond to the vibrations caused by noise by clamping down on the rock although at the benchmark level this is not likely to aversely affect the biotope. Therefore tolerant has been recorded.
Visual Presence (see benchmark)	The key structural and important characterizing species are unlikely to have mechanisms for detecting visual presence and, therefore, tolerant has been recorded.
Abrasion & physical disturbance (see benchmark)	The canopy species in this biotope are likely to be adversely affected by abrasion and physical disturbance at the benchmark level. *Ascophyllum nodosum* is particularly intolerant of abrasion from trampling (Holt *et al.*, 1997). Abrasion may cause damage to the fronds and germlings of all the algal species in this biotope, although the turf species are likely to escape unscathed due to the protection provided by the canopy layer. Human trampling can significantly reduce the cover of fucoids on the shore (Holt *et al.*, 1997). Severe abrasion, for instance through a vessel stranding, is likely to be considerably more detrimental to the biotope. The forces involved in such an event are likely to scour a large area of the rocky shore of macroalgae and sessile invertebrates. Furthermore, if the vessel remained on the shore, it would prevent light reaching any surviving algae under the vessel and therefore lead to their death. Epifaunal species have also been found to be particularly adversely affected by trawling or dredging activities, either due to direct damage or modification of the substratum (Jennings & Kaiser, 1998). Patches of hydroids and bryozoans, and encrusting fauna such as colonial ascidians and sponges are likely to be scraped off the rock and the shells of limpets and periwinkles may be crushed by the weight and force of the abrasion. Some epifaunal species have been reported to exhibit increased abundances on high fishing effort areas, probably due to their ability to colonize and grow rapidly (Bradshaw *et al.*, 2000). The sea squirt *Ascidiella scabra* was found to have become more abundant in a study of the long term effects of scallop dredging (Bradshaw *et al.*, 2002). Overall, many species associated with this biotope are likely to experience some mortality although depending on the size of the population, the majority of the population is likely to remain. Therefore, intolerance has been

	assessed as intermediate. Recoverability has been assessed as high because *Ascophyllum nodosum* (that has a low recoverability from factors to which it is highly intolerant) is not likely to experience significant changes in abundance and most of the intolerant species produce planktonic larvae and are therefore likely to be able to recolonize quickly from surrounding areas.
Displacement (see benchmark)	The majority of the characterizing and key species associated with this biotope are permanently attached to the substratum and would not survive displacement. The displacement of species including *Ascophyllum nodosum*, *Ascidiella scabra* and *Halichondria panicea* will have a similar effect to substratum loss and will result in the loss of the entire biotope. Accordingly, intolerance has been assessed as high. *Ascophyllum nodosum* has poor recruitment rates and is slow growing, therefore limiting recovery (Holt *et al.*, 1997). Due to the fact that the *Ascophyllum nodosum* canopy is central to the survival and characterization of the biotope, recoverability is likely to be low (see additional information).
Chemical Factors	
Synthetic compound contamination (see benchmark)	• The disappearance of *Ascophyllum nodosum* from Oslofjord has been attributed to the reduced ability of germlings to recruit at highly polluted sites (Sjoetun & Lein, 1993). However, Hoare & Hiscock (1974) observed that *Ascophyllum nodosum* was found within 100 m of an acidified, halogenated effluent discharge, although plants had abnormal and retarded growth. • *Fucus vesiculosus* is extraordinarily highly intolerant of chlorate, such as from pulp mill effluents. In the Baltic, the species has disappeared in the vicinity of pulp mill discharge points and is affected even at immediate and remote distances (Kautsky, 1992). • Scanlan & Wilkinson (1987) found that the spermatozoa and newly fertilized eggs of *Fucus serratus* were the most intolerant of biocides, while adult plants were only just significantly affected at 5 ml/l of the biocides Dodigen v181-1, Dodigen v 2861-1 and ML-910. • O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination, possibly due to the susceptibility of phycoerythrins to destruction. Laboratory studies of the effects of oil and dispersants on several red algal species concluded that they were all sensitive to oil/dispersant mixtures, with little difference between adults, sporelings, diploid or haploid life stages (Grandy, 1984, cited in Holt *et al.*, 1995). • Ascidians may be intolerant of synthetic chemicals such as tri-butyl-tin (TBT) anti-foulants. Rees *et al.* (2001), working in the Crouch estuary, observed that six ascidian species were recorded at one station in 1997 compared with only two at the same station in 1987, shortly following the banning of TBT in antifouling paints. Also, there was a marked increase in the abundance of ascidians especially *Ascidiella aspersa* and *Ascidia conchilega* in the estuary. • Limpets including *Patella vulgata* are extremely intolerant of aromatic solvent based dispersants used in oil spill clean-up (see *MarLIN* Web site). During the clean-up response to the *Torrey Canyon* oil spill nearly all the limpets were killed in areas close to dispersant spraying. A concentration of 5ppm killed half the limpets tested in 24 hours (Southward & Southward, 1978; Hawkins & Southward, 1992). Hoare & Hiscock (1974) reported that in Amlwch Bay *Patella vulgata* was excluded from sites within 100-150 m of the discharge of acidified, halogenated effluent. • Gastropod molluscs are known to be intolerant of endocrine disruption from synthetic chemicals such as tri-butyl tin (Cole *et al.*, 1999). No specific information was found concerning the effects of synthetic chemicals of *Littorina obtusata* although *Littorina littorea* is thought to have only a low intolerance (see *MarLIN* Web site).

	In summary, all the key and important characterizing species in this biotope are reported to have at least some intolerance to synthetic chemicals although the fast water flow may ameliorate initial intolerance and subsequent recoverability by flushing out the contaminant. On balance, an intolerance of intermediate has been assessed, with a high recovery.
Heavy metal contamination (see benchmark)	• Fucoids accumulate heavy metals and may be used as indicators for monitoring. It is generally accepted that adult plants are relatively tolerant of heavy metal pollution (Holt *et al.*, 1997). The disappearance of *Ascophyllum nodosum* from Oslofjord has been attributed to an increase in pollution and copper at concentrations of 1039 nM (66 µg/L) have been found to inhibit the growth of *Ascophyllum nodosum* (Strömgren, 1979). However, the species penetrates into the metal polluted middle reaches of Restronguet Creek in the Fal estuary system where concentrations of both copper and zinc are in the region of 1000-2000 µg/g in the sediment and 10-100 µg/l in seawater (Bryan & Gibbs, 1983). Earlier life stages of *Ascophyllum nodosum*, and *Fucus serratus* (below), are probably more sensitive than adult plants. • The effect of heavy metals on the growth rate of adult *Fucus serratus* plants has been studied by Strömgren (1979b; 1980a & b). Copper significantly reduces the growth rate of vegetative apices at 25 µg/l over 10 days (Strömgren, 1979b). Zinc, lead, cadmium & mercury significantly reduce growth rate at 1400 µg/l, 810 µg/l, 450 µg/l and 5 µg/l respectively (Strömgren, 1980a, b). • Bryan (1984) suggested that gastropods are rather tolerant of heavy metals. In the Fal estuary *Patella vulgata* occurs at, or just outside, Restronguet Point at the end of the creek where metal concentrations are high, e.g. Zinc (Zn) exists at concentrations of 100-2000 µg/l (Bryan & Gibbs, 1983). However, Davies (1992) found that, in the laboratory, *Patella vulgata* was found to be intolerant of small changes in environmental concentrations of Cd and Zn. Furthermore, exposure to Cu at a concentration of 100 µg/l for one week resulted in progressive brachycardia (slowing of the heart beat) and the death of limpets (Marchan *et al.*, 1999). • No specific information was found concerning the effects of heavy metals on *Littorina obtusata* although *Littorina littorea* was assessed as being of intermediate intolerance (see *MarLIN* Web site). No information was found concerning the specific effects of heavy metals on the other important and characterizing species although an intolerance of intermediate has been recorded in light of the above evidence. Recovery is likely to be high although recovery from the effects of highly persistent metal and their compounds may take significantly longer.
Hydrocarbon contamination (see benchmark)	• Experimental studies have found that long-term exposure to low levels of diesel reduces the growth rate in *Ascophyllum nodosum*. For example, in mesocosm experiments, Bokn (1987) observed growth inhibition at a diesel concentration of 130 ppb and that inhibition stops when the oil is removed. Thus, a limited amount of oil pollution need not be detrimental to a population with good recruitment (Sjoetun & Lein, 1993). However, *Ascophyllum nodosum* generally has poor recruitment and hydrocarbon contamination may also prevent fertilization and germination. • Adult *Fucus serratus* plants are tolerant of exposure to spills of crude oil although very young germlings are intolerant of relatively low concentrations of 'water soluble' extractions of crude oils. Exposure of eggs to these extractions (at 1.5 µg/ml for 96 hours) interferes with adhesion during settling and (at 0.1 µg/ml) prevents further development (Johnston, 1977). • *Fucus vesiculosus* shows limited intolerance to oil. After the *Amoco Cadiz* oil spill it was observed that *Fucus vesiculosus* suffered very little (Floc'h &

	Diouris, 1980). Indeed, *Fucus vesiculosus* may increase significantly in abundance on a shore if grazing gastropods are killed by the oil. However, very heavy fouling could reduce light available for photosynthesis, and in Norway, a heavy oil spill reduced fucoid cover. Recovery occurred within four years in sheltered conditions (Holt *et al.*, 1997). • Observations have shown that filamentous red algae are among the most severely affected by the toxic properties of oil (O'Brien & Dixon, 1976). Effects including bleaching and loss of photosynthetic pigments have been observed in red algal species following contamination with fuel oil (O' Brien & Dixon, 1976). The long term effects on *Chondrus crispus* of continuous doses of the water accommodated fraction (WAF) of diesel oil were determined in experimental mesocosms (Bokn *et al.*, 1993). Mean hydrocarbon concentrations tested were 30.1 µg/l and 129.4 µg/l. After 2 years, there were no demonstrable differences in the abundance patterns of *Chondrus crispus*. Furthermore, Kaas (1980, cited in Holt *et al.*, 1995) reported that the reproduction of adult *Chondrus crispus* plants on the French coast was normal following the *Amoco Cadiz* oil spill. • It appears that *Halichondria panicea* survived in areas affected by the *Torrey Canyon* oil spill (Smith, 1968), although few observations were made. • In areas of moderate oil deposit, up to about 1/2 cm thick, on rocks after the *Torrey Canyon* oil spill, limpets had survived unscathed over a month after the event and feeding continued even though a coating of oil smothered their food source of algae and diatoms (Smith, 1968). However, thick layers of oil smothering individuals will interfere with respiration and feeding. In West Angle Bay, where fresh oil from the *Sea Empress* tanker reached rocky shores within one day of the spill, limpet mortality was 90% (Glegg *et al.*, 1999). A significant reduction in the density of juvenile limpets was also observed at all sites known to have been oiled by the *Sea Empress* spill (Moore, 1997). • Experience of and observations from oil spills such as the *Sea Empress* and *Amoco Cadiz* suggest that gastropod molluscs are highly intolerant of hydrocarbon pollution but that recovery is usually rapid. On balance, it is likely that many of the associated species will suffer reduced viability and, in some cases, some mortality. Therefore, intolerance has been assessed as high. Recoverability is likely to be high and the fast water flow associated with this biotope may help to flush the pollutants from the area.
Radionuclide contamination (see benchmark)	Insufficient information was found concerning the effects of radionuclides on the important and characterizing species to be able to assess sensitivity.
Changes in nutrient levels (see benchmark)	Plant growth is often limited by nutrient availability and an influx of nutrients into this biotope could serve to stimulate the growth of the associated macroalgae. However, phytoplankton are also likely to be stimulated and, under certain conditions, the formation of plankton blooms may occur. Not only do the presence of thick blooms and mats of algae reduce light penetration, which has the potential to reduce photosynthesis, but the eventual degradation of the blooms requires significant oxygen consumption. Despite the fact that fucoids appear relatively resistant to sewage, and have been observed to grow within 20m of an outfall discharging sewage in the Isle of Man (Holt *et al.*, 1997), Steen & Rueness (2004) reported that along the Norwegian Skagerrak coast, *Ascophyllum nodosum* and *Fucus serratus* showed a decline in biomass in eutrophic areas, even disappearing in some places. *Ascophyllum nodosum* plants, when transplanted into sewage-stressed areas have become heavily infested with epiphytes and frequently overgrown by *Ulva* species and there are reports of a decline in populations of the species in the North Atlantic as a result of increased eutrophication (Fletcher, 1996). Chronic nutrient enrichment could potentially alter the recognizable biotope. However, in a

	tide-swept biotope such as this an influx of nutrients from a single event is unlikely to adversely affect it. On balance, intolerance has been assessed as low with a very high recovery.
Increase in salinity (see benchmark)	SLR.Asc.T is found in areas of full salinity and therefore an increase in salinity is not relevant.
Decrease in salinity (see benchmark)	SLR.Asc.T is an intertidal biotope and its associated flora and fauna will therefore be tolerant, to a certain extent, of cyclical changes in salinity. *Ascophyllum nodosum* is euryhaline with a salinity tolerance of about 15 to 37 psu (Baardseth, 1970). The species can also withstand periodic emersion in freshwater (Baardseth, 1970) and frequently inhabits estuaries where salinity is variable. Doty & Newhouse (1954) reported *Ascophyllum nodosum* from estuarine waters with a maximum salinity of 17.3 psu and a minimum of 0 psu. Further evidence is provided by Chock & Mathieson (1979) who found *Ascophyllum nodosum* plants in the laboratory exhibited net photosynthesis at salinities from 0 to 40 psu although the long term effects within this range were not evaluated. In the UK, *Fucus vesiculosus* tolerates salinity down to 11 psu, below which it is replaced by *Fucus ceranoides* (Suryono & Hardy, 1997). *Fucus serratus* is able to compensate for these changes in salinity by adjusting internal ion concentrations. Salinity affects the photosynthetic rate and hence growth rate of seaweed. For *Fucus serratus*, growth rate is maximal at a salinity of 20 psu and therefore, a decrease in salinity into the 'low' salinity category would be of preference to the plant. Other important / characterizing species associated with this biotope are also likely to be tolerant of a reduction in salinity. The breadcrumb sponge *Halichondria panicea* and carrageen *Chondrus crispus* are found in of low salinity and *Ascidiella scabra* and *Patella vulgata* can be found in reduced salinity conditions. A rapid fall in salinity of two categories on the MNCR scale from variable to low salinity could result in more adverse effects on the whole community and therefore intolerance has been assessed as low but with a very high recovery.
Changes in oxygenation (see benchmark)	No specific information was found concerning the effects of reduced oxygenation on the key / characterizing species although Cole *et al.* (1999) suggested possible adverse effects on marine species below 4 mg/l and probably adverse effects below 2 mg/l. Some of the associated fauna may be tolerant of low oxygen environments and the strong water flow rates associated with this biotope are likely to ameliorate any reductions in oxygenation. Overall, an intolerance of low has been suggested although recoverability is expected to be very high on return to 'normal' conditions.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	No information was found concerning the effects of and occurrence of microbial pathogen infestations on the key and characterizing species. Therefore, insufficient information was available to assess sensitivity.
Introduction of non-native species (see benchmark)	There are no known alien or invasive species that are known to compete with or displace the important characterizing species associated with this biotope.

Extraction of key or important characterizing species (see benchmark)	The two important characterizing species, *Halichondria panicea* and *Ascidiella scabra* are not known to be targeted for extraction. However, *Ascophyllum nodosum* is collected in several countries and it is likely to pose a significant threat to this biotope if the whole plant is removed. Removal of the entire plant has a considerable impact and recovery can take anything from 3-8 Years (Norway) (Seip, 1980, cited in Holt *et al.*, 1997) to more than 8 years (England) (Knight & Parke,

	1950). If the plants are not fully removed, *Ascophyllum nodosum* can regenerate from the basal proportions that remain (Holt *et al.*, 1997). Printz (1956, cited in Holt *et al.*, 1997) found that, in Norway, plants cut at 15 cm recovered fully within 5 years. However, regular harvesting is reported to change the size distribution of the population (Ang *et al.*, 1993, cited in Holt *et al.*, 1997). Baardseth (1970) stated that if stumps 10-20 cm high are left, harvesting is possible again after 3 to 6 years. Due to the fact that the *Ascophyllum nodosum* canopy is central to the survival and characterization of the biotope, the loss of this main canopy species would lead to the generation of the recognizable biotope. As Jenkins *et al.* (2004) observed, in *Ascophyllum nodosum* canopy clearance experiments, the turf species would become bleached and die and the substratum would become progressively dominated by limpet grazed areas. Accordingly, intolerance has been assessed as high with a low recovery (see additional information).
Extraction of important species (see benchmark)	Three of the other important species (*Fucus serratus, Fucus vesiculosus* and *Chondrus crispus*) are all targeted for extraction. Although none of these species are characterizing species, the two fucoids provide substratum for various epiphytes, especially the hydroids *Dynamena pumila* and *Clava multicornis*. Hydroids are not considered to be important characterizing species in SLR.Asc.T either, although their loss, in addition to the loss of the fucoids, would result in a decline in species diversity. The reduction in the thickness of the canopy that would be caused by the loss of the fucoids may be detrimental to some of the underlying red algal species which may perish if bleached by the sun. Furthermore, the removal of the fucoids would remove a large source of potential food for *Patella vulgata* and this species may subsequently focus grazing on encrusting red algae, and the fine green and red algae. This also has the potential to reduce species diversity. Although the recognizable biotope is likely to remain, the fact that targeted extraction could lead to the removal of three important species, and the associated knock on effects mentioned above, intolerance has been assessed as low. Recoverability will be immediate because the recognizable biotope will remain.

Additional information

Recoverability

The *Ascophyllum nodosum* canopy is paramount to the survival and characterization of this biotope. It provides shade for the diverse red algal understory and substratum for a profusion of filter feeders. *Ascophyllum nodosum* is a long lived, slow growing alga with poor recruitment rates that limit recovery (Holt *et al.*, 1997). The lack of recovery of *Ascophyllum nodosum* from harvesting is well documented and recovery from the loss of this species from SLR.Asc.T is likely to be low, i.e. full recovery will take up to 25 years. Jenkins *et al.* (2004) studied the long term effects of *Ascophyllum nodosum* canopy removal on the whole understory community structure on a sheltered rocky shore on the Isle of Man. They reported that, even after twelve years, major effects of the canopy removal were still apparent. At the culmination of the study, mean cover of *Ascophyllum nodosum* was still only about 50% of its original level compared with control plots. However, the most alarming changes were evident in the understory community. Previously, this community was characterized by a balance between patches of red algal turf and patches grazed by *Patella vulgata*. Removal of the canopy layer broke down the balance between these two 'functional units' to the extent that the community showed no signs of reverting to its pre-disturbance state. In a cascade of events, the red algal turf deteriorated from the lack of canopy protection which in turn increased the available area for limpet grazing, thereby increasing the limpet population. An increase in the abundance of limpets would also hamper recolonization by *Ascophyllum nodosum* sporelings. Furthermore, Hawkins & Hartnoll (1985) found that when the *Ascophyllum nodosum* canopy was removed on a moderately sheltered shore on the Isle of Man, the *Fucus vesiculosus* canopy in the zone above it was able to achieve an 80% cover after just one year. The establishment of a canopy layer of another species is likely to make the re-establishment of the *Ascophyllum nodosum* canopy take even longer.

Ascophyllum nodosum takes by far the longest time to recover when compared to other important and characterizing species. Should any of the other important and characterizing species be lost from the biotope, recovery is likely to be high and should be complete within about five years.

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors							
	Ascophyllum nodosum	***Halichondria panicea***	***Ascidiella scabra***	***Fucus serratus***	***Fucus vesiculosus***	***Patella vulgata***	***Chondrus crispus***
Community Importance	Key Structuring	Important characterizing	Important characterizing	Important other	Important other	Important other	Important other
Substratum Loss	High	High	High	High	Intermediate	High	High
Smothering	High	High	Low	High	High	High	Intermediate
Increase in suspended sediment	Low	Low	Low	Low	Low	Low	Intermediate
Decrease in suspended sediment	See explanation	Not Sensitive	Not Sensitive	See explanation	See explanation	Low	Not Sensitive
Desiccation	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Low	Intermediate
Increase in emergence regime	High	Intermediate	Intermediate	Intermediate	Intermediate	Low	Intermediate
Decrease in emergence regime	See explanation	Not Sensitive	Not Sensitive*	See explanation	See explanation	See explanation	Not Sensitive
Increase in water flow rate	Intermediate	Intermediate	Low	Intermediate	Intermediate	Low	Intermediate
Decrease in water flow rate	See explanation	Low	Low	See explanation	See explanation	See explanation	Intermediate
Increase in temperature	Low	Low	Not Sensitive	Not Sensitive	Not Sensitive	Low	Low
Decrease in temperature	See explanation	Low	Not Sensitive	See explanation	See explanation	See explanation	Low
Increase in turbidity	Low	Not Sensitive	Not Sensitive	Low	Low	Low	Low
Decrease in turbidity	See explanation	Not Sensitive	Not Sensitive*	See explanation	See explanation	See explanation	Not Sensitive*
Increase in wave exposure	High	Intermediate	Intermediate	High	Intermediate	Low	Intermediate
Decrease in wave exposure	See explanation	Low	Not Sensitive*	See explanation	See explanation	See explanation	Low
Noise	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Low	Not Sensitive
Visual Presence	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive
Abrasion & physical disturbance	High	Intermediate	High	Intermediate	Intermediate	Low	Low
Displacement	High	High	High	High	High	Intermediate	High
Chemical factors							
	Ascophyllum nodosum	***Halichondria panicea***	***Ascidiella scabra***	***Fucus serratus***	***Fucus vesiculosus***	***Patella vulgata***	***Chondrus crispus***
Community Importance	Key Structuring	Important characterizing	Important characterizing	Important other	Important other	Important other	Important other

Synthetic compound contamination	Intermediate	Insufficient information	Intermediate	High	Intermediate	High	High
Heavy metal contamination	Low	Insufficient information	Insufficient information	Low	Low	Intermediate	Insufficient information
Hydrocarbon contamination	Low	Low	Insufficient information	Intermediate	Low	High	Low
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	Intermediate	Insufficient information	Insufficient information	Intermediate	Intermediate	Low	Intermediate
Increase in salinity	Low	Low	Not Sensitive	Low	Low	Low	Not Sensitive
Decrease in salinity	See explanation	Low	Intermediate	See explanation	See explanation	See explanation	Low
Changes in oxygenation	Insufficient information	Intermediate	Low	Low	Insufficient information	Intermediate	Insufficient information
Biological factors							
	Ascophyllum nodosum	***Halichondria panicea***	***Ascidiella scabra***	***Fucus serratus***	***Fucus vesiculosus***	***Patella vulgata***	***Chondrus crispus***
Community Importance	Key Structuring	Important characterizing	Important characterizing	Important other	Important other	Important other	Important other
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Intermediate
Introduction of non-native species	Insufficient information	Insufficient information	Not Sensitive	Insufficient information	Insufficient information	Not Relevant	Insufficient information
Extraction of this species	Intermediate	Not Relevant	Not Relevant	Intermediate	Intermediate	Intermediate	Intermediate
Extraction of other species	Not Sensitive	High	Not Relevant	Not Sensitive	Insufficient information	Low	Insufficient information

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors							
	Ascophyllum nodosum	***Halichondria panicea***	***Ascidiella scabra***	***Fucus serratus***	***Fucus vesiculosus***	***Patella vulgata***	***Chondrus crispus***
Community Importance	Key Structuring	Important characterizing	Important characterizing	Important other	Important other	Important other	Important other
Substratum Loss	Low	High	Very high	High	High	High	High
Smothering	Low	High	Immediate	High	High	High	High
Increase in suspended sediment	Immediate	Immediate	Immediate	Very high	Immediate	High	High
Decrease in suspended sediment	See explanation	Not Relevant	Not Relevant	See explanation	See explanation	High	Not Relevant
Desiccation	Moderate	Very high	Very high	High	High	High	High
Increase in emergence regime	Low	Very high	Very high	High	High	High	High
Decrease in	See	Not Relevant	Not Relevant	See	See	See	Not Relevant

emergence regime	explanation			explanation	explanation	explanation	
Increase in water flow rate	Low	Very high	Immediate	High	High	High	High
Decrease in water flow rate	See explanation	Immediate	Immediate	See explanation	See explanation	See explanation	High
Increase in temperature	Moderate	Very high	Not Relevant	Not Relevant	Not Relevant	High	Very high
Decrease in temperature	See explanation	Very high	Not Relevant	See explanation	See explanation	See explanation	Very high
Increase in turbidity	Immediate	Not Relevant	Not Relevant	Very high	Immediate	Very high	Very high
Decrease in turbidity	See explanation	Not Relevant	Not Relevant	See explanation	See explanation	See explanation	Not Relevant
Increase in wave exposure	Low	Very high	Very high	High	High	High	High
Decrease in wave exposure	See explanation	Very high	Not Relevant	See explanation	See explanation	See explanation	Very high
Noise	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	High	Not Relevant
Visual Presence	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Abrasion & physical disturbance	Low	High	Very high	High	High	Very high	Very high
Displacement	Low	High	Very high	High	High	High	High
Chemical factors							
	Ascophyllum nodosum	***Halichondria panicea***	***Ascidiella scabra***	***Fucus serratus***	***Fucus vesiculosus***	***Patella vulgata***	***Chondrus crispus***
Community Importance	Key Structuring	Important characterizing	Important characterizing	Important other	Important other	Important other	Important other
Synthetic compound contamination	Low	Not Relevant	Very high	High	High	High	High
Heavy metal contamination	High	Not Relevant	Not Relevant	High	High	High	Insufficient information
Hydrocarbon contamination	Moderate	High	Not Relevant	High	High	High	Very high
Radionuclide contamination	Insufficient information	Not Relevant	Not Relevant	Insufficient information	Not Relevant	Insufficient information	Insufficient information
Changes in nutrient levels	High	Not Relevant	Not Relevant	High	High	High	High
Increase in salinity	High	High	Not Relevant	Very high	High	High	Not Relevant
Decrease in salinity	See explanation	High	Very high	See explanation	See explanation	See explanation	Very high
Changes in oxygenation	Insufficient information	High	Immediate	Very high	Not Relevant	High	Insufficient information
Biological factors							
	Ascophyllum nodosum	***Halichondria panicea***	***Ascidiella scabra***	***Fucus serratus***	***Fucus vesiculosus***	***Patella vulgata***	***Chondrus crispus***
Community Importance	Key Structuring	Important characterizing	Important characterizing	Important other	Important other	Important other	Important other
Introduction of microbial pathogens/parasites	Not Relevant	Not Relevant	Not Relevant	Insufficient information	Not Relevant	Insufficient information	High
Introduction of non-native species	Not Relevant	Not Relevant	Not Relevant	Insufficient information	Not Relevant	Not Relevant	Insufficient information
Extraction of this species	Low	Not Relevant	Not Relevant	High	High	High	High

Extraction of other species	Not Relevant	High	Not Relevant	Not Relevant	Not Relevant	High	Insufficient information

Importance

Marine natural heritage importance

Listed under:	**UK Biodiversity Action Plan**
National importance	Not available
Habitat Directive feature (Annex 1)	Reefs Large shallow inlets and bays Estuaries Lagoons
UK Biodiversity Action Plan habitat	Tidal rapids

Biotope importance

The lush canopy associated with this biotope may provide many motile invertebrates with protection from insolation and desiccation at low tide. In addition to the flat periwinkle, *Littorina obtusata*, other invertebrates may lay their eggs within the canopy layer and it may act as a nursery ground for shallow water fish.

Exploitation

Of the key, characterizing and important species, it is only the algal species that are exploited regularly. Details of their exploitation and uses are summarized below.

- *Ascophyllum nodosum* is harvested in Ireland and Scotland for use in alginates, fertilizers and for the manufacture of seaweed meal for animal and human consumption. The species is also harvested in Europe, Canada and the north-west Atlantic. Poor resource management and over-exploitation have led to severely depleted populations in many regions.
- *Fucus serratus* is collected, dried and used as a soil additive. Various fucalean algae are used in the production of alginates which, in turn, are used widely in the pharmaceutical and cosmetics industries.
- *Fucus vesiculosus* is also collected although only a small amount of the available resource is reported to be used and is hand cut or collected as drift (Morrissey *et al.*, 2001). Morrissey *et al.* (2001) listed many uses for *Fucus vesiculosus* including fertilizer, bodycare products, such as shower gels and body creams, and health supplements (kelp tablets). The boiled broth can also be used as a health drink (Guiry & Blunden, 1991).
- *Chondrus crispus* is harvested commercially in Ireland, Spain, France, Portugal and North America for the extraction of carrageenan (Guiry & Blunden, 1991). In Ireland, harvesting has generally remained sustainable through pickers developing an intuitive feel for the annual cycle of local stocks and certain practices which involve pulling only the bushy top half of the frond off leaving the base and holdfast behind (Morrissey *et al.*, 2001). The gelling and thickening properties of carrageenan are used widely in the food, pharmaceutical and cosmetics industries (see *MarLIN* Web site).

Harvesting *Ascophyllum nodosum*, thereby removing the dominant and characterizing canopy species, could be catastrophic for the biotope if the whole plant was removed (see 'Extraction of key and important characterizing species' in Sensitivity section).

Additional information

No text entered

This Biology and Sensitivity Key Information review can be cited as follows:
Marshall, C.E., 2005. *Ascophyllum nodosum*, sponges and ascidians on tide-swept mid eulittoral rock. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 20/01/2005]. Available from: <http://www.marlin.ac.uk>

Fucus serratus, sponges and ascidians on tide-swept lower eulittoral rock (SLR.Fserr.T)

Key information authored by: Charlotte Marshall

Last updated 24/01/2005

This information is not refereed.

No image available.

Recorded and expected SLR.Fserr.T distribution for Britain and Ireland

If you would be willing to supply *MarLIN* with an image of this species/habitat please contact marlin@mba.ac.uk

Description of biotope

Sheltered to extremely sheltered lower eulittoral bedrock, boulders and cobbles that are subject to increased tidal water movement and characterized by the wrack *Fucus serratus* and a rich assemblage of filter-feeding fauna. This community is encouraged by the increased water movement. It includes species such as the sponges *Grantia compressa*, *Halichondria panicea* and *Hymeniacidon perleve*, which occur frequently on steep and overhanging faces. Underneath the *Fucus serratus* canopy is a diverse flora of foliose red seaweeds including *Mastocarpus stellatus*, *Lomentaria articulata*, *Membranoptera alata* and *Chondrus crispus*. The green seaweeds *Cladophora* spp., *Ulva intestinalis* and *Ulva lactuca* and the wrack *Ascophyllum nodosum* are present though usually in small numbers. On the rock underneath the seaweed canopy, species such as the limpet *Patella vulgata*, the barnacles *Semibalanus balanoides* and *Balanus crenatus* and the whelk *Nucella lapillus* can be found though in lower abundance than higher up the shore. Also present on the rock are the tube-forming polychaetes *Pomatoceros triqueter* and spirorbids and more mobile species such as the winkle *Littorina mariae*, the top shell *Gibbula cineraria* and the crab *Carcinus maenas*. Lastly, several species of bryozoans are usually present including *Electra pilosa*, *Flustrellidra hispida* and *Alcyonidium gelatinosum*, all competing for space with the hydroid *Dynamena pumila*, which can form dense populations on the *Fucus serratus* fronds. (Information taken from the Marine Biotope Classification for Britain and Ireland, Version 04.05: Connor *et al.*, 2004.).

Welsh variation

Although the Welsh examples of many of the biotopes in this report follow the British and Irish classification description closely, some regional variation may exist. Reference should be made to Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

No text entered

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Habitat complex	SLR	Sheltered littoral rock (fucoid shores)
Biotope complex	SLR.F	Dense fucoids (stable rock)
Biotope	SLR.Fserr.T	*Fucus serratus*, sponges and ascidians on tide-swept lower eulittoral rock

Other biotope classification schemes

European Union Classification Information System (EUNIS) habitat classification: A1.3151-*Fucus serratus*, sponges and ascidians on tide-swept lower eulittoral rock (Davies & Moss, 1998).

Ecology

Ecological and functional relationships

- Due to the moderately strong to very strong currents associated with this biotope, suspension feeders are the dominant trophic group, indicating the importance of a planktonic input to the benthic community. Suspension feeders frequently associated with this biotope include the sponges *Halichondria panicea* and *Hymeniacidon perleve*, ascidians such as *Ascidiella scabra* and *Dendrodoa grossularia*, hydroids including *Dynamena pumila*, bryozoans, spirorbid and serpulid worms, and barnacles.
- Herbivores include the common periwinkle *Littorina littorea*, the grey top shell *Gibbula cineraria* and common limpet *Patella vulgata*. The common periwinkle grazes on microorganisms and fine green algae including *Ulva* sp., apparently rejecting the brown seaweed *Ascophyllum nodosum* (Fish & Fish, 1996). The common limpet can graze on tough plants including *Fucus* sp. and encrusting red algae whereas the grey top shell is unable to consume the tough cell walls and feeds mainly on detritus and microalgae (Fish & Fish, 1996). Grazing by *Patella vulgata* can be an important structuring feature on rocky shores and it is often considered to be a keystone species on north-east Atlantic rocky shores. Reductions in limpet density have been observed to have a significant impact on rocky shore community composition, particularly of fucoid algae and barnacles (Hawkins & Hartnol, 1985; Raffaelli & Hawkins, 1999).
- The common shore crab *Carcinus maenas* is the largest mobile predator frequently associated with this biotope and is likely to move between the boulders and pebbles feeding primarily on small molluscs, especially *Littorina* sp. and *Mytilus edulis*, annelids and other crustacea. It is a true omnivore and will also consume algal material. The predatory mollusc *Nucella lapillus*, the dog whelk, is also frequently associated with this biotope and feeds primarily on the common mussel *Mytilus edulis* and acorn barnacles (Fish & Fish, 1996) such as *Semibalanus balanoides* which may also be found.
- Autotrophs in the biotope are varied and include representatives from the brown, green and red algal groups such as *Fucus serratus*, *Cladophora rupestris* and *Mastocarpus stellatus* respectively. The algae themselves, especially the *Fucus serratus* canopy, may provide substratum for epiphytes including hydroids, sponges and ascidians. The distribution of epifauna into different areas on the *Fucus serratus* is such that competition for space is likely to be reduced. On heavily encrusted *Fucus serratus* fronds tunicates and sponges are largely basally located, most bryozoans, hydroids and spirorbids occur further out on the central parts of the plants whilst *Electra* is predominantly found distally (Seed, 1985). In addition, clumps of algae are likely to provide refuge for smaller crabs and periwinkles which may otherwise be washed away by the strong currents.
- Due to the eulittoral position of this biotope, the associated fauna are likely to experience some predation from larger predators, namely birds, when exposed at low tide and shallow water fish at high tides.

Seasonal and longer term change

The plants in this biotope are likely to experience some seasonal change in abundance, the general pattern being a lower percentage cover over the winter months. Periodic storms may remove older and weaker plants and reduce the overall biomass of the plants. If the forces were strong enough, the cobbles and boulders may also be moved around, to the detriment of the epilithic fauna. For example, if colonies of sponges and ascidians landed face down on the bedrock, parts of the colony may be crushed and lost. However, this biotope is limited to habitats that are sheltered to extremely sheltered from wave exposure and therefore, increases in wave exposure during winter and the occurrence of winter storms are unlikely to affect it to the same extent that more exposed habitats would be affected. In some habitats, the surface cover of *Fucus serratus* may reach 95% in the summer months. Ephemeral green algae especially, increase in abundance over the summer months.

Habitat structure and complexity

The substratum within this biotope is varied and offers a wide variety of potential habitats including bedrock, and the cracks and crevices therein, boulders and cobbles. In addition, the various seaweeds including *Fucus serratus* and foliose red seaweeds such as *Mastocarpus stellatus* offer a substratum for colonization by epiflora including bryozoans, sponges, ascidians and spirorbid worms. 91 taxa of associated fauna were found on 65 specimens of *Fucus serratus* in Strangford Lough, Northern Ireland (Boaden *et al.*, 1975). Clumps of seaweed also offer refuge for *Carcinus maenas* and the grazers *Gibbula cineraria* and *Littorina littorea*. The empty shells of the molluscs also provide some heterogeneity to the substratum.

Dominant trophic groups	Photoautotrophs Suspension feeders

Productivity

Rocky shore communities are highly productive and are an important source of food and nutrients for members of neighbouring terrestrial and marine ecosystems (Hill *et al.*, 1998). Rocky shores make a contribution to the food of many marine species through the production of planktonic larvae and propagules which contribute to pelagic food chains.

Raffaelli & Hawkins (1999) reported an estimate of the productivity of intertidal fucoids as 160 gC/m^2/year, although this figure was an estimate for moderately wave exposed habitats. The *Fucus serratus* canopy and other macroalgae associated with this biotope can exude dissolved organic carbon, which is taken-up readily by bacteria and may even be taken-up directly by some larger invertebrates. Dissolved organic carbon, algal fragments and microbial film organisms are continually removed by the sea, which may enter the food chain of local subtidal ecosystems, or be exported further offshore. Many of the species associated with this biotope make a contribution to the food of many marine species through the production of planktonic larvae and propagules, which contribute to pelagic food chains. The productivity in this biotope is likely to be greater than SLR.FserX.T (*Fucus serratus* with sponges, ascidians and red seaweeds on tide-swept lower eulittoral mixed substrata) that is similar is terms of exposure, water flow and species composition but with a mixed substrata as opposed to bedrock.

Major sources of organic carbon	Photosynthesis (macroalgae and/or halophytic plants) Plankton Detritus

Recruitment processes

For the majority of important characterizing species and other important species within this biotope, reproduction and recruitment is an annual process. For some of the species, various stages in the reproductive process, including gametogenesis, the timing of spawning and/or recruitment, are variable depending on, for example, environmental factors and geographic location. Recruitment in the major groups present is summarized below.

- Reproduction in *Fucus serratus* commences in late spring and continues until November, with a peak in August and October. Eggs and sperm are produced separately and fertilized externally to form a planktonic zygote. Recruitment is therefore possible from sources outside the biotope.
- *Chondrus crispus* has an extended reproductive period (e.g. Pybus, 1977; Fernandez & Menendez, 1991; Scrosati *et al*, 1994) and produces large numbers of spores (Fernandez & Menendez, 1991). The sexual life cycle of *Mastocarpus stellatus* involves the upright gametophyte plants developing carpospores that settle to produce a tetrasporophyte crust phase. An apomictic cycle has also been noted whereby upright fronds produce carpospores (without fertilization) which give rise to further apomictic plants (Dudgeon *et al.*, 1999). This species (studied as *Gigartina stellata*) had a peak in

mature carposporangia in winter in Galway Bay, Ireland (Pybus, 1977). The spores of red algae are non-motile (Norton, 1992) and therefore entirely reliant on the hydrographic regime for dispersal. Hence, it is expected that both *Chondrus crispus* and *Mastocarpus stellatus* would normally only recruit from local populations and that recovery of remote populations would be much more protracted.

- There is some debate as to the nature of reproduction in the breadcrumb sponge *Halichondria panicea* but it is likely that it has a short, annual season of reproduction (see *MarLIN* Web site).
- *Ascidiella scabra* has a high fecundity and settles readily, probably for an extended period from spring to autumn. Eggs and larvae are free-living for only a few hours and so recolonization would have to be from existing individuals no more than a few km away. It is also likely that *Ascidiella scabra* larvae are attracted by existing populations and settle near to adults (Svane *et al.*, 1987).
- Hayward & Ryland (1995a) and Dons (1927) stated that growth in *Pomatoceros triqueter* is rapid and that sexual maturity is reached in approximately 4 months. Hayward & Ryland (1995a) and Segrove (1941) suggested that breeding probably takes place throughout the year although a breeding peak in spring and summer has been noted and records from Port Erin by Moore (1937) indicated that breeding only took place in April in this location. Castric-Fey (1983) stated that only very rare settlement was observed during winter and maximum settlement occurred in April, June, August and Sept-Oct. Larvae are pelagic for about 2-3 weeks in the summer. However, in the winter this amount of time increases to about 2 months (Hayward & Ryland, 1995a). The settlement of the tubeworm *Spirorbis spirorbis* (studied as *Spirorbis borealis*) on *Fucus serratus* was reported to occur over the summer months in the north east of England (Daly, 1978, cited in Seed *et al*., 1981).
- *Patella vulgata* become sexually mature as males aged about nine months. Reproduction is an annual process with peaks within a defined spawning season (October - January) depending on location. Planktonic trophic larvae are produced although the larvae are only planktonic for a few days.
- Dispersal of the hydroid *Dynamena pumila* is restricted to the planula stage which usually settles and starts to metamorphose within 60 hours of release (Orlov, 1996). Orlov (1996) that long-distance dispersal was further restricted by the dense bushes of neighbouring algae which serve to trap the larvae in the area. Seed *et al*. (1981) reported that the reproductive zooids of *Dynamena pumila* were in abundance between May and August in Strangford Lough, Northern Ireland.
- The larvae of *Alcyonidium gelatinosum* have only a brief planktonic life and brooding of the embryos has been reported from several localities during spring or autumn (Fish & Fish, 1996).

Time for community to reach maturity

No information was found concerning the development of this biotope. However, the important characterizing species all reach sexual maturity within a few years and have annual reproductive episodes suggesting that the time taken for the community to develop is likely to be less than five years. However, if adverse environmental conditions prevail, time taken to reach maturity could take significantly longer.

Additional information

No text entered

Habitat preference and distribution

Distribution in Britain and Ireland

This biotope is found on the west (and south-west) coasts of Britain. It has been recorded in the mouths of several river / estuary systems in the south-west of England including Plymouth Sound and the River Fowey. In Wales it exists in Milford Haven and in the Menai Strait. In Scotland it has been recorded in several locations in the Inner and Outer Hebrides, the Orkneys, the Shetlands and on the north-west coast of the mainland.

Habitat preferences

Temperature range preferences	Data deficient
Water clarity preferences	Data deficient
Limiting nutrients	Data deficient

Other preferences	Moderately strong to strong tidal flows.

Additional information

This biotope is associated with sheltered to extremely sheltered habitats.

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	Species name	Common Name
Key Structuring	*Fucus serratus*	Toothed wrack
Important characterizing	*Ascidiella scabra*	A sea squirt
Important characterizing	*Halichondria panicea*	Breadcrumb sponge
Important other	*Chondrus crispus*	Carrageen
Important other	*Dynamena pumila*	A hydroid
Important other	*Alcyonidium gelatinosum*	A bryozoan
Important other	*Pomatoceros triqueter*	A tubeworm
Important other	*Patella vulgata*	Common limpet

Explanation

Fucus serratus forms a canopy within this biotope that provides protection from desiccation for the various underlying foliose red seaweeds in addition to providing a substratum for a diverse range of epifauna. It plays an important structural role and its removal would lead to the loss of the biotope. Of the two phyla that give the biotope this name, the ascidian *Ascidiella scabra* and sponge *Halichondria panicea* are most frequently associated with this biotope and have been listed as important characterizing species. The hydroid *Dynamena pumila*, the bryozoan *Alcyonidium gelatinosum* and the tubeworm *Spirorbis spirorbis* has been included as other important species as they are the most common representatives (in this biotope) of the diverse range of suspension feeders. These three species were also found to be the most prominent of 91 taxa found on 65 *Fucus serratus* plants in Strangford Lough, Northern Ireland (Boaden *et al*., 1975). Although the false Irish moss *Mastocarpus stellatus* was the red seaweed found most often in records of this biotope, more information was available on *Chondrus crispus*, to which it is thought to be very similar, and this has been used to indicate sensitivity of the red seaweeds likely to be found under the *Fucus serratus* canopy.

Species found especially in biotope

No text entered

Additional information

The MNCR recorded 393 species in 56 records of this biotope, although not all of the species occurred in all records of the biotope (JNCC, 1999).

Biotope sensitivity

Physical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	Moderate	Moderate	Major Decline	Moderate
Smothering	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Increase in suspended sediment	Intermediate	High	Low	Minor Decline	Low
Decrease in suspended sediment	Tolerant*	Not Relevant	Not sensitive*	No Change	Low
Desiccation	Intermediate	High	Low	Decline	Moderate
Increase in emergence regime	Intermediate	High	Low	Major Decline	Low
Decrease in emergence regime	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Increase in water flow rate	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Decrease in water flow rate	Intermediate	High	Low	Decline	Moderate
Increase in temperature	Low	Very high	Very Low	Minor Decline	Low
Decrease in temperature	Low	Very high	Very Low	Minor Decline	Low
Increase in turbidity	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Decrease in turbidity	Tolerant*	Not Relevant	Not sensitive*	No Change	Not Relevant
Increase in wave exposure	High	Moderate	Moderate	Major Decline	Moderate
Decrease in wave exposure	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Noise	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Visual Presence	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Abrasion & physical disturbance	Intermediate	High	Low	Decline	Moderate
Displacement	High	Moderate	Moderate	Major Decline	Moderate
Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	Intermediate	High	Low	Minor Decline	Low
Heavy metal contamination	Low	Very high	Very Low	No Change	Low
Hydrocarbon contamination	Low	High	Low	Minor Decline	Low
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Changes in nutrient levels	Low	Very high	Very Low	No Change	Low
Increase in salinity	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Decrease in salinity	Low	Very high	Very Low	Minor Decline	Low
Changes in oxygenation	Low	Very high	Very Low	Minor Decline	Low

Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Introduction of non-native species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Extraction of key or important characterizing species	High	Moderate	Moderate	Major Decline	Low
Extraction of important species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	Loss of the substratum will result in the loss of the entire biotope and therefore intolerance has been assessed as high. Some species may survive as epiphytes on the *Fucus serratus*, *Chondrus crispus* and other algae but these plants will soon be washed away in the strong currents. Recoverability is likely to be moderate (see additional information).
Smothering (see benchmark)	Smothering by a 5 cm layer of sediment is unlikely to adversely affect this biotope given that it is associated with areas of moderately strong to very strong water flow. The sediment layer will be washed away and 'normal' conditions will resume rapidly. The suspension feeders may experience some short-lived interference with feeding but, at the level of the benchmark, this is not likely to adversely affect their viability. Therefore, the biotope has been assessed as being tolerant to smothering.
Increase in suspended sediment (see benchmark)	An increase in suspended sediment, in combination with the strong water flow with which this biotope is associated, may be of detriment to the important characterizing species. Sand scour may damage the fronds of the *Fucus serratus*, *Chondrus crispus* and other algae in the biotope and reduce available light for photosynthesis (see turbidity). The feeding apparatus of suspension feeders may become bombarded with particles and interfere with their feeding and respiratory currents. Over the course of the benchmark this may lead to a reduction in total ingestion and a reduced scope for growth, especially since cleaning the feeding apparatus is likely to be energetically expensive. For short lived species such as the bryozoans and sea squirts, this may prove fatal. Robbins (1985) undertook experiments to establish the possible effects of high inorganic particulate concentrations on the sea squirt *Ascidiella scabra*. He concluded that growth rate was likely to be reduced and mortality was possible in high levels of suspended sediment. On balance, a decline in faunal species diversity is expected and accordingly, intolerance has been assessed as intermediate. Recovery is likely to be high due to the fact that most of the intolerant species produce planktonic larvae and are therefore likely to be able to recolonize quickly from surrounding areas.
Decrease in suspended sediment (see benchmark)	A decrease in suspended sediment could be beneficial to both the algae and the suspension feeding community in SLR.Fserr.T. Sand scour will be reduced and so will any interference with the feeding apparatus of the suspension feeders. Over the course of one month, a reduction in total suspended sediment may result in an increased scope for growth, especially for short lived species such as the bryozoans and sea squirts. Overall, tolerant* has been suggested.
Desiccation	Due to the fact that SLR.Fserr.T is an intertidal biotope, the benchmark level for desiccation is equivalent to a change in position of one biological vertical zone on

(see benchmark)	the shore for one year. In this case, that would mean a transition from the lower eulittoral to the mid eulittoral. The toothed wrack *Fucus serratus* and carrageen *Chondrus crispus* are both intertidal species that will be adapted to a degree of periodic desiccation. However, seaweeds have a critical water content and for *Fucus serratus*, it is 40%. Two hours of sunshine can result in this critical water content being exceeded and therefore this species will probably be of intermediate intolerance to desiccation at the benchmark level. Mathieson & Burns (1971) measured the photosynthetic rate of *Chondrus crispus* at varying degrees of desiccation and found that after loss of 65% of its water content, the rate of photosynthesis was only 55% of the control rate (see *MarLIN* Web site). In *Palmaria palmata*, 50% of the plant's water content can be lost in less than 4 hours in dry air at 25 °C (Kain & Norton, 1990). This scenario can reasonably be expected at low tide in summer in Britain, although the *Fucus* canopy is likely to protect the underlying red algae to some extent. Many of the invertebrates will also be protected from extreme levels of desiccation by the canopy. • The tissue of the breadcrumb sponge *Halichondria panicea* holds some water and it is tolerant of a certain degree of desiccation anyway. However, at the benchmark level, bleaching and tissue death in colonies at the upper shore extent of the population are likely to occur. • The sea squirt *Ascidiella scabra* has a soft body and is therefore vulnerable to desiccation. It is afforded some protection to desiccation by its location under seaweed and in damp crevices. However, some individuals at the highest point on the shore may dry out and die at the benchmark level. • Some colonies of *Dynamena pumila* occur on rock and survive exposure to air on every low tide (pers. obs. in Gili & Hughes, 1995). • Other important species associated with this biotope have mechanisms for reducing the effects of desiccation, for example, the common limpet *Patella vulgata*. This limpet has a 'home scar' in the bedrock. The 'home scar' is a shallow depression in the rock which fits closely the shape of the limpet's shell thereby reducing water loss from the soft tissues during emersion. Furthermore, *Patella vulgata* occurs higher up the shore and so is clearly able to survive desiccation. *Pomatoceros triqueter* combats desiccation by closing the operculum of the tube thus reducing water loss. However, the amount of time available for feeding and respiration will be reduced as a result, and therefore the population's viability may be reduced. Some individuals may die. Overall it is likely that some individuals from several species will experience some mortality, including some sponges and ascidians that give the biotope its name. Accordingly, intolerance has been assessed as intermediate with a high recoverability (see additional information).
Increase in emergence regime (see benchmark)	This biotope is found in the intertidal and the associated species are likely to be adapted to cyclical immersion and emersion. However, at the level in the benchmark, an increase in emergence is likely to adversely affect the dominant trophic group (suspension feeders) within this biotope. It will greatly reduce feeding opportunities for the suspension feeders, for which immersion is a prerequisite to feeding. Over the course of a year, this decrease is likely to prove fatal for short lived species such as the bryozoans and ascidians. The longer lived species such as *Halichondria panicea* and *Pomatoceros triqueter*, although unlikely to die, will probably experience reduced growth and reproductive potential and abundance of these species may decline. The upper shore extent of the *Fucus serratus* and *Chondrus crispus* populations may be replaced by species more tolerant of desiccation and more characteristic of the mid-eulittoral such as *Fucus vesiculosus* or *Ascophyllum nodosum*. False Irish moss, *Mastocarpus stellatus*, is also likely to increase in abundance as this species is capable of out-competing

	Chondrus crispus at higher levels on the shore due to its ability to tolerate greater extremes of temperature, for instance, (Dudgeon *et al.*, 1999). Although the biotope is unlikely to disappear completely, its extent on the shore is likely to be reduced and accordingly, intolerance has been assessed as intermediate. Recoverability is likely to be high (see additional information).
Decrease in emergence regime (see benchmark)	A decrease in emergence is likely to benefit this biotope. Feeding opportunity for suspension feeders will increase, and desiccation and temperature stresses for all flora and fauna will be reduced. The recognizable biotope may extend further up the shore but this extension is likely to be counteracted by a reduction in the lower shore extent of the biotope that is likely to be taken over by seaweeds more characteristic of the sublittoral fringe. Encrusting red algae and kelp species, for example, may become more dominant. Furthermore, predation by the common shore crab *Carcinus maenas* is likely to increase. Overall, it is possible that the biotope will just shift further up the shore and not necessarily increase or decrease in its extent on the shore. Therefore this biotope has been assessed to be tolerant of a decrease in emergence.
Increase in water flow rate (see benchmark)	This biotope is associated with areas of moderately strong to very strong water flow rates (>6 knots, the highest flow rate in the benchmark). In the Menai Strait, where this biotope was recorded, water flow rates can exceed 8 knots during spring tides. Therefore, an increase in water flow rate is not considered to be relevant.
Decrease in water flow rate (see benchmark)	The rich community of suspension feeders in this biotope is, in part, due to the strong tidal streams with which it is associated. Strong currents provide the suspension feeders with a continual supply of food and removes sediment that would otherwise interfere with their feeding apparatus. A decrease in water flow rate at the level in the benchmark could result in a negligible water flow rate. This would lead to siltation, to the detriment of the filter feeders. Some filter feeders have the ability to cope with siltation and excess suspended material. For example, *Ascidiella scabra* can extend its siphons, to a small extent, above silt and can also most likely maintain a passage through the silt to the siphons. It also attaches to other erect biota and, in such situations, may escape smothering effects. The breadcrumb sponge *Halichondria panicea* has a mechanism for sloughing off its complete outer tissue layer together with any debris (Barthel & Wolfrath, 1989). However, there is an energetic cost in cleaning, and this species, together with other filter feeders, would probably experience reduced growth over the benchmark. For annual species, including the star ascidian *Botryllus schlosseri*, reduced growth could prove fatal. The hydroid *Dynamena pumila* experienced marked decline in areas with increased silt content in Strangford Lough, Northern Ireland (Seed *et al.*, 1983). The toothed wrack *Fucus serratus* and red seaweeds including *Ceramium* sp. and *Chondrus crispus*, although tolerant of low flow rates, are likely to suffer from the reduced light caused by siltation. Rates of photosynthesis are likely to decrease and, over the course of one year, the plants may experience some negative growth. Furthermore, grazers unable to cope with the strong flow rates normally associated with this biotope may be able to graze more efficiently, resulting in the loss of a greater number of plants. Therefore, on balance, this biotope is likely to be of intermediate intolerance to a decrease in water flow rates although recovery is expected to be high.
Increase in temperature (see benchmark)	The distribution of various important species associated with this biotope, including *Halichondria panicea*, *Fucus serratus*, *Chondrus crispus*, *Patella vulgata*, *Ascidiella scabra* and *Pomatoceros triqueter*, is such that it is likely that they will be tolerant of a 2 °C increase in temperature over one year. However, it is possible that acute changes in temperature may adversely affect some of the species and accordingly, an intolerance of low has been suggested. Recoverability is expected to be very high.

Decrease in temperature (see benchmark)	The distribution of various important species associated with this biotope, including *Halichondria panicea*, *Fucus serratus*, *Chondrus crispus*, *Patella vulgata* and *Ascidiella scabra*, is such that it is likely that they will be tolerant of a 2 °C decrease in temperature over one year. However, it is possible that acute temperature reductions may be more harmful. Below a temperature of 7 °C, *Pomatoceros triqueter* is unable to build calcareous tubes (Thomas, 1940). This means that, although adults may be able to survive a decrease in temperature, larvae would not be able to attach to the substratum. However, due to the fact that this species is not actually characteristic of the biotope but more a representative of annelid suspension feeders, the biotope as a whole has been assessed as being of low intolerance. Recovery is expected to be very high.
Increase in turbidity (see benchmark)	This biotope has been recorded in the Menai Strait where turbidity levels are known to be very high and an increase in turbidity is unlikely to adversely affect the suspension feeders within this biotope. Indeed, if the turbidity were associated with an increase in organic particulate concentration, they may benefit actually from it. *Ascidiella scabra*, for example, lives in estuaries and other enclosed areas where turbidity may increase to high levels. The height of colonies of the hydroid *Dynamena pumila* fell to almost half their original height less than 6 weeks after the *Fucus serratus* plants on which they were attached were transferred from a relatively clean, fast flowing site to a turbid site in Strangford Lough (Seed & Boaden, 1977, cited in Seed *et al*., 1981). However, this may be related to the associated decrease in flow rate and in any case, this hydroid is not a characterizing species and occurred in less than half the records of this biotope. The algal component of the biotope may suffer due to the associated reduction in light. Over the course of one year, *Fucus serratus* may experience a reduction in total growth. Red algae can tolerate a wider range of light levels than any other group of photosynthetic plants (Kain & Norton, 1990) and an increase in the abundance of *Mastocarpus stellatus* and *Chondrus crispus*, for example, may be observed as they out-compete finer green and brown algal species. However, the *Fucus serratus* canopy will still remain and a large change in the recognizable biotope is unlikely. Therefore, tolerant has been assessed.
Decrease in turbidity (see benchmark)	The algal component of this biotope would benefit from a decrease in turbidity and they may experience enhanced photosynthesis and increased total growth over the benchmark period. The proportion of ephemeral green algae, in particular, may increase.
Increase in wave exposure (see benchmark)	This biotope occurs in sheltered to extremely sheltered habitats. An increase in exposure of two ranks of the wave exposure scale would mean that the biotope could become wave exposed. Hiscock (1983) noted that strong wave action may damage delicate feeding apparatus or lead to its retraction which would, ultimately, result in a reduction in total ingestion over the year. If the increase in wave exposure was coupled with the resuspension of sediments, energetic costs in cleaning the feeding apparatus would also need to be considered. The tubeworm *Pomatoceros triqueter* can tolerate very wave exposed habitats although the ascidian *Ascidiella scabra* would be outside its preferred habitat in moderately exposed habitats. Furthermore, short lived species such as the star ascidian *Botryllus schlosseri* would probably die. The boulders and cobbles in the biotope are likely to move around which could serve to dislodge plants from the cobbles, boulders and bedrock, and crush the tubes of serpulid and spirorbid worms and colonies of sponges, hydroids and ascidians. In addition, some algal species are known to change morphologically according to the degree of exposure. *Fucus serratus* would be outside its zone of preference, in terms of wave exposure and, over the course of the year the recognizable biotope is likely to be lost and replaced with opportunistic species and those species better adapted to high energy environments. Intolerance has been assessed as high with a moderate recovery.

Decrease in wave exposure (see benchmark)	This biotope occurs in sheltered to extremely sheltered habitats and therefore a decrease in wave exposure is not relevant.
Noise (see benchmark)	The key structural and important characterizing species are unlikely to have mechanisms for detecting noise. Some of the other important species, including *Patella vulgata* and *Pomatoceros triqueter*, may respond to the vibrations caused by noise by clamping down on the rock and withdrawing into the tube respectively. This would temporarily reduce feeding opportunity although at the benchmark level this is not likely to aversely affect the biotope. Therefore tolerant has been recorded.
Visual Presence (see benchmark)	The key structural and important characterizing species are unlikely to have mechanisms for detecting visual presence. Shadows detected by the photoreceptive surface of serpulid polychaetes may result in withdrawal of the worm back into its tube (Kinne, 1970). This would temporarily reduce feeding opportunity although at the benchmark level this is not likely to aversely affect the biotope. Therefore tolerant has been recorded.
Abrasion & physical disturbance (see benchmark)	At the benchmark level of abrasion, many of the associated species would be adversely affected. The fronds of the toothed wrack *Fucus serratus*, carrageen *Chondrus crispus* and other algal species, are likely to be torn off thus decreasing their photosynthetic capabilities. The holdfasts of *Chondrus crispus* are likely to escape unscathed and, due to the fact that the species is capable of regenerating from its holdfasts (e.g. Dudgeon & Johnson, 1992), no mortality is expected for this species. However, Dudgeon *et al*., reported that, on the coast of Maine, *Chondrus crispus* was more susceptible than *Mastocarpus stellatus* to dislodgement. Epifaunal species have been found to be particularly adversely affected by trawling or dredging activities, either due to direct damage or modification of the substratum (Jennings & Kaiser, 1998). However, some epifaunal species have been reported to exhibit increased abundances on high fishing effort areas, probably due to their ability to colonize and grow rapidly (Bradshaw *et al.*, 2000). In a study of the long term effects of scallop dredging, Bradshaw *et al.* (2002) reported that *Ascidiella* species had become more abundant and suggested that they were probably able to survive by regeneration of damage and budding. Individuals are easily ripped from the substratum and are unlikely to re-attach and will die. Patches of hydroids and bryozoans and encrusting fauna such as colonial ascidians and sponges are likely to be scraped off the rock although a proportion of the colonies are likely to remain. The shells of limpets, tubeworms and periwinkles may be crushed by the weight and force of the abrasion. However, Hiscock (1983) noted that a community, under conditions of scour and abrasion from stones and boulders moved by storms, developed into a community consisting of fast growing species such as *Pomatoceros triqueter*. Scour and abrasion will probably remove a proportion of the population although it demonstrates rapid growth and recruitment. The abundance of *Pomatoceros triqueter* may increase due to decreased competition from other species. However, *Pomatoceros triqueter* is not a characterizing species and, on balance, intolerance has been assessed as intermediate due to the fact that after a single event, a proportion of all of the species is likely to remain. This in turn will favour recoverability and accordingly, recoverability has been assessed as high. Intolerance to trampling is likely to be lower than to the effects of a passing scallop dredge.
Displacement (see benchmark)	All of the important characterizing species and the majority of 'important other' species in this biotope are sessile and permanently attached to the hard substrata. Displacement would probably result in the death of some species including *Fucus serratus*, *Chondrus crispus*, *Halichondria panicea*, *Ascidiella scabra*, *Alcyonidium gelatinosum* and *Patella vulgata*. Thomas (1940) found that if *Pomatoceros*

	triqueter is removed from its tube, it will start to make a new one in a few hours. Therefore, it is likely that the worm will be able to leave the old tube to start constructing another. However, this would involve considerable energetic cost and, furthermore, this is not a characterizing species. The displacement of the key and important species is likely to have a similar effect to substratum loss on the biotope and therefore, an intolerance of high has been recorded.
Chemical Factors	
Synthetic compound contamination (see benchmark)	The species frequently associated with this biotope are known to have varying degrees of tolerance to synthetic chemicals. In general, however, most of the species show at least some intolerance to synthetic chemical contamination. • Scanlan & Wilkinson (1987) found that the spermatozoa and newly fertilized eggs of *Fucus serratus* were the most intolerant of biocides, while adult plants were only just significantly affected at 5 ml/l of the biocides Dodigen v181-1, Dodigen v 2861-1 and ML-910. • O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination, possibly due to the susceptibility of phycoerythrins to destruction. Laboratory studies of the effects of oil and dispersants on several red algal species concluded that they were all sensitive to oil/dispersant mixtures, with little difference between adults, sporelings, diploid or haploid life stages (Grandy, 1984, cited in Holt *et al.*, 1995). • Ascidians may be intolerant of synthetic chemicals such as tri-butyl-tin (TBT) anti-foulants. Rees *et al.* (2001), working in the Crouch estuary, observed that six ascidian species were recorded at one station in 1997 compared with only two at the same station in 1987, shortly following the banning of TBT in antifouling paints. Also, there was a marked increase in the abundance of ascidians especially *Ascidiella aspersa* and *Ascidia conchilega* in the estuary after TBT had been banned. • Insufficient information was available on the specific effects of synthetic chemicals on the breadcrumb sponge and other important species including the common limpet and tubeworm *Pomatoceros triqueter*. On balance, it is likely that many of the species characteristic of this biotope will experience some mortality and accordingly, intolerance has been assessed as intermediate. Due to the strong water flow with which this biotope is associated, recoverability is expected to be high, although recovery from the effects of highly persistent chemicals may take significantly longer.
Heavy metal contamination (see benchmark)	Fucoid algae readily accumulate heavy metals within their tissues. The effect of heavy metals on the growth rate of adult *Fucus serratus* plants has been studied by Strömgren (1979b; 1980a, b). Copper significantly reduces the growth rate of vegetative apices at 25 µg/l over 10 days (Strömgren, 1979b). Zinc, lead, cadmium & mercury significantly reduce growth rate at 1400 µg/l , 810 µg/l, 450 µg/l and 5 µg/l respectively (Strömgren, 1980a, b). No information was found concerning the specific effects of heavy metals on the other important and characterizing species although an intolerance of low has been recorded to take account of the sub-lethal effects on *Fucus serratus* mentioned above. Recovery is likely to be very high although recovery from the effects of highly persistent metal and their compounds may take significantly longer.
Hydrocarbon contamination (see benchmark)	• Adult *Fucus serratus* plants are tolerant of exposure to spills of crude oil although very young germlings are intolerant of relatively low concentrations of 'water soluble' extractions of crude oils. Exposure of eggs to these extractions (at 1.5 µg/ml for 96 hours) interferes with adhesion during settling and (at 0.1 µg/ml) prevents further development (Johnston, 1977). • Observations have shown that filamentous red algae are among the most

	severely affected by the toxic properties of oil (O'Brien & Dixon, 1976). Effects including bleaching and loss of photosynthetic pigments have been observed in red algal species following contamination with fuel oil (O' Brien & Dixon, 1976). The long term effects on *Chondrus crispus* of continuous doses of the water accommodated fraction (WAF) of diesel oil were determined in experimental mesocosms (Bokn *et al.*, 1993). Mean hydrocarbon concentrations tested were 30.1 µg/l and 129.4 µg/l. After 2 years, there were no demonstrable differences in the abundance patterns of *Chondrus crispus*. Furthermore, Kaas (1980, cited in Holt *et al.*, 1995) reported that the reproduction of adult *Chondrus crispus* plants on the French coast was normal following the *Amoco Cadiz* oil spill. • It appears that *Halichondria panicea* survived in areas affected by the *Torrey Canyon* oil spill (Smith, 1968), although few observations were made. No information was found concerning the effects of hydrocarbon contamination on the other characterizing and important species. However, given the evidence above, an intolerance of low has been suggested with very high recovery.
Radionuclide contamination (see benchmark)	No information was found concerning the effects of radionuclides on any of the four important characterizing species or most of the other important species. Therefore, insufficient information was available in order to assess sensitivity.
Changes in nutrient levels (see benchmark)	An influx of nutrients into the biotope is likely to stimulate phytoplankton production, depending on other environmental conditions. This means that the amount of food potentially available to the suspension feeders will increase. In the long term, a sustained increase in nutrients could lead to the formation of algal blooms. Algal blooms have the potential to block light from underlying plants, thereby reducing their photosynthetic capacity. In addition, the eventual biodegradation of the blooms / mats involves the consumption of a large amount of oxygen, although the moderately strong water flows with which this biotope is associated means are likely to ameliorate this (see oxygenation). It is possible, therefore, that *Fucus serratus* and other plants may experience some reduced growth over time but it is unlikely that any species will experience mortality. *Chondrus crispus* may be out-competed by faster growing or ephemeral species. Johansson *et al.* (1998) investigated the changes in the algal vegetation of the Swedish Skagerrak coast, an area heavily affected by eutrophication, between 1960 and 1997. Slow growing species, including *Chondrus crispus* declined in abundance, probably due to competition from faster growing red algal species such as *Phycodrys rubens* and *Delesseria sanguinea*. Overall, the recognizable biotope would be unaffected *per se* and accordingly, an intolerance of low has been assessed with a very high recoverability.
Increase in salinity (see benchmark)	SLR.Fserr.T is an intertidal biotope that will most likely experience cyclical periods of hypo- and hyper-salinity. It is found in areas of variable to full salinity and therefore an increase in salinity is not relevant. Short periods of hyper-salinity may occur where patches of surface water on the bedrock evaporate although this is unlikely to continue for periods of time similar to those benchmark and only small areas of substratum will be affected anyway.
Decrease in salinity (see benchmark)	SLR.Fserr.T is an intertidal biotope that will most likely experience cyclical periods of hypo- and hyper-salinity. *Fucus serratus* is able to compensate for these changes in salinity by adjusting internal ion concentrations. Salinity affects the photosynthetic rate and hence growth rate of seaweed. For *Fucus serratus*, growth rate is maximal at a salinity of 20 psu and therefore, a decrease in salinity into the 'low' salinity category would be of preference to the plant. Other important / characterizing species associated with this biotope are also likely to be tolerant of a reduction in salinity. The breadcrumb sponge *Halichondria panicea* and carrageen *Chondrus crispus* are found in low salinity and *Ascidiella scabra* and *Patella vulgata* can be found in reduced salinity conditions. *Patella vulgata* can survive in

	salinities down to about 20 psu. However, growth and reproduction may be impaired in reduced salinity. Little *et al.* (1991), for example, observed reduced levels of activity in limpets after heavy rainfall and in the laboratory activity completely stopped at 12 psu. *Patella vulgata* can endure periods of low salinity and was found to die only when the salinity was reduced to 3-1psu (Fretter & Graham, 1994). Therefore, a rapid fall in salinity of two categories on the MNCR scale from variable to low salinity could result in more adverse effects on the whole community but over one week, intolerance has been assessed as low. Recovery is expected to be very high.
Changes in oxygenation (see benchmark)	No specific information was found concerning the effects of reduced oxygenation on the key / characterizing species although Cole *et al.* (1999) suggested possible adverse effects on marine species below 4 mg/l and probably adverse effects below 2 mg/l. Some of the associated fauna may be tolerant of low oxygen environments and the strong water flow rates associated with this biotope are likely to ameliorate any reductions in oxygenation. Overall, an intolerance of low has been suggested although recoverability is expected to be very high on return to 'normal' conditions.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	No information was found concerning the effects of and occurrence of microbial pathogen infestations on the key and characterizing species. Therefore, insufficient information was available to assess sensitivity.
Introduction of non-native species (see benchmark)	There are no known alien or invasive species that are likely to compete with or displace the important characterizing species associated with this biotope. The Australasian barnacle *Elminius modestus* was introduced to British waters on ships during the second world war. The species does well in estuaries and bays, where it can displace *Semibalanus balanoides*. However, *Semibalanus balanoides* is not a characterizing species within SLR.Fserr.T and, therefore, not relevant to the sensitivity assessment of the biotope.
Extraction of key or important characterizing species (see benchmark)	*Fucus serratus*, *Chondrus crispus* and *Mastocarpus stellatus* are the only key / characterizing species known to be targeted for extraction (see 'Importance'). The extraction of *Fucus serratus* would lead to the loss of the recognizable biotope, as the plant gives the biotope its name. In addition to the loss of these plants, many epiphytic species would be lost including proportions of populations of *Dynamena pumila* (found especially on fucoid species), *Halichondria panicea*, *Ascidiella scabra*, *Alcyonidium gelatinosum* and *Spirorbis spirorbis*. Intolerance has therefore been assessed as high. *Fucus serratus* is highly fecund and the eggs are broadcast into the water column allowing a potentially large dispersal distance. Recovery has been assessed as moderate (see additional information).
Extraction of important species (see benchmark)	There are no important structural or functional species associated with this biotope.

Additional information

Recoverability (i.e. recruitment) in the key and characterizing species varies in terms of timescales but, in general, recoverability of the individual species is considered to be high. For the majority of other important species within this biotope, reproduction and recruitment is an annual process (see recruitment processes). In addition, many of the species have planktonic larvae thereby facilitating recruitment from local sources.

The settlement of new colonies of the breadcrumb sponge *Halichondria panicea* is likely within one year and growth rate is rapid. *Ascidiella scabra* has a high fecundity and settles readily, probably for an extended period from spring to autumn. Eggs and larvae are free-living for only a few hours and so recolonization would have to be from existing individuals no more than a few km away. It is also likely that *Ascidiella scabra* larvae are attracted by existing populations and settle near to adults (Svane *et al.*, 1987). Fast growth means that a dense cover could be established within as little as two months. However, if mortality and the consequent establishment of free space available occur at a time when larvae are not being produced, other species may settle and dominate. In this case, recolonization by *Ascidiella scabra* may take several years.

Fucus serratus is also highly fecund and the eggs are broadcast into the water column allowing a potentially large dispersal distance. The species is found on all British and Irish coasts so there are few mechanisms isolating populations. Recruitment may occur through reproduction of the remaining population or from other populations and, providing that some of the population remains, it is unlikely that other species will come to dominate and recovery will probably have occurred after one or two years. At this point, the available substratum for epiphytic species will increase also, thereby facilitating their colonization of the biotope.

However, the loss of the entire *Fucus serratus* canopy or loss of the entire biotope would result in a complete disruption in the equilibrium of the community. The understory algal species may become bleached and die if the canopy layer was lost. As a result, the abundance of limpets is likely to increase which would prevent further recruitment of the fucoids. Fucoid abundance would subsequently decrease and it wouldn't be until the level of algae had increased to such a point that there was an insufficient amount to sustain the limpet population that fucoids could start to return. Hawkins & Southward (1992) found that, after the *Torrey Canyon* oil spill, it took between 10 and 15 years for the *Fucus* sp. to return to 'normal' levels of spatial and variation in cover on moderately exposed shores. Therefore, for factors which are likely to totally destroy the biotope (i.e. to which SLR.Fserr.T is highly intolerant), recoverability is likely to be moderate.

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors						
	Fucus serratus	***Ascidiella scabra***	***Halichondria panicea***	***Chondrus crispus***	***Pomatoceros triqueter***	***Patella vulgata***
Community Importance	Key Structuring	Important characterizing	Important characterizing	Important other	Important other	Important other
Substratum Loss	High	High	High	High	High	High
Smothering	High	Low	High	Intermediate	High	High
Increase in suspended sediment	Low	Low	Low	Intermediate	Low	Low
Decrease in suspended sediment	See explanation	Not Sensitive	Not Sensitive	Not Sensitive	Low	Low
Desiccation	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Low
Increase in emergence regime	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Low
Decrease in emergence regime	See explanation	Not Sensitive*	Not Sensitive	Not Sensitive	Not Sensitive*	See explanation
Increase in water flow rate	Intermediate	Low	Intermediate	Intermediate	Not Sensitive*	Low
Decrease in water flow rate	See explanation	Low	Low	Intermediate	Not Sensitive	See explanation
Increase in temperature	Not Sensitive	Not Sensitive	Low	Low	Not Sensitive*	Low
Decrease in temperature	See explanation	Not Sensitive	Low	Low	Intermediate	See explanation
Increase in turbidity	Low	Not Sensitive	Not Sensitive	Low	Not Sensitive	Low
Decrease in turbidity	See explanation	Not Sensitive*	Not Sensitive	Not Sensitive*	Not Sensitive	See explanation
Increase in wave	High	Intermediate	Intermediate	Intermediate	Low	Low

exposure	🟥	🟨	🟨	🟨	🟦	🟦
Decrease in wave exposure	See explanation	Not Sensitive*	Low	Low	Not Sensitive	See explanation
Noise	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Low
Visual Presence	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive
Abrasion & physical disturbance	Intermediate	High	Intermediate	Low	Intermediate	Low
Displacement	High	High	High	High	Low	Intermediate
Chemical factors						
	Fucus serratus	***Ascidiella scabra***	***Halichondria panicea***	***Chondrus crispus***	***Pomatoceros triqueter***	***Patella vulgata***
Community Importance	Key Structuring	Important characterizing	Important characterizing	Important other	Important other	Important other
Synthetic compound contamination	High	Intermediate	Insufficient information	High	Insufficient information	High
Heavy metal contamination	Low	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Intermediate
Hydrocarbon contamination	Intermediate	Insufficient information	Low	Low	Insufficient information	High
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	Intermediate	Insufficient information	Insufficient information	Intermediate	Insufficient information	Low
Increase in salinity	Low	Not Sensitive	Low	Not Sensitive	Not Sensitive	Low
Decrease in salinity	See explanation	Intermediate	Low	Low	High	See explanation
Changes in oxygenation	Low	Low	Intermediate	Insufficient information	Insufficient information	Intermediate
Biological factors						
	Fucus serratus	***Ascidiella scabra***	***Halichondria panicea***	***Chondrus crispus***	***Pomatoceros triqueter***	***Patella vulgata***
Community Importance	Key Structuring	Important characterizing	Important characterizing	Important other	Important other	Important other
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information	Intermediate	Insufficient information	Insufficient information
Introduction of non-native species	Insufficient information	Not Sensitive	Insufficient information	Insufficient information	Not Sensitive	Not Relevant
Extraction of this species	Intermediate	Not Relevant	Not Relevant	Intermediate	Not Relevant	Intermediate
Extraction of other species	Not Sensitive	Not Relevant	High	Insufficient information	Not Relevant	Low

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors						
	Fucus serratus	***Ascidiella scabra***	***Halichondria panicea***	***Chondrus crispus***	***Pomatoceros triqueter***	***Patella vulgata***
Community Importance	Key Structuring	Important characterizing	Important characterizing	Important other	Important other	Important other
Substratum Loss	High	Very high	High	High	High	High
Smothering	High	Immediate	High	High	High	High
Increase in suspended sediment	Very high	Immediate	Immediate	High	High	High
Decrease in suspended sediment	See explanation	Not Relevant	Not Relevant	Not Relevant	High	High
Desiccation	High	Very high	Very high	High	High	High
Increase in emergence regime	High	Very high	Very high	High	High	High
Decrease in emergence regime	See explanation	Not Relevant	Not Relevant	Not Relevant	Not Relevant	See explanation
Increase in water flow rate	High	Immediate	Very high	High	Not Relevant	High
Decrease in water flow rate	See explanation	Immediate	Immediate	High	Not Relevant	See explanation
Increase in temperature	Not Relevant	Not Relevant	Very high	Very high	Not Relevant	High
Decrease in temperature	See explanation	Not Relevant	Very high	Very high	High	See explanation
Increase in turbidity	Very high	Not Relevant	Not Relevant	Very high	Not Relevant	Very high
Decrease in turbidity	See explanation	Not Relevant	Not Relevant	Not Relevant	Not Relevant	See explanation
Increase in wave exposure	High	Very high	Very high	High	High	High
Decrease in wave exposure	See explanation	Not Relevant	Very high	Very high	Not Relevant	See explanation
Noise	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	High
Visual Presence	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Abrasion & physical disturbance	High	Very high	High	Very high	Immediate	Very high
Displacement	High	Very high	High	High	High	High
Chemical factors						
	Fucus serratus	***Ascidiella scabra***	***Halichondria panicea***	***Chondrus crispus***	***Pomatoceros triqueter***	***Patella vulgata***
Community Importance	Key Structuring	Important characterizing	Important characterizing	Important other	Important other	Important other
Synthetic compound contamination	High	Very high	Not Relevant	High	Not Relevant	High
Heavy metal contamination	High	Not Relevant	Not Relevant	Insufficient information	Not Relevant	High
Hydrocarbon contamination	High	Not Relevant	High	Very high	Not Relevant	High
Radionuclide contamination	Insufficient information	Not Relevant	Not Relevant	Insufficient information	Not Relevant	Insufficient information
Changes in nutrient levels	High	Not Relevant	Not Relevant	High	Not Relevant	High
Increase in salinity	Very high	Not Relevant	High	Not Relevant	Not Relevant	High

Decrease in salinity	See explanation	Very high	High	Very high	High	See explanation
Changes in oxygenation	Very high	Immediate	High	Insufficient information	Not Relevant	High
Biological factors						
	Fucus serratus	***Ascidiella scabra***	***Halichondria panicea***	***Chondrus crispus***	***Pomatoceros triqueter***	***Patella vulgata***
Community Importance	Key Structuring	Important characterizing	Important characterizing	Important other	Important other	Important other
Introduction of microbial pathogens/parasites	Insufficient information	Not Relevant	Not Relevant	High	Not Relevant	Insufficient information
Introduction of non-native species	Insufficient information	Not Relevant	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Extraction of this species	High	Not Relevant	Not Relevant	High	Not Relevant	High
Extraction of other species	Not Relevant	Not Relevant	High	Insufficient information	Not Relevant	High

Importance

Marine natural heritage importance

Listed under:	**UK Biodiversity Action Plan**
National importance	Scarce
Habitat Directive feature (Annex 1)	Reefs Large shallow inlets and bays Estuaries Lagoons
UK Biodiversity Action Plan habitat	Tidal rapids

Biotope importance

The toothed wrack *Fucus serratus* and false Irish moss *Mastocarpus stellatus* are both harvested commercially (see 'Exploitation').

Exploitation

Within this biotope, at least two of the algal species are known to be targeted for extraction, namely *Fucus serratus* and *Chondrus crispus*. *Fucus serratus* is collected, dried and used as a soil additive. Various fucalean algae are used in the production of alginates and these are used widely in the pharmaceutical and cosmetics industries. *Chondrus crispus* is harvested commercially in Ireland, Spain, France, Portugal and North America for the extraction of carrageenan (Guiry & Blunden, 1991). In Ireland, harvesting has generally remained sustainable through pickers developing an intuitive feel for the annual cycle of local stocks and certain practices which involve pulling only the bushy top half of the frond off leaving the base and holdfast behind (Morrissey *et al*., 2001). The gelling and thickening properties of carrageenan are used widely in the food, pharmaceutical and cosmetics industries (see *MarLIN* Web site). *Mastocarpus stellatus* may also be collected with *Chondrus crispus*. It is known to what extent *Fucus serratus* is collected in Britain and Ireland, although if large sections of the canopy are removed, this will probably have an adverse effect on the biotope (see 'Sensitivity').

Additional information

No text entered

This Biology and Sensitivity Key Information review can be cited as follows:
Marshall, C.E., 2005. *Fucus serratus*, sponges and ascidians on tide-swept lower eulittoral rock. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 25/01/2005]. Available from: <http://www.marlin.ac.uk>

Fucus serratus with sponges, ascidians and red seaweeds on tide-swept lower eulittoral mixed substrata (SLR.FserX.T)

Key information authored by: Charlotte Marshall

Last updated 01/12/2004

This information is not refereed.

If you would be willing to supply *MarLIN* with an image of this species/habitat please contact marlin@mba.ac.uk

Recorded and expected SLR.FserX.T distribution for Britain and Ireland

Description of biotope

Sheltered lower shore boulders, cobbles and pebbles on muddy sediments that are subject to enhanced tidal water movement may be characterized by a rich community of sponges (*Halichondria panicea* and *Hymeniacidon perleve*), hydroids (*Dynamena pumila*), bryozoans (*Anguinella palmata* and *Walkeria uva*), ascidians (*Ascidiella aspersa*, *Ascidiella scabra*, *Styela clava* and *Botryllus schlosseri*) and red seaweed (*Halurus flosculosus, Ceramium* sp., *Gracilaria verrucosa* and *Chondrus crispus*). The brown algae *Dictyota dichotoma*, *Fucus serratus* and *Ectocarpus* sp. may be found on any more stable substrata. Patches of sand or mud are often characterized by the sand mason worm *Lanice conchilega*, the peacock worm *Sabella pavonina* and the anemone *Sagartia troglodytes*. Aggregations of the mussel *Mytilus edulis* and, in southern and eastern England, the slipper limpet *Crepidula fornicata* may also be found attached to cobbles and pebbles. Sites in Scottish sealochs may support maerl *Lithothamnion corallioides* and bivalves *Venerupis senegalensis* (see also IMX.VsenMtru). (Information taken from the Marine Biotope Classification for Britain and Ireland, Version 97.06: Connor *et al.*, 1997a, b).

Welsh variation

Although the Welsh examples of many of the biotopes in this report follow the British and Irish classification description closely, some regional variation may exist. Reference should be made to Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

No text entered

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Habitat complex	SLR	Sheltered littoral rock (fucoid shores)

Biotope complex	SLR.FX	Fucoids, barnacles or ephemeral seaweeds (mixed substrata)
Biotope	SLR.FserX.T	*Fucus serratus* with sponges, ascidians and red seaweeds on tide-swept lower eulittoral mixed substrata

Other biotope classification schemes

European Nature Classification Information System (EUNIS) habitat classification: A1.3241-*Fucus serratus* with sponges, ascidians and red seaweeds on tide-swept lower eulittoral mixed substrata (Davies & Moss, 1998).

Ecology

Ecological and functional relationships

- Due to the moderately strong currents associated with this biotope, suspension feeders are the dominant trophic group, indicating the importance of a planktonic input to the benthic community. Suspension feeders frequently associated with this biotope represent four phyla: the sponges *Halichondria panicea* and *Hymeniacidon perleve*, ascidians such as *Ascidiella aspersa*, molluscs including the slipper limpet *Crepidula fornicata* and common mussel *Mytilus edulis* and crustaceans such as barnacle *Elminius modestus*.
- The sand mason *Lanice conchilega* (a polychaete worm) is primarily a deposit feeder, feeding preferentially on detritus. However, when *Lanice conchilega* occurs in high densities, competition at the sediment surface forces it to suspension feed (Buhr & Winter, 1977).
- The common periwinkle *Littorina littorea* is a herbivore and commonly feeds on fine brown, green and red algae. The chiton *Lepidochitona cinerea* also grazes on algae and micro organisms.
- The common shore crab *Carcinus maenas* is the largest mobile predator frequently associated with this biotope and is likely to move between the boulders and pebbles feeding primarily on small molluscs, especially *Littorina* sp. and *Mytilus edulis*, annelids and other crustacea. It is a true omnivore and will also consume algal material.
- Autotrophs in the biotope are varied and include representatives from the brown, green and red algal groups such as *Fucus serratus*, *Bryopsis plumosa* and *Chondrus crispus* respectively. The algae themselves may provide substratum for epiphytes including hydroids, sponges and ascidians. In addition, clumps of algae are likely to provide refuge for smaller crabs and periwinkles which may otherwise be washed away by the strong water flow.
- Due to the eulittoral position of this biotope, the associated fauna are likely to experience some predation from birds, when exposed at low tide and shallow water fish at high tides.

Seasonal and longer term change

The plants in this biotope are likely to experience some seasonal change in abundance, the general pattern being a lower percentage cover over the winter months. However, this biotope is limited to habitats that are sheltered to extremely sheltered from wave exposure and, therefore, increases in wave exposure during winter and the occurrence of winter storms are unlikely to affect it to the same extent that more exposed habitats would be affected. In some habitats, the surface cover of *Fucus serratus* may reach 95% in the summer months. Ephemeral green algae especially, increase in abundance over the summer months.

Any increase in wave exposure and storm frequency over the winter months is likely to result in the resuspension and subsequent redeposition of the mixed sediment substratum. If the forces were strong enough, the pebbles and boulders may also be moved around. Redistribution of the larger pebbles and boulders may be to the detriment of the epilithic fauna. For example, if colonies of sponges and ascidians on the rock landed face down into the sediment, their feeding would be interrupted and that part of the colony would die. In the Bay of Fundy, Canada, the abundance of the hydroid *Dynamena pumila* declined dramatically over the winter months as a result of ice scour (Henry, 2002) which is likely to have a similar effect to the scour of the mixed sediment in this biotope. Similarly, if plants were trapped under the boulders they may also die unless subsequent movement of the boulders released them. Periodic storms may remove older and weaker plants and reduce the overall biomass of the plants.

Habitat structure and complexity

The substratum within this biotope is mixed and structurally complex, offering a wide variety of potential habitats including boulders, cobbles, pebbles and muddy sediments. This means that there will be a mix of both infauna, epifauna and epilithic species. In addition, *Fucus serratus* and red seaweeds offer a substratum for colonization by epiflora including bryozoans and sponges. 91 taxa of associated fauna were found on 65 specimens of *Fucus serratus* in Strangford Lough, Northern Ireland (Boaden *et al.*, 1975). Clumps of seaweed also offer refuge for *Carcinus maenas* and the grazer *Littorina littorea*. Small patches of the mussel *Mytilus edulis* may provide refuge for a diverse range of small invertebrates including polychaetes and *Littorina* sp.. The empty shells of the molluscs also provide some heterogeneity to the substratum.

Dominant trophic groups	Suspension feeders

Productivity

Very little is known about the productivity of this biotope, or indeed of intertidal mixed sediment communities in general. However, the small patches of macroalgae associated with this biotope can exude dissolved organic carbon, which is taken-up readily by bacteria and may even be taken-up directly by some larger invertebrates. Dissolved organic carbon, algal fragments and microbial film organisms are continually removed by the sea. This may enter the food chain of local subtidal ecosystems, or be exported further offshore. Many of the species associated with this biotope make a contribution to the food of many marine species through the production of planktonic larvae and propagules, which contribute to pelagic food chains. There is likely to be less productivity than on fucoid dominated rocky shore such as MLR.MytFves and MLR.BF.

Major sources of organic carbon	Plankton Detritus

Recruitment processes

For the majority of important characterizing species and other important species within this biotope, reproduction and recruitment is an annual process. For some of the species, such as the common mussel *Mytilus edulis*, common shore crab *Carcinus maenas* and common periwinkle *Littorina littorea*, various stages in the reproductive process, including gametogenesis, the timing of spawning and/or recruitment, are variable depending on, for example, environmental factors and geographic location. Recruitment in the major groups present is summarized below.

- Reproduction in *Fucus serratus* commences in late spring and continues until November, with a peak in August and October. Eggs and sperm are produced separately and fertilized externally to form a planktonic zygote. Recruitment is therefore possible from sources outside the biotope.
- *Chondrus crispus* has an extended reproductive period (e.g. Pybus, 1977; Fernandez & Menendez, 1991; Scrosati *et al.*, 1994) and produces large numbers of spores (Fernandez & Menendez, 1991). Although growth of sporelings is not rapid in comparison to other macroalgae, maturity is probably reached approximately 2 years after initiation of the basal disc (Pybus, 1977). The spores of red algae are non-motile (Norton, 1992) and therefore entirely reliant on the hydrographic regime for dispersal. Hence, it is expected that *Chondrus crispus* would normally only recruit from local populations and that recovery of remote populations would be much more protracted.
- There is some debate as to the nature of reproduction in the breadcrumb sponge *Halichondria panicea* but it is likely that it has a short, annual season of reproduction (see *MarLIN* Web site).
- The larvae of the sea squirt *Ascidiella aspersa* have a short free-swimming planktonic stage. However, time taken from fertilization until settlement and metamorphosis is only about 24 hours at 20 °C (Niermann-Kerkenberg & Hofmann, 1989) and, therefore, widespread dispersal seems unlikely.
- *Mytilus edulis* has a protracted spawning in many places and fecundity is affected by many factors (see *MarLIN* Web site). The planktonic life of larvae may exceed two months and, hence, there is a good chance of wide dispersal and recruitment from external sources. Due to the highly gregarious nature of *Mytilus edulis* settlement, persistent mussel beds can be maintained by relatively low levels of recruitment.
- The larvae of the sand mason *Lanice conchilega* can spend up to sixty days in the plankton therefore providing good potential for dispersal and recruitment from external sources.
- The duration of the breeding season in the common shore crab *Carcinus maenas* depends on the geographic location of the population. Females on the south coast of Britain can bear eggs all year round and fecundity is high (see *MarLIN* Web site).
- Fecundity in the common periwinkle *Littorina littorea* can reach 100,000 eggs in large females. The

reproductive season is annual and episodic with a pelagic phase of up to six weeks. *Littorina littorea* can also breed all year, although the length and timing of the season depend on climate.
- Dispersal of the hydroid *Dynamena pumila* is restricted to the planula stage which usually settles and starts to metamorphose within 60 hours of release (Orlov, 1996). Orlov (1996) that long-distance dispersal was further restricted by the dense bushes of neighbouring algae which serve to trap the larvae in the area.

Time for community to reach maturity

No information was found concerning the development of this biotope. However, the important characterizing species all reach sexual maturity within three years and have annual reproductive episodes suggesting that the time taken for the community to develop is likely to be less than five years. However, if adverse environmental conditions prevail, time taken to reach maturity could take significantly longer.

Additional information

No text entered

Habitat preference and distribution

Distribution in Britain and Ireland

This biotope is not particularly widespread, especially on the east coast of Britain. It has been recorded from the Welsh coast of the Bristol Channel, Morecambe Bay, Luce Bay and two areas on the north west coast of the Scotland. On the east coast of Britain, it has only been recorded from the Essex and Suffolk coasts. In Ireland, the biotope has been recorded solely in Galway Bay on the west coast.

Habitat preferences

Temperature range preferences	Data deficient
Water clarity preferences	Data deficient
Limiting nutrients	Data deficient
Other preferences	Moderately strong tidal streams

Additional information

SLR.FserX.T occurs in sheltered to extremely sheltered habitats. Connor *et al.* (1997b) consider this biotope to be uncommon in Britain.

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	Species name	Common Name
Important characterizing	*Fucus serratus*	Toothed wrack
Important characterizing	*Halichondria panicea*	Breadcrumb sponge
Important characterizing	*Ascidiella aspersa*	A sea squirt
Important characterizing	*Chondrus crispus*	Carrageen
Important other	*Lanice conchilega*	Sand mason
Important other	*Crepidula fornicata*	Slipper limpet
Important other	*Littorina littorea*	Common periwinkle

Important other	*Mytilus edulis*	Common mussel

Explanation

The toothed wrack *Fucus serratus* gives the biotope its name and is therefore important for characterizing this biotope. This biotope is associated with a diverse fauna, dominated by a wide range of suspension feeders. The breadcrumb sponge *Halichondria panicea* (that occurred in every record of this biotope) and sea squirt *Ascidiella aspersa* have been listed as important characterizing species as they are representative of the sponges and ascidians that give the biotope its name. Carrageen *Chondrus crispus* is listed to represent a variety of red seaweeds that may be found in this biotope, although this species was the red seaweed found most frequently in records of this biotope. The common mussel *Mytilus edulis*, slipper limpet *Crepidula fornicata* and sand mason worm *Lanice conchilega* have been included as other important species because they are frequently associated with this biotope and they represent suspension feeders from another two phyla. *Littorina littorea*, a herbivore, was found in almost all of the records of this biotope and, accordingly, has also been listed as another important species.

Species found especially in biotope

No text entered

Additional information

The MNCR recorded 423 species in 22 records of this biotope although not all of the species occurred in all records of the biotope (JNCC, 1999).

Biotope sensitivity

Physical Factors	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	High	Moderate	Major Decline	Moderate
Smothering	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Increase in suspended sediment	Low	Very high	Very Low	Minor Decline	Low
Decrease in suspended sediment	Intermediate	High	Low	Decline	Low
Desiccation	High	High	Moderate	Decline	Moderate
Increase in emergence regime	Intermediate	High	Low	Decline	Low
Decrease in emergence regime	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Increase in water flow rate	High	High	Moderate	Major Decline	Moderate
Decrease in water flow rate	Intermediate	High	Low	Decline	Moderate
Increase in temperature	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Decrease in temperature	Low	Very high	Very Low	Minor Decline	Low
Increase in turbidity	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Decrease in turbidity	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Increase in wave exposure	High	High	Moderate	Major Decline	Low
Decrease in wave exposure	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Noise	Tolerant*	Not Relevant	Not sensitive*	No Change	Not Relevant
Visual Presence	Tolerant*	Not Relevant	Not sensitive*	No Change	Not Relevant

Abrasion & physical disturbance	Intermediate	High	Low	Decline	Moderate
Displacement	High	High	Moderate	Major Decline	Low
Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	Intermediate	High	Low	Decline	Moderate
Heavy metal contamination	Intermediate	High	Low	Decline	Moderate
Hydrocarbon contamination	Low	Very high	Very Low	Minor Decline	Very low
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Changes in nutrient levels	Low	Very high	Very Low	No Change	Low
Increase in salinity	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Decrease in salinity	Low	Very high	Very Low	Minor Decline	Low
Changes in oxygenation	Low	Very high	Very Low	Minor Decline	Low
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Introduction of non-native species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Extraction of key or important characterizing species	High	High	Moderate	Decline	Moderate
Extraction of important species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	Loss of the substratum will result in the loss of the entire biotope and therefore intolerance has been assessed as high. Some species may survive as epiphytes on the *Fucus serratus*, *Chondrus crispus* and other algae but these plants will soon be washed away in the moderately strong currents. Recoverability is likely to be high (see additional information).
Smothering (see benchmark)	Smothering by a 5 cm layer of sediment is unlikely to adversely affect this biotope given that it is associated with areas of moderately strong water flow. The sediment layer will be washed away and 'normal' conditions will resume rapidly. The suspension feeders may experience some short lived interference with feeding but, at the level of the benchmark, this is not likely to adversely affect their viability. Therefore, the biotope has been assessed as being tolerant to smothering.
Increase in suspended sediment (see benchmark)	An increase in suspended sediment, in combination with the moderately strong flow with which this biotope is associated, may be of detriment to the important characterizing species. Sand scour may damage the fronds of the *Fucus serratus*, *Chondrus crispus* and other algae in the biotope and reduce available light for photosynthesis (see turbidity). The feeding apparatus of suspension feeders may become bombarded with particles and interfere with their feeding and respiratory

	currents. Over the course of the benchmark this may lead to a reduction in total ingestion and a reduced scope for growth, especially since cleaning the feeding apparatus is likely to be energetically expensive. In contrast, an increase in suspended sediment may increase the amount of available food for the suspension feeders, especially if the organic fraction of the particulate material increased. On balance, the biotope has been assessed to be of low intolerance to an increase in suspended sediment and recoverability is expected to be very high.
Decrease in suspended sediment (see benchmark)	A decrease in suspended sediment could be of detriment to the suspension feeding community as available food is likely to be reduced. Over the course of one month, a reduction in total ingestion is likely to result in a reduced scope for growth and reproductive success. For short lived species such as the bryozoans and sea squirts, this may prove to be fatal. A decline in faunal species diversity is expected and accordingly, intolerance has been assessed as intermediate. Recovery is likely to be high due to the fact that most of the intolerant species produce planktonic larvae and are therefore likely to be able to recolonize quickly from surrounding areas.
Desiccation (see benchmark)	Due to the fact that SLR.FserX.T is an intertidal biotope, the benchmark level for desiccation is equivalent to a change in position of one biological vertical zone on the shore for one year. In this case, that would mean a transition from the lower eulittoral to the mid eulittoral. The toothed wrack *Fucus serratus* and carrageen *Chondrus crispus* are both intertidal species that will be adapted to a degree of periodic desiccation. However, seaweeds have a critical water content and for *Fucus serratus*, it is 40%. Two hours of sunshine can result in this critical water content being exceeded and therefore this species will probably be of intermediate intolerance to desiccation at the benchmark level. Mathieson & Burns (1971) measured the photosynthetic rate of *Chondrus crispus* at varying degrees of desiccation and found that after loss of 65% of its water content, the rate of photosynthesis was only 55% of the control rate (see *MarLIN Web site*). In *Palmaria palmata*, 50% of the plant's water content can be lost in less than 4 hours in dry air at 25 °C (Kain & Norton, 1990). This scenario can reasonably be expected at low tide in summer in Britain. The tissue of the breadcrumb sponge *Halichondria panicea* holds some water and is tolerant of a certain degree of desiccation. However, at the benchmark level, bleaching and tissue death are likely to occur. The sea squirt *Ascidiella aspersa* has a soft body and is therefore vulnerable to desiccation. It is afforded some protection to desiccation by its location under seaweed and in damp crevices. However, some individuals at the highest point on the shore may dry out and die at the benchmark level. Other important species associated with this biotope have mechanisms for reducing the effects of desiccation, for example, the common periwinkle *Littorina littorea* (see *MarLIN* Web site). Two other molluscs frequently associated with this biotope, namely the common mussel *Mytilus edulis* and slipper limpet *Crepidula fornicata*, are considered to be of low intolerance to desiccation and *Mytilus edulis* can be found in the upper eulittoral. Although muddy sediments associated with this biotope will hold some water and protect the infauna and epibenthic fauna to some extent, it is likely that overall, all of the important characterizing species will experience some decline in abundance and consequently, the recognizable biotope may be lost. An intolerance of high has therefore been recorded. Recovery is likely to be high (see additional information).
Increase in emergence regime (see benchmark)	SLR.FserX.T is found in the intertidal and the associated species are likely to be adapted to cyclical immersion and emersion. However, at the level in the benchmark, an increase in emergence is likely to adversely affect the dominant trophic group (suspension feeders) within this biotope. It will greatly reduce feeding opportunities for the suspension feeders, for whom immersion is a prerequisite to

	feeding. Over the course of a year, this decrease is likely to prove fatal for short lived species such as the bryozoans and ascidians. The longer lived species including *Halichondria panicea* and *Crepidula fornicata*, although unlikely to die, will probably experience reduced growth and reproductive potential and abundance of these species may decline. The upper shore extent of the *Fucus serratus* and *Chondrus crispus* populations may be replaced by species more tolerant of desiccation and more characteristic of the mid-eulittoral such as *Fucus vesiculosus*, *Ascophyllum nodosum* or *Mastocarpus stellatus*. In terms of infauna, the sand mason *Lanice conchilega* and peacock work *Sabella pavonina* will be protected from desiccation to some extent by their burrows. However, they may also experience greater predation from shore birds. Although the biotope is unlikely to disappear completely, its extent on the shore is likely to be reduced and accordingly, intolerance has been assessed as intermediate. Recoverability is likely to be high (see additional information).
Decrease in emergence regime (see benchmark)	A decrease in emergence is likely to benefit this biotope. Feeding opportunity for suspension feeders will increase, desiccation and temperature stresses for all flora and fauna will be reduced as will predation from birds. The recognizable biotope may extend further up the shore (if suitable substrata are present) but this extension is likely to be counteracted by a reduction in the lower shore extent of the biotope that is likely to be taken over by seaweeds more characteristic of the sublittoral fringe. Encrusting red algae, for example, may become more dominant on the larger boulders than the green and brown algal species. Furthermore, predation by the common shore crab *Carcinus maenas* is likely to increase. Overall, it is possible that the biotope will just shift further up the shore and not necessarily increase or decrease in its extent on the shore. Therefore this biotope has been assessed to be tolerant of a decrease in emergence.
Increase in water flow rate (see benchmark)	An increase in water flow rate from moderately strong to very strong is likely to adversely affect this biotope. The mixed nature of the substratum means that suspended sediment of various sizes will be re-suspended and cobbles and pebbles are likely to move across the seabed. Fine sediments are likely to be lost. Re-suspended sediment is likely to interfere with the suspension feeders feeding apparatus and respiratory currents to their detriment (see suspended sediment above). In wave sheltered areas such as this biotope, the breadcrumb sponge *Halichondria panicea* grows in massive forms. Poorly attached massive forms may be ripped off by an increase in water flow rate leading to the death of large colonies. The sand may scour the fronds of *Fucus serratus*, *Chondrus crispus* and other algae and sand tolerant algae may prevail. Additionally, an increase to 'very strong' flows may inhibit settlement of spores. The movement of pebbles, cobbles and boulders across the sea floor may scour epilithic sponges, bryozoans and hydroids off the rocks and clumps of algae may become dislodged. Overall, it is likely that many of the associated species will be adversely affected and therefore this biotope is considered to be highly intolerant to an increase in water flow rate at the benchmark level although recovery is expected to be high.
Decrease in water flow rate (see benchmark)	The rich community of suspension feeders in this biotope is, in part, due to the moderately strong tidal streams with which it is associated. It provides the suspension feeders with a continual supply of food and removes sediment that would otherwise interfere with their feeding apparatus. A decrease in water flow rate at the level in the benchmark could result in a negligible water flow rate. This would lead to siltation, to the detriment of the filter feeders. In addition, the clumps of *Crepidula fornicata* and *Mytilus edulis* have the capacity to produce and accumulate biodeposits including pseudofaeces. Such deposits would accumulate causing the substratum to become highly silted. Annual species, including the star ascidian *Botryllus schlosseri* are likely to

	experience some mortality. The hydroid *Dynamena pumila* experienced marked decline in areas with increased silt content in Strangford Lough, Northern Ireland (Seed *et al*., 1983). The toothed wrack *Fucus serratus* and red seaweeds including *Ceramium* sp. and *Chondrus crispus*, although tolerant of low flow rates, are likely to suffer from the reduced light caused by siltation. Rates of photosynthesis are likely to decrease and, over the course of one year, the plants may experience some negative growth. Furthermore, grazers unable to cope with the moderately strong flow rates normally associated with this biotope may be able to graze more efficiently, resulting in the loss of a greater number of plants. Some filter feeders have the ability to cope with siltation and excess suspended material. For example, the breadcrumb sponge *Halichondria panicea* has a mechanism for sloughing off their complete outer tissue layer together with any debris (Barthel & Wolfrath, 1989). *Mytilus edulis* possesses efficient shell cleaning and pseudofaeces expulsion mechanisms to remove silt (Moore, 1977), although it should be noted that pseudofaeces production involves an energetic burden (Navarro & Widdows, 1997). However, over the course of one year, the majority of the sponges and ascidians are likely to be lost and accordingly SLR.FserX.T has been assessed as being of high intolerance to a decrease in water flow rates although recovery is expected to be high.
Increase in temperature (see benchmark)	The distribution of *Halichondria panicea*, *Fucus serratus* and *Chondrus crispus* in Britain is towards the centre of their distribution in the north east Atlantic and the two species are therefore likely to be tolerant of an increase in temperature at the benchmark level (see *MarLIN* Web site). The sea squirt *Ascidiella scabra* (of the same genus as the important characterizing species *Ascidiella aspersa*) has also been assessed as being tolerant of an increase in temperature. Other important species associated with this biotope including *Mytilus edulis*, *Littorina littorea* and *Lanice conchilega* are thought be of low tolerance to an increase in temperature. However, due to the fact that these are not actually characteristic of the biotope but more a representative of various different phyla, the biotope as a whole has been assessed as tolerant.
Decrease in temperature (see benchmark)	The distribution of *Halichondria panicea*, *Fucus serratus* and *Chondrus crispus* in Britain is towards the centre of their distribution in the north east Atlantic and the two species are therefore likely to be tolerant of a decrease in temperature at the benchmark level (see *MarLIN* Web site). The sea squirt *Ascidiella scabra* (of the same genus as the important characterizing species *Ascidiella aspersa*) has also been assessed as being tolerant of a decrease in temperature. However, the sand mason *Lanice conchilega* was assessed as being highly intolerant of low temperatures and other important species associated with this biotope including *Mytilus edulis* and *Littorina littorea* are thought to have a low tolerance (see *MarLIN* Web site). Due to the fact that these are not actually characteristic of the biotope but more a representative of various different phyla, the biotope as a whole has been assessed as being of low intolerance. Recovery is expected to be very high.
Increase in turbidity (see benchmark)	An increase in turbidity is unlikely to affect the suspension feeders within this biotope. Indeed, if the turbidity were associated with an increase in organic particulate concentration, they may benefit actually from it. The height of colonies of the hydroid *Dynamena pumila* fell to almost half their original height less than 6 weeks after the *Fucus serratus* plants on which they were attached were transferred from a relatively clean, fast flowing site to a turbid site in Strangford Lough (Seed & Boaden, 1977, cited in Seed *et al.*, 1981). However, this may be related to the associated decrease in flow rate and in any case, this hydroid is not a characterizing species and occurred in less than half the records of this biotope. The algal component of the biotope may suffer due to the associated reduction in light. Over the course of one year, *Fucus serratus* may experience a reduction in total growth. Red algae can tolerate a wider range of light levels than any other group of photosynthetic plants (Kain & Norton, 1990) and an increase in the abundance of

	Ceramium sp. and *Chondrus crispus*, for example, may be observed as they out-compete green and brown seaweed. However, the patches of *Fucus serratus* will still remain and a large change in the recognizable biotope is unlikely. Therefore, tolerant has been assessed.
Decrease in turbidity (see benchmark)	The algal component of this biotope would benefit from a decrease in turbidity and they may experience enhanced photosynthesis. The proportion of ephemeral green algae may increase and accordingly, tolerant* has been suggested.
Increase in wave exposure (see benchmark)	This biotope occurs in sheltered to extremely sheltered habitats. An increase in exposure of two ranks of the wave exposure scale would mean that the biotope could become wave exposed. Due to the shallow water depth in which this biotope is found (lower eulittoral), a wave exposed habitat could be catastrophic for the biotope. The silt / mud and finer sediments and gravels would be continually re-suspended and the habitat for the sand mason *Lanice conchilega* and peacock worm *Sabella pavonina* would probably be lost. The increase in suspended sediment would most likely interfere with the feeding apparatus of the suspension feeders (see suspended sediment above) thus reducing total ingestion over the year or incurring energetic costs in cleaning. Short lived species such as the star ascidian *Botryllus schlosseri* would probably die. Aside from the suspended sediment, the cobbles and pebbles would probably move around too. This could serve to dislodge plants from the cobbles and boulders, break the tubes of the peacock worms and scour colonies of sponges, hydroids and ascidians from the rocks and plants. In addition, some algal species are known to change morphologically according to the degree of exposure. Gutierrez & Fernandez (1992) described morphological variability of *Chondrus crispus* according to wave exposure and emersion (see *MarLIN* Web site). Over the course of the year the recognizable biotope is likely to be lost and replaced with opportunistic species and those species better adapted to high energy environments. Intolerance has been assessed as high with a high recovery.
Decrease in wave exposure (see benchmark)	This biotope occurs in sheltered to extremely sheltered habitats and therefore a decrease in wave exposure is not relevant.
Noise (see benchmark)	The important characterizing species are unlikely to have mechanisms for detecting noise. Furthermore, the biotope may indirectly benefit from noise disturbance because the birds and crabs that represent the main predators on the associated fauna may be scared off by the noise.
Visual Presence (see benchmark)	The important characterizing species are unlikely to have mechanisms for detecting visual presence. Furthermore, the biotope may indirectly benefit from visual disturbance because the birds and crabs that represent the main predators on the associated fauna may be scared off by the presence of, for example, humans on the shore.
Abrasion & physical disturbance (see benchmark)	At the benchmark level of abrasion, a scallop dredge but more likely lower shore sediment scour or ship grounding, many of the associated species would be adversely affected. The fronds of the toothed wrack *Fucus serratus* and carrageen *Chondrus crispus* and parts of these plants, in addition to those of other algal species, are likely to be torn off thus decreasing their photosynthetic capabilities. The holdfasts of *Chondrus crispus* are likely to escape unscathed and, due to the fact that the species is capable of regenerating from its holdfasts (e.g. Dudgeon & Johnson, 1992), no mortality is expected for this species. Patches of hydroids and bryozoans, and encrusting fauna such as colonial ascidians and sponges, are likely to be scraped off the rock although a proportion of the colonies are likely to remain. The shells of mussels, limpets and periwinkles may be crushed by the weight and force of the abrasion, as will the tubes of the peacock worm. Intolerance to trampling, given the soft nature of much of the substratum, is likely to be lower than to the effects of a passing scallop dredge although on balance, intolerance has been assessed as intermediate due to the fact that after a single event, a proportion of all

	of the species is likely to remain. This in turn will favour recoverability and accordingly, recoverability has been assessed as high.
Displacement (see benchmark)	All of the important characterizing species and the majority of 'important other' species in this biotope are sessile and permanently attached to the hard substrata. Displacement would ultimately result in the death of some species including *Fucus serratus*, *Chondrus crispus*, *Halichondria panicea*, *Ascidiella scabra*, *Botryllus schlosseri* and *Crepidula fornicata*. Due to the fact that *Crepidula fornicata* lives in chains of up to 12 individuals, only the individual attached to the substratum would be likely to die, due to increased risk of predation, and Johnson (1972) demonstrated that transplanted individuals continue to grow normally. Young (1985) reported that detached *Mytilus edulis* produced 8 byssal threads within 24 hours once detached. Although these two species are probably of intermediate intolerance to displacement, the three important characterizing species are highly intolerant and therefore, an intolerance of high has been recorded.
Chemical Factors	
Synthetic compound contamination (see benchmark)	The species frequently associated with this biotope are known to have varying degrees of tolerance to synthetic chemicals. In general, however, most of the species show at least some intolerance to synthetic chemical contamination. • Scanlan & Wilkinson (1987) found that the spermatozoa and newly fertilized eggs of *Fucus serratus* were the most intolerant of biocides, while adult plants were only just significantly affected at 5 ml/l of the biocides Dodigen v181-1, Dodigen v 2861-1 and ML-910. • O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination, possibly due to the susceptibility of phycoerythrins to destruction. Laboratory studies of the effects of oil and dispersants on several red algal species concluded that they were all sensitive to oil/dispersant mixtures, with little difference between adults, sporelings, diploid or haploid life stages (Grandy, 1984, cited in Holt *et al.*, 1995) (see *MarLIN* Web site). • Ascidians may be intolerant of synthetic chemicals such as tri-butyl-tin (TBT) anti-foulants. Rees *et al.* (2001), working in the Crouch estuary, observed that six ascidian species were recorded at one station in 1997 compared with only two at the same station in 1987, shortly following the banning of TBT in antifouling paints. Also, there was a marked increase in the abundance of ascidians especially *Ascidiella aspersa* and *Ascidia conchilega* in the estuary after the ban. • Insufficient information was available on the specific effects of synthetic chemicals on the breadcrumb sponge. • The effects of contaminants, including synthetic chemicals, on the common mussel *Mytilus edulis* has been the focus of a large amount of research (see *MarLIN* Web site) and overall, this species has been assessed as being of intermediate intolerance to synthetic chemicals. • Oehlmann *et al.* (1998) reported that the gastropod *Littorina littorea* was found to be able to tolerate high levels of TBT. On balance, it is likely that many of the species characteristic of this biotope will experience some mortality and accordingly, intolerance has been assessed as intermediate. Due to the mixed nature of the substratum and moderately strong water flow, recoverability is expected to be high, although recovery from the effects of highly persistent chemicals may take significantly longer.
Heavy metal contamination (see benchmark)	• Fucoid algae readily accumulate heavy metals within their tissues. The effect of heavy metals on the growth rate of adult *Fucus serratus* plants has been studied by Strömgren (1979b; 1980a, b). Copper significantly reduces the growth rate of vegetative apices at 25 µg/l over 10 days (Strömgren, 1979b). Zinc, lead, cadmium & mercury significantly reduce growth rate at

	1400 µg/l, 810 µg/l, 450 µg/l and 5 µg/l respectively (Strömgren, 1980a, b). • No information was found concerning the specific effects of heavy metals on the other three characterizing species, *Chondrus crispus*, *Halichondria panicea* and *Ascidiella aspersa*. • The effects of contaminants, including heavy metals, on the common mussel *Mytilus edulis* has been the focus of a large amount of research (see *MarLIN* Web site) and overall, this species has been assessed as being of intermediate intolerance to heavy metals. • Sub-lethal concentrations of mercury were shown to impair growth and condition of young adult *Crepidula fornicata* and impair reproductive capacity at 0.25 µg/l. Nelson *et al.* (1983) investigated the effects of exposure to silver. Reproductive output was found to be impaired following exposure to the highest concentration of silver nitrate (10 µg/l) for 24 months. The evidence suggests that high concentrations of heavy metals will cause mortality in *Crepidula fornicata* and lower concentrations could impair growth, condition and reproductive output and will therefore affect the long term health of the population. On balance, it is likely that many of the species characteristic of this biotope will experience some mortality and accordingly, intolerance has been assessed as intermediate. Due to the mixed nature of the substratum and moderately strong water flow, recoverability is expected to be high, although recovery from the effects of highly persistent contaminants may take significantly longer.
Hydrocarbon contamination (see benchmark)	Soft sediment communities are particularly affected by oil pollution (Suchanek, 1993), although the mixed nature of the substratum within this biotope and the moderately strong water flow with which it is associated mean that the extent of hydrocarbon contamination may be reduced. • Adult *Fucus serratus* plants are tolerant of exposure to spills of crude oil although very young germlings are intolerant of relatively low concentrations of 'water soluble' extractions of crude oils. Exposure of eggs to these extractions (at 1.5 micrograms/ml for 96 hours) interferes with adhesion during settling and (at 0.1 micrograms/ml) prevents further development (Johnston, 1977). • Observations have shown that filamentous red algae are among the most severely affected by the toxic properties of oil (O'Brien & Dixon, 1976). Effects including bleaching and loss of photosynthetic pigments have been observed in red algal species following contamination with fuel oil (O' Brien & Dixon, 1976). The long term effects on *Chondrus crispus* of continuous doses of the water accommodated fraction (WAF) of diesel oil were determined in experimental mesocosms (Bokn *et al.*, 1993). Mean hydrocarbon concentrations tested were 30.1 µg/l and 129.4 µg/l. After 2 years, there were no demonstrable differences in the abundance patterns of *Chondrus crispus*. Furthermore, Kaas (1980) (cited in Holt *et al.*, 1995) reported that the reproduction of adult *Chondrus crispus* plants on the French coast was normal following the *Amoco Cadiz* oil spill. • It appears that *Halichondria panicea* survived in areas affected by the *Torrey Canyon* oil spill (Smith, 1968), although few observations were made. • A 20 year study investigating community effects after the Amoco Cadiz oil spill of 1978 (Dauvin, 2000) found that a population of *Lanice conchilega* was established between 1978-84 but disappeared after 1985. No information was found concerning the effects of hydrocarbon contamination in the other characterizing species. However, given the evidence above, an intolerance of low has been suggested with very high recovery.
Radionuclide contamination	No information was found concerning the effects of radionuclides on neither of the four important characterizing species nor most of the other important species.

(see benchmark)	However, Greenberber *et al.* (1986) exposed larval *Crepidula fornicata* to doses of X-ray radiation between 500 and 20,000 rads in total and found that, after 20 days, there was a dose dependent decrease in larval shell growth rate and a significant increase in larval mortality following doses above 2000 rads. These levels of radiation are extremely high compared to background levels in the environment but lower levels may have sub-lethal effects on growth and reproduction. Overall, insufficient information was available in order to assess sensitivity.
Changes in nutrient levels (see benchmark)	An influx of nutrients into the biotope is likely to stimulate phytoplankton production, depending on other environmental conditions. This means that the amount of food potentially available to the suspension feeders will increase. In the long term, a sustained increase in nutrients could lead to the formation of algal blooms. Algal blooms have the potential to block light from underlying plants, thereby reducing their photosynthetic capacity. In addition, the eventual biodegradation of the blooms / mats involves the consumption of a large amount of oxygen, although the moderately strong water flows with which this biotope is associated are likely to ameliorate this (see oxygenation). It is possible, therefore, that *Fucus serratus* and other plants may experience some reduced growth over time but it is unlikely that any species will experience mortality. *Chondrus crispus* may be out-competed by faster growing or ephemeral species. Johansson *et al.* (1998) investigated the changes in the algal vegetation of the Swedish Skagerrak coast, an area heavily affected by eutrophication, between 1960 and 1997. Slow growing species, including *Chondrus crispus* declined in abundance, probably due to competition from faster growing red algal species such as *Phycodrys rubens* and *Delesseria sanguinea*. However, as long as some red seaweeds remained, the recognizable biotope would be unaffected *per se*. Accordingly, an intolerance of low has been assessed with a very high recoverability.
Increase in salinity (see benchmark)	SLR.FserX.T is an intertidal biotope that will most likely experience cyclical periods of hypo- and hyper-salinity. It is found in areas of variable to full salinity and therefore an increase in salinity is not relevant. Short periods of hyper-salinity may occur where patches of surface water on the muddy sediment evaporate although this is unlikely to continue for periods of time similar to those benchmark and only small areas of substratum will be affected anyway.
Decrease in salinity (see benchmark)	SLR.FserX.T is an intertidal biotope that will most likely experience cyclical periods of hypo- and hyper-salinity. *Fucus serratus* is able to compensate for these changes in salinity by adjusting internal ion concentrations. Salinity affects the photosynthetic rate and hence growth rate of seaweed. For *Fucus serratus*, growth rate is maximal at a salinity of 20 psu and therefore, a decrease in salinity into the 'low' salinity category would be of preference to the plant. Other important characterizing species associated with this biotope are also likely to be tolerant of a reduction in salinity. The breadcrumb sponge *Halichondria panicea* and carrageen *Chondrus crispus* are found in of low salinity, *Ascidiella scabra* (in the same genus as *Ascidiella aspersa*) is found in reduced salinity conditions, the star ascidian *Botryllus schlosseri* is found in brackish water and *Crepidula fornicata* is described as euryhaline (Blanchard, 1997). However, a rapid fall in salinity of two categories on the MNCR scale from variable to low salinity could result in more adverse effects on the whole community and therefore intolerance has been assessed as low but with a very high recovery.
Changes in oxygenation (see benchmark)	No specific information was found concerning the effects of reduced oxygenation on the important characterizing species although Cole *et al.* (1999) suggested possible adverse effects on marine species below 4 mg/l and probably adverse effects below 2 mg/l. Some of the associated fauna may be tolerant of low oxygen environments. *Littorina littorea*, for example, can endure long periods of oxygen deprivation by drastically reducing their metabolic rate (MacDonald & Storey, 1999). However,

	this reduces feeding rate and thus the viability of a population may be reduced. In general, it is likely that, at the benchmark level, some of important characterizing fauna may be of low intolerance to reduced oxygenation although recoverability is expected to be very high on return to 'normal' conditions.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	Some of the important species, for example *Mytilus edulis* and *Chondrus crispus* are known to be adversely affected by infestation by microbial pathogens (See *MarLIN Web site*). However, even if microbial infestation resulted in the loss of these two species from the biotope, the recognizable biotope *per se* would no be affected. The actual occurrence of and effects of pathogens on most of the species associated with this biotope are not known and therefore, insufficient information was available to assess sensitivity.
Introduction of non-native species (see benchmark)	*Crepidula fornicata* is an introduced species that has spread widely since its introduction to the United Kingdom at the end of the 19th century. It has the ability to recover rapidly from environmental perturbation and colonize new areas. *Crepidula fornicata* can form large mats in some areas and the boulders and cobbles within SLR.FserX.T could potentially become infested with them, although it is not known under what circumstances this species would change from being an important component of the biotope to a dominant species. The Portuguese oyster *Crassostrea gigas* is another introduced species that has established itself in the wild after being introduced in England in 1926 for cultivation purposes. The species can form dense beds e.g. in the Netherlands, and, together with *Crepidula fornicata*, have the potential to cover large patches on the shore. Although *Crassostrea gigas* was not recorded in this biotope (JNCC, 1999), in areas where SLR.FserX.T presently coincides with the distribution of *Crassostrea gigas*, i.e. the south coast of Devon and coast of Essex, the oyster could become dominant. On balance, it is suggested that SLR.FserX.T is of intermediate intolerance to the introduction of alien species since both *Crassostrea gigas* and *Crepidula fornicata* have the potential to alter the recognizable biotope. If these two species came to dominate the biotope, recoverability would only be possible if the majority of the two species were removed (through either natural or unnatural process) to allow the re-establishment of other species. Therefore, recoverability has not been assessed.
Extraction of key or important characterizing species (see benchmark)	*Fucus serratus* and *Chondrus crispus* are the only important characterizing species known to be targeted for extraction (see 'Importance'). The extraction of *Fucus serratus* would lead to the loss of the recognizable biotope, as the plant gives the biotope its name. In addition to the loss of either of the two species, many epiphytic species would be lost including proportions of bryozoan species such as *Dynamena pumila* (found especially on fucoid species), the star ascidian *Botryllus schlosseri*, and the breadcrumb sponge *Halichondria panicea*. Furthermore, the larvae of *Dynamena pumila* are thought to settle and metamorphose in response to the microbial films on the surface of this algae and subsequent recruitment of this hydroid will also be affected. Intolerance has therefore been assessed as high. *Fucus serratus* is highly fecund and the eggs are broadcast into the water column allowing a potentially large dispersal distance. Recovery has been assessed as high as it will probably have occurred after one year (see additional information).
Extraction of important species (see benchmark)	There are no important structural or functional species associated with this biotope.

Additional information

Recoverability in the four important characterizing species, and indeed most of the other important species, is considered to be high and therefore, the recoverability of this biotope from factors to which it is considered highly tolerant is also likely to be high.

Fucus serratus is highly fecund and the eggs are broadcast into the water column allowing a potentially large dispersal distance. The species is found on all British and Irish coasts so there are few mechanisms isolating populations. Recruitment may occur through reproduction of the remaining population of from other populations and, providing that some of the population remains, it is unlikely that other species will come to dominate. Recovery will probably have occurred after one year.

Chondrus crispus has an extended reproductive period (e.g. Pybus, 1977; Fernandez & Menendez, 1991; Scrosati *et al.*, 1994) and produces large numbers of spores (Fernandez & Menendez, 1991). Recovery of a population of *Chondrus crispus* following a perturbation is likely to be largely dependent on whether holdfasts remain, from which new thalli can regenerate (Holt *et al.*, 1995). In addition, the spores of red algae are non-motile (Norton, 1992) and therefore entirely reliant on the hydrographic regime for dispersal. Hence, it is expected that *Chondrus crispus* would normally only recruit from local populations and that recovery of remote populations would be much more protracted.

Minchinton *et al.* (1997) documented the recovery of *Chondrus crispus* after a rocky shore in Nova Scotia, Canada, was totally denuded by an ice scouring event. Initial recolonization was dominated by diatoms and ephemeral macroalgae, followed by fucoids and then perennial red seaweeds. After 2 years, *Chondrus crispus* had re-established approximately 50% cover on the lower shore and after 5 years it was the dominant macroalga at this height, with approximately 100% cover. The authors pointed out that although *Chondrus crispus* was a poor colonizer, it was the best competitor. Therefore, recovery by *Chondrus crispus* will be relatively rapid (approximately 18 months) in situations where intolerance to a factor is intermediate and some holdfasts remain for regeneration of fronds. In situations of high intolerance, where the entire population of *Chondrus crispus* is removed, recovery will be limited by recruitment from a remote population and would be likely to take up to 5 years.

The settlement of new colonies of the breadcrumb sponge *Halichondria panicea* is likely within one year and growth rate is rapid. The larvae of the sea squirt *Ascidiella aspersa* have a short free-swimming planktonic stage. Time taken from fertilization until settlement and metamorphosis is only about 24 hours at 20 °C (Niermann-Kerkenberg & Hofmann, 1989). However, due to the moderately strong flow rates with which this biotope is associated, there is still the possibility for this species to disperse over considerable distances. The sea squirt *Ascidiella scabra* (of the same genus as *Ascidiella aspersa*) has a high fecundity and settles readily, probably for an extended period from spring to autumn. Svane (1988) describes it as "an annual ascidian" and demonstrated recruitment onto artificial and scraped natural substrata. It is also likely that *Ascidiella scabra* larvae are attracted by existing populations and settle near to adults (Svane *et al.*, 1987). Fast growth means that a dense cover could be established within about 2 months. However, if mortality and the consequent establishment of free space available occurs at a time when larvae are not being produced, other species may settle and dominate.

For the majority of other important species within this biotope, reproduction and recruitment is an annual process (see recruitment processes). In addition, many of the species have planktonic larvae thereby facilitating recruitment from local sources.

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors							
	Fucus serratus	***Halichondria panicea***	***Chondrus crispus***	***Lanice conchilega***	***Crepidula fornicata***	***Littorina littorea***	***Mytilus edulis***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important other	Important other	Important other	Important other
Substratum Loss	High	High	High	High	High	High	High
Smothering	High	High	Intermediate	Low	Low	High	Intermediate
Increase in suspended sediment	Low	Low	Intermediate	Not Sensitive	Low	Intermediate	Low
Decrease in suspended sediment	See explanation	Not Sensitive	Not Sensitive	Low	Low	See explanation	Low
Desiccation	Intermediate	Intermediate	Intermediate	Intermediate	Low	Low	Low
Increase in emergence regime	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Low	Low
Decrease in emergence regime	See explanation	Not Sensitive	Not Sensitive	Not Sensitive*	Not Sensitive	See explanation	Low
Increase in water flow rate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Low
Decrease in water flow rate	See explanation	Low	Intermediate	Intermediate	Not Sensitive	See explanation	Low
Increase in temperature	Not Sensitive	Low	Low	Low	Low	Low	Low
Decrease in temperature	See explanation	Low	Low	High	Intermediate	See explanation	Low
Increase in turbidity	Low	Not Sensitive	Low	Not Sensitive	Low	Low	Not Sensitive
Decrease in turbidity	See explanation	Not Sensitive	Not Sensitive*	Not Sensitive	Not Sensitive	See explanation	Not Sensitive
Increase in wave exposure	High	Intermediate	Intermediate	High	High	Intermediate	Intermediate
Decrease in wave exposure	See explanation	Low	Low	Low	Not Sensitive	See explanation	Intermediate
Noise	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive*
Visual Presence	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive*
Abrasion & physical disturbance	Intermediate	Intermediate	Low	Intermediate	Intermediate	Intermediate	Intermediate
Displacement	High	High	High	Intermediate	Intermediate	Not Sensitive	Intermediate

Chemical factors							
	Fucus serratus	***Halichondria panicea***	***Chondrus crispus***	***Lanice conchilega***	***Crepidula fornicata***	***Littorina littorea***	***Mytilus edulis***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important other	Important other	Important other	Important other
Synthetic compound contamination	High	Insufficient information	High	High	High	Low	Intermediate
Heavy metal contamination	Low	Insufficient information	Insufficient information	Intermediate	Intermediate	Intermediate	Intermediate
Hydrocarbon contamination	Intermediate	Low	Low	Intermediate	Intermediate	High	Intermediate
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Intermediate	Insufficient information	Insufficient information
Changes in nutrient levels	Intermediate	Insufficient information	Intermediate	Intermediate	Insufficient information	Not Sensitive	Intermediate
Increase in salinity	Low	Low	Not Sensitive	Not Relevant	Not Sensitive	Not Sensitive	Low
Decrease in salinity	See explanation	Low	Low	Intermediate	Low	See explanation	Low
Changes in oxygenation	Low	Intermediate	Insufficient information	Intermediate	Intermediate	Low	Low
Biological factors							
	Fucus serratus	***Halichondria panicea***	***Chondrus crispus***	***Lanice conchilega***	***Crepidula fornicata***	***Littorina littorea***	***Mytilus edulis***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important other	Important other	Important other	Important other
Introduction of microbial pathogens/ parasites	Insufficient information	Insufficient information	Intermediate	Insufficient information	Low	Insufficient information	Intermediate
Introduction of non-native species	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Not Sensitive	Insufficient information	Insufficient information

Extraction of this species	Intermediate	Not Relevant	Intermediate	Not Relevant	Intermediate	Intermediate	Intermediate
Extraction of other species	Not Sensitive	High	Insufficient information	Intermediate	Not Sensitive*	Not Sensitive	Low

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors							
	Fucus serratus	***Halichondria panicea***	***Chondrus crispus***	***Lanice conchilega***	***Crepidula fornicata***	***Littorina littorea***	***Mytilus edulis***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important other	Important other	Important other	Important other
Substratum Loss	High	High	High	High	High	High	High
Smothering	High	High	High	High	Very high	High	High
Increase in	Very high	Immediate	High	Not Relevant	Very high	High	Immediate

suspended sediment							
Decrease in suspended sediment	See explanation	Not Relevant	Not Relevant	High	Very high	See explanation	Immediate
Desiccation	High	Very high	High	High	Very high	Immediate	Immediate
Increase in emergence regime	High	Very high	High	High	High	Immediate	Very high
Decrease in emergence regime	See explanation	Not Relevant	Not Relevant	Not Relevant	Not Relevant	See explanation	Very high
Increase in water flow rate	High	Very high	High	High	High	High	Very high
Decrease in water flow rate	See explanation	Immediate	High	High	Not Relevant	See explanation	Very high
Increase in temperature	Not Relevant	Very high	Very high	High	Very high	Immediate	Very high
Decrease in temperature	See explanation	Very high	Very high	High	High	See explanation	Very high
Increase in turbidity	Very high	Not Relevant	Very high	Not Relevant	Very high	Very high	Not Relevant
Decrease in turbidity	See explanation	Not Relevant	Not Relevant	Not Relevant	Not Relevant	See explanation	Not Relevant
Increase in wave exposure	High	Very high	High	High	High	High	High
Decrease in wave exposure	See explanation	Very high	Very high	High	Not Relevant	See explanation	High
Noise	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Visual Presence	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Abrasion & physical disturbance	High	High	Very high	Very high	High	High	High
Displacement	High	High	High	Very high	High	Not Relevant	High
Chemical factors							
	Fucus serratus	***Halichondria panicea***	***Chondrus crispus***	***Lanice conchilega***	***Crepidula fornicata***	***Littorina littorea***	***Mytilus edulis***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important other	Important other	Important other	Important other
Synthetic compound contamination	High	Not Relevant	High	High	High	Very high	High
Heavy metal contamination	High	Not Relevant	Insufficient information	High	High	High	High
Hydrocarbon contamination	High	High	Very high	High	High	High	High
Radionuclide contamination	Insufficient information	Not Relevant	Insufficient information	Not Relevant	High	Insufficient information	Not Relevant
Changes in nutrient levels	High	Not Relevant	High	Moderate	Not Relevant	Not Relevant	High
Increase in salinity	Very high	High	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Very high
Decrease in salinity	See explanation	High	Very high	High	Very high	See explanation	Very high
Changes in oxygenation	Very high	High	Insufficient information	High	High	Very high	Very high

Biological factors							
	Fucus serratus	***Halichondria panicea***	***Chondrus crispus***	***Lanice conchilega***	***Crepidula fornicata***	***Littorina littorea***	***Mytilus edulis***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important other	Important other	Important other	Important other
Introduction of microbial pathogens/ parasites	Insufficient information	Not Relevant	High	Insufficient information	Very high	Insufficient information	High
Introduction of non-native species	Insufficient information	Not Relevant	Insufficient information	Insufficient information	Not Relevant	Insufficient information	Not Relevant
Extraction of this species	High	Not Relevant	High	Not Relevant	Moderate	High	High
Extraction of other species	Not Relevant	High	Insufficient information	Moderate	Not Relevant	Not Relevant	Very high

Importance

Marine natural heritage importance

Listed under:	**UK Biodiversity Action Plan**
National importance	Uncommon
Habitat Directive feature (Annex 1)	Reefs Large shallow inlets and bays Estuaries
UK Biodiversity Action Plan habitat	Tidal rapids

Biotope importance

Many of the invertebrate species associated with this biotope will be an important food source for shore birds and waders. *Mytilus edulis*, for example, is an important food source for oystercatchers and herring gulls and the sand mason *Lanice conchilega* is part of the diet of wading birds. The toothed wrack *Fucus serratus* and common mussel *Mytilus edulis* are both harvested commercially but will probably only occur in small patches within this biotope, it is unlikely that they will be targeted for extraction.

Exploitation

Of the important characterizing and 'other' important species associated with this biotope, only three are known to targeted for extraction, namely toothed wrack *Fucus serratus*, carrageen *Chondrus crispus* and the common mussel *Mytilus edulis*. *Fucus serratus* is collected, dried and used as a soil additive. Various fucalean algae are used in the production of alginates and these are used widely in the pharmaceutical and cosmetics industries. *Chondrus crispus* is harvested commercially in Ireland, Spain, France, Portugal and North America for the extraction of carrageenan (Guiry & Blunden, 1991). In Ireland, harvesting has generally remained sustainable through pickers developing an intuitive feel for the annual cycle of local stocks and certain practices which involve pulling only the bushy top half of the frond off leaving the base and holdfast behind (Morrissey *et al.*, 2001). The gelling and thickening properties of carrageenan are used widely in the food, pharmaceutical and cosmetics industries (see *MarLIN* Web site). The common mussel is also collected but there has been a move away from the exploitation of wild stocks to cultivation of this species in Britain (Edwards, 1997).

However, the eulittoral position of this biotope and the fact that the algae and mussels are unlikely to grow in particularly large patches will mean that they are unlikely to be heavily exploited.

Additional information

No text entered

This Biology and Sensitivity Key Information review can be cited as follows:

Marshall, C.E., 2004. *Fucus serratus* with sponges, ascidians and red seaweeds on tide-swept lower eulittoral mixed substrata. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 19/01/2005]. Available from: <http://www.marlin.ac.uk>

Corallina officinalis and coralline crusts in shallow eulittoral rockpools (LR.Cor)

Key information authored by: Georgina Budd

Last updated 13/11/2002

This information is not refereed.

Pool in *Pelvetia* zone *Corallina officinalis* and coralline crusts (LR.Cor). Image width ca 50 cm.
Image: David Connor / Joint Nature Conservation Committee

Recorded and expected LR.Cor distribution for Britain and Ireland

Description of biotope

Shallow rockpools throughout the eulittoral zone may be characterized by a covering of encrusting coralline algae on which *Corallina officinalis* often forms a dense turf. These 'coralline' pools have a striking appearance as they are dominated predominantly by red algae. Filamentous and foliose red algae found in these pools include *Dumontia contorta*, *Mastocarpus stellatus* and *Ceramium rubrum* [now *Ceramium virgatum*]. The green algae *Cladophora rupestris* and *Ulva* spp. can also occur. The pools may hold large numbers of grazing molluscs, particularly *Littorina littorea* (which often occurs in exceptionally high densities in upper shore pools), *Patella vulgata* and *Gibbula cineraria*. Gastropods may graze these pools to such an extent that they are devoid of any foliose red algae, and are reduced to encrusting coralline algae and large numbers of gastropods. Large brown algae are generally absent (compare with LR.FK), although small *Halidrys siliquosa* may be present. Within the pools, pits and crevices are often occupied by the anemone *Actinia equina* and small *Mytilus edulis*. Similar sized pools in the littoral fringe generally lack the encrusting coralline algae and are characterized by green algae (see LR.G). In Ireland, the sea urchin *Paracentrotus lividus* can dominate these shallow coralline pools (see LR.Cor.Par - Coralline crusts and *Paracentrotus lividus* in shallow eulittoral rockpools). In south-west Britain, the brown alga *Bifurcaria bifurcata* (LR.Cor.Bif - *Bifurcaria bifurcata* in shallow eulittoral rockpools) or *Cystoseira* spp. (LR.Cor.Cys - *Cystoseira* spp. in shallow eulittoral rockpools) can be regionally dominant. (Information taken from the Marine Biotope Classification for Britain and Ireland, Version 97.06: Connor *et al.*, 1997a, b).

Welsh variation

Although the Welsh examples of many of the biotopes in this report follow the British and Irish classification description closely, some regional variation may exist. Reference should be made to Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

In the extreme south west of Britain, another coralline algae, *Jania rubens*, which is similar to *Corallina officinalis*, may occur in large amounts, almost certainly within this biotope.

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Biotope complex	LR.Rkp	Rockpools
Biotope	LR.Cor	*Corallina officinalis* and coralline crusts in shallow eulittoral rockpools.

Biotopes represented by this Key Information review:

LR.Cor.Par	Coralline crusts and *Paracentrotus lividus* in shallow eulittoral rockpools
LR.Cor.Bif	*Bifurcaria bifurcata* in shallow eulittoral rockpools
LR.Cor.Cys	*Cystoseira* spp. in shallow eulittoral rockpools

Other biotope classification schemes

European Union Nature Information System (EUNIS) habitat classification code: A1.511/B-LR.Rkp.Cor - *Corallina officinalis* and coralline crusts in shallow eulittoral rockpools (Davies & Moss, 1998).

Ecology

Ecological and functional relationships

The coralline algae are the dominant species in this biotope. To a great extent the rockpool biotope is an upward extension of ELR.Coff, although the rockpool biotope has its own characteristics.

- *Corallina officinalis* and various lithothamnia are successful in the upper half of the eulittoral zone, especially in shallow, well-lit rockpools (Lewis, 1964). In this zone, some limitation on species develops and not all lower littoral species of the open rock surface can colonize upper shore in rockpools. For example, *Fucus serratus* can do so but *Laurencia pinnatifida*, *Lomentaria articulata* and *Rhodymenia* become much less plentiful, almost to the point of exclusion (Lewis, 1964).
- Other filamentous and foliose red algae found in the pools include *Dumontia contorta*, *Mastocarpus stellatus*, *Ceramium nodulosum* and *Chaetomorpha*, *Ectocarpus*, *Polysiphonia* and *Scytosiphon* species. The green seaweeds *Cladophora rupestris*, *Ulva* spp. and *Ulva lactuca* can also occur in high abundance.
- Seaweeds provide primary productivity either directly to grazing fish and invertebrates or indirectly, to detritivores and decomposers, in the form of detritus and drift algae or as dissolved organic material and other exudates.

The faunal communities of coralline turfs are described in detail by Hagerman (1968), Dommasnes (1968, 1969), Hicks (1985), Grahame & Hanna (1989), Crisp & Mwaiseje (1989), Bamber (1988) and Bamber & Irving (1993). (see ELR.Coff for details).

- *Corallina officinalis* provides substratum for spirorbid worms (e.g. *Spirorbis corallinae*), epiphytes, periphyton, microflora (e.g. bacteria, blue green algae, diatoms and juvenile larger algae), and interstices between the fronds provide refuges from predation for a variety of small invertebrates.
- Amphipods (e.g. *Parajassa pelagica* and *Stenothoe monoculoides*), isopods (e.g. *Idotea pelagica* and *Jaera albifrons*) and other mesoherbivores graze the epiphytic flora and senescent macroalgal tissue, which may benefit the macroalgal host, and may facilitate dispersal of the propagules of some macroalgal species (Brawley, 1992; Williams & Seed, 1992). Mesoherbivores may also graze the macroalgae but do not normally adversely affect the canopy (Brawley, 1992). Grazing is likely to be advantageous to encrusting corallines owing to the removal of epiphytes.
- Foliose seaweeds are grazed by large numbers of molluscs, especially the winkle, *Littorina littorea*, the limpet, *Patella vulgata* and top shell, *Gibbula cineraria*. Littorinids show definite preferences for particular algal foods. *Littorina littorea* tends to prefer the green algae such as *Ulva* to perennial red algae (Little & Kitching, 1996). Thin filamentous or membranous seaweeds, such as *Ulva*, *Ceramium* and *Polysiphonia*, are likely to more edible than tougher leathery forms. Some red seaweeds such as *Corallina officinalis* and coralline crusts (*Lithothamnion*, *Lithophyllum*) protect their thalli with a coating of calcium carbonate and are probably relatively grazing resistant (Littler & Kauker, 1984). Ephemeral algal species may be able to escape herbivory in time and space, owing to the fact that they are less predictable for herbivores, occurring at different times and in

different places, usually as a result of disturbance (Raffaelli & Hawkins, 1999). The chiton, *Lepidochitona cinerea* probably grazes the corallines directly.
- Grazers of periphyton (bacteria, blue-green algae and diatoms) or epiphytic algae include harpacticoid copepods, small gastropods (e.g. *Rissoa* spp. and *Littorina neglecta*.
- Within the pools, pits and crevices are likely to be occupied by the beadlet anemone, *Actinia equina* and small mussels, *Mytilus edulis*. The food of anemones consists of a wide variety of crustaceans, molluscs, worms, other invertebrates and even fishes, caught using nematocysts borne on its tentacles.
- The barnacle *Semibalanus balanoides* may be found over the rock surface. It and small mussels, are preyed upon by the whelk, *Nucella lapillus*.

Seasonal and longer term change

As communities in rockpools remain constantly submerged and the danger of desiccation is absent, it might be expected that rockpools form an easier environment in which to live for marine life than drying rock surfaces, and that species from regions lower on the shore would be able to extend much further up the shore. However, much of the lower shore open rock fauna is absent from rockpools. Rockpools constitute a distinct environment for which physiological adaptations by the flora and fauna may be required (Lewis, 1964). Conditions within rockpools are the consequence of prolonged separation from the main body of the sea, and physico-chemical parameters within them fluctuate dramatically (Huggett & Griffiths, 1986). In general, larger and deep rockpools low on the shore tend to correspond to the sublittoral habitat with a more stable temperature and salinity regime. In contrast, small and shallow pools higher on the shore are especially influenced by insolation, air temperature and rainfall, the effects of which become more significant towards the high shore, where pools may be isolated from the sea for a number of days or weeks (Lewis, 1964).

- Weather conditions exert a considerable influence on temperature and salinity. Water temperature in pools follows the temperature of the air more closely than that of the sea. In summer, shallow pools or the surface waters of deeper pools are warmer by day, but may be colder at night, and in winter may be much colder than the sea (Pyefinch, 1943). In deeper pools, the vertical temperature gradation usually present in summer reverses during winter owing to density stratification, so that ice may form (Naylor & Slinn, 1958).
- High air temperatures cause surface evaporation of water from pools, so that salinity steadily increases, especially in pools not flooded by the tide for several days. Alternatively, high rainfall will reduce pool salinity or create a surface layer of brackish/nearly fresh water for a period. The extent of temperature and salinity change is affected by the frequency and time of day at which tidal inundation occurs. If high tide occurs in early morning and evening the diurnal temperature follows that of the air, whilst high water at midday suddenly returns the temperature to that of the sea (Pyefinch, 1943). Heavy rainfall, followed by tidal inundation can cause dramatic fluctuations in salinity, and values ranging from 5-30 psu have been recorded in rockpools over a period of 24 hrs (Ranade, 1957). Rockpools in the supralittoral, littoral fringe and upper eulittoral are liable to gradually changing salinities followed by days of fully marine or fluctuating salinity at times of spring tide (Lewis, 1964).
- Other physico-chemical parameters in rockpools demonstrate temporal change. The biological community directly affects oxygen concentration, carbon dioxide concentration and pH, and are themselves affected by changes in the chemical parameters. Throughout the day, algae photosynthesize and produce oxygen, the concentration of which may rise to three times its saturation value, so that bubbles are released. During photosynthesis algae absorb carbon dioxide and as concentrations fall, the pH rises. Morris & Taylor (1983) recorded pH values >9 in rockpools on the Isle of Cumbrae. At night changes occur in the opposite direction a respiration utilizes much of the available oxygen and pH decreases.

Corallina officinalis may be overgrown by epiphytes, especially during summer. This overgrowth regularly leads to high mortality of fronds due to light reduction (Wiedemann, pers. comm.). The ephemeral green seaweeds *Ulva intestinalis* and *Ulva lactuca* are likely to be more abundant in summer. In summer, corallines may be bleached and loose their pink pigment but in some species, e.g. *Phymatolithon*, this does not necessarily result in death of the plant and pigment may be re-synthesized (Little & Kitching, 1996).

Habitat structure and complexity

Bedrock forms the substratum of the biotope. Rockpools vary greatly in their physical features. Pools may be shallow and well-lit or deep and shaded with overhanging sides and vertical surfaces. Algae growing within provide additional surfaces for colonization and there is also a tendency for loose substrata (sand, stones, rocks) to accumulate in pools, the instability of which may affect species diversity. Within rockpools, crevices and pits may be found and exploited by species such the mussel *Mytilus edulis* and the beadlet anemone, *Actinia equina*, while the underside of stones and boulders support underboulder communities (see MLR.Fser.Fser.Bo for example).

Dominant trophic groups	Photoautotrophs Herbivores (grazers)

Productivity

Little information concerning the productivity of coralline turf communities was found. The red algae, algal epiphytes and periphyton provide primary productivity to grazers, while their spores and phytoplankton provide primary productivity to suspension feeders. For instance, spore production by the encrusting 'coralline' algae *Lithophyllum incrustans* may be up to 18 million m²/yr (Edyvean & Ford, 1986).

Secondary productivity of the invertebrate fauna may be high and coralline turf may support high abundances of invertebrates. For example, Choat & Kingett (1982) recorded the following numbers of epiphytic fauna: amphipods 1038 / 0.01m²; ostracods 219 / 0.01m².

Major sources of organic carbon	Photosynthesis (macroalgae and/or halophytic plants) Photosynthesis (microalgae)

Recruitment processes

Recruitment processes of some of the characterizing species of the biotope are given below:

- *Corallina officinalis* has isomorphic sexual (gametophyte) and asexual (sporophyte) stages (see *MarLIN* Web site). Settled tetraspores develop into a perennial crustose base, from which the upright, articulate fronds develop. Sporelings formed within 48 hrs, a crustose base within 72 hrs, fronds being initiated after 3 weeks and the first intergeniculum (segment) formed within 13 weeks of settlement (Jones & Moorjani, 1973). Settlement and development of fronds is optimal on rough surfaces but settlement can occur on smooth surfaces (Harlin & Lindbergh, 1977; Wiedeman pers. comm.). *Corallina officinalis* settled on artificial substrata within 1 week of their placement in the intertidal in New England summer suggesting that recruitment is high (Harlin & Lindbergh, 1977).
- Besides having a meristem, *Lithophyllum incrustans* has its conceptacles (reproductive organs) buried in its calcified thallus, and connected to the exterior by canals (Edyvean & Ford, 1986). Reproductive types (gametangial and tetrasporangial plants) occur from October to April but decline into summer although some conceptacles are present throughout the year (Irvine & Chamberlain 1994). It has been calculated that 1 mm x 1mm of reproductive thallus produces 17.5 million bispores per year with average settlement of only 55 sporelings/year (Edyvean & Ford 1984).
- All the spores of red algae are non flagellate and dispersal is wholly a passive process (Fletcher & Callow, 1992). Spores vary in their sinking rate as determined by size and density. In general, due to the difficulties of re-entering the benthic boundary layer, it is likely that successful colonization is achieved under conditions of limited dispersal and/or minimum water current activity. Norton (1992) reported that although spores may travel long distances the reach of the furthest propagule does not equal its useful dispersal range, and most successful recruitment probably occurs within 10m of the parent plants. It is expected, therefore, that recruitment of foliose macroalgae in the biotope would occur from local populations and that establishment and recovery of isolated populations would be patchy and sporadic.
- *Littorina littorea* is an iteroparous breeder with high fecundity (up to 100,000 for a large female (27 mm shell height)) that lives for several (at least 4) years. *Littorina littorea* can breed throughout the year but the length and timing of the breeding period are extremely dependent on climatic conditions. *Littorina littorea* sheds egg capsules directly into the sea and release is synchronized with spring tides on several separate occasions. Larval settling time or pelagic phase can be up to six weeks (Fish, 1972).

- Recruitment of *Patella vulgata* fluctuates from year to year and from place to place (Bowman, 1981). Fertilization is external and the larvae are pelagic for up to two weeks before settling on rock at a shell length of about 0.2 mm. Winter breeding occurs only in southern England, in the north of Scotland it breeds in August and in north-east England in September.
- Gammarid amphipods brood their embryos and offspring but are highly mobile as adults and probably capable of colonizing new habitats from the surrounding area (e.g. see *Hyale prevostii* review on *MarLIN* Web site). Similarly isopods such as *Idotea* species and *Jaera* species brood their young. *Idotea* species are mobile and active swimmers and probably capable of recruiting to new habitats from the surrounding area by adult migration. *Jaera albifrons*, however, is small and may take longer to move between habitats and Carvalho (1989) suggested that under normal circumstances movement was probably limited to an area of less than 2 m. Hicks (1985) noted that epiphytic harpacticoid copepods lack planktonic dispersive larval stages but are active swimmers, which is therefore the primary mechanism for dispersal and colonization of available habitats. Some species of harpacticoids are capable to moving between low and mid-water levels on the shore with the tide, while in others, colonization rates decrease with increasing distance from the resident population. Overall immigration and *in situ* reproduction were thought to maintain equilibrium populations exposed to local extinction, although there may be local spatial variation in abundance (see Hicks, 1985).

Time for community to reach maturity

The epiphytic species diversity of the coralline turf in the rockpool is dependant on the *Corallina officinalis* cover and its growth form (Dommasnes, 1968, 1969; Seapy & Littler, 1982; Crisp & Mwaiseje, 1989). *Corallina officinalis* was shown to settle on artificial substances within 1 week of their placement in the intertidal in New England summer suggesting that recruitment is high (Harlin & Lindbergh, 1977). New fronds of *Corallina officinalis* appeared on sterilized plots within six months and 10% cover was reached with 12 months (Littler & Kauker, 1984). In experimental plots, up to 15% cover of *Corallina officinalis* fronds returned within 3 months after removal of fronds and all other epiflora/fauna (Littler & Kauker, 1984). Bamber & Irving (1993) reported that new plants grew back in scraped transects within 12 months, although the resistant crustose bases were probably not removed. New crustose bases may recruit and develop quickly but the formation of new fronds from these bases and recovery of original cover may take longer. Once a coralline turf has developed it will probably be colonized by epiphytic invertebrates such as harpacticoids, amphipods and isopods relatively quickly from the surrounding area. Therefore, the biotope would be recognizable once the coralline turf has regrown, which is likely to be quite rapid if the resistant crustose bases remain. Recruitment of red algae probably equally rapid, and once the algal turf has developed most of the epiphytic invertebrates would colonize quickly, although some species e.g. small brooding gastropods would take longer.

Additional information

No text entered.

Habitat preference and distribution

Distribution in Britain and Ireland

Found on rocky shores on all coasts of Britain and Ireland.

Habitat preferences

Temperature range preferences	Data deficient
Water clarity preferences	Very high clarity / Very low turbidity High clarity / Low turbidity
Limiting nutrients	Nitrogen (nitrates) Phosphorus (phosphates)
Other preferences	Rockpools

Additional information

No text entered.

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	**Species name**	**Common Name**
Key structural	*Corallina officinalis*	Coral weed
Important characterizing	*Lithophyllum incrustans*	Encrusting coralline algae
Important structural	*Littorina littorea*	Common periwinkle
Important structural	*Patella vulgata*	Common limpet
Important structural	*Gibbula cineraria*	Grey top shell
Important structural	*Hyale prevostii*	An amphipod

Explanation

Corallina officinalis is the dominant characterizing species within the biotope and provides substratum and refuges for a diverse epifauna. Therefore, the community is dependant on the presence of *Corallina officinalis* and it has been included as key structuring. Encrusting coralline algae such as *Lithophyllum incrustans* are characteristic of the biotope. Gastropods *Littorina littorea*, *Patella vulgata* and *Gibbula cineraria* may graze pools in the eulittoral zone to such an extent that they are devoid of any foliose red algae and are reduced to encrusting coralline algae. They have been included as important structural species. Epiphytic grazers, such as amphipods, isopods small gastropods probably keep the turf free of epiphytic algae and are important structural species. Reference has been made to reviews of *Hyale prevostii* to represent the sensitivity of amphipods and small crustaceans.

Species found especially in biotope

Corallina officinalis Coral weed
Lithophyllum incrustans An encrusting coralline alga

Additional information

The MNCR recorded ca 577 species in 176 records of this biotope, although not all species occurred in all records of the biotope (Connor *et al.*, 1997b; JNCC, 1999).

Biotope sensitivity

Physical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	High	Moderate	Major Decline	High
Smothering	Intermediate	High	Low	Decline	Moderate
Increase in suspended sediment	Intermediate	Very high	Low	Minor Decline	Low
Decrease in suspended sediment	Tolerant	Not Relevant	Tolerant	Not Relevant	Low
Desiccation	High	Very high	Low	Decline	Low
Increase in emergence regime	Intermediate	Very high	Low	Decline	Low
Decrease in emergence regime	High	High	Moderate	Rise	Low

Decrease in water flow rate	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Increase in temperature	Intermediate	Very high	Low	Decline	Low
Decrease in temperature	Tolerant	Not Relevant	Tolerant	No Change	Moderate
Increase in turbidity	Tolerant	Not Relevant	Tolerant	Not Relevant	Low
Decrease in turbidity	Tolerant	Not Relevant	Tolerant	No Change	Moderate
Increase in wave exposure	Tolerant	Not Relevant	Tolerant	Not Relevant	Low
Decrease in wave exposure	Low	Very high	Very Low	Minor Decline	Very low
Noise	Tolerant	Not Relevant	Tolerant	No Change	Low
Visual Presence	Tolerant	Not Relevant	Tolerant	No Change	Moderate
Abrasion & physical disturbance	Intermediate	High	Low	Minor Decline	Low
Displacement	High	High	Moderate	Decline	Moderate
Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	High	High	Moderate	Major Decline	High
Heavy metal contamination	Intermediate	High	Low	Decline	Moderate
Hydrocarbon contamination	High	High	Moderate	Major Decline	Moderate
Radionuclide contamination	Insufficient information	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Changes in nutrient levels	Low	Very high	Very Low	No Change	Low
Increase in salinity	Tolerant	Not Relevant	Tolerant	No Change	Moderate
Decrease in salinity	Tolerant	Not Relevant	Tolerant	No Change	Moderate
Changes in oxygenation	Low	Very high	Very Low	Minor Decline	Low
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Insufficient information	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Introduction of non-native species	Low	Very high	Very Low	Minor Decline	Low
Extraction of key or important characterizing species	Intermediate	Very high	Low	Decline	Low
Extraction of important species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant

Explanation of sensitivity and recoverability	
Physical Factors	
Substratum Loss (see benchmark)	Removal of the substratum would result in loss of the coralline turf and its associated community. Therefore an intolerance of high has been recorded. Recoverability is likely to be high (see additional information below).
Smothering (see benchmark)	*Corallina* spp. accumulate more sediment than any other alga (Hicks, 1985). Significant sediment cover of the middle to lower intertidal in a South Californian shore, resulting from fresh water runoff, caused substantial decline in *Corallina* spp. cover as the fronds died back (Seapy & Littler, 1982). Although the fronds of *Corallina officinalis* may be intolerant of, rapid recovery will result from the resistant crustose bases (see additional information below). Encrusting coralline algae are frequently subject to cover by sediment and appear to survive well. Faunal components of the biotope may be more intolerant of smothering than algae. If *Littorina littorea* cannot regain the surface then death may occur. Smothering of limpets by 5cm of sediment for one month is likely to interfere with locomotion, grazing and respiration. Mobile epifauna, such as amphipods and isopods are likely to be able to move through the sediment or debris to escape smothering. The species food source may be affected because smothering can reduce photosynthesis but *Hyale prevostii* for instance may migrate to alternative food sources on other parts of the shore. At the benchmark, level intolerance to smothering has been assessed to be intermediate as important structural species may be lost. Recoverability has been assessed to be high. For instance, *Littorina littorea* is an iteroparous breeder with high fecundity that lives for several (at least 4) years. Breeding can occur throughout the year. The planktonic larval stage is long (up to 6 weeks) although larvae do tend to remain in waters close to the shore so recruitment rates should be good.
Increase in suspended sediment (see benchmark)	*Corallina* species accumulate more sediment than any other alga (Hicks, 1985). Hence an increase in suspended sediment is likely to accumulate in the coralline turf. A significant increase may result in smothering (see above). An accumulation of sediment within the turf may attract more sediment dwelling interstitial invertebrates such as nematodes, harpacticoids and polychaetes, although in more wave exposed locations accumulation of sediment is likely to be minimal. Increased suspended sediment may also result in increased scour, which may adversely affect the fleshy red algae, and interfere with settling spores and recruitment if the factor is coincident with their major reproductive period. However, coralline algae, especially the crustose forms are thought to be resistant of sediment scour (Littler & Kauker, 1984), and will probably not be adversely affected at the benchmark level. Therefore, an increase in suspended sediment may reduce the epiphytic species diversity in the immediacy, and adversely affect the cover of fleshy red algae and an intolerance of intermediate has been recorded. Recoverability is likely to be very high as species are likely to remain *in situ* from which recruitment can occur.
Decrease in suspended sediment (see benchmark)	This community is unlikely to be dependant on suspended sediment. Although accumulated sediment within coralline turf habitats is likely to increase the species diversity of the epiphytic fauna, in very wave exposed locations, accumulated sediment in the habitat is likely to be minimal. A reduction in suspended sediment will probably reduce the risk of scour, and reduce food availability for the few suspension feeding species in the biotope (e.g. barnacles and spirorbids present). Therefore not sensitive has been recorded.
Desiccation (see benchmark)	*Corallina officinalis* inhabits damp or wet gullies and rock pools and does not inhabit open rock in the upper shore. Fronds are highly intolerant of desiccation and do not recover from a 15%water loss, which might occur within 40-45

	minutes during a spring tide in summer (Wiedemann, 1994). Occurrence of encrusting coralline algae seems to be critically determined by exposure to air and sunlight. Colonies survive in damp conditions under algal canopies or in pools but not on open rock where desiccation effects are important. An intolerance assessment of high has been made owing to the fact that should a rockpool community dominated by coralline algae 'loose its water' and be subject to continuous emersion for an hour and hence desiccation it is likely that the key structuring species will suffer loss. Mobile epifauna are likely to seek shelter elsewhere and species such as *Patella vulgata* found throughout the intertidal zone are likely to tolerate a desiccation event to some extent. On return to prior conditions, recoverability of the key structuring species has been assessed to be very high (see additional information below).
Increase in emergence regime (see benchmark)	Bleached corallines were observed 15 months after the 1964 Alaska earthquake which elevated areas in Prince William Sound by 10 m. Similarly, increased exposure to air caused by upward movement of 15 cm due to nuclear tests at Armchitka Island, Alaska adversely affected *Corallina pilulifera* (Johansen, 1974). However, the upper extent of LR.Coff is determined by the availability of rock pools and wet gullies. An increase in emergence and concomitant increase in desiccation on the open shore is of lesser importance where moisture is provided by standing water and shade. An increase in emergence will, however, expose the rockpool to increased evaporation, rainfall, and heating or cooling, so that some adverse effects on the fauna and flora are likely. Therefore, an intolerance of intermediate has been recorded. Recovery of the coralline algal community is likely to be very high (see additional information below).
Decrease in emergence regime (see benchmark)	A greater period of immersion will lessen the physico-chemical extremes that prevent the colonization of the mid to upper shore by species more typical of the lower shore. Desiccation stress will be lessened and temperature and salinity changes less severe. Thus the LR.Cor community has been assessed to have a high intolerance to decreased emergence as it will probably allow the 'up-lift' of lower shore species into the biotope and will it begin to change to another biotope. On return to prior conditions, it is likely that species which entered the biotope would be lost owing to intolerance, and recoverability has been assessed to be high to indicate that colonizing species may persist for a period but disappear as the biotope community re-stabilizes.
Increase in water flow rate (see benchmark)	Water flow rate in this biotope is typically only that of the ebb and flood tide speed, which hardly affects intertidal habitats and is far exceeded by the strength of wave action. An increase in water flow rate is therefore considered not relevant.
Decrease in water flow rate (see benchmark)	Wave action is far more important than tidal flow so not relevant has been recorded.
Increase in temperature (see benchmark)	In general, the water temperature of rockpools follows that of the air more closely than that of the sea and throughout any 24 hour period dramatic changes in temperature may be observed. For instance, Pyefinch (1943) plotted diurnal changes in a pool lying above mean high water during July. When the pool was out of contact with the sea, water temperature increased by 5 °C from 14 to 19 °C over a three hour period, and decreased suddenly to 14 °C within 1.5 hours when the incoming tide reached it. Hence, the community that inhabits such environments needs to be especially tolerant of acute temperature changes. Mobile species (e.g. littorinids, isopods and intertidal fish) will exhibit physiological and behavioural adaptations to temperature change and will probably migrate to deeper water within the rockpool if possible, or migrate to the surrounding rock surface to escape extreme temperatures, while fixed species such as macroalgae will need to tolerate the temperature change (see Newell,

	1979). Lüning (1990) reported that *Corallina officinalis* from Helgoland survived one week exposure to temperatures between 0 °C and 28 °C. An abrupt increase in temperature of 10 °C caused by the hot, dry 'Santa Anna' winds (between January -and February) in Santa Cruz, California resulted in die back of several species of algae exposed at low tide (Seapy & Littler, 1984). Although fronds of *Corallina* spp. dramatically declined, summer regrowth resulted in dense cover by the following October, suggesting that the crustose bases survived. Severe damage was noted in *Corallina officinalis* as a result of desiccation during unusually hot and sunny weather in summer 1983 (an increase of between 4.8 and 8.5 °C) (Hawkins & Hartnoll, 1985). Littler & Kauker (1984) suggested that the crustose base was more resistant of desiccation or heating than fronds. Most of the other species within the biotope are distributed to the north and south of Britain and Ireland and unlikely to be adversely affected by long-term temperature change. But Hawkins & Hartnoll (1985) suggested that typical understorey red algae were susceptible to hot dry weather and that occasional damaged specimens of *Palmaria palmata*, *Osmundea pinnatifida* and *Mastocarpus stellatus* were observed after the hot summer of 1983. It is likely that *Corallina officinalis* fronds are intolerant of abrupt short term temperature increase although they may not be affected by long term chronic change and the crustose bases are probably less intolerant of than fronds. Epifaunal species will decline due to loss of coralline turf cover. Similarly, acute increases in temperature will probably reduce the cover of the characterizing red algae. The rockpool community is probably tolerant of a short term 5 °C change in temperature (see benchmark) and under normal circumstances the body of water protects species from the immediate effects of desiccation. But a long term increase in average temperature may expose the community to extremes of temperature above the tolerance limits, resulting in loss of some species, especially red algae and a reduced abundance of coralline algae. Therefore, an intolerance of intermediate has been recorded. Recoverability is probably very high (see additional information below).
Decrease in temperature (see benchmark)	In general, the water temperature of rockpools follows that of the air more closely than that of the sea and dramatic temporal changes in temperature may be observed. Under extremely low temperatures, components of the community demonstrate tolerance. Lüning (1990) reported that *Corallina officinalis* from Helgoland survived 0 °C when exposed for one week. New Zealand specimens were found to tolerate -4 °C (Frazer *et al.*, 1988). Lüning (1990) suggested that most littoral algal species were tolerant of cold and freezing. For example, the photosynthetic rate of *Chondrus crispus* recovered after 3hrs at -20 °C but not after 6hrs (Dudgeon *et al.*, 1990). The photosynthetic rate of *Mastocarpus stellatus* higher on the shore fully recovered from 24hrs at -20°C. *Littorina littorea* is a hardy intertidal species and can tolerate long periods of exposure to the air and consequently wide variations in temperature. Adult snails can easily tolerate sub-zero temperatures and the freezing of over 50% of their extracellular body fluids (English & Storey, 1998). Adults of *Patella vulgata* are also largely unaffected by short periods of extreme cold. Ekaratne & Crisp (1984) found adult limpets continuing to grow over winter when temperatures fell to -6 °C, and stopped only by still more severe weather. However, loss of adhesion after exposure to -13 °C has been observed with limpets falling off rocks and therefore becoming easy prey to crabs or birds (Fretter & Graham, 1994). However, in the very cold winter of 1962-3 when temperatures repeatedly fell below 0 °C over a period of 2 months large numbers of *Patella vulgata* were found dead (Crisp, 1964). Nevertheless, the community has been assessed not sensitive to decreased temperature at the benchmark level.

Increase in turbidity (see benchmark)	The biotope essentially occur in shallow waters where light attenuation due to increase turbidity is probably low. Red algae and coralline algae especially are known to be shade tolerant and are common components of the understorey on seaweed dominated shores. Therefore, a decrease in light intensity is unlikely to adversely affect the biotope.
Decrease in turbidity (see benchmark)	An increase in light intensity is unlikely to adversely affect the biotope.
Increase in wave exposure (see benchmark)	The biotope may occur on the upper shore in locations with varying wave exposures (very exposed to sheltered) (Connor *et al.*, 1997b). The effects of wave exposure upon rockpool communities high on the shore are likely to depend on tidal amplitude as within a shore, and where the tidal amplitude is significant, the time for which organisms are subjected to wave action will vary along the intertidal gradient. For instance, during neap tide periods, mid and higher shore rockpools may remain isolated from the main body of the sea for several days or weeks in succession. During such times, wave action is unlikely to be of direct influence other than generating a spray, whilst during periods of tidal immersion wave action may directly affect the community. The changes in community composition that occur with increased wave exposure are accompanied by striking changes in the vertical levels of zones on the shore. In north-west Europe, all the zones become greater in vertical extent as wave exposure increases, and thus are found at greater heights above chart datum (Little & Kitching, 1996). In balance, over a year it is likely that as a result of increased wave action the vertical extent of the biotope up the shore will increase with no major changes in community composition occurring, so an assessment of not sensitive has been made.
Decrease in wave exposure (see benchmark)	The biotope may occur on the upper shore in locations with varying wave exposures (very exposed to sheltered) (Connor *et al.*, 1997b). A decrease in wave action (directly effective only when the biotope is immersed) may mean that siltation and smothering of epifauna may occur and remain in the long term (see smothering above). Overall, only limited adverse effects are likely and an intolerance assessment of low has been made. However, in situations where the biotope occurs on the upper shore due to wave splash, and reduction in wave exposure may result in loss these examples of the biotope.
Noise (see benchmark)	None of the species in this biotope are know to respond to noise or vibration at the benchmark level, an assessment of not sensitive has been made.
Visual Presence (see benchmark)	The mobile invertebrates are probably capable of responding to localized shading, experienced by the approach of a predator. But their visual acuity is likely to be low and they are unlikely to respond to visual disturbance at the benchmark level.
Abrasion & physical disturbance (see benchmark)	Abrasion by an anchor or mooring may remove some fronds of the foliose red algae and scrape coralline turf, although most species would grow back from their remaining holdfasts. Trampling may be more damaging (see ELR.Coff) but is likely to be less significant in rockpool than on open rock surfaces. Therefore an intolerance assessment of intermediate has been made.
Displacement (see benchmark)	The majority of the characterizing fauna, such as the limpets, winkles, top shells isopods, amphipods and harpacticoid copepods are either highly mobile or would be able to re-attach to the substratum if undamaged, and are unlikely to be adversely affected by displacement. But the dominant macroalgae are permanently attached to the substratum and if removed will be lost, resulting in loss of the biotope overall. If their holdfasts and bases are also removed then recovery will be prolonged but still relatively rapid
Chemical Factors	
Synthetic compound contamination	Smith (1968) reported that oil and detergent dispersants from the *Torrey Canyon* spill affected high water plans of *Corallina officinalis* more than low shore plants

(see benchmark)	and some plants were protected in deep pools. In areas of heavy spraying, however, *Corallina officinalis* was killed (Smith, 1968). Regrowth of fronds had begun within two months after spraying ceased (Smith 1968). O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination, possibly due to the susceptibility of phycoerythrins to destruction. They also reported that red algae are effective indicators of detergent damage since they undergo colour changes when exposed to relatively low concentration of detergent. However, Smith (1968) reported that red algae such as *Chondrus crispus*, *Mastocarpus stellatus*, and *Laurencia pinnatifida* were amongst the algae least affected by detergents. Laboratory studies by Grandy (1984) on the effects of oil and dispersants on several red algal species concluded that they were all sensitive to oil/dispersant mixtures, with little difference between adults, sporelings, diploid or haploid life stages. Cole *et al*. (1999) suggested that herbicides were (not surprisingly) very toxic to algae and macrophytes. Hoare & Hiscock (1974) noted that with the exception of *Phyllophora* species, all red algae including encrusting coralline forms, were excluded from the vicinity of an acidified halogenated effluent discharge in Amlwch Bay, Anglesey and that intertidal populations of *Corallina officinalis* occurred in significant amounts only 600m east of the effluent. Chamberlain (1996) observed that although *Lithophyllum incrustans* was quickly affected by oil during the *Sea Empress* spill, recovery occurred within about a year. The oil was found to have destroyed about one third of the thallus thickness but regeneration occurred from thallus filaments below the damaged area. Most pesticides and herbicides were suggested to be very toxic for invertebrates, especially crustaceans (amphipods isopods, mysids, shrimp and crabs) and fish (Cole *et al.*, 1999). Intolerance to synthetic chemicals has been assessed to be high, owing to the likely loss of key structural and important characterizing as well as other red foliose algae from the rockpools. On return to prior conditions, recoverability has been assessed to be high (see additional information below).
Heavy metal contamination (see benchmark)	Little information was found concerning the effects of heavy metals on turf forming and encrusting coralline algae. However, Bryan (1984) suggested that the general order for heavy metal toxicity in seaweeds is: organic Hg> inorganic Hg > Cu > Ag > Zn> Cd>Pb. Most of the information available suggests that adult gastropod molluscs are rather tolerant of heavy-metal toxicity (Bryan, 1984). Winkles may absorb metals from the surrounding water by absorption across the gills or from their diet, and evidence from experimental studies on *Littorina littorea* suggest that diet is the most important source (Bryan *et al.*, 1983). The species has been suggested as a suitable bioindicator species for some heavy metals in the marine environment. Bryan *et al.* (1983) suggested that the species is a reasonable indicator for Ag, Cd, Pb and perhaps As. In the Fal estuary *Patella vulgata* occurs at, or just outside, Restronguet Point, at the end of the creek where metal concentrations are in the order: Zinc (Zn) 100-2000 µg/l, copper (Cu) 10-100µg/l and cadmium (Cd) 0.25-5µg/l (Bryan & Gibbs, 1983). However, in the laboratory *Patella vulgata* was found to be intolerant of small changes in environmental concentrations of Cd and Zn by Davies (1992). At concentrations of 10µg/l pedal mucus production and levels of activity were both reduced, indicating a physiological response to metal concentrations. Exposure to Cu at a concentration of 100 µg/l for one week resulted in progressive brachycardia (slowing of the heart beat) and the death of limpets. Zn at a concentration of 5500 µg/l produced the same effect (Marchan *et al.*, 1999). An intolerance assessment of intermediate has been made as evidence suggests that important grazers in the biotope would be adversely affected by heavy metal

	pollution of the biotope. Recruitment patterns of such species suggest that recoverability would be high.
Hydrocarbon contamination (see benchmark)	Where exposed to direct contact with fresh hydrocarbons, encrusting coralline algae appear to have a high intolerance. Crump *et al*. (1999) described "dramatic and extensive bleaching" of '*Lithothamnia*' following the *Sea Empress* oil spill. Observations following the *Don Marika* oil spill (K. Hiscock, pers. comm.) were of rockpools with completely bleached coralline algae. However, Chamberlain (1996) observed that although *Lithophyllum incrustans* was affected in a short period of time by oil during the *Sea Empress* spill, recovery occurred within about a year. The oil was found to have destroyed about one third of the thallus thickness but regeneration occurred from thallus filaments below the damaged area. Following the *Torrey Canyon* oil spill in 1967, oil and detergent dispersants affected high shore specimens of *Corallina officinalis* more than low shore specimens. Plants in deep pools were afforded some initial protection, although probably later affected by contaminated runoff. In areas of heavy spraying, however, *Corallina officinalis* was killed. (Smith, 1968). Intolerance to hydrocarbon pollution has been assessed to be high, as key structural and important characterizing coralline algal species will be lost and the biotope not be recognized in their absence. Recoverability of the key structural and important characterizing turf forming and encrusting coralline algae has been assessed to be high (see additional information below).
Radionuclide contamination (see benchmark)	Insufficient information.
Changes in nutrient levels (see benchmark)	Corallines seem to be tolerant and successful in polluted waters. Kindig & Littler (1980) demonstrated that *Corallina officinalis* var. *chilensis* in South California showed equivalent or enhanced health indices, highest productivity and lowest moralities (amongst the species examined) when exposed to primary or secondary sewage effluent. Little difference in productivity was noted in chlorinated secondary effluent or pine oil disinfectant. However, specimens from unpolluted areas were less tolerant, suggesting physiological adaptation to sewage pollution (Kindig & Littler 1980). Also, increased nutrients may result in overgrowth of coralline algae by other epiphytic algae. Grazers in the biotope may benefit from increase availability of food resources. An intolerance assessment of low has been made as key structural and important characterizing species may experience reduced viability. On return to prior conditions, recovery has been assessed to be very high as, although the biotope will recover to typical abundances, some species may remain abnormally abundant for a period whilst the biotope community re-stabilizes.
Increase in salinity (see benchmark)	Conditions within rockpools are the consequence of prolonged separation from the main body of the sea, and physico-chemical parameters within them fluctuate dramatically (Huggett & Griffiths, 1986). Small and shallow pools are especially influenced by insolation, air temperature and rainfall, the effects of which become more significant towards the high shore, where pools may be isolated from the sea for a number of days or weeks (Lewis, 1964). Rockpools in the mid eulittoral are likely to experience lesser changes in salinity than those of the supralittoral, littoral fringe and upper eulittoral which are liable to gradually changing salinities followed by days of fully marine or fluctuating salinity at times of spring tide (Lewis, 1964). The community has been assessed to be not sensitive to increased salinity at the benchmark level because it represents a lesser change in salinity than the community might normally be expected to experience and the community persists owing to the tolerance of species to short-term acute changes.

Decrease in salinity (see benchmark)	Conditions within rockpools are the consequence of prolonged separation from the main body of the sea, and physico-chemical parameters within them fluctuate dramatically (Huggett & Griffiths, 1986). Small and shallow pools are especially influenced by insolation, air temperature and rainfall, the effects of which become more significant towards the high shore, where pools may be isolated from the sea for a number of days or weeks (Lewis, 1964). Rockpools in the mid eulittoral are likely to experience lesser changes in salinity than those of the supralittoral, littoral fringe and upper eulittoral which are liable to gradually changing salinities followed by days of fully marine or fluctuating salinity at times of spring tide (Lewis, 1964). Salinity values ranging from 5-30 psu have been recorded in upper shore rockpools over a period of 24 hrs (Ranade, 1957). The community has been assessed to be not sensitive to decreased salinity at the benchmark level because it represents a lesser change in salinity than the community might normally be expected to experience and the community persists owing to the tolerance of species to short-term acute changes.
Changes in oxygenation (see benchmark)	Oxygenation of the rockpool is usually high due to photosynthetic activity and frequent water exchange. During the day, algae within rockpools produce oxygen by photosynthesis, and oxygen concentrations may rise to three times the saturation value, so that it is released as bubbles. The effect of oxygen production is to increase the pH of water in the pool owing to utilization of carbon dioxide. At night, when photosynthesis has ceased, algal respiration may utilize much of the available oxygen and minimum values of 1-5 % saturation of oxygen have been recorded *in situ* (Morris & Taylor, 1983). The algal component of the biotope may be intolerance of reduced oxygen concentration in darkness when they can only respire. However, corallines may be more tolerant than most algae due to their low rates of respiration (see Littler & Kauker 1984 for values). *Littorina littorea* can endure long periods of oxygen deprivation. The snails can tolerate anoxia by drastically reducing their metabolic rate (down to 20% of normal) (MacDonald & Storey, 1999). However, this reduces feeding rate and thus the viability of a population may be reduced. *Patella vulgata* was assessed to have an intermediate intolerance to low oxygen concentrations (see *MarLIN* Web site). At the benchmark level, the community has been assessed to have a low intolerance to reduced oxygenation of the water. Mobile species are likely to leave unfavourable locations, whilst immobile species are likely to suffer energy expenditure, e.g. owing to changes in metabolism, in order to survive. On return to optimal conditions, recoverability has been assessed to be very high.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	Several coralline and non-coralline species are epiphytic on *Corallina officinalis*. Irvine & Chamberlain (1994) cite tissue destruction caused by *Titanoderma corallinae*. However, no information on pathogenic organisms in the British Isles was found. In Rhodophycota, viruses have been identified by means of electron microscopy (Lee, 1971) and they are probably widespread. However, nothing is known of their effects on growth or reproduction in red algae and experimental transfer from an infected to an uninfected specimen has not been achieved (Dixon & Irvine, 1977). Overall, insufficient information was found to make an assessment
Introduction of non-native species (see benchmark)	The non-native wireweed *Sargassum muticum* may occur extensively in examples of this biotope. But the biotope persists, probably because of the small area of basal attachment of *Sargassum*. *Sargassum* probably competes with other macroalgae for light and nutrients so an intolerance of low has been recorded.
Extraction of key or important characterizing species	*Corallina officinalis* was used in Europe as a vermifuge although it no longer seems to be collected for this purpose (Guiry & Blunden, 1991). *Corallina officinalis* is collected for medical purposes; the fronds are dried and converted to

(see benchmark)	hydroxyapatite and used as bone forming material (Ewers *et al.*, 1987). It is also sold as a powder for use in the cosmetic industry. A European research proposal for cultivation of *Corallina officinalis* is pending as of May 2000 (Wiedemann, pers. comm.). Both *Chondrus crispus* and *Mastocarpus stellatus* are collected as 'carragheen' by hand picking and racking in Europe (Guiry & Blunden, 1991). Removal of 50% of the macroalgal community (see benchmark) would obviously reduce its extent and cover but also significantly reduce the resident epiphytic fauna. However, as long as holdfasts remain recovery will probably be rapid.
Extraction of important species (see benchmark)	None of the associated important species are likely to be subject to extraction.

Additional information

Recoverability:
Corallina officinalis probably has good recruitment and settled on artificial substances within 1 week of their placement in the intertidal in New England summer (Harlin & Lindbergh, 1977). New fronds of *Corallina officinalis* appeared on sterilized plots within six months and 10% cover was reached with 12 months (Littler & Kauker, 1984). Bamber & Irving (1993) reported that new plants grew back in scraped transects within 12 months, although the resistant crustose bases were probably not removed. Similarly, in experimental plots, up to 15% cover of *Corallina officinalis* fronds returned within 3 months after removal of fronds and all other epiflora/fauna but not the crustose bases (Littler & Kauker 1984). Although new crustose bases may recruit and develop quickly the formation of new fronds from these bases and recovery of original cover may take longer, and it is suggested that a population is likely to recover within a few years.

Chamberlain (1996) observed that although *Lithophyllum incrustans* was quickly affected by oil during the *Sea Empress* spill, recovery occurred within about a year. The oil was found to have destroyed about one third of the thallus thickness but regeneration occurred from thallus filaments below the damaged area. A recoverability of high is therefore suggested. If colonies were completely destroyed new growth would be slow and, because of low growth rates, recoverability would be low If death occurred, recoverability will be slow. Spores will settle and new colonies will arise rapidly on bare substratum but growth rate is slow (2-7 mm per annum - see Irvine & Chamberlain 1994).

Recolonization of *Patella vulgata* on rocky shores is rapid as seen by the appearance of limpet spat 6 months after the *Torrey Canyon* oil spill reaching peak numbers 4-5 years after the spill (Southward & Southward, 1978). The epifauna are mainly composed of mobile species that will recruit quickly from surrounding habitats, and will therefore, recover quickly once the coralline turf has developed.

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors					
	Corallina officinalis	***Lithophyllum incrustans***	***Littorina littorea***	***Patella vulgata***	***Hyale prevostii***
Community Importance	Key structural	Important characterizing	Important structural	Important structural	Important structural
Substratum Loss	High	High	High	High	High
Smothering	Intermediate	Low	High	High	Low
Increase in suspended sediment	Intermediate	Low	Intermediate	Low	Low
Decrease in suspended sediment	See explanation	Not Sensitive*	See explanation	Low	See explanation
Desiccation	High	High	Low	Low	Intermediate
Increase in emergence	Intermediate	High	Low	Low	Low

regime					
Decrease in emergence regime	See explanation	Not Sensitive	See explanation	See explanation	See explanation
Increase in water flow rate	Low	Low	Intermediate	Low	Low
Decrease in water flow rate	See explanation	Low	See explanation	See explanation	See explanation
Increase in temperature	Intermediate	Not Sensitive	Low	Low	Intermediate
Decrease in temperature	See explanation	Not Sensitive	See explanation	See explanation	See explanation
Increase in turbidity	Low	Low	Low	Low	Low
Decrease in turbidity	See explanation	Not Sensitive*	See explanation	See explanation	See explanation
Increase in wave exposure	Low	Not Sensitive	Intermediate	Low	Intermediate
Decrease in wave exposure	See explanation	Low	See explanation	See explanation	See explanation
Noise	Not Sensitive	Not Sensitive	Not Sensitive	Low	Low
Visual Presence	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Low
Abrasion & physical disturbance	Low	Intermediate	Intermediate	Low	Intermediate
Displacement	Low	Low	Not Sensitive	Intermediate	Low
Chemical factors					
	Corallina officinalis	***Lithophyllum incrustans***	***Littorina littorea***	***Patella vulgata***	***Hyale prevostii***
Community Importance	Key structural	Important characterizing	Important structural	Important structural	Important structural
Synthetic compound contamination	Intermediate	High	Low	High	Intermediate
Heavy metal contamination	Insufficient information	Insufficient information	Intermediate	Intermediate	Intermediate
Hydrocarbon contamination	Low	High	High	High	High
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	Low	Low	Not Sensitive	Low	Intermediate
Increase in salinity	Intermediate	Insufficient information	Not Sensitive	Low	Low
Decrease in salinity	See explanation	Intermediate	See explanation	See explanation	See explanation
Changes in oxygenation	Insufficient information	Insufficient information	Low	Intermediate	High
Biological factors					
	Corallina officinalis	***Lithophyllum incrustans***	***Littorina littorea***	***Patella vulgata***	***Hyale prevostii***
Community Importance	Key structural	Important characterizing	Important structural	Important structural	Important structural
Introduction of microbial pathogens/parasites	Low	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Introduction of non-native species	Not Relevant	Insufficient information	Insufficient information	Not Relevant	Not Relevant
Extraction of this species	Intermediate	Not Relevant	Intermediate	Intermediate	Intermediate
Extraction of other species	Intermediate	Intermediate	Not Sensitive	Low	Low

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors					
	Corallina officinalis	***Lithophyllum incrustans***	***Littorina littorea***	***Patella vulgata***	***Hyale prevostii***
Community Importance	Key structural	Important characterizing	Important structural	Important structural	Important structural
Substratum Loss	High	Low	High	High	Moderate
Smothering	Very high	Very high	High	High	High
Increase in suspended sediment	Very high	Very high	High	High	High
Decrease in suspended sediment	See explanation	Not Relevant	See explanation	High	See explanation
Desiccation	High	Low	Immediate	High	High
Increase in emergence regime	Very high	Low	Immediate	High	High
Decrease in emergence regime	See explanation	Not Relevant	See explanation	See explanation	See explanation
Increase in water flow rate	Very high	Very high	High	High	High
Decrease in water flow rate	See explanation	Very high	See explanation	See explanation	See explanation
Increase in temperature	High	Not Relevant	Immediate	High	High
Decrease in temperature	See explanation	Not Relevant	See explanation	See explanation	See explanation
Increase in turbidity	Immediate	Very high	Very high	Very high	High
Decrease in turbidity	See explanation	Not Relevant	See explanation	See explanation	See explanation
Increase in wave exposure	Very high	Not Relevant	High	High	High
Decrease in wave exposure	See explanation	Immediate	See explanation	See explanation	See explanation
Noise	Not Relevant	Not Relevant	Not Relevant	High	High
Visual Presence	Not Relevant	Not Relevant	Not Relevant	Not Relevant	High
Abrasion & physical disturbance	High	High	High	Very high	High
Displacement	High	Very high	Not Relevant	High	High
Chemical factors					
	Corallina officinalis	***Lithophyllum incrustans***	***Littorina littorea***	***Patella vulgata***	***Hyale prevostii***
Community Importance	Key structural	Important characterizing	Important structural	Important structural	Important structural
Synthetic compound contamination	High	Low	Very high	High	High
Heavy metal contamination	Insufficient information	Not Relevant	High	High	High
Hydrocarbon contamination	Very high	High	High	High	Moderate
Radionuclide contamination	Insufficient information	Not Relevant	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	Very high	High	Not Relevant	High	High
Increase in salinity	High	Not Relevant	Not Relevant	High	High
Decrease in salinity	See explanation	High	See explanation	See explanation	See explanation
Changes in oxygenation	Insufficient information	Not Relevant	Very high	High	High

Biological factors					
	Corallina officinalis	***Lithophyllum incrustans***	***Littorina littorea***	***Patella vulgata***	***Hyale prevostii***
Community Importance	Key structural	Important characterizing	Important structural	Important structural	Important structural
Introduction of microbial pathogens/parasites	Very high	Not Relevant	Insufficient information	Insufficient information	Insufficient information
Introduction of non-native species	Not Relevant	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Extraction of this species	High	Not Relevant	High	High	High
Extraction of other species	High	High	Not Relevant	High	High

Importance

Marine natural heritage importance

Listed under:	**UK Biodiversity Action Plan** **EC Habitats Directive**
National importance	Not available
Habitat Directive feature (Annex 1)	Reefs Large shallow inlets and bays Estuaries Lagoons
UK Biodiversity Action Plan habitat	Saline lagoons Littoral rock (broad habitat statement)

Biotope importance

Corallina officinalis turf provides substratum for various epiphytes, and supports a diverse, species rich invertebrate community due to its provision of interstices and build up of sediment within its fronds. This community includes harpacticoid copepods, amphipods, ostracods and isopods and the serpulid *Spirorbis corallinae*, which is rarely found on other algae (Dommasnes, 1968; Crisp & Mwaiseje 1989; Grahame & Hanna 1989; Bamber & Irving, 1993; Hull, 1997).

Exploitation

Corallina officinalis was used in Europe as a vermifuge although it no longer seems to be collected for this purpose (Guiry & Blunden, 1991). *Corallina officinalis* is collected for medical purposes; the fronds are dried and converted to hydroxyapatite and used as bone forming material (Ewers *et al.*, 1987). It is also sold as a powder for use in the cosmetic industry. A European research proposal for cultivation of *Corallina officinalis* is pending as of May 2000 (Wiedemann, pers. comm.). Both *Chondrus crispus* and *Mastocarpus stellatus* are collected as 'carragheen' by hand picking and racking in Europe (Guiry & Blunden, 1991).

Additional information

No text entered

This Biology and Sensitivity Key Information review can be cited as follows:
Budd, G.C., 2002. *Corallina officinalis* and coralline crusts in shallow eulittoral rockpools. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 19/01/2005]. Available from: <http://www.marlin.ac.uk>

Fucoids and kelps in deep eulittoral rockpools (LR.FK)

Key information authored by: Dr Harvey Tyler-Walters

Last updated 26/01/2005

This information is not refereed.

Fucoids and kelps in deep eulittoral rockpools. Image width ca XX m.
Image: Jon Davies / Joint Nature Conservation Committee

Recorded and expected LR.FK distribution for Britain and Ireland

Description of biotope

Deep rockpools in the mid to lower eulittoral zone often contain a community characterized by *Fucus serratus* and *Laminaria digitata*. Other large brown algae, including *Laminaria saccharina*, *Himanthalia elongata* and *Halidrys siliquosa*, may also occur. The rock surface is usually covered by encrusting coralline algae. A wide variety of filamentous and foliose algae, which are typical of lower shore and shallow sublittoral zones (e.g. *Palmaria palmata*, *Chondrus crispus*, *Ceramium* spp., *Membranoptera alata* and *Gastroclonium ovatum*) occur beneath the brown algal canopy. Algal-free vertical and overhanging faces often support the sponge *Halichondria panicea* and anemones *Actinia equina*. The abundance of grazing molluscs varies considerably. In some, large numbers of littorinids and limpets are probably responsible for the limited variety of red seaweeds present. In other pools, fewer grazers may result in an abundance of these algae. Where boulders occur in these pools they provide a greater variety of micro-habitats which support a variety of fauna. Mobile crustaceans (*Pagurus bernhardus* and *Carcinus maenas*), brittlestars (*Ophiothrix fragilis* and *Amphipholis squamata*), encrusting bryozoans and ascidians are typically found beneath and between boulders. (Information taken from the Marine Biotope Classification for Britain and Ireland, Version 97.06: Connor *et al.*, 1997a, b).

Welsh variation

Although the Welsh examples of many of the biotopes in this report follow the British and Irish classification description closely, some regional variation may exist. Reference should be made to Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

Factors such as pool depth, surface area, volume, orientation to sunlight, shading, internal topography, sediment content and type, together with wave exposure, shore height, and hence flushing rate, and the presence of absence of freshwater runoff, results in large spatial variation in community structure, even between adjacent pools at the same shore height (Ganning, 1971; Metaxas & Scheibling, 1993). Individual rockpools and the communities that occupy them are highly variable.

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Biotope complex	LR.Rkp	Rockpools
Biotope	LR.FK	Fucoids and kelps in deep eulittoral rockpools

Other biotope classification schemes

European Nature Information System (EUNIS) habitat classification - A1.512 - Fucoids and kelps in deep eulittoral rockpools (Davies & Moss, 1998).

Ecology

Ecological and functional relationships

The rockpool environment varies depending on factors such as pool depth, surface area, volume, orientation to sunlight, shading, internal topography, sediment content and type, together with wave exposure, shore height, and hence flushing rate, and the presence of absence of freshwater runoff. As a result, no two rockpools exhibit exactly the same physio-chemical conditions and exhibit large spatial variation in community structure, even between adjacent pools at the same shore height (Ganning, 1971; Metaxas & Scheibling, 1993; Metaxas *et al.*, 1994). Any given rockpool is effectively unique (Metaxas & Scheibling, 1993). Therefore, while the organisms detailed below have been recorded in this rockpool biotope, not all of the organisms, and hence the relationships between them, may occur in any one rockpool.

As communities in rockpools remain constantly submerged and the danger of desiccation is absent, it might be expected that rockpools form an easier environment in which to live for marine life than drying rock surfaces, and that species from regions lower on the shore would be able to extend much further up the shore. However, the rockpool environment differs from that of the surrounding emergent rock surfaces, so that not all species that thrive on the surrounding rock occur abundantly in rockpools and much of the lower shore open rock fauna is absent from rockpools (Lewis, 1964). Rockpools constitute a distinct environment for which physiological adaptations by the flora and fauna may be required (Lewis, 1964; Metaxas & Scheibling, 1993). The following description is based on reviews by Lewis (1964), Ganning (1971) and Metaxas & Scheibling (1993), the species listed in the MNCR database (JNCC, 1999) and additional references as cited.

- Macroalgae such as kelps, fucoids, red algae, green algae, encrusting red algae, erect and encrusting corallines provide primary productivity either directly to grazing invertebrates and fish or indirectly to detritivores and decomposers, in the form of detritus and drift algae or as dissolved organic material and other exudates. Benthic microalgae, periphyton and phytoplankton (e.g. diatoms) also add to primary productivity.
- Where present, large macroalgae such as the laminarians (e.g. *Laminaria digitata*, *Laminaria saccharina* and occasional *Laminaria hyperborea* and *Saccorhiza polyschides*), *Halidrys siliquosa* and fucoids (e.g. *Fucus serratus*, *Fucus vesiculosus*) shade the substratum (depending on density) so that understorey plants tend to be shade tolerant red algae and corallines. Understorey algae, by effectively restricting access to the substratum, may also inhibit or restrict recruitment of other species of macroalgae (Hawkins & Harkin, 1985; Hawkins *et al.*, 1992).
- Macroalgae provide substrata and refuges for a variety of invertebrates and epiphytic algae. The stipes and lamina of *Laminaria* spp. may support bryozoans (e.g. *Membranipora membranipora* or *Electra pilosa*) and grazing blue-rayed limpets (*Helcion pellucida*), while their holdfasts provide additional refuges for meiofauna and small invertebrates. If present, the stipes of *Laminaria hyperborea* may support numerous epiphytes such as *Palmaria palmata*, *Phycodrys rubens* and *Cladophora rupestris* (Goss-Custard *et al.*, 1979). Where present, *Halidrys siliquosa* provide substratum for epiphytes, depending on location, including microflora (e.g. bacteria, blue green algae, diatoms and juvenile larger algae), *Ulothrix* sp. and *Ceramium* sp., hydroids (e.g. *Obelia* spp.), bryozoans (e.g. *Scrupocellaria* spp.), and ascidians (e.g. *Apilidium* spp., *Botryllus schlosseri*, and *Botrylloides leachi*) (Lewis, 1964; Moss, 1982; Connor *et al.*, 1997b).
- The macroalgae provide refuges for small invertebrates, such as isopods, amphipods, ostracods and copepods. *Corallina officinalis* provides a substratum for small spirorbids e.g. *Spirorbis corallinae*,

which is only found on *Corallina officinalis*. Increasing density of *Spirorbis corallinae* was shown to increase the species richness of the epiphytic fauna. The invertebrate fauna of *Corallina officinalis* is detailed in LR.Cor.

- Amphipods (e.g. Gammaridae), isopods (e.g. *Idotea spp.* and *Jaera* sp.) and other mesoherbivores graze the epiphytic flora and senescent macroalgal tissue, which may benefit the macroalgal host, and may facilitate dispersal of the propagules of some macroalgal species (Brawley, 1992; Williams & Seed, 1992). Mesoherbivores also graze the macroalgae but do not normally adversely affect the canopy (Brawley, 1992).
- Grazers of periphyton (bacteria, blue-green algae and diatoms) or epiphytic algae include harpacticoid copepods, the limpets *Patella vulgata* and *Patella ulyssiponensis*, the blue-rayed limpet *Helcion pellucidum*, and gastropods such as *Gibbula cineraria, Gibbula umbilicalis, Littorina saxatilis, Littorina littorea, Littorina obtusata* and *Rissoa* spp. Limpets and littorinids also graze macroalgal sporelings and green algae especially.
- Coralline algae are probably relatively grazing resistant (Littler & Kauker, 1984) and few species graze the corallines directly except perhaps chitons (e.g. *Acanthochitona* spp. and *Lepidochitona cinerea*) and limpets of the genus *Tectura*.
- Grazing by littorinids and gammarid amphipods has been shown to significantly affect macroalgal abundance and diversity. For example in cage experiments in littoral fringe pools, Parker *et al.* (1993) found that gammarid amphipods significantly reduced the erect macroalgal canopy, while littorinids grazed microalgae and macroalgal sporelings, and prevented the establishment of erect and encrusting algal canopies. Both groups reduced the species richness of the algal canopy (Parker *et al.*, 1993). In tidepools in Nova Scotia, Chapman (1990) and Chapman & Johnson (1990) reported that grazers (especially littorinids) reduced the abundance of *Fucus* spp. sporelings and juveniles but increased the abundance of ephemeral algae, while having no effect on the encrusting red alga *Hildenbrandia rubra* (Metaxas & Scheibling, 1993). Conversely, Lubchenco (1978) noted that the addition of littorinids to mid-shore pools in Massachusetts decreased the abundance of dominant *Ulva* spp. (as *Enteromorpha* spp.) in favour of *Chondrus crispus* (Metaxas & Scheibling, 1993) a less palatable red alga. Wolfe & Harlin (1988a) noted that Rhode Island tidepools with the highest littorinid densities had the lowest abundance of macroalgae. Similarly, removal of the limpet *Patella vulgata* from high tidal pools at Lough Ine resulted in an increased abundance of *Ulva* sp. (as *Enteromorpha*) (Goss-Custard *et al.*, 1979).
- Where present, suspension feeders include the barnacles (e.g. *Semibalanus balanoides, Balanus crenatus* and *Verruca stroemia*), the mussel *Mytilus edulis*, hydroids (e.g. the epiphytic *Dynamena pumila*), tubeworms (e.g. *Spirorbis* spp. and *Pomatoceros* spp.), ascidians (e.g. *Botrylloides leachi, Botryllus schlosseri*, and *Dendrodoa grossularia*), bryozoans (e.g. *Membranipora membranacea* and *Electra pilosa*) and sponges (e.g. *Halichondria panicea* and *Hymeniacidon perleve*). Deep low shore pools may also support the plumose anemone *Metridium senile*. However, the abundance of barnacles and mussels in rockpools is usually low (Lewis, 1964), presumably due to heavy predation on juveniles by the dog whelk *Nucella lapillus* and crabs (e.g. *Carcinus maenas* and *Cancer pagurus*) and poor survival of spat or juveniles.
- Macroalgae compete for space with sessile invertebrates such as sponges, hydroids, ascidians and bryozoans. However, sessile epifauna predominate on vertical rock surfaces, overhangs and under boulders within the pool.
- Scavengers include shrimps (e.g. *Palaemon* spp.), brittlestars (e.g. *Amphipholis squamata* and *Ophiothrix fragilis*), cushion stars (*Asterina gibbosa*), gastropods (e.g. *Hinia* spp.), hermit crabs (e.g. *Pagurus bernhardus*) and crabs (e.g. *Carcinus maenas* and *Cancer pagurus*).
- Invertebrate predators include turbellarians, nemerteans and polychaetes (e.g. *Eulalia viridis* and *Harmothoe* spp.) feeding on small invertebrates such as copepods and small gastropods. Lower to mid shore rockpools provide refugia for dog whelks *Nucella lapillus* feeding on barnacles and small mussels within the rockpool and /or leaving the rockpool to forage at high tide. Similarly, crabs such as *Carcinus maenas* and *Cancer pagurus* are generalist predators of gastropods (e.g. littorinids) and bivalves as well as scavengers. Passive carnivores include sea anemones such as *Anemonia viridis, Actinia equina, Cereus pedunculatus, Sagartia elegans* and *Urticina felina*. In addition, intertidal fish such as the shanny *Lipophrys pholis* and gobies prey on small invertebrates such as copepods, amphipods and isopods.
- As with grazing, predation pressure is potentially higher in mid to low shore rockpools, since predators can continue feeding irrespective of the state of the tide. For example, in New South Wales, whelks were shown to reduce the abundance of barnacles, tubeworms and limpets

(Fairweather, 1987; Metaxas & Scheibling, 1993). Dethier (1984) concluded that harpacticoid copepod abundance in mid to low shore pools was low due to the presence of predators such as fish and to a lesser extent anemones. The reduced abundance of barnacles and mussels observed in rockpools (Lewis, 1964) is probably partly due to increased predation pressure.

Seasonal and longer term change

Conditions within rockpools are the consequence of prolonged separation from the main body of the sea, and physico-chemical parameters within them fluctuate dramatically (Pyefinch, 1943; Ganning, 1971; Daniel & Boyden, 1975; Goss-Custard *et al.*, 1979; Morris & Taylor, 1983; Huggett & Griffiths, 1986; Metaxas & Scheibling, 1993; Metaxas *et al.*, 1994). In general, larger and deep rockpools low on the shore tend to correspond to the sublittoral habitat with a more stable temperature and salinity regime. In contrast, small and shallow pools higher on the shore are especially influenced by insolation, air temperature and rainfall, the effects of which become more significant towards the high shore, where pools may be isolated from the sea for a number of days or weeks (Lewis, 1964).

Weather conditions exert a considerable influence on temperature and salinity. Water temperature in pools follows the temperature of the air more closely than that of the sea.

Temperature

The temperature of pools fluctuates with air temperature and sunlight, and tends to warm throughout the day, especially if in direct sunlight (Daniel & Boyden, 1975; Goss-Custard *et al.*, 1979). Shaded pools exhibit less dramatic changes in temperature (Daniel & Boyden, 1975). For example, the temperature of a high shore pool exposed to direct sunlight rose quickly in the morning to a maximum of 25 °C, while a shaded high shore pools only rose by 1 °C, even though air temperatures reached 20 °C (Daniel & Boyden, 1975). In addition, deeper pools may become stratified, with warmer water near the surface and cooler near the bottom (Daniel & Boyden, 1975), primarily due to sunlight. They noted that pool temperatures remained almost constant at night and suggested that pool temperatures would fluctuate slowly during the day under overcast conditions. In deeper pools, the vertical temperature gradation present in summer may reverse during winter owing to density stratification, so that ice may form (Naylor & Slinn, 1958). Morris & Taylor (1983) reported warmer water at the bottom of the pools and cooler at the surface, which they attributed to cooling of the surface water by wind. Examples of temperature ranges reported for mid to low shore pools include annual maxima and minima of 1-25 °C and 2-22 °C (Morris & Taylor, 1983), a diurnal range of 24 °C (day) and 13 °C (night) for a mid shore pool (Daniel & Boyden, 1975), and surface water temperature ranges of 14-19.25 °C and 15.5-20.75 °C in mid shore pools (Pyefinch, 1943). Smaller (or shallower pools) are more affected by climatic change in temperature than larger and/or deeper ones (Ganning, 1971). Morris & Taylor (1983) noted that temperature showed the greatest seasonal variation of all the physical parameters examined. In summer, the minimum recorded temperatures were greater than the maximum temperatures recorded in winter, and the daily temperature ranges were greater in summer than in winter, in both high and low shore pools (Morris & Taylor, 1983).

Salinity

High air temperatures cause surface evaporation of water from pools, so that salinity steadily increases, especially in pools not flooded by the tide for several days. Alternatively, high rainfall will reduce pool salinity or create a surface layer of brackish/nearly fresh water for a period. In addition, freezing of surface water increases the salinity of the underlying water (Ganning, 1971; Metaxas & Scheibling, 1993). Daniel & Boyden (1975) and Morris & Taylor (1983) reported little variability in salinity over one tidal cycle, and Ganning (1971) suggested that changes in salinity were of limited importance. However, heavy rain resulted in a layer of low salinity water on the surface of pools. Morris & Taylor (1983) stated that a low salinity layer of 2-10 mm was normal but after one storm the low salinity layer increased in depth, eventually resulting in a homogeneous pool of brackish water. But the deep pools characterized by this biotope are unlikely to become brackish. Morris & Taylor (1983) reported an annual salinity range in mid to low shore pools of 26-36.5 ppt.

The extent of temperature and salinity change is affected by the frequency and time of day at which tidal inundation occurs. If high tide occurs in early morning and evening the diurnal temperature follows that of the air, whilst high water at midday suddenly returns the temperature to that of the sea (Pyefinch, 1943). Rockpools in the supralittoral, littoral fringe and upper eulittoral are liable to gradually changing salinities followed by days of fully marine or fluctuating salinity at times of spring tide (Lewis, 1964).

Oxygenation

The biological community directly affects oxygen concentration, carbon dioxide concentration and pH, and are themselves affected by changes in the chemical parameters. Throughout the day, algae photosynthesize and produce oxygen, the concentration of which may rise to three times its saturation value, so that bubbles are released (Pyefinch, 1943; Ganning, 1971; Daniel & Boyden, 1975; Goss-Custard *et al.*, 1979; Morris & Taylor, 1983; Metaxas & Scheibling, 1993). In summer, rockpools are likely to be supersaturated with oxygen during the day (Pyefinch, 1943). For example, the greatest range of oxygen saturation of 101.7% occurred in a seaweed dominated, sediment floored pool, which reached over 190%saturation on some days (Pyefinch, 1943). Daniel & Boyden (1975) noted that a mid shore, seaweed dominated pool reached 194% saturation (ca 15 mg O_2/l) but that oxygenation was also marked in shaded pools. A pool with dense fauna exhibited a maximum saturation of 210% (Pyefinch, 1943). During photosynthesis algae absorb carbon dioxide and, as concentrations fall, the pH rises. Morris & Taylor (1983) recorded pH values >9 in rockpools on the Isle of Cumbrae.

At night, changes occur in the opposite direction as respiration utilizes much of the available oxygen and pH decreases. Daniel & Boyden (1975) reported oxygen depletion at night, with mid to low shore pools reduced to 8-44% saturation. They noted that the crab *Carcinus maenas* leaves the pools at night, and that other species with the ability to air-breathe could also do so, e.g. limpets, littorinids, and the shanny *Lipophrys pholis*. They also observed that shrimps gathered at the edge of high shore pools at night, presumably to take advantage of the better oxygenated surface layer (Daniel & Boyden, 1975). Daily fluctuation in oxygen concentration and pH also vary seasonally, and with the height of the pool on the shore or pool depth (Daniel & Boyden, 1975; Morris & Taylor, 1983; Metaxas & Scheibling, 1993). Morris & Taylor (1983) noted variation in oxygen concentration with pools with pool depth and proximity to pool algae. Again, inundation by the rising tide causes sudden changes in oxygenation, either sudden drops during the day or increases at night.

Ganning (1971) noted that the temperature of sediment at the bottom of pools showed little variation in temperature, and noted that diurnal fluctuations of greater than 1 °C were rarely observed in bottom sediments of pools deeper than 0.5 m, although a temperature of fall 0.5-1 °C was observed at the water/sediment interface. The presence of sediment in pools increases the risk of scour, which is likely to vary seasonally, increasing in winter storms. In addition, anoxic conditions within the sediment could potentially cause significant and sudden decreases in oxygen levels if the sediment was stirred up by wave action, although no evidence of this effect was found.

Seasonal change in communities

Tidepool community structure has been show to vary markedly over time, particularly with season (Metaxas & Scheibling, 1993). However, most studies have examined tidepools overseas, or different tidepools communities to those that occur in LR.FK (Dethier, 1984; Wolf & Harlin, 1988a,b; Kooistra *et al.*, 1989; Metaxas *et al.*, 1994) so that the species concerned are very different. Seasonal changes in macroalgal cover and diversity were associated with changes in water temperature, light intensity and day length, and reduced grazing pressure from littorinids in winter, although the community types were relatively stable over time in Rhode Island pools (Wolfe & Harlin, 1988a,b). Metaxas *et al.* (1994) noted that sheet forming algae (e.g. *Ulva lactuca*) were found throughout the year, filamentous forms (e.g. *Cladophora* and *Ceramium*) were present in late spring and summer (although other studies found them to be present from late spring to late autumn) while thick leathery and encrusting forms did not vary seasonally. However, macroalgal diversity was lowest in summer and autumn, especially in mid shore pools, probably due to grazing. Metaxas *et al.* (1994) also noted that the abundance of mussels, littorinids and whelks in Rhode Island peaked in summer due to recruitment but varied significantly between pools.

Many of the macroalgae within the biotope are perennial. However, they show seasonal variation in reproduction, with *Halidrys siliquosa* releasing spores in the winter months, potentially enabling them to colonize free space opened up by increased wave action in winter storms and the dying back of annual species (see Kain, 1975). Growth rate of *Laminaria digitata* is seasonally controlled with a period of rapid growth from February to July and one of slower growth from August to January. *Laminaria saccharina* grows fastest from late winter to spring then growth declines from June onwards and may cease in late summer. Increased wave exposure and storms in winter months are likely to erode *Laminaria* blades so that they appear tattered in winter months and overall standing biomass is reduced. Annual species, e.g. *Chorda filum* are likely to proliferate in spring, reaching maximum abundance in summer (high insolation and temperature). In *Fucus serratus* reproduction commences in late spring/early summer and continues through summer and autumn, peaking in August - October, and in the summer months it can reach 95% cover on emergent rock (see *MarLIN* Web site). In England, *Fucus vesiculosus* has a protracted reproduction period of about six months which varies only slightly in timing between a population at Wembury on the south coast of Devon and one at Port Erin, Isle of Man (Knight & Parke, 1950). Gametes may be produced from mid winter until late summer with a peak of fertility in May and June.

Red algae exhibit seasonal variation in growth and reproduction and red algal turf declines in abundance during the winter months, partly due to die back and abrasion during winter storms. Although protected from wave action in deep pools, macroalgae will be susceptible to damage and abrasion by wave action and winter storms near the surface or in shallower pools. For example, *Delesseria sanguinea* exhibits a strong seasonal pattern of growth and reproduction. New blades appear in February and grow to full size by May - June becoming increasing battered or torn and the lamina are reduced to midribs by December (Maggs & Hommersand, 1993). The maximum growth of *Furcellaria lumbricalis* occurs in March/April (Austin, 1960b) and release of carpospores and tetraspores occurs in December/January (Bird *et al.*, 1991). Reproductive bodies are present on the gametophytes of *Ahnfeltia plicata* between July and January and mature carposporophytes occur between October and July (Maggs & Paschal, 1989). Dickinson (1963) reported that *Chondrus crispus* was fertile in the UK from autumn to spring, but that the exact timing varied according to local environmental conditions. In the Bristol Channel, Bamber & Irving (1993) noted that the biomass of *Corallina officinalis* increased steadily through spring and summer and began to decline after July. *Mastocarpus stellatus* (as *Gigartina stellata*) was reported have a perennial holdfast, losing many erect fronds in winter, which grow back in spring (Dixon & Irvine, 1977). *Osmundea pinnatifida* also shows seasonal variation in growth, expanding its perennial holdfast in June to September, and producing erect fronds from October onwards reaching a maximum in February to May (Maggs & Hommersand, 1993). Maggs & Hommersand (1993) reported that spermatangia of *Ceramium virgatum* (as *nodulosum*) are recorded in January, March-April, June and August-September; cystocarps in January-February and April-September; tetrasporangia in February-September. The advantage of being fertile through the winter, as in the case of *Ahnfeltia plicata, Furcellaria lumbricalis* and *Chondrus crispus*, is the availability of substrata for colonization as other annual species die back (Kain, 1975)

Corallina officinalis may be overgrown by epiphytes, especially during summer. This overgrowth regularly leads to high mortality of fronds due to light reduction (Wiedemann, pers. comm.). The ephemeral green seaweeds *Ulva intestinalis* and *Ulva lactuca* are likely to be more abundant in summer depending on grazing pressure. In summer, erect and encrusting corallines may be bleached (especially in shallow pools or near the surface or deep pools) and loose their pink pigment but in some species, e.g. *Phymatolithon*, this does not necessarily result in death of the plant and pigment may be re-synthesized (Little & Kitching, 1996).

Habitat structure and complexity

As already noted, no two rockpools exhibit exactly the same physio-chemical conditions and exhibit large spatial variation in community structure, even between adjacent pools at the same shore height (Ganning, 1971; Metaxas & Scheibling, 1993; Metaxas *et al.*, 1994). Habitat complexity will vary with macroalgal cover, the dominant macroalgal species, shore height, pool depth and topography. Deeper pools are likely to be more complex than shallower pools. This biotope resembles the mid and low tidal pools described by Goss-Custard *et al.* at Carrigathorna near Lough Ine, Ireland.

In deep pools the underlying rock is likely to be covered by erect and encrusting corallines. Large macroalgal species (e.g. kelps and fucoids) may dominate the surface of the pool. Their depth within the pool (vertical zonation) is limited by self-shading so that only corallines and red algae occur beneath them. The upper limit of some species of algae within the pool may be limited by the summer surface water temperatures e.g. *Bifurcaria bifurcaria* (Kooistra *et al.*, 1989), and or desiccation after evaporation (e.g. corallines). For example, Goss-Custard *et al.* (1979) noted that *Laminaria* spp. and *Halidrys siliquosa* formed a margin in deep mid shore pools of 0.5-0.6 m deep, with *Laminaria hyperborea* below them, wherever the substratum was stable enough. The *Corallina officinalis* supported colonies of bryozoans, encrusting corallines and spirorbids and provided refuge for a wide variety of fauna including polychaetes, isopods, rissoid gastropods, amphipods, and *Hiatella arctica* (Goss-Custard *et al.*, 1979; and 'ecological relationships' above). The *Laminaria* spp. provide substratum for specialist grazers such as *Helcion pellucidum* and epiphytic bryozoans and algae (see 'ecological relationships' above). Goss-Custard *et al.* (1979) noted that the edge of pools that lost water slowly due to leakage during emersion was dominated by ephemeral green algae, e.g. *Ulva* spp. Grazing intensity due to littorinids may also affect the abundance of fleshy macroalgae, so that the pools may be dominated by less palatable red algae (e.g. *Chondrus crispus* and *Mastocarpus stellatus*). In deep pools the understorey is likely to be dominated by coralline turf and red algae. For example, Goss-Custard *et al.* (1979) reported that, in their deepest pool, the laminarians thinned below 0.5 m and the brown algae *Dictyota dichotoma*, *Desmarestia ligulata* appeared, together with *Dilsea carnosa*, *Delesseria sanguinea*, while *Chondrus crispus* and *Corallina officinalis* remained. Below 2m, the laminarians were absent and replaced by a mixed algal shrub of *Dictyota dichotoma*, *Phyllophora crispa*, *Nitophyllum punctatum* and *Cryptopleura ramosa* (Goss-Custard *et al.*, 1979)

Vertical surfaces within deep pools, and crevices or overhangs present, are likely to be dominated by encrusting fauna e.g. the sponges *Halichondria panicea* and *Hymeniacidon perleve*, tubeworms (*Pomatoceros* spp.) and anemones. For example, Goss-Custard *et al.* (1979) noted *Corynactis viridis* and *Sagartia elegans* on the sides of deep mid shore pools.

The presence of boulders and large stones at the bottom of the pools provides additional niches. The surface of larger stones and pebbles may support tubeworms, spirorbids and the holdfasts of kelps or *Chorda filum*, if stable enough and not too deep. The undersides support typical underboulder communities (see MLR.Fser.Fser.Bo; Gordon, 1972), likely to include encrusting sponges, bryozoans and tubeworms, small ascidians, the saddle oyster *Anomia ephippium*, and the porcelain crabs *Porcellana platycheles* and *Pisidia longicornis*. Underboulder habitats also provide refugia for crabs (e.g. *Carcinus maenas* and *Necora puber*) and fish.

The holdfasts of kelps and fucoids, and fronds of filamentous species and erect corallines provide refuges for small invertebrates (e.g. amphipods, isopods and small gastropods) or meiofauna (e.g. copepods) (see ecological relationships above). In addition, the shade of macroalgae provide refuges for shrimps (e.g. *Palaemon* spp.) and intertidal fish (e.g. blennies and gobies), while crevices provide additional refuges for crabs.

Rockpool species also display zonation patterns, similar to the emergent species. For example, brown algae and corallines are usually dominant in mid to low shore pools, while green algae tend to dominate high shore pools (Metaxas & Scheibling, 1993). Kooistra *et al.* (1989) noted vertical zonation within pools and found that macroalgal communities could be allocated to different depths within pools in the lower or higher parts of the shore. However, the communities studied in Brittany differed markedly from those found in this biotope. Similarly, zonation patterns have also been reported in flatworms, rotifers, oligochaetes, cladoceans, copepods, ostracods, barnacles, amphipods, isopods, chironomid larvae and fish (see Metaxas & Scheibling, 1993). *Littorina littorea*, mussels, whelks, limpets and sea urchins tend to dominate in lower shore pools, while other littorinids dominate higher on the shore (Metaxas & Scheibling, 1993). Nevertheless, Metaxas *et al.* (1994) noted that horizontal spatial variability between pools within the same shore height appeared to be as great as variability along the intertidal gradient, and suggested that the physical setting of the pool may be of primary importance in determining the macroalgal abundance. Dethier (1984) examined the effect of natural disturbance rockpool communities in the coast of Washington State. She noted that disturbance such as heat stress in summer and wave action in winter occurred regularly (ca 1.6 times per year per pool). The observed disturbances affected dominant species, so that no one dominant species could occupy all the pools within the tidal range at any one time. None of the tidal pool assemblages observed were stable over many generations and disturbances resulted in a mosaic of species assemblages within pools in any one region (Dethier, 1984).

Dominant trophic groups	Photoautotrophs Herbivores (grazers)

Productivity

Although little information on rockpool productivity was found, rocky shore communities are highly productive and are an important source of food and nutrients for members of neighbouring terrestrial and marine ecosystems (Raffaelli & Hawkins, 1999; Hill *et al.*, 1998). Macroalgae exude considerable amounts of dissolved organic carbon which are absorbed readily by bacteria and may even be taken-up directly by some larger invertebrates. Only about 10% of the primary production is directly cropped by herbivores (Raffaelli & Hawkins, 1999). Dissolved organic carbon, algal fragments and microbial film organisms are continually removed by the sea. This may enter the food chain of local, subtidal ecosystems, or be exported further offshore. Rocky shores make a contribution to the food of many marine species through the production of planktonic larvae and propagules which contribute to pelagic food chains. Accumulations of algal debris are also likely in rockpools and such detrital material contributes to overall productivity.

Information specific to the community was not found but Workman (1983) gave an estimate of primary production by microalgal films on the lower shore in the British Isles to be in the region of 100 g C/m²/yr, much of which will be utilized directly by grazers, while primary productivity for fucoids on sheltered shores was estimated to be 1250 g C/m²/yr (Hawkins *et al.*, 1992) and for encrusting corallines to be 1000 g C/m²/yr (Dawes *et al.*, 1991; Raffaelli & Hawkins, 1999). Ganning & Wulff (1970) reported primary productivity values in terms of gross photosynthesis of between 2 and 3.5 O_2/m^3/ hr in brackish water rock pools dominated by green algae. Overall, deep rockpools with abundant macroalgae are likely to be highly productive mesocosms on the shore.

Major sources of organic carbon	Photosynthesis (macroalgae and/or halophytic plants) Photosynthesis (microalgae)

Recruitment processes

As with the emergent rock surfaces, variation and unpredictability in recruitment of species contributes to the variation in dominant species within rockpool communities and hence spatial variation between rockpools (Dethier, 1984). Recruitment processes of characteristic or dominant species are described here.

Flora

- Vadas *et al.* (1992) reviewed recruitment and mortality of early post settlement stages of benthic algae. They concluded that grazing, canopy and turf effects were the most important but that desiccation and water movement may be as important for the early stages. The review indicated that recruitment is highly variable and episodic and that mortality of algae at this period is high. Chance events during the early post settlement stages are therefore likely to play a large part in survival.
- *Laminaria hyperborea* and *Laminaria digitata* produce vast numbers of spores, however they need to settle and form gametophytes within about 1 mm of each other to ensure fertilization and therefore may suffer from dilution effects over distance. However, Chapman (1981) demonstrated that substantial recruitment of *Laminaria digitata* plants to areas barren of kelp plants was possible up to 600 m away from reproductive plants. *Laminaria saccharina*, is short-lived (2-4 years), reaches maturity quickly and colonizes bare substratum rapidly (ca 6 months) (Kain, 1975; Kain, 1979; Birkett *et al.*, 1998; see *MarLIN* Web site) and may be regarded as relatively opportunistic.
- Fucoids (e.g. *Fucus serratus* and *Fucus vesiculosus*) recruit readily to cleared areas, especially in the absence of grazers (Holt *et al.*, 1997). However, fucoid propagules tend to settle near to the parent plants, due to turbulent deposition by water flow. Within monospecific stands recruitment of conspecifics is most likely, and community recovery is likely to be rapid. However, in cleared areas, recruitment is likely to be rapid but recovery of the original community structure is likely to take some years (Holt *et al.*, 1997). Sousa *et al.* (1981) reported that experimental removal of sea urchins significantly increased recruitment in long-lived brown algae. In experimental plots cleared of algae and sea urchins in December, *Halidrys dioica* colonized the plots, in small numbers, within 3-4 months. Plots cleared in August received few, if any recruits, suggesting that recolonization was dependant on zygote availability and therefore the season. *Halidrys dioica* did not colonize plots grazed by urchins in their experiments (Sousa *et al.*, 1981). Wernberg *et al.* (2001) suggested that the lack of long range dispersal success in *Halidrys siliquosa* was responsible for its regional distribution in the north east Atlantic.
- Settlement of algal spores is partly dependant on their motility (if any) and adhesive properties together with preferences for topography (surface roughness), the chemical nature of the substratum and water movement (Norton 1992; Fletcher & Callow 1992). As with all red algae, the spores of *Chondrus crispus*, *Palmaria palmata* and *Ceramium virgatum* are non-flagellate and therefore dispersal is a wholly passive process (Fletcher & Callow, 1992). In general, due to the difficulties of re-entering the benthic boundary layer, it is likely that successful colonization is achieved under conditions of limited dispersal and/or minimum water current activity. Norton (1992) reported that although spores may travel long distances (e.g. *Ulva* sp. 35 km, *Phycodrys rubens* 5 km), the reach of the furthest propagule does not equal useful dispersal range, and most successful recruitment occurs within 10 m of the parent plants. It is expected, therefore, that recruitment of red algae, e.g. *Chondrus crispus*, *Palmaria palmata*, *Furcellaria lumbricalis*, *Mastocarpus stellatus* and the majority of other macroalgae in the biotope would occur from local populations on the surrounding emergent rock but that establishment and recovery of isolated populations would be patchy and sporadic. Scrosati *et al.* (1994) commented that viability of spores of *Chondrus crispus* was low (<30%) and suggested that reproduction by spores probably does not contribute much to

maintenance of the intertidal population in Nova Scotia, compared to vegetative growth of gametophytes. However, macroalgae are highly fecund and widespread in the coastal zone so that recruitment may be still be rapid, especially in the rapid growing ephemeral species such as *Ulva* spp., which reproduce throughout the year with a peak in summer. Similarly, *Ceramium* species produce reproductive propagules throughout the year, while *Mastocarpus stellatus* produce propagules from February to December, and exhibit distinct reproductive papillae in summer (Dixon & Irvine, 1977; Burrows, 1991; Maggs & Hommersand, 1993).

- *Lithophyllum incrustans*, representing the encrusting corallines in the biotope, it has been calculated that 1 mm x 1mm of reproductive thallus produces 17.5 million bispores per year with average settlement of only 55 sporelings/year (Edyvean & Ford, 1984). Dispersal is likely to be in excess of 5 km and spores will settle and new colonies will arise rapidly on bare substratum, although the growth rate is slow (2-7 mm per annum - see Irvine & Chamberlain, 1994). The erect coralline *Corallina officinalis* has isomorphic sexual (gametophyte) and asexual (sporophyte) stages (see *MarLIN* Web site). Settlement and development of fronds is optimal on rough surfaces but settlement can occur on smooth surfaces (Harlin & Lindbergh, 1977; Wiedeman pers comm.). *Corallina officinalis* settled on artificial substrata within 1 week of their placement in the intertidal in New England summer suggesting that recruitment is high (Harlin & Lindbergh, 1977).

Fauna

- Gastropods exhibit a variety of reproductive life cycles. The common limpets *Patella vulgata* and *Patella ulyssiponensis*, the top shell *Gibbula umbilicalis*, and *Littorina littorea* have pelagic larvae with a high dispersal potential, although recruitment and settlement is probably variable. However, *Littorina obtusata* lays its eggs on the fronds of fucoids form which hatch crawl-away miniature adults. Similarly, the dog whelk *Nucella lapillus* lays egg capsules on hard substrata in damp places on the shore, from which crawl-always emerge. Therefore, their dispersal potential is limited but probably designed to colonize an abundant food source. In addition, most gastropods are relatively mobile, so that a large proportion of recruitment of available niches would involve migration. *Nucella lapillus* is an exception, as they generally do not move far, averaging 100 mm /tidal cycle, or between 30 cm or 10 m per year when in the vicinity of an abundant food source (see *MarLIN* Web site for details; Fish & Fish, 1996).
- Many species of mobile epifauna have long lived pelagic larvae and/or are highly motile as adults. Gammarid amphipods brood their embryos and offspring but are highly mobile as adults and probably capable of colonizing new habitats from the surrounding area (e.g. see *Hyale prevostii* review on *MarLIN* Web site for example). Similarly, isopods such as *Idotea* species brood their young. *Idotea* species are mobile and active swimmers and probably capable to recruiting to new habitats from the surrounding area by adult migration. Hicks (1985) noted that epiphytic harpacticoid copepods lack planktonic dispersive larval stages but are active swimmers, which is therefore the primary mechanism for dispersal and colonization of available habitats. Some species of harpacticoids are capable to moving between low and mid-water levels on the shore with the tide, while in others colonization rates decrease with increasing distance form resident population. Overall immigration and *in situ* reproduction were thought to maintain equilibrium populations exposed to local extinction, although there may be local spatial variation in abundance (see Hicks, 1985).
- Epiphytic and sessile fauna, such as sponges, hydroids, bryozoans and ascidians, have pelagic but short lived larvae with relatively short effective dispersal ranges, depending on the local hydrography. However, most epiphytic species are widespread and ubiquitous and would probably recruit rapidly from adjacent or nearby populations.

Time for community to reach maturity

Development of the community in this biotope, from bare or denuded rock, is likely to follow a similar successional pattern to emergent sheltered rocky shore communities. The loss of grazing species results in an initial proliferation of ephemeral green then fucoid algae, which then attracts mobile grazers, and encourages settlement of other grazers. Limpet grazing reduces the abundance of fucoids allowing barnacles to colonize the shore. After the *Torrey Canyon* oil spill in March 1967, recovery rates were dependant on local variation in recruitment and mortality so that sites varied in recovery rates, for example maximum cover of fucoids occurred within 1-3 years, barnacle abundance increased in 1-7 years, limpet number were still reduced after 6-8 years and species richness was regained in 2 to >10 years (Southward & Southward, 1978; Hawkins & Southward, 1992; Raffaelli & Hawkins, 1999). Where only the rockpool was affected, recruitment is potentially good, especially in motile species. However, variability in rockpool communities and their response to disturbance (recovery) has been attributed to variation and seasonality in recruitment (Metaxas & Scheibling, 1993).

Dethier (1984) noted that few rockpool populations, even of dominant species, remained static over time, based on long-term observations over several years. On the coast of Washington State, partial disturbance (a reduction in abundance or cover) resulted in relatively rapid recovery of the community, for examples encrusting corallines recovered in over 2 months, erect corallines attained 87% of its original cover in 2 years. The red algae *Rhodomela* sp. exhibited 39% recovery from total loss after 2 years and *Cladophora* sp. exhibited 77% recovery after total loss. Dethier (1984) concluded that disturbance was a factor that developed a mosaic of different communities in rockpools within an area and that, at any point in time, rockpool communities were probably in different stages of recovery.

Additional information

None entered

Habitat preference and distribution

Distribution in Britain and Ireland

Recorded from suitable locations around the coast of Britain and Ireland.

Habitat preferences

Temperature range preferences	See additional information
Water clarity preferences	No information found
Limiting nutrients	No information found
Other preferences	Deep rockpools

Additional information

This biotope is characterized by macroalgal dominated, deep rockpools. The physical characteristics of the rockpool environment are described under 'Seasonal and longer term change' on the 'Ecology' page. Pyefinch (1943) and Goss-Custard *et al.* (1979) provide detailed species lists for the rockpools they studied in British and Irish waters.

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	**Species name**	**Common Name**
Important characterizing	*Laminaria digitata*	Oarweed
Important characterizing	*Laminaria saccharina*	Sugar kelp
Important characterizing	*Fucus serratus*	Toothed wrack
Important characterizing	*Halidrys siliquosa*	Sea oak
Important Structural	*Palmaria palmata*	Dulse
Important Structural	*Chondrus crispus*	Carrageen
Important Structural	*Ceramium virgatum*	A red seaweed

Important Structural	*Corallina officinalis*	Coral weed
Important functional	*Littorina littorea*	Common periwinkle
Important functional	*Patella vulgata*	Common limpet
Important functional	*Amphipoda*	Amphipods

Explanation

Laminaria digitata, *Laminaria saccharina*, *Fucus serratus* and *Halidrys siliquosa* have been selected as important characterizing species since they are faithful fucoids and kelps within the biotope (see Connor *et al.*, 1997b). However, loss of any one of these species would not in itself result in loss of a recognizable biotope. Therefore, for the sake of sensitivity assessment the fucoids and kelps have been treated as a functional group.

Palmaria palmata and *Ceramium virgatum* have been chosen to represent the sensitivity of characteristic foliose and filamentous red algae, and *Corallina officinalis* to represent corallines. Littorinids, limpets and amphipods have been shown to be important grazers in rockpool environments (see 'ecological relationships') that affect community structure and development. Their sensitivities are represented by *Littorina littorea* and *Patella vulgata*. The sensitivity of amphipods is treated as a functional group, although reference has been made to relevant species reviews e.g. *Hyale prevostii*.

Species found especially in biotope

No text entered

Additional information

The MNCR database lists 667 species in 213 records of this biotope (JNCC, 1999), although not all species occur in all records of the biotope. Lewis (1964) noted that deep pools in the lower shore, especially in the southwest, are rich areas for collecting the rarer species of algae.

Biotope sensitivity

Physical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	Moderate	Moderate	Major Decline	Low
Smothering	High	Moderate	Moderate	Decline	Low
Increase in suspended sediment	Intermediate	High	Low	Decline	Low
Decrease in suspended sediment	Tolerant	Not Relevant	Not sensitive	No Change	Low
Desiccation	Intermediate	High	Low	Decline	Low
Increase in emergence regime	High	Moderate	Moderate	Decline	Low
Decrease in emergence regime	Low	Very high	Very Low	Rise	Low
Increase in water flow rate	Not Relevant	Not Relevant	Not relevant	Not Relevant	Moderate
Decrease in water flow rate	Not Relevant	Not Relevant	Not relevant	Not Relevant	Moderate

Increase in temperature	Low	Very high	Very Low	Minor Decline	Low
Decrease in temperature	Intermediate	High	Low	Minor Decline	Low
Increase in turbidity	Intermediate	High	Low	Minor Decline	Low
Decrease in turbidity	Low	Very high	Very Low	No Change	Low
Increase in wave exposure	High	Moderate	Moderate	Minor Decline	Low
Decrease in wave exposure	High	Moderate	Moderate	Major Decline	Low
Noise	Tolerant	Not Relevant	Not sensitive	No Change	High
Visual Presence	Tolerant	Not Relevant	Not sensitive	No Change	High
Abrasion & physical disturbance	Intermediate	High	Low	Minor Decline	Low
Displacement	High	Moderate	Moderate	Decline	Low
Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	High	Moderate	Moderate	Major Decline	Low
Heavy metal contamination	Intermediate	High	Low	Minor Decline	Low
Hydrocarbon contamination	Intermediate	Moderate	Moderate	Major Decline	Low
Radionuclide contamination	Insufficient information	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Changes in nutrient levels	Intermediate	High	Low	Decline	Low
Increase in salinity	Low	Very high	Very Low	No Change	Low
Decrease in salinity	Tolerant	Not Relevant	Not sensitive	No Change	Low
Changes in oxygenation	Tolerant	Not Relevant	Not sensitive	No Change	Low
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Low	Very high	Very Low	No Change	Low
Introduction of non-native species	Intermediate	None	Very High	Decline	Moderate

Extraction of key or important characterizing species	Intermediate	High	Low	No Change	Low
Extraction of important species	Low	Very high	Very Low	No Change	Low

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	Loss of the substratum would involve loss of all the species within the rockpool and hence loss of the biotope. Break up of the rocky substratum (e.g. by a grounded vessel) and or infill of the rockpool would constitute loss of available substratum and hence the habitat. Infilling of the rockpool by permanent material (e.g. by cement) or occlusion by revetment material would constitute a permanent loss of the rockpool and biotope. However, in other instances the species could recolonize the remaining pool and recoverability is likely to be high (see additional information below).
Smothering (see benchmark)	Seapy & Littler (1982) reported a decrease in macroalgal cover from 47.3 to 37.5% on a Californian rocky shore due to sediment deposition on the mid to lower shore following rain and flooding. *Corallina* sp. and *Pelvetia* sp. were the most affected macroalgal species, while associated red algae were only slightly affected by the resultant scour. Macroinvertebrates declined in cover from 15.8% to 6.5% particularly barnacle species. Daly & Mathieson (1977) examined intertidal zonation on a shore affected by sand scour, and noted that fucoids were reduced to small or young plants, while sand tolerant species such as *Ahnfeltia plicata* dominated on areas affected by sediment. Smothering by 5 cm of sediment (see benchmark) is likely to increase scour and be detrimental to macroalgae, especially *Corallina officinalis* and fucoids, and the more fleshy red algae. While laminarians and red algae such as *Chondrus crispus* and *Ceramium* spp. are large enough not to be smothered completely by 5 cm of sediment, the resultant scour is likely to damage fronds but, in particular, remove juveniles, sporelings and other propagules. In addition, the rockpool environment is likely to be more vulnerable to smothering as sediment is likely to accumulate in, and be retained by the rockpool itself, effectively increasing the depth of the sediment layer in the pool. In wave exposed conditions the sediment may be removed but in sheltered areas it is likely to be retained for longer than indicated by the benchmark. In deep pools, the macroalgae and associated invertebrates are likely to reduce in depth penetration into the pool while sediment tolerant algae increase. Overall, smothering is likely to reduce the macroalgal diversity of the pool, exclude grazing littorinids, and smother small epifaunal species such as sponges, bryozoans, small anemones and ascidians, although large anemones may survive (e.g. *Urticina felina*). Where sediment is retained the sediment tolerant algae may come to dominate and the biotope will resemble LR.SwSed. Therefore, an intolerance of high has been recorded. Recoverability is likely to be moderate (see additional information below). However, in extremely high suspended sediment loads, as found in estuaries, rockpools may become completely filled with fine sediment, so that only infaunal species survive.
Increase in suspended sediment (see benchmark)	An increase in suspended sediment could potentially result in increased turbidity (see below), smothering, especially on sheltered shores (see above), and increased scour. Fucoids, kelps and other macroalgae, and the community they support, are likely to be adversely affected, as shown above (Daly & Mathieson, 1977; Seapy & Littler, 1982). On wave sheltered shores, sediment may accumulate in low to mid shore pools, which will favour sand tolerant species and infauna. Overall, macroalgae are likely to be damaged but the biotope is likely to remain but the species diversity decrease (for example see Daly & Mathieson, 1977). Therefore, an intolerance of intermediate has been recorded, although recovery is potentially high (see additional information below). However, in extreme situations deposition of fine sediments may result in smothering of the rockpool (see above).

Decrease in suspended sediment (see benchmark)	A decrease in suspended sediment could reduce the turbidity (see below) and potentially reduce the food availability for suspension feeders, due to a reduction in organic particulates. However, suspension feeders will continue to feed on available plankton and detritus and be little affected. Similarly, the resident macroalgae are unlikely to be adversely affected by reduced sediment loads, except that scour is reduced. Therefore, tolerant has been recorded.
Desiccation (see benchmark)	Rockpools are natural refuges from desiccation but may be drained due to slow seepage or due to 'bucketing' by shore users, resulting in a decrease in the water level and hence desiccation exposure. Many members of the biotope are common on the emergent rock surface (e.g. fucoids, red algae, littorinids) and therefore, exhibit relative tolerance of desiccation. However, the presence of the rockpool allows species to occur in niches higher on the shore than they would otherwise. Low shore, sublittoral fringe or sublittoral species within the pool would be particularly intolerant of desiccation, e.g. *Furcellaria lumbricalis* and low shore algae. However, such drainage is likely to be short-lived, and the water level return to normal levels after the next high tide. Therefore, an increase in desiccation at the benchmark level, an increase equivalent to a rise in shore height, is likely to result in a decrease in species richness, although the biotope itself is likely to remain and an intolerance of intermediate has been recorded. Recoverability is likely to be high (see additional information).
Increase in emergence regime (see benchmark)	An increase in emergence is likely to significantly affect physico-chemical environment of the rockpool and its resident community. An increase in emergence will increase the time that the pool is exposed to fluctuating air temperatures, wind, rain and sunlight, all of which will affect the temperature and salinity regime within the pool. Lower shore pools will come to resemble mid shore pool communities, with a reduction in sublittoral species and species sensitive to extremes of temperature, for example the laminarians (see individual reviews). For example, the upper limit of *Bifurcaria bifurcaria* within rockpools in Roscoff, France was shown to be limited by the summer temperatures where the surface pool water temperatures exceeded 20 °C (Kooistra *et al.*, 1989). Mid shore examples of LR.FK are likely to be worst affected. High shore pools tend to support communities of temperature tolerant or opportunistic algae, especially green algae such as *Ulva* spp., and temperature and salinity tolerant species such as harpacticoid copepods, ostracods, and small gastropods (for example see LR.G). This biotope would be lost from mid shore areas as a result of an increase in emergence at the benchmark level. Therefore, an intolerance of high has be recorded and recoverability is probably moderate (see additional information below).
Decrease in emergence regime (see benchmark)	A decrease in emergence will reduce the time the pool spends exposed to the air and cut off from the sea. Therefore, the range of temperatures and oxygen levels characteristic of rockpool environments is likely to decrease. Hence the mid shore pool communities will come to resemble low shore pools. Low shore pools are characterized by higher abundance of large macroalgae, such as *Halidrys siliquosa, Cystoseira* sp. and laminarians and a larger diversity of red algae and macrofauna. Low shore pools will probably be colonized by an increasing number of sublittoral species. Therefore, although the community is likely to increase in diversity the biotope is likely to remain. Therefore, an intolerance of low has been recorded to reflect changes in community structure.
Increase in water flow rate (see benchmark)	Water flow rate in this biotope is typically only that of the ebb and flood tide speed, which hardly affects intertidal habitats and is far exceeded by the strength of wave action. A change in water flow rate is therefore considered not relevant.
Decrease in water flow rate (see benchmark)	Water flow rate in this biotope is typically only that of the ebb and flood tide speed, which hardly affects intertidal habitats and is far exceeded by the strength of wave action. A change in water flow rate is therefore considered not relevant.
Increase in temperature	Rockpools experience variation in temperature on a daily and seasonal basis. The range and extremes of temperature change increasing with shore height but also dependent on shading, aspect, topography and depth of the pool (Pyefinch, 1943; Ganning, 1971;

(see benchmark)	Daniel & Boyden, 1975; Goss-Custard *et al.*, 1979; Morris & Taylor, 1983; Huggett & Griffiths, 1986; Metaxas & Scheibling, 1993). For example, reported temperature ranges for mid to low shore pools include annual maxima and minima of 1-25 °C and 2-22 °C (Morris & Taylor, 1983), a diurnal range of 24 °C (day) and 13 °C (night) for a mid shore pool (Daniel & Boyden, 1975), and surface water temperature ranges of 14-19.25 °C and 15.5-20.75 °C in mid shore pools (Pyefinch, 1943). Temperature stratification within pools may result in higher surface temperatures and lower deep water temperatures in sunlight (Daniel & Boyden, 1977) or be reversed due to wind cooling, night or in winter (Naylor & Slinn, 1958; Ganning, 1971; Morris & Taylor, 1983). The temperature range will limit the distribution of sensitive species within the pools, especially normally sublittoral species, e.g. laminarians (see individual reviews). For example, the upper limit of *Bifurcaria bifurcaria* within rockpools in Roscoff, France was shown to be limited by the summer temperatures where the surface pool water temperatures exceeded 20 °C (Kooistra *et al.*, 1989). Therefore, an increase in ambient temperatures is likely to reduce the abundance or vertical extent of sensitive species within the biotope, especially in shallower examples of the biotope. However, the range and extremes of temperature routinely experienced by the biotope are greater than the benchmark level and an intolerance of low has been recorded to represent a potential decrease in species diversity.
Decrease in temperature (see benchmark)	Rockpools experience variation in temperature on a daily and seasonal basis. The range and extremes of temperature change increasing with shore height but also dependent on shading, aspect, topography and depth of the pool (Pyefinch, 1943; Ganning, 1971; Daniel & Boyden, 1975; Goss-Custard *et al.*, 1979; Morris & Taylor, 1983; Huggett & Griffiths, 1986; Metaxas & Scheibling, 1993). For example, reported temperature ranges for mid to low shore pools include annual maxima and minima of 1-25 °C and 2-22 °C (Morris & Taylor, 1983), a diurnal range of 24 °C (day) and 13 °C (night) for a mid shore pool (Daniel & Boyden, 1975), and surface water temperature ranges of 14-19.25 °C and 15.5-20.75 °C in mid shore pools (Pyefinch, 1943). Temperature stratification within pools may result in higher surface temperatures and lower deep water temperatures in sunlight (Daniel & Boyden, 1977) or be reversed due to wind cooling, or in winter (Naylor & Slinn, 1958; Ganning, 1971; Morris & Taylor, 1983). Morris & Taylor (1983) reported that the surface of an upper shore was seen to freeze one winter night, although that this was a rare event. Freezing is likely to be rare in mid or low shore pools. Nevertheless the severe winter of 1962/63 resulted in a wide variety of mortalities in the intertidal and shallow subtidal (Crisp, 1964). For example, few macroalgae were damaged but specimens of *Cystoseira* spp. in the south and south west were smaller than usual. However, the anemone *Anemonia viridis* was missing from shallow pools and that only a single specimen of *Cereus pedunculatus* was found in an area of usual abundance, while many dead specimens of both species were found in south Wales. Similarly, many dead porcelain crabs (*Porcellana* spp.) were found. *Patella vulgata* exhibited increasing mortality with shore height and hence emersion (Crisp, 1964), and several species of gastropod exhibited mortality. Although southern, lusitanian, species were worst affected, mortalities of individual species varied with location. However, rockpools, especially deep pools and low shore pools are likely to represent a buffer from the extreme cold and frosts experienced by fauna and flora on the emergent rock surface. Overall, the range of temperatures routinely experienced by mid to low shore rock pools is greater than the benchmark level. However, the severe winter of 1962/63 suggests that some sensitive species, particularly limpets and gastropods, and anemones near the surface of deep pools may be affected. The loss of grazers may benefit the macroalgal community, resulting in increased growth of fucoids and green algae. Therefore, an intolerance of intermediate has been recorded to represent the loss of species diversity and changes in community structure, especially in mid shore examples of the biotope. Recoverability is probably high (see additional information below).
Increase in turbidity	An increase in turbidity due to suspended sediment, dissolved organics or phytoplankton blooms will reduce the depth that light can penetrate the pool and hence

(see benchmark)	the depth within the pool that different groups of algae can grow, particularly kelps. For example, in the silt-laden waters around Helgoland, Germany the depth limit for *Laminaria digitata* growth may be reduced to between 0 m and 1.5 m (Birkett *et al.*, 1998). Increased turbidity around a sewage treatment plant was thought to be responsible for the absence of *Laminaria digitata* plants in the Firth of Forth (Read *et al.*, 1983). In Narragansett Bay, Rhode Island growth rates of *Laminaria digitata* fell during a summer bloom of microalgae that dramatically reduced down welling irradiance. Quality of light is also important with blue light necessary for gametogenesis and development of gametophytes in laminarians. Dissolved organic materials (yellow substance or gelbstoff) absorbs blue light strongly, therefore changes in riverine input or other land based runoff are likely to influence kelp density and distribution. Light levels often determine the maximum depth for survival of *Laminaria saccharina* at a particular site (Lüning & Dring, 1975; Gerard, 1988) therefore an increase in turbidity may lead to the mortality of some plants towards the deeper end of their depth range, although Gerard (1988) reported that *Laminaria saccharina* populations may adapt to low or variable light conditions. Moss & Sheader (1973) demonstrated that the growth of *Halidrys siliquosa* germlings was dependent on light intensity but that germlings could survive total darkness for 120 days (see general biology). *Fucus serratus* can normally photosynthesize when emersed so that increased turbidity on emergent rocks is unlikely to be detrimental although growth rates are likely to be reduced. Overall, an increase in turbidity of the water will reduce the depth within the pool that macroalgae can grow, so that kelps and to a lesser extent the fucoids are likely to be limited to the upper margin of the pool. However, shade tolerant red algae may benefit and dominate the deeper parts of the pool. An increase in turbidity at the benchmark level may result in loss of laminarians from deep pools, especially *Laminaria digitata*, but fucoids and hence the biotope will probably remain at the surface. Therefore, an intolerance of intermediate has been recorded to represent the potential loss of kelp species, although recoverability is likely to be high.
Decrease in turbidity (see benchmark)	A decrease in turbidity will increase light penetration, and hence the growth of all macroalgae, especially kelps species, and increase the depth at which red algae or fucoids may grow, possibly increasing competition for space between the algae themselves and other space occupiers such as sponges and ascidians. However, the effects are likely to depend on the size of the pool. In smaller pools, increased growth of kelps and fucoids is likely to result in self-shading, so that the net effect is likely to be minimal. Therefore, an intolerance of low has been recorded.
Increase in wave exposure (see benchmark)	This rockpool biotope occurs in wave sheltered to wave exposed habitats. The rockpool provides a degree of shelter from wave action, especially deep pools, allowing more fragile sublittoral algae to survive. However, an increase in wave exposure from, for example moderately exposed to very exposed is likely change the community. Fucoid abundance in characteristic of wave sheltered conditions, and on more wave exposed shores shallow rockpools are dominated by *Corallina officinalis* (see LR.Cor). Therefore, an increase in wave exposure at the benchmark level is likely to reduce the abundance or remove fucoids from the margin of the pool, in favour of corallines. *Laminaria digitata* is likely to be replaced by *Alaria esculenta*, which tolerates strong water movement. Lewis (1964) noted that *Halidrys siliquosa*, and *Cystoseira* spp. were restricted to deep mid shore pools with increasing wave exposure. Similarly, the increased turbulence within the pool itself will favour species that prefer strong water movement, such as the passive suspension feeders e.g. hydroids (e.g. *Tubularia larynx*) and anemones (e.g. *Metridium senile*) and other epifauna, together with more wave exposure tolerant red algae, e.g. *Porphyra* sp., *Plocamium* sp. and *Gigartina* sp.. However, with increasing wave exposure the biotope is likely to change, and may come to resemble *Corallina officinalis* rockpool biotopes, depending on the relative abundance of *Bifurcaria bifurcata* (in the south west) and *Cystoseira* spp (see LR.Cor). Therefore, the biotope is likely to be lost, and although replaced by another healthy community, an intolerance of high has been recorded. Recoverability is likely to be moderate (see additional information below).

Decrease in wave exposure (see benchmark)	This rockpool biotope occurs in wave sheltered to wave exposed habitats. A decrease in wave exposure from e.g. sheltered to very sheltered, or extremely sheltered is likely to adversely affect the biotope. The resultant lack of water movement is likely to result in increased suspended sediment and siltation of the rockpool, smothering and filing the rockpool. Fucoids will survive on the margins of the pool and emergent rock, however laminarians, and epifauna are likely to be lost and only sediment tolerant red algae survive within the pool. The biotope may come to resemble LR.SwSed, or in worst case situations become silted up, so that only infauna survive. Therefore, an intolerance of high has been recorded, with moderate recoverability (see additional information below).
Noise (see benchmark)	Few organisms within the biotope are likely to respond to noise or vibration at the benchmark level. Fish may attempt to leave the biotope at high tide but would otherwise be trapped at low tide. Overall, little if any effect on the biotope is expected.
Visual Presence (see benchmark)	Mobile invertebrates and fish are able to react to shading, usually darting to cover in order to avoid a potential predator. However, their visual acuity is low, and they are unlikely to be adversely affected by visual presence.
Abrasion & physical disturbance (see benchmark)	Abrasion by an anchor or mooring may remove some fronds of the large macroalgae, foliose red algae and coralline turf, although most species would grow back from their remaining holdfasts. However, trampling may be more damaging. Deep pools are protected by their depth but shallower pools or the shallower margins of larger pools are probably more vulnerable. No studies of the effects of trampling on rockpools were found but studies of the effects on emergent algal communities are probably indicative. For example, moderate (50 steps per 0.09 square metre) or more trampling on intertidal articulated coralline algal turf in New Zealand reduced turf height by up to 50%, and the weight of sand trapped within the turf to about one third of controls. This resulted in declines in densities of the meiofaunal community within two days of trampling. Although the community returned to normal levels within 3 months of trampling events, it was suggested that the turf would take longer to recover its previous cover (Brown & Taylor, 1999). Similarly, Schiel & Taylor (1999) noted that trampling had a direct detrimental effect on fucoid algae and coralline turf species on the New Zealand rocky shore. Low trampling intensity (10 tramples) reduced fucoid cover by 25%, while high intensity (200 tramples) reduced fucoid cover by over 90%, although over 97% cover returned within 21 months after spring trampling; autumn treatments took longer to recover due to the delay in recruitment. Coralline bases were seen to peel from the rocks (Schiel & Taylor, 1999) due to increased desiccation caused by loss of the algal canopy. Brosnan & Cumrie (1994) demonstrated that foliose species (e.g. fucoids and *Mastocarpus papillatus*) were the most susceptible to trampling disturbance, while turf forming species were more resistant. Barnacles were also crushed and removed. However, the algae and barnacles recovered in the year following the trampling (Brosnan & Cumrie, 1994). Similarly, Boalch *et al.* (1974) and Boalch & Jephson (1981) noted a reduction in fucoid cover (especially of *Ascophyllum nodosum*) at Wembury, Devon, when compared with the same transects surveyed 43 years previously. They suggested that the reduction in fucoid cover was due to the large number of visitors and school groups received by the site. Rockpools form natural mesocosms and so attract considerable attention from the general public, educational events and scientists alike. In addition to trampling within shallower pools and the margins of deeper pools, turning of rocks within the pool is likely to disturb underboulder communities (e.g. see MLR.Fser.Fser.Bo). Overall, a proportion of the macroalgal community, and the invertebrates it supports are likely to be removed, depending on trampling intensity, and an intolerance of intermediate has been recorded. Recoverability is likely to be high (see additional information below) once trampling has stopped. However, it should be noted that ongoing trampling is likely to result in a long term reduction in the diversity of the margins of the affected

	pools.
Displacement (see benchmark)	The majority of the epiphytic fauna, such as the isopods, amphipods and harpacticoid copepods are highly mobile are unlikely to be adversely affected by displacement. Similarly, gastropods are likely to survive and migrate back to suitable feeding areas. But the dominant macroalgae and sessile epifauna (e.g. barnacles and tubeworms) are permanently attached to the substratum and if removed will be lost. Loss of the fucoids and kelps especially will result in loss of the biotope overall. If macroalgal holdfasts and bases are also removed then recovery will be prolonged.
Chemical Factors	
Synthetic compound contamination (see benchmark)	The different groups of organisms within the biotope are likely to vary in their response to synthetic chemical pollution. Key examples are summarized below. • Cole *et al.* (1999) suggested that the following were very toxic to macrophytes: atrazine; simazine; diuron; and linuron (herbicides). Atrazine was lethal to young sporophytes of *Laminaria hyperborea* at 1 mg/l and caused growth suppression at 10 µg/l in short term experiments (Hopkin & Kain, 1978). Mixed detergents, herbicides (dalapon and 2,4-D) were not toxic at the levels tested (Hopkin & Kain, 1978). Although *Laminaria hyperborea* sporelings and gametophytes are intolerant of atrazine (and probably other herbicides) overall mature specimens may be relatively tolerant of synthetic chemicals probably due to the presence of alginates (Holt *et al.* 1995). • *Laminaria hyperborea* survived within >55m from the acidified halogenated effluent discharge polluting Amlwch Bay, Anglesey, albeit at low density. These specimens were greater the 5 years of age, suggesting that spores and/or early stages were more intolerant (Hoare & Hiscock, 1974). However, *Laminaria digitata* was less tolerant, and although it was found within Amlwch Bay, it was excluded from >90 m of the effluent source (Hoare & Hiscock, 1974). *Helcion pellucidum* was excluded from Amlwch Bay by the pollution and the species richness of the holdfast fauna decreased with proximity to the effluent discharge; amphipods were particularly intolerant although polychaetes were the least affected (Hoare & Hiscock, 1974). The richness of epifauna/flora decreased near the source of the effluent and epiphytes were absent from *Laminaria hyperborea* stipes within Amlwch Bay. • Fucoids are generally quite robust in terms of chemical pollution (Holt *et al.*, 1997). However, *Fucus vesiculosus* is extraordinarily highly intolerant of chlorate, such as from pulp mill effluents. In the Baltic, the species has disappeared in the vicinity of pulp mill discharge points and is affected even at immediate and remote distances (Kautsky, 1992). The different life stages of *Fucus serratus* differ in their intolerance to synthetic chemicals. Scalan & Wilkinson (1987) found that spermatozoa and newly fertilized eggs of *Fucus serratus* were the most intolerant of biocides, while adult plants were only just significantly affected at 5 ml/l of the biocides Dodigen v181-1, Dodigen v 2861-1 and ML-910. • O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination, possibly due to the susceptibility of phycoerythrins to destruction. They also suggested that red algae were effective indicators of detergent damage since they undergo colour changes when exposed to relatively low concentration of detergent. Smith (1968) reported that red algae such as *Ahnfeltia plicata*, *Chondrus crispus*, *Furcellaria fastigiata*, *Mastocarpus stellatus*, *Polyides rotundus* and *Osmundea pinnatifida* were amongst the algae least affected by detergents, whereas other species, including *Ceramium* spp., *Cryptopleura ramosa*, *Cladophora rupestris*, *Lomentaria articulata* and *Ulva lactuca* were either killed or unhealthy, although the effects were worst higher on the shore, which had received the most detergents. *Delesseria sanguinea* was probably to most intolerant since it was damaged at depths of 6m (Smith, 1968). Holt *et al.* (1995) suggested that *Delesseria*

sanguinea is probably generally sensitive of chemical contamination. Laboratory studies of the effects of oil and dispersants on several red algal species concluded that they were all sensitive to oil/dispersant mixtures, with little difference between adults, sporelings, diploid or haploid life stages (Grandy, 1984; cited in Holt *et al.*, 1995). Hoare & Hiscock (1974) noted that all red algae except *Phyllophora* sp. were excluded from near to an acidified halogenated effluent discharge in Amlwch Bay, Anglesey and that intertidal populations of *Corallina officinalis* occurred in significant amounts only 600 m east of the effluent.

- Smith (1968) reported that oil and detergent dispersants from the *Torrey Canyon* spill affected high water specimens of *Corallina officinalis* more than low shore specimens and some specimens were protected in deep pools. In areas of heavy detergent spraying, however, *Corallina officinalis* was killed, and was affected down to 6m depth at one site, presumably due to wave action and mixing (Smith, 1968). However, regrowth of fronds had begun within 2 months after spraying ceased (Smith, 1968).
- Gastropods and amphipods were found to be amongst the most sensitive species to detergents and oils. For example, limpets are extremely intolerant of aromatic solvent based dispersants used in oil spill clean-up. During the clean-up response to the *Torrey Canyon* oil spill nearly all the limpets were killed in areas close to dispersant spraying. Viscous oil will not be readily drawn in under the edge of the shell by ciliary currents in the mantle cavity, whereas detergent, alone or diluted in sea water, would creep in much more readily and be liable to kill the limpet (Smith, 1968). A concentration of 5 ppm killed half the limpets tested in 24 hours (Southward & Southward, 1978; Hawkins & Southward, 1992). Toxicity experiments with gastropods demonstrated that 10 ppm of BP1002 was enough to cause the animals to close and stop climbing (Smith, 1968). Smith (1968) noted that over a 100 ppm of BP1002 was required to kill the majority of *Nucella lapillus* in experiments, while different concentrations of BP1002 killed the majority of the following: *Littorina littorea* (100 ppm); *Calliostoma zizyphinum* (10 ppm); *Aplysia punctata* (50 ppm), and *Patella vulgata* (5 ppm) (see individual reviews). *Nucella lapillus* and other muricid gastropods are noted for their sensitivity to tri-butyl tin contamination (see review).
- Smith (1968) also noted that after detergent treatment, only beadlet anemone *Actinia equina*, and tufts of *Bifurcaria* sp., *Corallina* sp., and other algae were present in a rockpool. The pool had previously supported a community of anemones, gastropods, *Corallina, Lithophyllum, Enteromorpha*, crabs, prawns and fish.
- Most pesticides and herbicides were suggested to be very toxic for invertebrates, especially crustaceans (amphipods, isopods, mysids, shrimp and crabs) and fish (Cole *et al.*, 1999). For example, lindane was shown to be very toxic to gobies (*Gobius* spp.; see *Pomatoschistus minutus* review) (Ebere & Akintonwa, 1992). The pesticide ivermectin is very toxic to crustaceans, and has been found to be toxic towards some benthic infauna such as *Arenicola marina* (Cole *et al.*, 1999).

Overall, the evidence suggests that, on balance, the characterizing red algae are probably very intolerant to synthetic chemicals, while resident gastropods, crustaceans and fish vary in their sensitivity. Loss of grazing invertebrates will affect community structure. Contamination with herbicides or other pesticides, e.g. from agricultural runoff, could adversely affect all components of the community. Therefore, biotope intolerance is assessed as high. Rockpools might be expected to accumulate chemical contaminants, depending on the rate of flushing, so that mid shore pools may be more vulnerable than low shore examples of the biotope. Recoverability is probably moderate (see additional information below).

Heavy metal contamination (see benchmark)	Bryan (1984) suggested that the general order for heavy metal toxicity in seaweeds is: organic Hg > inorganic Hg > Cu > Ag > Zn > Cd >Pb. Cole *et al.* (1999) reported that Hg was very toxic to macrophytes. The sub-lethal effects of Hg (organic and inorganic) on the sporelings of an intertidal red algae, *Plumaria elegans*, were reported by Boney (1971). 100% growth inhibition was caused by 1 ppm Hg. Burdin & Bird (1994) reported that both gametophyte and tetrasporophyte forms of *Chondrus crispus* accumulated Cu, Cd, Ni, Zn, Mn and Pb when immersed in 0.5 mg/l solutions for 24 hours. No effects were reported however, and no relationship was detected between hydrocolloid characteristics and heavy metal accumulation. It is generally accepted that adult fucoids are relatively tolerant of heavy metal pollution (Holt *et al.*, 1997). The effect of heavy metals on the growth rate of adult *Fucus serratus* plants has been studied by Strömgren (1979b;1980a, b). Copper significantly reduces the growth rate of vegetative apices at 25 µg/l over 10 days (Strömgren, 1979b). Zinc, lead, cadmium & mercury significantly reduce growth rate at 1400 µg/l, 810 µg/l, 450 µg/l and 5 µg/l respectively (Strömgren, 1980a, b). Zinc was found to inhibit growth in *Laminaria digitata* at a concentration of 100 µg/L and at 515 µg/L growth had almost completely ceased (Bryan, 1969). Axelsson & Axelsson (1987) investigated the effect of exposure to mercury (Hg), lead (Pb) and nickel (Ni) for 24 hours by measuring ion leakage to indicate plasma membrane damage. Inorganic and organic Hg concentrations of 1 mg/L resulted in the loss of ions equivalent to ion loss in seaweed that had been boiled for 5 minutes. *Laminaria digitata* was unaffected when subjected to Pb and Ni at concentrations up to 10 mg/L. Their results also indicated that the species is intolerant of the tin compounds butyl-Sn and phenyl-Sn. Sporophytes of *Laminaria saccharina* have a low intolerance to heavy metals but the early life stages are more intolerant (Thompson & Burrows, 1984). Growth of sporophytes was significantly inhibited at 50 µg Cu /l, 1000 µg Zn/l and 50 µg Hg/l. Zoospores were found to be more intolerant and significant reductions in survival rates were observed at 25 µg Cu/l, 1000 µg Zn/l and 5 µg/l (Thompson & Burrows, 1984). Bryan (1984) suggested that adult gastropod molluscs were relatively tolerant of heavy metal pollution. Cole *et al.* (1999) suggested that Pb, Zn, Ni and As were very toxic to algae, while Cd was very toxic to Crustacea (amphipods, isopods, shrimp, mysids and crabs), and Hg, Cd, Pb, Cr, Zn, Cu, Ni, and As were very toxic to fish. Bryan (1984) reported sublethal effects of heavy metals in crustaceans at low (ppb) levels. In laboratory investigations Hong & Reish (1987) observed 96 hr LC_{50} of between 0.19 and 1.83 mg/l in the water column for several species of amphipod. Cd, Hg, Pb, Zn and Cu are highly persistent, have the potential to bioaccumulate significantly and are all considered to be very toxic to fish (Cole *et al.*, 1999). Mueller (1979) found that in *Pomatoschistus* sp., very low concentrations of Cd, Cu and Pb (0.5 g/l Cd^{2+}; 5 g/l Cu^{2+}; 20 g/l Pb^{2+}) brought about changes in activity and an obstruction to the gill epithelia by mucus. This may also be true for other goby species. Inorganic Hg concentrations as low as 30 µg/l (96-h LC_5) are considered to be toxic to fish, whereas organic Hg concentrations are more toxic to marine organisms (WHO, 1989, 1991). Oertzen *et al*. (1988) found that the toxicity of the organic Hg complex exceeded that of $HgCl_2$ by a factor of 30 for the goby *Pomatoschistus microps*. The intolerance of crustaceans to heavy metal contaminants suggests that amphipod and isopod grazers would be lost, allowing rapid growth of opportunistic algae such as *Ulva* spp. In addition, the characterizing laminarians and their propagules may be adversely affected, and the growth rates of fucoids reduced. Therefore, an intolerance of intermediate has been recorded to represent a decrease in species diversity, although a recognizable biotope is likely to remain. Recoverability is likely to be high (see additional information below).
Hydrocarbon contamination	Hydrocarbon contamination, e.g. from spills of fresh crude oil or petroleum products, may cause significant loss of component species in the biotope, through impacts on

(see benchmark)	individual species viability or mortality, and resultant effects on the structure of the community. Rockpools are potentially vulnerable habitats, depending on depth, flushing rate and tidal height. Rockpool organisms may be protected, since oil will float on the pool surface. However, rockpool organisms will be exposed to the water soluble fraction of fresh oils, and a surface film of oil will prevent gaseous exchange and may reduce or exclude light. If exposed to oil the resident sediment is likely to adsorb oil and release it slowly, causing chronic long-term contamination and potentially prolonged recovery. The effects of oil contamination on marine organisms were reviewed by Suchanek (1993) and are summarized below. • *Laminaria digitata* is less susceptible to coating with oil than some other seaweeds because of its preference for exposed locations where wave action will rapidly dissipate oil. The effects of oil accumulation on the thalli are mitigated by the perennial growth of kelps. No significant effects of the *Amoco Cadiz* spill were observed for *Laminaria* populations and the *World Prodigy* spill of 922 tons of oil in Narragansett Bay had no discernible effects on *Laminaria digitata* (Peckol *et al.*, 1990). Mesocosm studies in Norwegian waters showed that chronic low level oil pollution (25 µg/L) reduced growth rates in *Laminaria digitata* but only in the second and third years of growth (Bokn, 1985). • Holt *et al.* 1995 reported that oil spills in the USA and from the 'Torrey Canyon' had little effect on kelp forest. Similarly, surveys of subtidal communities at a number sites between 1-22.5m below chart datum, including *Laminaria hyperborea* communities, showed no noticeable impacts of the *Sea Empress* oil spill and clean up (Rostron & Bunker, 1997) • *Fucus vesiculosus* shows limited intolerance to oil. After the *Amoco Cadiz* oil spill *Fucus vesiculosus* suffered very little (Floc'h & Diouris, 1980). Indeed, *Fucus vesiculosus* may increase significantly in abundance on a shore where grazing gastropods have been killed by oil, although very heavy fouling could reduce light available for photosynthesis and in Norway a heavy oil spill reduced fucoid cover. • Littoral barnacles (e.g. *Semibalanus balanoides*) have a high resistance to oil (Holt *et al.*, 1995) but may suffer some mortality due to the smothering effects of thick oil (Smith, 1968). • Gastropods (e.g. *Littorina littorea* and *Patella vulgata*) and especially amphipods have been shown to be particularly intolerant of hydrocarbon and oil contamination (see Suchanek, 1993). • The abundance of littorinids decreased after the *Esso Bernica* oil spill in Sullom Voe in December 1978 (Moore *et al.*, 1995). The abundance of *Patella* sp., *Littorina saxatilis, Littorina littorea* and *Littorina neglecta* and *Littorina obtusata* were reduced but had returned to pre-spill levels by May 1979. In heavily impacted sites, subjected to clean-up, where communities were destroyed in the process, *Littorina saxatilis* recovered an abundance similar to pre-spill levels within ca 1 year, while *Littorina littorea* took ca 7 years to recover prior abundance (Moore *et al.*, 1995). • Widdows *et al.* (1981) found *Littorina littorea* surviving in a rockpool, exposed to chronic hydrocarbon contamination due to the presence of oil from the *Esso Bernica* oil spill. • The anemones *Actinia* and *Anthopleura* were reported to survive in waters with severe oil pollution (Smith, 1968; Suchanek, 1993). • Echinoderms are thought to be especially sensitive to oil (Suchanek, 1993). In a survey of rock pool at West Angle Bay, Pembrokeshire, Crump & Emson (1997) noted that limpets, crustaceans (amphipods and *Palaemon*) and the echinoderms *Amphipholis squamata* and the rare *Asterina phylactica* were adversely affected. However, the majority of adult *Asterina gibbosa* survived. The macrofauna, except *Asterina phylactica*, had recovered its diversity and abundance within 12 weeks of the spill (Crump & Emson, 1997). • Laboratory studies of the effects of oil and dispersants on several red algae

	species (Grandy, 1984, cited in Holt *et al.*, 1995) concluded that they were all intolerant of oil/ dispersant mixtures, with little differences between adults, sporelings, diploid or haploid life stages. O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination. However, Smith (1968) noted that ed algae such as *Ahnfeltia plicata*, *Chondrus crispus*, *Furcellaria fastigiata*, *Mastocarpus stellatus*, *Polyides rotundus* and *Osmundea pinnatifida* were amongst the algae least affected by detergents, whereas other species, including *Ceramium* spp., *Cryptopleura ramosa*, *Cladophora rupestris*, *Lomentaria articulata* and *Ulva lactuca* were either killed or unhealthy, although the effects were worst higher on the shore, which had received the most detergents. • Cole *et al.* (1999) suggested a moderate to high toxicity of oils and petrochemicals for fish. Bowling *et al.* (1983) found that anthracene, a Polyaromatic hydrocarbon (PAH) had a photo-induced toxicity to the bluegill sunfish. They reported that when exposed to sunlight anthracene was at least 400 times more toxic than when no sunlight was present. According to Ankley *et al*. (1997) only a subset of PAH's are phototoxic (fluranthene, anthracene, pyrene etc.). Effects of these compounds are destruction of gill epithelia, erosion of skin layers, hypoxia and asphyxiation (Bowling *et al.*, 1983). In PAH contaminated areas, fish have been observed to develop tumours (GESAMP, 1993). Oil spills were reported to have low acute toxicity to adult fish (GESAMP, 1993), probably since adults can avoid contaminated areas, but that fish kills may occur after exposure to emulsified oil in shallow waters, e.g. after the *Braer* oil spill (GESAMP, 1993). However, in the rockpool environment, fish are unlikely to be able to avoid the water soluble fractions, and may suffer chronic or acute toxicity depending on the oil type and fish species concerned. • Loss of grazing gastropods and mesoherbivores after oil spills results in marked increases in the abundance of ephemeral green algae (e.g. *Ulva* spp.) and fucoids (Southward & Southward, 1978; Hawkins & Southward, 1992; Raffaelli & Hawkins, 1999). Overall, red algae, gastropods, amphipods and other crustaceans, and echinoderms within the rockpool community are likely to be adversely affected. However, kelps, fucoids and some of the characterizing red algae (e.g. *Chondrus crispus*) are likely to survive and the biotope is likely to remain, although with a greatly reduced species richness. Therefore, an intolerance of intermediate has been recorded. The loss of grazers will allow increased growth of ephemeral greens and fucoids. However, the extent of damage may be exaggerated by the clean-up techniques employed e.g. detergents (see synthetic chemicals above) or high pressure water sprays. High water pressure sprays are likely to denude the rock surface of most life. On wave exposed rocky coasts oil will be removed relatively quickly. Recovery of rocky shore populations was intensively studied after the *Torrey Canyon* oil spill in March 1967. Loss of grazers results in an initial flush of ephemeral green then fucoid algae, followed by recruitment by grazers including limpet, which free space for barnacle colonization. On shores that were not subject to clean up procedures, the community recovered within ca 3 years, however, in shores treated with dispersants recovery took 5-8 years but was estimated to take up to 15 years on the worst affected shores (Southward & Southward, 1978; Hawkins & Southward, 1992; Raffaelli & Hawkins, 1999). Therefore, the community may take longer to recover, especially in oil is retained within pool bound sediments or as a coating of tar. Hence, a recoverability of moderate has been recorded (see additional information below).
Radionuclide contamination (see benchmark)	Insufficient information
Changes in nutrient levels	Little information on the nutrient regime of rockpools was found. Rockpools are cut off from the sea for periods of time, depending on their shore height, and hence nutrients

(see benchmark)	could potentially become limiting (e.g. nitrogen and phosphorous) within the period of emersion. Similarly, pools could also become eutrophic due to the presence of washed up seaweeds and bird droppings and in some cases sewage effluent. The effluent from rotting seaweeds on the strandline can severely impact upper shore pools (e.g. at Wembury, Devon) although lower shore pools are unlikely to be affected in LR.FK. However, eutrophication only likely to be a problem in high shore pools cut off from the sea for days at a time. Increased nutrient may increase growth in fast growing species (e.g. *Ulva* spp.) to the detriment of slower growing species of macroalgae. However, *Fucus vesiculosus* was observed to grow in the vicinity of a sewage outfall (Holt *et al.*, 1997) and is probably not sensitive. Eutrophication can potentially increase oxygen consumption leading to deoxygenation. However, the rockpool environment normally experience considerable variation in oxygen levels. Overall, an intolerance of intermediate has been recorded.
Increase in salinity (see benchmark)	High air temperatures cause surface evaporation of water from pools, so that salinity steadily increases, especially in pools not flooded by the tide for several days. However, Daniel & Boyden (1975) and Morris & Taylor (1983) reported little variability in salinity over one tidal cycle, and Ganning (1971) suggested that changes in salinity were of limited importance. Morris & Taylor (1983) reported an annual maximum salinity of 36.5 ppt in the pools studied on the west coast of Scotland. Goss-Custard *et al.* (1979) recorded salinities of 34.8 and 35.05 ppt in mid-shore pools. Therefore, the biotope is probably tolerant of small increases in salinity and an intolerance of low has been recorded. High shore pools exhibit greater variation and higher extremes of salinity (Pyefinch, 1943; Ganning, 1971) and different communities but mid to low shore pools are unlikely to experience such extremes unless the emergence regime is increased (see above) or they are exposed to hypersaline effluents.
Decrease in salinity (see benchmark)	During periods of emersion, high rainfall will reduce pool salinity or create a surface layer of brackish/nearly fresh water for a period. The extremes of salinity experienced will depend on the depth of the pool, shore height and flushing rate, and season. For example, Morris & Taylor (1983) stated that a low salinity layer of 2-10 mm was normal but after one storm the low salinity layer increased in depth, eventually resulting in a homogeneous pool of brackish water. Morris & Taylor (1983) reported an annual salinity range in mid to low shore pools of 26-36.5 ppt. Mid shore examples of this biotope may lack more sensitive species, such as *Laminaria digitata* and some sublittoral species. Nevertheless, decreases in salinity equivalent of a reduction from full to reduced (see benchmark) are likely to be a regular occurrence in rockpool communities, and the biotope is unlikely to be adversely affected. Hence, tolerant has been recorded.
Changes in oxygenation (see benchmark)	During emergence rockpools are closed systems and gaseous exchange occurs over the air/water interface. In shallow pools the volume to surface area ratio is likely to be high, whereas in deep pools the ratio is likely to be low. In addition, the oxygen concentration is dependant on the community present. During the day, photosynthesis uses up CO_2 and produces O_2, in excess of respiration. However, at night respiration by flora and fauna deplete oxygen levels. As a result rockpool environments exhibit marked variation in oxygen levels. In summer, rockpools are likely to be supersaturated with oxygen during the day (Pyefinch, 1943). For example, the greatest range of oxygen saturation of 101.7% occurred in a seaweed dominated, sediment floored pool, which reach over 190% saturation on some days (Pyefinch, 1943). Daniel & Boyden (1975) noted that a mid shore, seaweed dominated pool reached 194% saturation (ca 15 mg O_2/l) but that oxygenation was also marked in shaded pools. A pool with dense fauna exhibited a maximum saturation of 210% (Pyefinch, 1943). During photosynthesis algae absorb carbon dioxide and as concentrations fall, the pH rises. Morris & Taylor (1983) recorded pH values >9 in rockpools on the Isle of Cumbrae. At night, oxygen levels may fall below 100% saturation and pH will decrease as CO_2 levels increase. Morris & Taylor (1983) noted an annual maximum of oxygen concentration

	of 400-422 mm Hg (ca 23.4-24.7 mg/l) and an annual minimum of 18-38 mm Hg (ca 1-2.2 mg/l) in mid shore pools. Daniel & Boyden (1975) reported oxygen depletion at night, with mid to low shore pools reduced to 8-44% saturation. They noted that the crab *Carcinus maenas* leaves the pools at night, and that other species with the ability to air-breathe could also do so, e.g. limpets, littorinids, and the shanny *Lipophrys pholis*. They also observed that shrimps gathered at the edge of high shore pools at night, presumably to take advantage of the better oxygenated surface layer (Daniel & Boyden, 1975). Goss-Custard *et al.* (1979) noted that oxygen saturation levels decreased with depth in deep mid shore pools, while Morris & Taylor (1983) noted that oxygen saturation varied with depth and proximity to algae, especially green algae such as *Cladophora* spp. The range of extremes in oxygen concentration were greater in summer than in winter. On immersion, the rockpool community was exposed to potentially large, sudden fluctuations in oxygen concentrations depending on season and time of day (Morris & Taylor, 1983). Therefore, rockpools communities are probably exposed to variations equivalent to or greater than the benchmark level on a regular basis and tolerant has been recorded.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	Laminarians are susceptible to brown spot disease, caused by the brown alga *Streblonema aecidioides*. Infected algae show symptoms of *Streblonema* disease, i.e. alterations of the blade and stipe ranging from dark spots to heavy deformations and completely crippled thalli (Peters & Scaffelke, 1996). The occurrence of hyperplasia or gall growths, seen as dark spots, on *Laminaria digitata* is well known and may be associated with the presence of endophytic brown filamentous algae. *Ectocarpus deformans*, for example, was considered the cause of galls in *Laminaria digitata* by Apt (1988). In Helgoland, Ellertsdottir and Peters (1997) found 86% of *Laminaria digitata* thalli infected with endophytic brown algae and all those that exhibited weak to moderate but visible thallus alterations such as dark spots on the lamina or small warts on the stipe were infected. Several coralline and non-coralline species are epiphytic on *Corallina officinalis*. Irvine & Chamberlain (1994) cite tissue destruction caused by *Titanoderma corallinae*. However, no information on pathogenic organisms in the British Isles was found. In Rhodophycota, viruses have been identified by means of electron microscopy (Lee, 1971) and they are probably widespread. However, nothing is known of their effects on growth or reproduction in red algae and experimental transfer from an infected to an uninfected specimen has not been achieved (Dixon & Irvine, 1977). Intertidal gastropods often act a secondary hosts for trematode parasites of sea birds. For example, *Nucella lapillus* may be infected by cercaria larvae of the trematode *Parorchis acanthus*. Infestation causes castration and continued growth (Feare, 1970; Kinne, 1980; Crothers, 1985). Overall, a wide variety of pathogens may affect members of the community but no information on associated mortality was found. Therefore, an intolerance of low has been recorded.
Introduction of non-native species (see benchmark)	*Sargassum muticum* is a non-native macroalgae spreading around the coasts of Britain and Europe (see Eno *et al.*, 1997) and is often found in low to mid shore rockpools in the intertidal in areas it has colonized. Although, no studies on its effects on rockpool species were found, studies of its effect on shallow sublittoral macroalgae suggest that it can out-compete fucoids and kelps. For example, Stæhr *et al.* (2000) reported that an increase in the abundance of *Sargassum muticum* in the Limfjorden (Denmark) from 1990 to 1997 was accompanied by a decrease in the abundance of thick, slow growing macroalgae such as *Laminaria saccharina, Codium fragile, Halidrys siliquosa, Fucus vesiculosus*, and *Fucus serratus*, together with other algae such as *Ceramium nodulosum* (as *rubrum*) and *Dictyota dichotoma*. In *Sargassum muticum* removal experiments on the coast of Washington State, Britton-Simmonds (2004) concluded that *Sargassum muticum* reduced the abundance of native canopy algae (especially kelps) by 75% and native understorey algae by 50% probably as a result of shading. However, Viejo (1999) noted that mobile epifauna (e.g. amphipods, isopods) successfully

	colonized *Sargassum muticum* which provided additional habitat. Overall, *Sargassum muticum* can successfully invade rockpools, and would probably out-compete resident fucoids and kelp species, and some red algae. In addition, mesoherbivores will probably adapt to the new substratum offered by *Sargassum muticum* since they feed primarily on epiphytes. Therefore, the biotope is likely to remain but with a reduced species richness due to the loss of some species of macroalgae and resemble the sub-biotope LR.FK.Sar. Therefore, an intolerance of intermediate has been recorded. Recovery is potentially high but assumes removal of *Sargassum muticum* which is unlikely. Hence, a recoverability of 'none' has been recorded since the biotope is likely to change, although a viable community will remain.
Extraction of key or important characterizing species (see benchmark)	Several of the characterizing red algae species are subject to harvesting. *Chondrus crispus* is extracted commercially in Ireland, but the harvest has declined since its peak in the early 1960s (Pybus, 1977). Mathieson & Burns (1975) described the recovery of *Chondrus crispus* following experimental drag raking (see *MarLIN* Web site) and concluded that control levels of biomass and population structure are probably re-established after 18 months of regrowth. *Palmaria palmata* is used as a vegetable substitute or animal fodder although harvesting on a commercial scale only takes place in Ireland and France (Guiry & Blunden, 1991). Overall, while rockpool in areas subject to commercial harvesting may be directly affected, most examples of the biotope are unlikely to be affected by commercial harvesting in the UK. In deep pools characterized by this biotope, only the margins of the pool are likely to be affected. However, due to the relative small size of the community, even small scale hand collecting may have a significant effect. Therefore, an intolerance of intermediate has been recorded to represent the loss of a proportion of the macroalgae and the invertebrate community it supports. However, recovery is likely to be rapid since holdfasts and sporelings are likely to remain.
Extraction of important species (see benchmark)	*Littorina littorea* are subject to harvesting in the UK and limpets in France. Hand collection may reduce the population of *Littorina littorea* within rockpools and hence reduce grazing pressure, resulting in an increase in macroalgal cover, especially of opportunistic green algae and epiphytes. However, the littorinid will probably recover quickly by migration and recruitment.

Additional information

Recoverability

Kain (1975) examined recolonization of cleared concrete blocks in a subtidal kelp forest. Red algae colonized blocks within 26 weeks in the shallow subtidal (0.8m) and 33 weeks at 4.4m. After about 2.5 years, *Laminaria hyperborea* standing crop, together with an understorey of red algae, was similar to that of virgin forest. Red algae were present throughout the succession increasing from 0.04 to 1.5 percent of the biomass within the first 4 years. Colonizing species varied with time of year, for example blocks cleared in August 1969 were colonized by primarily *Laminaria saccharina* and subsequent colonization by *Laminaria hyperborea* and other laminarians was faster than blocks colonized by *Saccorhiza polyschides*; within 1 year the block was occupied by laminarians and red algae only. Succession was similar at 4.4m, and *Laminaria hyperborea* dominated within about 3 years. Blocks cleared in August 1969 at 4.4m were not colonized by *Saccorhiza polyschides* but were dominated by red algae after 41 weeks, e.g. *Cryptopleura ramosa*. Kain (1975) cleared one group of blocks at two monthly intervals and noted that brown algae were dominant colonists in spring, green algae (solely *%*) in summer and red algae were most important in autumn and winter. Overall, red algae are likely to be able to recolonize and recover abundance with a year in some instances and probably within 5 years. Similarly, laminarians could potentially colonize low shore rockpools within 3-4 years, depending on grazing and competition for space. Red algae produce non motile spores, dependant on the hydrography and most recruitment is likely to occur within about 10 m of the parent plants (Norton, 1992). Therefore, within a rock pool or a pool surrounded by macroalgae, recruitment is likely to be good. However, recruitment from remote populations is likely to be more protracted and sporadic.

Recovery of a population of *Chondrus crispus* following a perturbation is likely to be largely dependent on whether holdfasts remain, from which new thalli can regenerate (Holt *et al.*, 1995). Following experimental harvesting by drag raking in New Hampshire, USA, populations recovered to 1/3 of their original biomass after 6 months and totally recovered after 12 months (Mathieson & Burns, 1975). Raking is designed to remove the large fronds but leave the small upright shoots and holdfasts. The authors suggested that control levels of biomass and reproductive capacity are probably re-established after 18 months of regrowth. It was noted however, that time to recovery was much extended if harvesting occurred in the winter, rather than the spring or summer (Mathieson & Burns, 1975). Minchinton *et al.* (1997) documented the recovery of *Chondrus crispus* after a rocky shore in Nova Scotia, Canada, was totally denuded by an ice scouring event. Initial recolonization was dominated by diatoms and ephemeral macroalgae, followed by fucoids and then perennial red seaweeds. After 2 years, *Chondrus crispus* had re-established approximately 50% cover on the lower shore and after 5 years it was the dominant macroalga at this height, with approximately 100% cover. The authors pointed out that although *Chondrus crispus* was a poor colonizer, it was the best competitor.

Fucoids (e.g. *Fucus serratus* and *Fucus vesiculosus*) recruit readily to cleared areas, especially in the absence of grazers (Holt *et al.*, 1997). However, fucoid propagules tend to settle near to the parent plants, due to turbulent deposition by water flow. Within monospecific stands recruitment of conspecifics is most likely, and community recovery is likely to be rapid. For example, after the *Torrey Canyon* oil spill, fucoids attained maximum cover within 1-3 years (Southward & Southward, 1978; Hawkins & Southward, 1992; Raffaelli & Hawkins, 1999). However, in cleared areas, recruitment is likely to be rapid but recovery of the original community structure is likely to take some years (Holt *et al.*, 1997). For example, after the *Torrey Canyon* oil spill, although maximum cover of fucoids occurred within 1-3 years, the abundance of barnacles increased in 1-7 years, limpet number were still reduced after 6-8 years and species richness was regained in 2 to >10 years (Southward & Southward, 1978; Hawkins & Southward, 1992; Raffaelli & Hawkins, 1999).

Sousa *et al.* (1981) reported that experimental removal of sea urchins significantly increased recruitment in long-lived brown algae. In experimental plots cleared of algae and sea urchins in December, *Halidrys dioica* colonized the plots, in small numbers, within 3-4 months. Plots cleared in August received few, if any recruits, suggesting that recolonization was dependant on zygote availability and therefore the season. Wernberg *et al*. (2001) suggested that the lack of long range dispersal success in *Halidrys siliquosa* was responsible for its regional distribution in the north east Atlantic

Corallina officinalis probably has good recruitment and settled on artificial substrata within 1 week of their placement in the intertidal during summer in New England (Harlin & Lindbergh, 1977). New fronds of *Corallina officinalis* appeared on sterilized plots within six months and 10% cover was reached with 12 months (Littler & Kauker 1984). Bamber & Irving (1993) reported that new plants grew back in scraped transects within 12 months, although the resistant crustose bases were probably not removed. Similarly, in experimental plots, up to 15% cover of *Corallina officinalis* fronds returned within 3 months after removal of fronds and all other epiflora/fauna but not the crustose bases (Littler & Kauker, 1984). Although new crustose bases may recruit and develop quickly the formation of new fronds from these bases and recovery of original cover may take longer, and it is suggested that the population is likely to recover within a few years.

Gastropods and other mobile grazers (e.g. amphipods, isopods) are likely to be attracted by developing microalgae and macroalgae and could return quickly by either migration or larval recruitment. Epifaunal species vary in their recruitment rates. Sebens (1985, 1986) reported that rapid colonizers such as encrusting corallines, encrusting bryozoans, amphipods and tubeworms recolonized cleared rock surfaces within 1-4 months. Ascidians such as *Aplidium* spp. achieved significant cover in less than a year, and, together with *Halichondria panicea*, reached pre-clearance levels of cover after 2 years. Anemones colonized within 4 years (Sebens, 1986) and would probably take longer to reach pre-clearance levels. The anemone *Urticina felina* has poor powers of recoverability due to poor dispersal (Sole-Cava *et al.*, 1994 for the similar *Tealia crassicornis*) and slow growth (Chia & Spaulding, 1972), though populations should recover within 5 years.

Overall, members of the rockpool community could potentially recolonize with a year and a recognizable biotope return within 5 years. However, rockpool recruitment is reported to be sporadic and variable (Metaxas & Scheibling, 1993). While a recognizable biotope will return the exact community may differ from that present prior to perturbation. In addition, although the biotope is likely to be recognizable within less than 5 years, if the community was completely destroyed by perturbation, it may take longer for a typically diverse community to become established, especially the biotopes supported anemones and the rarer red algal species.

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors										
	Laminaria digitata	***Laminaria saccharina***	***Fucus serratus***	***Halidrys siliquosa***	***Palmaria palmata***	***Chondrus crispus***	***Ceramium virgatum***	***Corallina officinalis***	***Littorina littorea***	***Patella vulgata***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important characterizing	Important Structural	Important Structural	Important Structural	Important Structural	Important functional	Important functional
Substratum Loss	High	High	High	High	High	High	High	High	High	High
Smothering	Intermediate	High	High	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	High	High
Increase in suspended sediment	Intermediate	Low	Low	Low	Low	Intermediate	Intermediate	Intermediate	Intermediate	Low
Decrease in suspended sediment	See explanation	See explanation	See explanation	Not Sensitive	See explanation	Not Sensitive	Not Sensitive*	See explanation	See explanation	Low
Desiccation	Intermediate	High	Intermediate	Intermediate	Intermediate	Intermediate	High	High	Low	Low
Increase in emergence regime	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Low	Low
Decrease in emergence regime	See explanation	See explanation	See explanation	Not Sensitive*	See explanation	Not Sensitive	Not Sensitive	See explanation	See explanation	See explanation
Increase in water flow rate	Low	Low	Intermediate	High	Intermediate	Intermediate	Intermediate	Low	Intermediate	Low
Decrease in water flow rate	See explanation	See explanation	See explanation	Low	See explanation	Intermediate	Not Sensitive	See explanation	See explanation	See explanation
Increase in temperature	Intermediate	Intermediate	Not Sensitive	Not Sensitive	Intermediate	Low	Low	Intermediate	Low	Low
Decrease in temperature	See explanation	See explanation	See explanation	Not Sensitive	See explanation	Low	Low	See explanation	See explanation	See explanation

Increase in turbidity	Intermediate	Low	Low	Intermediate	Low	Low	Not Sensitive	Low	Low	Low
Decrease in turbidity	See explanation	See explanation	See explanation	Not Sensitive*	See explanation	Not Sensitive*	Not Sensitive	See explanation	See explanation	See explanation
Increase in wave exposure	Low	High	High	High	Intermediate	Intermediate	Intermediate	Low	Intermediate	Low
Decrease in wave exposure	See explanation	See explanation	See explanation	Not Sensitive*	See explanation	Low	Not Sensitive	See explanation	See explanation	See explanation
Noise	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Relevant	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Low
Visual Presence	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Relevant	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive
Abrasion & physical disturbance	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Low	High	Low	Intermediate	Low
Displacement	High	Intermediate	High	High	High	High	High	Low	Not Sensitive	Intermediate
Chemical factors										
	Laminaria digitata	***Laminaria saccharina***	***Fucus serratus***	***Halidrys siliquosa***	***Palmaria palmata***	***Chondrus crispus***	***Ceramium virgatum***	***Corallina officinalis***	***Littorina littorea***	***Patella vulgata***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important characterizing	Important Structural	Important Structural	Important Structural	Important Structural	Important functional	Important functional
Synthetic compound contamination	Intermediate	Low	High	Intermediate	High	High	High	Intermediate	Low	High
Heavy metal contamination	Intermediate	Intermediate	Low	Low	Intermediate	Insufficient information	Insufficient information	Insufficient information	Intermediate	Intermediate
Hydrocarbon contamination	Low	Low	Intermediate	Low	High	Low	High	Low	High	High
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	Low	Intermediate	Intermediate	Not Sensitive*	Intermediate	Intermediate	Not Sensitive*	Low	Not Sensitive	Low
Increase in salinity	Intermediate	High	Low	Low	Intermediate	Not Sensitive	Not Relevant	Intermediate	Not Sensitive	Low

Decrease in salinity	See explanation	See explanation	See explanation	Low	See explanation	Low	Low	See explanation	See explanation	See explanation
Changes in oxygenation	Insufficient information	Insufficient information	Low	Insufficient information	Low	Insufficient information	Insufficient information	Insufficient information	Low	Intermediate
Biological factors										
	Laminaria digitata	***Laminaria saccharina***	***Fucus serratus***	***Halidrys siliquosa***	***Palmaria palmata***	***Chondrus crispus***	***Ceramium virgatum***	***Corallina officinalis***	***Littorina littorea***	***Patella vulgata***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important characterizing	Important Structural	Important Structural	Important Structural	Important Structural	Important functional	Important functional
Introduction of microbial pathogens/parasites	Low	Intermediate	Insufficient information	Insufficient information	Insufficient information	Intermediate	Insufficient information	Low	Insufficient information	Insufficient information
Introduction of non-native species	Low	Insufficient information	Insufficient information	High	Not Relevant	Insufficient information	Not Sensitive*	Not Relevant	Insufficient information	Not Relevant
Extraction of this species	Intermediate	Intermediate	Intermediate	Not Relevant	Intermediate	Intermediate	Not Relevant	Intermediate	Intermediate	Intermediate
Extraction of other species	Intermediate	Insufficient information	Not Sensitive	Not Sensitive*	Intermediate	Insufficient information	Not Relevant	Intermediate	Not Sensitive	Low

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors

	Laminaria digitata	***Laminaria saccharina***	***Fucus serratus***	***Halidrys siliquosa***	***Palmaria palmata***	***Chondrus crispus***	***Ceramium virgatum***	***Corallina officinalis***	***Littorina littorea***	***Patella vulgata***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important characterizing	Important Structural	Important Structural	Important Structural	Important Structural	Important functional	Important functional
Substratum Loss	High	High	High	High	High	High	Very high	High	High	High
Smothering	High	High	High	High	High	High	Very high	Very high	High	High
Increase in suspended sediment	High	High	Very high	Very high	High	High	Very high	Very high	High	High
Decrease in suspended sediment	See explanation	See explanation	See explanation	Not Relevant	See explanation	Not Relevant	Not Relevant	See explanation	See explanation	High
Desiccation	High	High	High	High	High	High	Very high	High	Immediate	High
Increase in emergence regime	High	High	High	High	High	High	Very high	Very high	Immediate	High
Decrease in emergence regime	See explanation	See explanation	See explanation	Not Relevant	See explanation	Not Relevant	Not Relevant	See explanation	See explanation	See explanation
Increase in water flow rate	High	High	High	High	High	High	Very high	Very high	High	High
Decrease in water flow rate	See explanation	See explanation	See explanation	Immediate	See explanation	High	Not Relevant	See explanation	See explanation	See explanation
Increase in temperature	High	High	Not Relevant	Not Relevant	High	Very high	Very high	High	Immediate	High
Decrease in temperature	See explanation	See explanation	See explanation	Not Relevant	See explanation	Very high	Very high	See explanation	See explanation	See explanation
Increase in turbidity	High	High	Very high	High	Very high	Very high	Not Relevant	Immediate	Very high	Very high

Decrease in turbidity	See explanation	See explanation	See explanation	Not Relevant	See explanation	Not Relevant	Not Relevant	See explanation	See explanation	See explanation
Increase in wave exposure	High	High	High	High	High	High	Very high	Very high	High	High
Decrease in wave exposure	See explanation	See explanation	See explanation	Not Relevant	See explanation	Very high	Not Relevant	See explanation	See explanation	See explanation
Noise	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	High
Visual Presence	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Abrasion & physical disturbance	High	Very high	High	High	High	Very high	Very high	High	High	Very high
Displacement	High	High	High	High	High	High	Very high	High	Not Relevant	High
Chemical factors										
	Laminaria digitata	***Laminaria saccharina***	***Fucus serratus***	***Halidrys siliquosa***	***Palmaria palmata***	***Chondrus crispus***	***Ceramium virgatum***	***Corallina officinalis***	***Littorina littorea***	***Patella vulgata***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important characterizing	Important Structural	Important Structural	Important Structural	Important Structural	Important functional	Important functional
Synthetic compound contamination	High	High	High	High	High	High	Very high	High	Very high	High
Heavy metal contamination	High	High	High	Very high	High	Insufficient information	Not Relevant	Insufficient information	High	High
Hydrocarbon contamination	High	High	High	Very high	High	Very high	Very high	Very high	High	High
Radionuclide contamination	Insufficient information	Not Relevant	Insufficient information	Not Relevant	Insufficient information	Insufficient information	Not Relevant	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	High	High	High	Not Relevant	High	High	Not Relevant	Very high	Not Relevant	High
Increase in salinity	High	High	Very high	Very high	High	Not Relevant	Not Relevant	High	Not Relevant	High
Decrease in salinity	See explanation	See explanation	See explanation	Very high	See explanation	Very high	Very high	See explanation	See explanation	See explanation

Changes in oxygenation	Insufficient information	Not Relevant	Very high	Not Relevant	Immediate	Insufficient information	Not Relevant	Insufficient information	Very high	High
Biological factors										
	Laminaria digitata	***Laminaria saccharina***	***Fucus serratus***	***Halidrys siliquosa***	***Palmaria palmata***	***Chondrus crispus***	***Ceramium virgatum***	***Corallina officinalis***	***Littorina littorea***	***Patella vulgata***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important characterizing	Important Structural	Important Structural	Important Structural	Important Structural	Important functional	Important functional
Introduction of microbial pathogens/parasites	High	High	Insufficient information	Not Relevant	Not Relevant	High	Not Relevant	Very high	Insufficient information	Insufficient information
Introduction of non-native species	Insufficient information	Not Relevant	Insufficient information	High	Not Relevant	Insufficient information	Very high	Not Relevant	Insufficient information	Not Relevant
Extraction of this species	High	High	High	Not Relevant	High	High	Not Relevant	High	High	High
Extraction of other species	High	Not Relevant	Not Relevant	Not Relevant	High	Insufficient information	Not Relevant	High	Not Relevant	High

Importance

Marine natural heritage importance

National importance	Common
Habitat Directive feature (Annex 1)	Reefs Large shallow inlets and bays Estuaries

Biotope importance

Little information on the importance of this biotope was found. However, rockpool environments, especially with macroalgal cover in the mid to lower shore, probably provide refuges for juvenile fish species, and juvenile and molting crabs (e.g. *Cancer pagurus*). Low shore pools provide additional habitat for some sublittoral or sublittoral fringe species, notably the anemones *Urticina felina*, *Corynactis* sp., *Sagartia elegans* and *Metridium senile*, and the limpet *Patella ulyssiponensis* (Lewis, 1964). Rockpools also allow some sublittoral fringe or lower shore species to extend their range up shore due to the removal of desiccation stress, although not as many species as might be expected, e.g. barnacles are a notably exception (Lewis, 1964). Lewis (1964) noted that deep pools in the lower shore, especially in the southwest, are rich areas for collecting the rarer species of algae.

Exploitation

Rockpools are attractive mesocosms, allowing easy investigation of the resident species. Therefore, rockpools receive considerable attention from the public, environmental education schemes and scientists. Inappropriate boulder turning and trampling within the pools may be detrimental (see sensitivity).

Additional information

No text entered

This Biology and Sensitivity Key Information review can be cited as follows:

Tyler-Walters, H., 2005. Fucoids and kelps in deep eulittoral rockpools. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 28/01/2005]. Available from: <http://www.marlin.ac.uk>

Hydroids, ephemeral seaweeds and *Littorina littorea* in shallow eulittoral mixed substrata pools (LR.H)

Key information authored by: Charlotte Marshall

Last updated 18/01/2005

This information is not refereed.

If you would be willing to supply *MarLIN* with an image of this species/habitat please contact marlin@mba.ac.uk

Recorded and expected LR.H distribution for Britain and Ireland

Description of biotope

Shallow pools on mixed cobbles, pebbles, gravel and sand may be colonized by hydroids (*Obelia longissima* and *Kirchenpaueria pinnata*), ephemeral green algae (*Ulva* sp.) and the winkle *Littorina littorea*. Within these pools, patches of sand may be occupied by the lugworm *Arenicola marina* and sand mason worms *Lanice conchilega*. These pools are often associated with mussel beds (SLR.MytX), with *Mytilus edulis* also present in the pools. Barnacles (*Semibalanus balanoides* and *Elminius modestus*) and the keel worm *Pomatoceros triqueter* may be attached to shells and small stones. (Information taken from the Marine Biotope Classification for Britain and Ireland, Version 97.06: Connor *et al.*, 1997a, b).

Welsh variation

Although the Welsh examples of many of the biotopes in this report follow the British and Irish classification description closely, some regional variation may exist. Reference should be made to Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

No text entered

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Biotope complex	LR.Rkp	Rockpools
Biotope	LR.H	Hydroids, ephemeral seaweeds and Littorina littorea in shallow eulittoral mixed substrata pools

Other biotope classification schemes

European Union Nature Information System (EUNIS) habitat classification: A1.514 - Hydroids, ephemeral seaweeds and *Littorina littorea* in shallow eulittoral mixed substrata pools (Davies & Moss, 1998).

Ecology

Ecological and functional relationships

This biotope is dominated by species able to withstand the frequent disturbance caused by wave action. The fact that LR.H rockpools are shallow and have a mixed substratum means that sand and pebbles will be frequently moved around the rockpool. This is especially true in stormy weather when larger cobbles and boulders may be moved into the pool and when the pool may be flushed clean of sediment. This in itself means that the community is unlikely to be a climax community, but more a transient community dominated by ephemeral, rapidly growing species that are able quickly to dominate space created by wave energy. Furthermore, both the flora and fauna are likely to vary both spatially, i.e. between rock pools, and on a temporal basis, depending on the frequency, severity and timing of disturbance.

- Primary producers in this biotope are represented by ephemeral green algae such as *Ulva* sp. *Ulva intestinalis* can grow rapidly and is tolerant of a range of temperatures and salinities. *Ulva intestinalis* is also the preferred food of *Littorina littorea* (see below).
- In terms of characterizing species, suspension feeders are the dominant trophic group in LR.H. The most common suspension feeders likely to be found in LR.H are the hydroid *Obelia longissima* and the common mussel *Mytilus edulis*. The acorn barnacle *Semibalanus balanoides* may also be common. *Semibalanus balanoides* actively feeds on detritus and zooplankton. *Mytilus edulis* actively feeds on bacteria, phytoplankton, detritus, and dissolved organic matter (DOM). *Obelia longissima* is a passive suspension feeder, feeding on small zooplankton, small crustaceans, oligochaetes, insect larvae and probably detritus. The branches of *Obelia longissima* may be used as substratum by *Mytilus edulis* pediveligers (Brault & Bourget, 1985). Other suspension feeders may include the barnacles *Semibalanus balanoides* and *Elminius modestus*, and the tubeworm *Pomatoceros triqueter*.
- The grazing gastropod *Littorina littorea* feeds on range of fine red, green and brown algae including *Ulva* sp., *Cladophora* sp. and *Ectocarpus* sp.
- Deposit feeding worms such as the sand mason *Lanice conchilega* and the lugworm *Arenicola marina* may be found if patches of sand are present in the pools. The sand mason is also capable of active suspension feeding.
- The common shore crab *Carcinus maenas* is the largest mobile predator frequently associated with LR.H. *Carcinus maenas* is likely to move in and out of the rockpool feeding on plant and animal material including *Semibalanus balanoides* and *Littorina littorea*.

Seasonal and longer term change

Rockpools constitute a distinct environment for which physiological adaptations by the flora and fauna may be required (Lewis, 1964). Conditions within rockpools are the consequence of prolonged separation from the main body of the sea, and physico-chemical factors within them fluctuate dramatically (Huggett & Griffiths, 1986). Shallow pools such as those associated with LR.H are especially influenced by insolation, air temperature and rainfall, the effects of which become more significant towards the high shore, where pools may be isolated from the sea for a number of days or weeks (Lewis, 1964).

Water temperature in pools follows the temperature of the air more closely than that of the sea. In summer, shallow pools are warmer by day, but may be colder at night, and in winter may be much colder than the sea (Pyefinch, 1943). It is also possible that shallow pools may freeze over in the coldest winter months.

High air temperatures cause surface evaporation of water from pools, so that salinity steadily increases, especially in pools not flooded by the tide for several days. Alternatively, high rainfall will reduce pool salinity or create a surface layer of brackish/nearly fresh water for a period. The extent of temperature and salinity change is affected by the frequency and time of day at which tidal inundation occurs. If high tide occurs in early morning and evening the diurnal temperature follows that of the air, whilst high water at midday suddenly returns the temperature to that of the sea (Pyefinch, 1943). Heavy rainfall, followed by tidal inundation can cause dramatic fluctuations in salinity, and values ranging from 5-30 psu have been recorded in rockpools over a period of 24 hrs (Ranade, 1957). Rockpools in the supralittoral, littoral fringe and upper eulittoral are liable to gradually changing salinities followed by days of fully marine or fluctuating salinity at times of spring tide (Lewis, 1964).

Due to the frequent disturbances likely to affect this biotope, any seasonal changes are likely to be masked by changes caused by wave energy. Some species of hydroids demonstrate seasonal cycles of growth in spring/summer and regression (die back) in late autumn/winter, over wintering as dormant stages or juvenile stages (Gili & Hughes, 1995). Many hydroids are opportunists adapted to rapid growth and reproduction (r-selected), taking advantage of the spring/summer phytoplankton bloom and more favourable (less stormy) conditions (Gili & Hughes, 1995). Brault & Bourget (1985) noted that *Obelia longissima* exhibited an annual cycle of biomass, measured as colony length, on settlement plates in the St Lawrence estuary. Colony length increased from settlement in June, reaching a maximum in November to March and then decreasing again until June, although the decline late in the year was attributed to predation, and data was only collected over a two year period. The ephemeral algae are also likely to experience an obvious decline in biomass over the winter months.

Habitat structure and complexity

The mixed substratum of the rockpool will give the habitat some heterogeneity since there is likely to be a mixture of sand, gravel, pebbles and cobbles. It is the surfaces of the larger pebbles and cobbles that are likely to be colonized by the algae, barnacles and tubeworms and hydroids although *Obelia longissima* can also grow on coarse clean sand. Clumps of mussels, whether the shells are empty or not, will also provide a substratum for the hydroids and barnacles. The mussel matrix will bind sediment and the sediment trapped between the shells may provide shelter for cryptic species and small worms, for example.

Dominant trophic groups	Suspension feeders

Productivity

No information was found regarding the productivity in LR.H, although it is expected to be low. At any given time it is unlikely that there will be a well established community, regardless of species composition.

Major sources of organic carbon	Plankton Detritus Dissolved organic matter

Recruitment processes

- *Obelia longissima* exhibits a typical leptolid life cycle consisting of a sessile colonial, vegetative hydroid stage, a free-living sexual medusoid stage, and a planula larval stage (see *MarLIN* Web site). In terms of reproduction and recruitment, *Obelia longissima* has a number of strategies.
    - *Obelia longissima* can grow vegetatively and branch to form a network across the substratum. It can also reproduce by fission or mechanical fragmentation of the colony which may aid dispersal (Gili & Hughes, 1995). Hydroids can also form frustules or gemmules, which are thought to be resting stages, in response to stress (Gili & Hughes, 1995). These frustules are adhesive and stick to the substratum where they can form new colonies (Cornelius, 1995a; Kosevich & Marfenin, 1986).
    - In terms of sexual reproduction, *Obelia longissima* is dioecious, producing male and female medusae. The medusoid stage lasts between 7 -30 days (Stepanjants, 1998). Eggs and sperm are released into the sea and fertilization is external, resulting in an embryo that develops into a typical planula larva (Cornelius, 1995a, b; Gili & Hughes, 1995). In Europe, the medusae of *Obelia longissima* are usually found in the water somewhere between April and July, depending on area (see *MarLIN* Web site). Assuming that all the medusae survive to release gametes, Cornelius (1990) estimated that an average colony could potentially produce about 20,000 planulae, although he also suggested that only one of these planulae was likely to survive to form a colony which itself might survive to reproduce.
- *Ulva intestinalis* is a rapidly growing opportunistic species. It can be found in reproductive condition at all times of the year, but maximum development and reproduction occur during the summer months (Burrows, 1991). The life history consists of an alternation between haploid gametophytic and diploid sporophytic generations (see *MarLIN* Web site). The haploid

gametophytes produce enormous numbers of biflagellate motile gametes which cluster and fuse to produce a sporophyte (diploid zygote). The sporophyte matures and produces large numbers of quadriflagellate zoospores that mature as gametophytes, and the cycle is repeated. Together spores and gametes are termed 'swarmers'. Mobility of swarmers belonging to *Ulva intestinalis* (studied as *Enteromorpha intestinalis*) can be maintained for as long as 8 days (Jones & Babb, 1968) and as a result, tend to have large dispersal shadows. Propagules have been found 35 km from the nearest adult plants (Amsler & Searles, 1980).

- *Littorina littorea* can breed throughout the year but the length and timing of the breeding period are extremely dependent on climatic conditions. Fertilization is internal and *Littorina littorea* sheds egg capsules directly into the sea during spring tides. Eggs are released on several occasions. Fecundity can be as much as 100,000 for a large female (27 mm shell height) per year. Larval settling time or pelagic phase can be up to six weeks.
- Spawning in *Mytilus edulis* is protracted in many populations, with a peak of spawning in spring and summer (see *MarLIN* Web site). Gametogenesis and spawning varies with geographic location, e.g. southern populations often spawn before more northern populations (Seed & Suchanek, 1992). The planktonic life can exceed two months in the absence of suitable substrata or optimal conditions (Bayne, 1965; Bayne, 1976). *Mytilus edulis* recruitment is dependant on larval supply and settlement, together with larval and post-settlement mortality. Larval mortality is probably due to adverse environmental conditions, especially temperature, inadequate food supply, inhalation by suspension feeding adult mytilids, difficulty in finding suitable substrata and predation (Lutz & Kennish, 1992). Widdows (1991) suggested that any environmental factor that increased development time, or the time between fertilization and settlement would increase larval mortality. Jorgensen (1981) estimated that larvae suffered a daily mortality of 13% in the Isefjord, Denmark but Lutz & Kennish (1992) suggested that larval mortality was approximately 99%. Recruitment in many *Mytilus* sp. populations is sporadic, with unpredictable pulses of recruitment (Seed & Suchanek, 1992). *Mytilus* is highly gregarious and final settlement often occurs around or in-between individual mussels of established populations.
- *Semibalanus balanoides* is an obligate cross-fertilising hermaphrodite. It produces one brood per year of 5000 -10,000 eggs/ brood in mature adults but this varies with age and location (see *MarLIN* Web site). Copulation takes place in the UK from November to early December and nauplii larvae are released from the barnacle between February and April, in synchronisation with the spring algal bloom. Nauplii larvae are planktotrophic and develop in the surface waters for about two months. They pass through six nauplii stages before eventually developing into a cyprid larva. Cyprid larvae are specialized for settlement and peak settlement occurs in April to May in the west and May to June in the east and north of Britain although settlement and subsequent recruitment are highly variable.

Time for community to reach maturity

LR.H is subjected to frequent small disturbances and the associated community is characterized by relatively short lived and opportunistic species. As a consequence, the time taken for the community to reach 'maturity' is likely to be fairly rapid, i.e. less than a few years.

- *Obelia longissima* is capable of growing rapidly, budding and forming stolons that allow it to colonize space rapidly. Hydroids are often the first organisms to colonize available space in settlement experiments (Gili & Hughes, 1995). Rapid growth, budding and the formation of stolons allows hydroids to colonize space rapidly. Cornelius (1992) stated that *Obelia longissima* could form large colonies within a matter of weeks.
- *Ulva intestinalis* is opportunistic and capable of rapidly colonizing bare substratum, providing the substratum is suitable. Kitching & Thain (1983), for example, reported that following the removal of the urchin *Paracentrotus lividus* (that grazes on the *Ulva* sp.) from areas of Lough Hyne, Ireland, *Ulva* sp. grew over the cleared area and reached a coverage of 100% within one year.
- *Littorina littorea* is a slow crawler but because LR.H rockpools are likely to be surrounded by other rockpools, active immigration of snails is possible from the surrounding rocky shore where *Littorina littorea* may be abundant.
- The establishment of the *Mytilus edulis* community may take significantly longer (see Sensitivity). However, this species is not characteristic of the biotope. Furthermore, if *Mytilus edulis* are present in LR.H, they will usually be part of a larger mussel bed (SLR.MytX) and this will favour recruitment to the area. Recovery of *Mytilus edulis* may take at least 5 years, although in certain

circumstances and under some environmental conditions recovery may take significantly longer.

Additional information

No text entered

Habitat preference and distribution

Distribution in Britain and Ireland

LR.H has not been recorded in Ireland. In Scotland, it has only been recorded at Devil's Thrashing Floor, Dumfries & Galloway. On the south Devon coast it is found near Brixham. On the west coasts it has been recorded near Port Talbot in Wales and at Duddon Sands and St Bees Head in Cumbria. It has also been recorded on the north coast of Norfolk and near Blackwater Estuary in Essex.

Habitat preferences

Temperature range preferences	Data deficient
Water clarity preferences	Data deficient
Limiting nutrients	Data deficient
Other preferences	Enclosed coasts (inlets, harbours)

Additional information

LR.H is found in moderately exposed to sheltered habitats. It is considered rare (Connor *et al.*, 1997b).

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	Species name	Common Name
Important characterizing	*Obelia longissima*	A hydroid
Important characterizing	*Littorina littorea*	Common periwinkle
Important characterizing	*Ulva intestinalis*	Gut weed
Important other	*Mytilus edulis*	Common mussel
Important other	*Semibalanus balanoides*	An acorn barnacle

Explanation

The hydroid *Obelia longissima* is particularly characteristic to this biotope. The common periwinkle is part of the biotope name and has therefore also been listed as an important characterizing species. *Ulva intestinalis*, although not a characterizing species *per se*, is representative of other ephemeral green algae that may be found in LR.H. It also provides a food source for the common periwinkle. The common mussel *Mytilus edulis* has been included as another important species since it was found in almost all records of the biotope, often in abundance, and mussel patches may provide some stability to this otherwise unstable and transient biotope. The acorn barnacle *Semibalanus balanoides* is likely to be found attached to stones and shells. It has been listed as important 'other' since it may be common is some LR.H pools.

Species found especially in biotope

No text entered

Additional information

The MNCR reported 129 species from this biotope, although not all species occur in all examples of the biotope (JNCC, 1999).

Biotope sensitivity

Physical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	Very high	Low	Major Decline	High
Smothering	High	Very high	Low	Major Decline	Moderate
Increase in suspended sediment	Low	Immediate	Not sensitive	No Change	Low
Decrease in suspended sediment	Tolerant*	Not Relevant	Not sensitive*	Not Relevant	Low
Desiccation	High	Very high	Low	Major Decline	Moderate
Increase in emergence regime	Intermediate	Very high	Low	Decline	Low
Decrease in emergence regime	Tolerant*	Not Relevant	Not sensitive*	Rise	Very low
Increase in water flow rate	High	Very high	Low	Major Decline	Very low
Decrease in water flow rate	Tolerant	Not Relevant	Not sensitive	Not Relevant	Very low
Increase in temperature	High	Very high	Low	Decline	Moderate
Decrease in temperature	Intermediate	Very high	Low	Decline	Moderate
Increase in turbidity	Low	Immediate	Not sensitive	No Change	Moderate
Decrease in turbidity	Tolerant*	Not Relevant	Not sensitive*	No Change	Low
Increase in wave exposure	High	Very high	Low	Major Decline	Low
Decrease in wave exposure	High	Very high	Low	Decline	Low
Noise	Tolerant	Not Relevant	Not sensitive	Not Relevant	Moderate
Visual Presence	Tolerant	Not Relevant	Not sensitive	Not Relevant	Moderate
Abrasion & physical disturbance	Intermediate	Very high	Low	Decline	Low
Displacement	Intermediate	Very high	Low	Minor Decline	Moderate

Chemical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	Intermediate	High	Low	Decline	Moderate
Heavy metal contamination	Intermediate	High	Low	Decline	Moderate
Hydrocarbon contamination	High	High	Moderate	Major Decline	Moderate
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Changes in nutrient levels	Intermediate	Very high	Low	Decline	Low
Increase in salinity	Low	Very high	Very Low	No Change	Low
Decrease in salinity	Low	Very high	Very Low	No Change	Low
Changes in oxygenation	Low	Immediate	Not sensitive	No Change	Low

Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Introduction of non-native species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Extraction of key or important characterizing species	Low	Very high	Very Low	No Change	Low
Extraction of important species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	The majority of the species associated with this biotope are attached permanently to the substratum and the removal of this substratum would result in the loss of the biotope. *Ulva intestinalis*, if detached from the substratum, may be buoyed up by gas and float to the surface where it continues to grow. However, the survival of this species in isolation will not constitute the biotope and therefore intolerance has been assessed as high. Recoverability is likely to be very high (see additional information).
Smothering (see benchmark)	*Obelia longissima* forms long flexible colonies so that smothering material is likely to bend the colony flat against the substratum. In addition, local hypoxic conditions are also likely to inhibit growth. Although hydranths are likely to regress and portions of the colony are likely to die or be reabsorbed, parts of the colony are likely to become dormant, or otherwise survive for a period of at least a month. *Ulva intestinalis* is highly intolerant to smothering due to its filamentous form. It is likely to be completely smothered at the benchmark level and photosynthesis would be prevented due to lack of light. Furthermore, the thin fronds of the algae may start to rot. *Littorina littorea* will normally die if it cannot reach the surface within 24 hours (Chandrasekara & Frid, 1998). Under 5 cm of the mixed substratum associated with LR.H, it is possible that they may not reach the surface in this time. However, the journey to the surface is facilitated in well oxygenated sediments that contain fluid. The mussel *Mytilus edulis* and acorn barnacle *Semibalanus balanoides* may only be of intermediate intolerance to smothering (see *MarLIN* Web site) but these species are not characteristic of the biotope. On balance, intolerance has been assessed as high since the characterizing species are likely to experience high levels of mortality. Recoverability is expected to be very high (see additional information).
Increase in suspended sediment (see benchmark)	An increase in suspended sediment may have a deleterious effect on the suspension feeding community in LR.H. It is likely to clog their feeding apparatus to some degree, resulting in a reduced ingestion over the benchmark period and, subsequently, a decrease in growth rate. For hydroids especially this could potentially lead to a reduction in overall biomass. Moreover, because the rockpool has a 'pulsed' influx of water, the suspended sediment is likely to settle between tides and, over the course of one month, increase the depth of sediment in the pool. Some smaller immobile species including barnacle and tubeworms may be temporarily smothered. Furthermore, hydranths toward the lower reaches of the hydroid colonies may be smothered and regress. On balance, intolerance has been assessed as low since, at most, there may be a reduction in the overall hydroid

	standing biomass and this will not affect the recognizable biotope. Hydroids exhibit remarkable powers of regeneration and *Obelia longissima* (as *commissularis*) rapidly heals cut ends of stolons or branches within 1-2 min, and new growth can rapidly occur from the cut end or both ends of an excised piece of stolon (Berrill, 1949). Assuming the majority of the colonies remained, recovery has been assessed as immediate.
Decrease in suspended sediment (see benchmark)	A decrease in suspended sediment is likely to benefit the community associated with LR.H. The suspension feeders may be able to feed more efficiently due to a reduction in time and energy spent cleaning feeding apparatus. Over the course of the benchmark the hydroids may increase in abundance and the mussels may experience an enhanced scope for growth. Therefore, tolerant* has been suggested.
Desiccation (see benchmark)	LR.H is found in the eulittoral. Moving the biotope up one vertical biological zone on the shore, in combination with the shallow nature of the pool, could mean that this biotope has the potential to dry out, especially if this shift coincided with hot, dry or windy weather. Alternatively, the biotope would be more at risk from freezing if the shift coincided with cold temperatures and icy winds. *Ulva intestinalis* can survive several weeks of living in completely dried out rock pools, while becoming completely bleached on the uppermost layers, but remaining moist underneath the bleached fronds. The *Littorina littorea* may be found at the high tide level on the shore and will probably be able to find some refuge underneath the damp fronds of the *Ulva intestinalis*. During long periods of exposure to desiccating influences, *Littorina littorea* forms a dried mucus seal around the shell aperture thereby reducing evaporation. In contrast, *Obelia longissima* is highly intolerant to desiccation and, at the benchmark level, the hydroids in LR.H are likely to experience mass mortality. Due to the fact that hydroids characterize this biotope, intolerance has been assessed as high. Even where the colonies are totally destroyed and/or removed, remaining resting stages or colony fragments, together with rapid growth and potentially good recruitment should result in rapid recovery. Recoverability has been assessed as very high.
Increase in emergence regime (see benchmark)	An increase in emergence would mean that this shallow rockpool would be at greater risk of desiccation (see above) and extremes of temperature (see below), since the pool would be exposed to the influences of air temperature for longer. The *Ulva intestinalis* may dry out and become bleached in the upper reaches of the rock pool although the majority of the plants would survive. The common periwinkles could move down into the wetter reaches of the pool when the pool wasn't immersed by the tide. The hydroids would most likely experience a decline in abundance since those in the upper reaches of the pool would die if the rockpool started to dry out. Overall, the biotope would probably remain but over a smaller area. Accordingly, intolerance has been assessed as intermediate but with a very high recovery (see additional information).
Decrease in emergence regime (see benchmark)	A decrease in emergence would mean that this shallow rock pool would be at less risk of desiccation. In addition, depending on the nature of the surrounding bedrock, the rockpool may become slightly deeper. As a result, it is possible that species diversity could increase as, for example, other hydroids colonized the pool. This could result in increased competition between the suspension feeders but, on the whole, LR.H is likely to be tolerant* of a decrease in emergence at the benchmark level.
Increase in water flow rate (see benchmark)	LR.H is found in shallow eulittoral rock pools and is not expected to experience any water flow, unless they covered by the tide, apart from wind driven water movement. An increase in water flow rate and the benchmark level is likely to flush much of the sediment from the pool. This would result in the vast majority of the hydroids, ephemeral green algae, lugworms and sand masons being lost. The *Littorina littorea*, *Mytilus edulis* and *Semibalanus balanoides* may well

	remain but this would not constitute a recognizable biotope in terms of LR.H. Intolerance has therefore been assessed as high. Recoverability is expected to be very high.
Decrease in water flow rate (see benchmark)	LR.H is found in shallow eulittoral rock pools and is not expected to experience any water flow, unless they covered by the tide, apart from wind driven water movement. *Obelia longissima* and *Littorina littorea* have both been recorded in very weak tidal streams (no information on *Ulva intestinalis*) and tolerant has been suggested.
Increase in temperature (see benchmark)	Due to the fact that LR.H is found in shallow eulittoral rockpools, the associated community must be adapted, to a certain degree, to frequent and often rapid changes in temperature. Air temperatures can be greatly elevated on hot days and due to the shallow nature of the pool, the water is likely to heat up quickly. *Ulva intestinalis*, *Littorina littorea* and *Mytilus edulis* all occur to the south of the British Isles and, because they are often found in upper shore rockpools, are likely to be tolerant to both chronic and acute increases in temperature. *Semibalanus balanoides* is pre-eminently a boreal species, adapted to cool environments. Reproduction in *Semibalanus balanoides* is inhibited by temperatures greater than 10 °C (Barnes, 1989) and it has been assessed as being of intermediate intolerance to an increase in temperature at the benchmark level (See *MarLIN* Web site). Cornelius (1995b) suggested that numerous records in the Indo-Pacific were probably attributable to *Obelia longissima* and it is unlikely to be adversely affected by chronic temperature change at the benchmark level within the British Isles. However, Berrill (1949) reported that hydranths did not start to develop unless the temperature was less than 20 °C. Furthermore, Berrill (1948) reported that *Obelia* species were absent from a buoy in July and August during excessively high summer temperatures in Booth Bay Harbour, Maine, USA and the abundance of *Obelia* species and other hydroids fluctuated greatly, disappearing and reappearing as temperatures rose and fell markedly above and below 20 °C during this period (see *MarLIN* Web site). Therefore it is likely that *Obelia longissima* is highly intolerant to an acute rise in temperature at the benchmark level since temperatures in excess of 20 °C can reasonably be expected over summer in a shallow eulittoral rockpool. As Berrill (1948) suggested, other hydroids may be equally intolerant. Overall, therefore, intolerance of LR.H to an acute increase in temperature has been assessed as high. Recoverability is expected to be very high (see additional information).
Decrease in temperature (see benchmark)	Due to the fact that LR.H is found in shallow eulittoral rockpools, the associated community must be adapted, to a certain degree, to frequent and often rapid changes in temperature. These pools may even freeze over during the coldest winter months. Kosevich & Marfenin (1986) reported that *Obelia longissima* was active all year round in the White Sea. Similarly, its northern limit lies in the Arctic Circle (Cornelius, 1995b; Stepanjants, 1998) suggesting that it probably tolerant of the lowest temperatures it is likely to encounter in Britain and Ireland. However, growth rates are reduced at low temperatures. Berrill (1949) reported that stolons grew, under optimal nutritive conditions, at less than 1 mm in 24 hrs at 10-12 °C, 10 mm in 24 hrs at 16-17 °C, and as much as 15-20 mm in 24 hrs at 20 °C. *Ulva intestinalis* occurs to the north of the British Isles, so is likely to be tolerant of chronic decreases in temperature at the benchmark level. *Ulva* sp. (as *Enteromorpha*) were reported to be tolerant of a temperature of -20 °C (Kylin, 1917). Adult *Littorina littorea* can easily tolerate sub-zero temperatures and the freezing of over 50% of their extracellular body fluids, although long term chronic temperature reductions may retard growth (see *MarLIN* Web site).

	Mytilus edulis can also withstand extreme cold and freezing, surviving when its tissue temperature drops to -10 °C (Williams, 1970; Seed & Suchanek, 1992) or exposed to -30°C for as long as six hours twice a day (Loomis, 1995). Bourget (1983) reported that cyclic exposure to otherwise sublethal temperatures, e.g. -8 °C every 12.4 hrs resulted in significant damage and death after 3-4 cycles. This suggests that *Mytilus edulis* can survive occasional, sharp frost events, but may succumb to consistent very low temperatures over a few days. Although *Mytilus edulis* may be intolerant of prolonged freezing temperatures, it is generally considered to be eurythermal. *Semibalanus balanoides* is pre-eminently a boreal species, adapted to cool environments. An exceptional tolerance to cold is acquired in December and January and is lost between February and April. The median lethal temperature in January was -17.6 °C in air for 18 hours, whereas animals in June could only withstand -6.0 °C (Crisp & Ritz, 1967). *Semibalanus balanoides* was not affected during the severe winter of 1962-63 in most areas, except the south east coast which suffered 20-100% mortality. (Crisp, 1964). On balance, intolerance of LR.H to a decrease in temperature at the benchmark level has been assessed as intermediate to reflect the possibility that some pool higher up the shore may freeze over. Recovery is expected to be very high (see additional information).
Increase in turbidity (see benchmark)	An increase in turbidity may reduce primary production in the rockpool. For pools further up the shore that have less contact with the sea to replenish the water and hence suspended matter, this may lead to a reduction on ingestion for suspension feeders. Over the course of the benchmark this may lead to a reduced scope for growth and *Ulva intestinalis* may also experience a slight reduction in growth. Intolerance has been assessed as low with an immediate recovery.
Decrease in turbidity (see benchmark)	A decrease in turbidity is likely to enhance primary productivity within the biotope. This will directly benefit *Ulva intestinalis* and indirectly benefit *Littorina littorea, Obelia longissima, Mytilus edulis* and *Semibalanus balanoides* through secondary productivity. Bourget *et al.* (in press), for example, noted that for any given water temperature on buoys in the Gulf of St Lawrence, water transparency and primary production influenced the biomass of fouling organisms, including *Obelia longissima*. Biomass was reported to increase with increasing transparency up to a transparency of 15 m after which it decreased again (see Figure 2, Bourget *et al.*, in press). Increased transparency was presumably correlated with increased primary production and hence food availability. Tolerant* has been recorded.
Increase in wave exposure (see benchmark)	An increase in wave exposure at the benchmark level is likely to adversely affect LR.H biotopes in the lower eulittoral. Both *Ulva intestinalis* and *Littorina littorea* are out of their preferred habitat in very wave exposed locations. If *Littorina littorea* were dislodged they are likely to be damaged, and may therefore become more susceptible to predation. Small patches of *Mytilus edulis* may also be susceptible to dislodgement in very exposed conditions. Dare (1976) noted that individual mussels swept or displaced from a mussel beds rarely survived, since they either became buried in sand or mud, or were scattered and eaten by oystercatchers. *Obelia longissima* is found in habitats with all levels of wave exposure because the branches and stems are flexible and probably able to withstand oscillatory flow (see Hunter, 1989). *Semibalanus balanoides* is tolerant of all levels of wave exposure. However, in LR.H pools in the lower eulittoral, very wave exposed shores would probably mean that the sediment would be flushed from the shallow pools, effectively removing the substratum (see above). In this case, the relative tolerance of *Obelia longissima* to increased wave exposure is irrelevant. It is likely that the entire biotope could be lost in the lower eulittoral and accordingly intolerance has been assessed as high. Recovery is expected to be very high.

Decrease in wave exposure (see benchmark)	A decrease in wave exposure is likely to adversely affect LR.H rockpools and it likely that, at the benchmark level, a different biotope will develop. The existence of LR.H is, in some respects, dependent on the influence of wave exposure. LR.H is dominated by ephemeral hydroids and seaweeds which thrive due to the disturbed nature of the habitat which prevents their competitive exclusion by late successional species. A reduction in wave exposure would remove this disturbance and therefore allow succession to take place in which the hydroids and ephemeral seaweeds would probably be out-competed by longer lived species. LR.H would be lost and, accordingly, intolerance has been assessed as high. Recoverability is expected to be very high (see additional information).
Noise (see benchmark)	None of the important characterizing species in LR.H are thought to have effective mechanisms for detecting noise and are likely to be tolerant of noise at the benchmark level.
Visual Presence (see benchmark)	None of the important characterizing species in LR.H are thought to have effective mechanisms for detecting visual presence and are likely to be tolerant of visual presence at the benchmark level.
Abrasion & physical disturbance (see benchmark)	The existence of LR.H is, in some respects, dependent on the influence of physical disturbance such as sand scour. LR.H is dominated by ephemeral hydroids and seaweeds which thrive due to the disturbed nature of the habitat which prevents their competitive exclusion by late successional species. However, abrasion by an anchor or fishing gear could potentially destroy parts of the biotope, depending on the size of the pool and on the size off the impact. The delicate filamentous fronds of *Ulva intestinalis* will easily be scraped off the surface of the rock. Parts of the delicate *Obelia longissima* colonies are also likely to be removed. However, the surface covering of hydrorhizae may remain largely intact, from which new uprights are likely to grow. In addition, the resultant fragments of colonies may be able to develop into new colonies (see displacement). If the shells of *Littorina littorea* or *Mytilus edulis* are damaged, the risk of predation and desiccation will increase. In most cases, it is very likely that some part of each population will remain and therefore, intolerance has been assessed as intermediate. Recovery is likely to be very high (see additional information).
Displacement (see benchmark)	If *Littorina littorea* was picked up and moved somewhere else it is unlikely that it would experience any adverse effects. Despite the other two characterizing species, *Obelia longissima* and *Ulva intestinalis*, being permanently attached to the substratum, they can be remarkably tolerant of displacement if replaced in water. Fragmentation is thought to be a possible mode of asexual reproduction in hydroids (Gili & Hughes, 1995). Therefore, it is possible that a proportion of displaced colonies (or fragments thereof) may attach to new substrata and survive. Cornelius (1995b) noted that detached specimens of *Obelia longissima* sometimes continue to grow if entangled in the intertidal. *Ulva intestinalis,* if detached from the substratum, may be buoyed up by gas and float to the surface where it continues to grow. *Mytilus edulis* may survive displacement (see *MarLIN* Web site) but Dare (1976) noted that individual mussels swept or displaced from mussel beds rarely survived, since they either became buried in sand or mud, or were scattered and eaten by oystercatchers. Furthermore, *Semibalanus balanoides* will not survive displacement. However, these two species are not characteristic of the biotope and their loss would not affect the visible biotope. On balance, an intolerance of intermediate has been recorded since it is likely that some hydroid colonies may die and not all of the displaced *Ulva intestinalis* will survive. Recoverability will be very high (see additional information).
Chemical Factors	
Synthetic compound contamination	• No information concerning the intolerance of *Obelia longissima* was found. However, evidence suggests that several species of hydroid exhibit sublethal effects due to synthetic chemical contamination and lethal

(see benchmark)	effects due to TBT contamination (see *MarLIN* Web site). • *Ulva intestinalis* has been assessed to have an intermediate intolerance to synthetic chemical pollution as available evidence highlights adverse effects upon the species viability and damage leading to death (see *MarLIN* Web site). Scarlett *et al.* (1997) analyzed water samples taken from the Plymouth Sound locality for the presence of the s-triazine herbicide, Irgarol 1051, which is an ingredient of antifouling paints used on pleasure boats and ships. The highest detected concentration of over 120 ng/L significantly inhibited the growth of *Ulva intestinalis*. Following the *Torrey Canyon* tanker oil spill, copious amounts of solvent based detergents were sprayed directly on to the shore. Algae on the higher shore were especially affected, and included *Ulva intestinalis* (as *Enteromorpha intestinalis* in high level rock pools where it was killed (Smith, 1968). • *Littorina littorea* is tolerant of high TBT levels (Oehlmann *et al.*, 1998) and has often been present in areas where the very TBT sensitive dog whelk *Nucella lapillus* has disappeared. Although imposex is rare in *Littorina littorea*, strong TBT contamination may affect a population significantly by reducing reproductive ability (Deutsch & Fioroni, 1996) through the development of intersex. Intersex is defined as a change in the female pallial oviduct towards a male morphological structure (Bauer *et al.*, 1995). However, only sexually immature and juvenile individuals of *Littorina littorea* are able to develop intersex. Also, owing to the reproductive strategy of *Littorina littorea*, which reproduces by means of pelagic larvae, populations do not necessarily become extinct as a result of intersex (Casey *et al.*, 1998). • The effects of contaminants on *Mytilus* sp. were extensively reviewed by Widdows & Donkin (1992) and Livingstone & Pipe (1992) and *Mytilus edulis* has been assessed as being of intermediate intolerance to synthetic chemicals (see *MarLIN* Web site). • Barnacles have a low resilience to chemicals such as dispersants, dependant on the concentration and type of chemical involved (Holt *et al.*, 1995) and most *Semibalanus balanoides* were killed in areas treated with dispersants (Smith, 1968). However, the barnacle population suffered indirectly as a result of the mass mortality of grazers. The resultant bloom of algae, and growth of fucoids, within 6 months, grew over and killed surviving barnacles (Hawkins & Southward, 1992). On balance, it has been suggested that the intolerance of LR.H to synthetic chemicals is intermediate. Despite the characterizing species showing primarily sublethal effects, the nature of the rockpool, especially those higher up on the shore, may mean that the contaminant takes some time to be flushed from the biotope. This would mean the sublethal effects may manifest themselves into a more adverse reaction. Due to the uncertainty with regards to contaminants leaving the system, a recoverability of high has been suggested.
Heavy metal contamination (see benchmark)	• Although no information on the effects of heavy metals on *Obelia longissima* was found, evidence suggests that hydroids may suffer at least sub-lethal effects and possibly morphological changes and reduced growth due to heavy metal contamination (see *MarLIN* Web site). • Evidence suggests that *Ulva* sp. are relatively tolerant of heavy metal exposure at environmentally realistic concentrations, but experience reduced growth. • Most of the information available suggests that adult gastropod molluscs are rather tolerant of heavy-metal toxicity (Bryan, 1984). Winkles may absorb metals from the surrounding water by absorption across the gills or from the diet, and evidence from experimental studies on *Littorina littorea* suggest that the diet is the most important source (Bryan *et al.*, 1983).

	Bryan *et al.* (1983) suggest that *Littorina littorea* is a reasonable bioindicator for Ag, Cd, Pb and perhaps As. It is not found to be a reliable indicator for other metals because of some interactions between metals and regulation of some, such as Cu and Zn (Langston & Zhou Mingjiang, 1986). The lethal dose of mercury (as mercury chloride) is between 1 and 10 ppm of seawater (Staines, 1996). This stems mainly from its ability to accumulate trace elements and compounds and consequential behavioural changes. • The effects of contaminants on *Mytilus* sp. were extensively reviewed by Widdows & Donkin (1992) and Livingstone & Pipe (1992). Overall, *Mytilus edulis* was assessed as being of intermediate intolerance to heavy metal contamination (see *MarLIN* Web site). Mussels were reported to be missing from a wider area than other shore organisms on a Cumbrian shore in the vicinity of a phosphate rich effluent outfall contaminated by a number of heavy metals (Holt *et al.*, 1998). • *Semibalanus balanoides* is considered to be of low intolerance to heavy metal exposure (see *MarLIN* Web site). On balance, it has been suggested that the intolerance of LR.H to heavy metals is intermediate. Despite the characterizing species showing primarily sublethal effects, the nature of the rockpool, especially those higher up on the shore, may mean that the contaminant takes some time to be flushed from the biotope. This would mean the sublethal effects may manifest themselves into a more adverse reaction. Due to the uncertainty with regards to contaminants leaving the system, a recoverability of high has been suggested.
Hydrocarbon contamination (see benchmark)	• Little information of the effects of hydrocarbons on hydroids was found although hydroid species adapted to a wide variation in environmental factors and with cosmopolitan distributions tend to be more tolerant of polluted waters (Boero, 1984; Gili & Hughes, 1995). The water soluble fractions of Monterey crude oil and drilling muds were reported to cause polyp shedding and other sublethal effects in the athecate *Tubularia crocea* in laboratory tests (Michel & Case, 1984; Michel *et al.*, 1986; Holt *et al.*, 1995). However, no information concerning the effects of hydrocarbons or oil spills on *Obelia* species was found. • *Ulva intestinalis* is likely to demonstrate intolerance to hydrocarbon contamination. Likely effects include smothering, inhibition of respiration and photosynthesis, bleaching, and interference with reproduction so that affected populations may be destroyed. However, the species tends to recover very rapidly from oil pollution incidents. For instance, after the *Torrey Canyon* tanker oil spill in 1967, grazing species were killed, and a dense flush of ephemeral green algae (such as *Ulva* and *Blidingia* sp.) appeared on the rocky shore within a few weeks and persisted for up to one year (Smith, 1968). • Observations from oil spills such as the *Sea Empress* and *Amoco Cadiz* suggest that gastropod molluscs are highly intolerant of hydrocarbon pollution because they become encrusted with oil and washed from the substratum where they are most likely eaten or die from desiccation (Suchanek, 1993). Given that *Littorina littorea* represents the most significant grazer in LR.H, it is likely that its disappearance will lead to a proliferation of ephemeral to the green algae, to the detriment of the hydroids with which the algae may compete for space. • A wealth of information concerning the effects of hydrocarbon contamination on *Mytilus edulis* was available (see *MarLIN* Web site. Overall, hydrocarbon tissue burden results in decreased scope for growth and, in some circumstances, may result in mortalities, reduced abundance or extent of the *Mytilus edulis*. • Littoral barnacles have a high resistance to oil (Holt *et al.*, 1995).

	However, after the *Torrey Canyon* oil spill, some mortality of barnacles was caused by the oil although most had been able to form a hole in the covering of oil and were 'in good order' (Smith, 1968). Significant reductions in densities of *Semibalanus balanoides* were observed after the *Exxon Valdez* oil spill (1989) , especially at high and mid shore (Highsmith *et al.*, 1996), although up to 98% reduction in barnacle cover resulted from treatment by hot-water washing. Experimentally, *Semibalanus balanoides* has been found to tolerate exposure to the water-accommodated fraction of diesel oil at 129.4 µg/l for two years (Bokn *et al.*, 1993). On balance, it has been suggested that the intolerance of LR.H to hydrocarbons is high. Despite the some of characterizing species showing primarily sublethal effects, the key grazers are likely to be lost and the biotope will become smothered with fast growing algae. The nature of the rockpool, especially those higher up on the shore, may mean that the contaminant takes some time to be flushed from the biotope. This would mean the sublethal effects may manifest themselves into a more adverse reaction. Due to the uncertainty with regards to contaminants leaving the system, a recoverability of high has been suggested.
Radionuclide contamination (see benchmark)	Apart from *Ulva intestinalis*, no information was found concerning the effects of radionuclides on the characterizing and other important species in LR.H and no assessment of sensitivity has been made. *Ulva* sp. are known to be able to acquire large concentrations of radioactive substances from surrounding water. In the vicinity of the Sellafield nuclear plant, England, *Ulva* (as *Enteromorpha*) sp. accumulated zirconium, niobium, cerium and plutonium-239, however the species appeared to be unaffected by the radionuclides (Clark, 1997).
Changes in nutrient levels (see benchmark)	In a shallow rockpool such as those associated with LR.H, an influx of nutrients could lead to an increase in the abundance of *Ulva intestinalis* since nitrogen enrichment has been shown to enhance its growth (Kamer & Fong, 2001). An increase in the standing biomass of *Ulva intestinalis* would benefit *Littorina littorea* which grazes on it. *Mytilus edulis* may also benefit from moderate nutrient enrichment, especially in the form of organic particulates and dissolved organic material. The resultant increased food availability may increase growth rates, reproductive potential and decrease vulnerability to predators. In contrast, *Obelia longissima* may be competitively displaced by the *Ulva intestinalis*, leading to a reduction in the abundance of hydroids. In respect of the possibility of a reduction in hydroid coverage, an intermediate intolerance has been suggested. Recoverability is likely to be very high since excess nutrients are likely to be utilized quickly.
Increase in salinity (see benchmark)	High air temperatures cause surface evaporation of water from pools, so that salinity steadily increases, especially in pools not flooded by the tide for several days. The extent of temperature and salinity change is affected by the frequency and time of day at which tidal inundation occurs. If high tide occurs in early morning and evening the diurnal temperature follows that of the air, whilst high water at midday suddenly returns the temperature to that of the sea (Pyefinch, 1943). Heavy rainfall, followed by tidal inundation can cause dramatic fluctuations in salinity, and values ranging from 5-30 psu have been recorded in rockpools over a period of 24 hrs (Ranade, 1957). As a consequence of such a regime, the entire LR.H community will be adapted, to a certain degree, to fluctuating salinities. For instance, during the summer, owing to excessive evaporation brine precipitation may occur in rockpools containing *Ulva intestinalis* and salinity has been reported to rise as high as 180 psu (Reed & Russell, 1979). At the benchmark level, an intolerance of low has been suggested to reflect the different experiences rockpools at the top and bottom of the eulittoral are likely to have.

Decrease in salinity (see benchmark)	High rainfall will reduce salinity in rock pools and may create a surface layer of brackish/nearly fresh water for a period. The extent of temperature and salinity change is affected by the frequency and time of day at which tidal inundation occurs. If high tide occurs in early morning and evening the diurnal temperature follows that of the air, whilst high water at midday suddenly returns the temperature to that of the sea (Pyefinch, 1943). Heavy rainfall, followed by tidal inundation can cause dramatic fluctuations in salinity, and values ranging from 5-30 psu have been recorded in rockpools over a period of 24 hrs (Ranade, 1957). Rockpools in the supralittoral, littoral fringe and upper eulittoral are liable to gradually changing salinities followed by days of fully marine or fluctuating salinity at times of spring tide (Lewis, 1964). As a consequence of such a regime, the entire LR.H community will be adapted, to a certain degree, to fluctuating salinities. *Ulva intestinalis*, for instance, is considered to be a remarkably euryhaline species, tolerant of extreme salinities ranging from 0 psu to 136 psu although reduced salinity can affect the growth rate of *Ulva intestinalis*. *Obelia longissima*, *Littorina littorea* and *Semibalanus balanoides* are also found in areas of reduced salinity. *Mytilus edulis* exhibits a defined behaviour to reducing salinity, initially only closing its siphons to maintain the salinity of the water in its mantle cavity, which allows some gaseous exchange and therefore maintains aerobic metabolism for longer. In extreme low salinities, e.g. resulting from storm runoff, large numbers of mussels may be killed (Keith Hiscock, pers comm.). In the long term (weeks) *Mytilus edulis* can acclimate to lower salinities (Almada-Villela, 1984; Seed & Suchanek, 1992; Holt *et al.*, 1998). Almada-Villela (1984) reported that the growth rate of individuals exposed to only 13 psu reduced to almost zero but had recovered to over 80 percent of control animals within one month. *Mytilus edulis* can also survive considerably reduced salinities, growing as dwarf individuals at 4-5psu in the Baltic. At the benchmark level, an intolerance of low has been suggested to reflect the different experiences rockpools at the top and bottom of the eulittoral are likely to have.
Changes in oxygenation (see benchmark)	Hydroids mainly inhabit environments in which the oxygen concentration exceeds 5 ml/l (Gili & Hughes, 1995). Although no information was found on oxygen consumption in *Obelia longissima*, Sagasti *et al.* (2000) reported that epifaunal species (including several hydroids and *Obelia bicuspidata*) in the York River, Chesapeake Bay, tolerated summer hypoxic episodes of between 0.5 and 2 mg O_2/l (0.36 and 1.4 ml/l) for 5-7 days at a time, with few changes in abundance or species composition. *Littorina littorea* can endure long periods of oxygen deprivation. The snails can tolerate anoxia by drastically reducing their metabolic rate down to 20% of normal (MacDonald & Storey, 1999). *Mytilus edulis* is regarded as euryoxic, tolerant of a wide range of oxygen concentrations including zero (Zwaan de & Mathieu, 1992). Diaz & Rosenberg (1995) suggest it is resistant to severe hypoxia. Adult mytilids exhibited high tolerance of anoxia and *Mytilus edulis* is capable of anaerobic metabolism. Jorgensen (1980) observed, by diving, the effects of hypoxia (0.2 -1 mg/l) on benthic macrofauna in marine areas in Sweden over a 3-4 week period. Mussels were observed to close their shell valves in response to hypoxia and survived for 1-2 weeks before dying (Cole *et al.*, 1999; Jorgensen, 1980). *Semibalanus balanoides* can respire anaerobically, so it can tolerate some reduction in oxygen concentration (Newell, 1979). When placed in wet nitrogen, where oxygen stress is maximal and desiccation stress is low, *Semibalanus balanoides* has a mean survival time of 5 days (Barnes *et al.*, 1963). No information was found concerning the effects of reduced oxygen concentration on *Ulva intestinalis*. On balance, *Mytilus edulis* and *Littorina littorea* are tolerant of hypoxia at the benchmark level (2 mg/l O_2 for 1 week) although such a reduction in oxygen concentration will incur a metabolic cost and, hence, reduced

	growth. Accordingly, an intolerance of low has been recorded. Once oxygen levels return to prior levels, both species are likely to recover condition within a few weeks.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	No information was found concerning the effects of microbial pathogens on two of the characterizing species (*Ulva intestinalis* and *Littorina littorea*) but *Obelia* species are infected by a number of parasites at various stages in their life cycles (see *MarLIN* review of *Obelia longissima*). However, no negative effects have been noted from such an infestation. *Mytilus* spp. and *Semibalanus balanoides* also host various microbial pathogens. *Mytilus edulis* host a wide variety of disease organisms, parasites and commensals from many animal and plant groups including bacteria, blue green algae, green algae, protozoa, boring sponges, boring polychaetes, boring lichen, the intermediary life stages of several trematodes, copepods and decapods (See *MarLIN* review of *Mytilus edulis*). However, *Mytilus edulis* and *Semibalanus balanoides* are not characterizing species and their viability will not affect the recognizable biotope. Overall, insufficient information was available to make an assessment of sensitivity.
Introduction of non-native species (see benchmark)	There are no alien species recorded in LR.H and no assessment of intolerance has been made.
Extraction of key or important characterizing species (see benchmark)	Of the important characterizing species, only the common periwinkle *Littorina littorea* is known to be targeted for extraction. This species is harvested by hand, without regulation, for human consumption. In some areas, notably Ireland, collectors have noted a reduction in the number of large snails available. Due to the shallow nature of the pools associated with LR.H and the fact they are likely to occur in accessible places, it would be easy for this species to be extracted from the biotope. However, only large individuals would be removed and smaller ones would probably be left behind. Intolerance has been assessed as low with a very high recoverability as adult snails would most probably crawl from nearby rock pools (see additional information). The 'other' important species, *Mytilus edulis*, has been fished for hundreds of years although the extraction of this species is unlikely to affect the recognizable biotope. Mussel beds may be exploited by hand collection or dredging. Holt *et al.*, (1998) suggest that when collected by hand at moderate levels using traditional skills the beds will probably retain most of their biodiversity. However, they also cite incidences of over-exploitation of easily accessible small beds by anglers for bait. Holt *et al.*, (1998) suggest that in particular embayments over-exploitation may reduce subsequent recruitment leading to long term reduction in the population or stock.
Extraction of important species (see benchmark)	The 'other' important species, *Mytilus edulis*, has been fished for hundreds of years although the extraction of this species is unlikely to affect the recognizable biotope. Mussel beds may be exploited by hand collection or dredging. Holt *et al.*, (1998) suggest that when collected by hand at moderate levels using traditional skills the beds will probably retain most of their biodiversity. However, they also cite incidences of over-exploitation of easily accessible small beds by anglers for bait. Holt *et al.*, (1998) suggest that in particular embayments over-exploitation may reduce subsequent recruitment leading to long term reduction in the population or stock.

Additional information

Hydroids have the ability to produce dormant resting stages that are far more resistant to environmental change than the colony itself. Therefore, although colonies may be removed or destroyed, the resting stages may survive attached to the substratum. The resting stages provide a mechanism for rapid recovery.
The medusoid and planula larval stages of *Obelia longissima* potentially result in significant powers of dispersal. In addition, few species of hydroids have specific substrata requirements, many are generalists, and *Obelia longissima* has been reported from a variety of hard substrata, together with sandy habitats (Cornelius, 1992; Cornelius, 1995b). Hydroids are also capable of asexual reproduction and many species produce dormant, resting stages that are very resistant of environmental perturbation (Gili & Hughes, 1995). Rapid growth, budding and the formation of stolons allows hydroids to colonize space rapidly. Cornelius (1992) stated that *Obelia longissima* could form large colonies within a matter of weeks. Hydroids are often the first organisms to colonize available space in settlement experiments (Gili & Hughes, 1995). For example, hydroids were reported to colonize an experimental artificial reef within less than 6 months becoming abundant in the following year (Jensen *et al.*, 1994). In similar studies, *Obelia* species recruited to the bases of reef slabs within 3 months and the slab surfaces within 6 months of the slabs being placed in the marine environment in summer (Hatcher, 1998). In the St Lawrence Estuary, Canada, settlement plates immersed in June were colonized by *Obelia longissima* within a few months, and *Obelia longissima* was a dominant member of the epifauna until the following July (Brault & Bourget, 1985).
Overall, *Obelia longissima* is likely to recover from damage very quickly. Even where the colonies are destroyed and/or removed, remaining resting stages or colony fragments, together with rapid growth and potentially good recruitment should result in rapid recovery.

Ulva intestinalis is generally considered to be an opportunistic species, with an '*r*-type' strategy for survival. The r-strategists have a high growth rate and high reproductive rate. The species is also capable of dispersal over a considerable distance. *Ulva intestinalis* is amongst the first multicellular algae to appear on substrata that have been cleared following a disturbance. Following the *Torrey Canyon* oil spill in March 1967, for instance, species of the genus *Ulva* rapidly recruited to areas where oil had killed the herbivores that usually grazed on them, so that a rapid greening of the rocks (owing to a thick coating of *Ulva*) was apparent by mid-May (Smith, 1968). The rapid recruitment of *Ulva* to areas cleared of herbivorous grazers was also demonstrated by Kitching & Thain (1983). Following the removal of the urchin *Paracentrotus lividus* from areas of Lough Hyne, Ireland, *Ulva* grew over the cleared area and reached a coverage of 100% within one year. Therefore, evidence suggests that *Ulva intestinalis* is likely to have a considerable ability for recovery within a year.

In the common periwinkle, the larvae form the main mode of dispersal. *Littorina littorea* is an iteroparous breeder with high fecundity that lives for several years. Breeding can occur throughout the year and the planktonic larval stage is long (up to 6 weeks) although larvae do tend to remain in waters close to the shore. Therefore recruitment and subsequent recovery rates should be high. Although adult immigration is usually an unlikely means of recovery, given their slow crawling, it may be possible in LR.H due to the likelihood of similar rockpools and *Littorina littorea* population sin close proximity.

Seed & Suchanek (1992) reviewed studies of recovery of 'gaps' (naturally or artificially induced) in mussel beds in Mytilus species. On rocky shores, gaps are often colonized by barnacles and fucoids, barnacles enhancing subsequent recruitment of mussels. Cycles of loss and recruitment leads to a patchy distribution of mussels on rocky shores. High intertidal and less exposed sites recovered slower than low shore, more exposed sites. Overall, Mytilus spp. populations were considered to have a strong ability to recover from environmental disturbance (Seed & Suchanek, 1992; Holt *et al.*, 1998). Larval supply and settlement could potentially occur annually but settlement is sporadic with unpredictable pulses of recruitment (Lutz & Kennish, 1992; Seed & Suchanek, 1992). Therefore, while good annual recruitment is possible, recovery may take at least 5 years, although in certain circumstances and under some environmental conditions recovery may take significantly longer.

Bennell (1981) recorded recovery of *Semibalanus balanoides* populations within 3 years on a site cleared of barnacles in North Wales. Barnacle recruitment is, however, dependent on a suite of environmental and biological factors and, therefore, populations may take longer to recover.

However, neither *Mytilus edulis* nor *Semibalanus balanoides* are important characteristic species. For the three important characterizing species (*Obelia longissima*, *Ulva intestinalis* and *Littorina littorea*), recovery is likely to be very high

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors				
	Obelia longissima	***Littorina littorea***	***Ulva intestinalis***	***Mytilus edulis***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important other
Substratum Loss	High	High	High	High
Smothering	Intermediate	High	High	Intermediate
Increase in suspended sediment	Intermediate	Intermediate	Intermediate	Low
Decrease in suspended sediment	Low	See explanation	Not Sensitive	Low
Desiccation	High	Low	Low	Low
Increase in emergence regime	Intermediate	Low	Not Sensitive*	Low
Decrease in emergence regime	Not Sensitive*	See explanation	Low	Low
Increase in water flow rate	Intermediate	Intermediate	Intermediate	Low
Decrease in water flow rate	Intermediate	See explanation	Not Sensitive	Low
Increase in temperature	High	Low	Not Sensitive*	Low
Decrease in temperature	Low	See explanation	Not Sensitive	Low
Increase in turbidity	Low	Low	Low	Not Sensitive
Decrease in turbidity	Low	See explanation	Not Sensitive*	Not Sensitive
Increase in wave exposure	Low	Intermediate	Low	Intermediate
Decrease in wave exposure	Intermediate	See explanation	Not Sensitive	Intermediate
Noise	Not Sensitive	Not Sensitive	Not Relevant	Not Sensitive*
Visual Presence	Not Sensitive	Not Sensitive	Not Relevant	Not Sensitive*
Abrasion & physical disturbance	Intermediate	Intermediate	High	Intermediate
Displacement	Intermediate	Not Sensitive	Not Sensitive	Intermediate
Chemical factors				
	Obelia longissima	***Littorina littorea***	***Ulva intestinalis***	***Mytilus edulis***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important other
Synthetic compound contamination	Intermediate	Low	Intermediate	Intermediate
Heavy metal contamination	Intermediate	Intermediate	Low	Intermediate
Hydrocarbon contamination	Insufficient information	High	High	Intermediate
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	Not Sensitive*	Not Sensitive	Not Sensitive*	Intermediate
Increase in salinity	Insufficient information	Not Sensitive	Not Sensitive	Low
Decrease in salinity	Intermediate	See explanation	Not Sensitive	Low
Changes in oxygenation	Low	Low	Insufficient information	Low
Biological factors				
	Obelia longissima	***Littorina littorea***	***Ulva intestinalis***	***Mytilus edulis***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important other
Introduction of microbial pathogens/parasites	Low	Insufficient information	Insufficient information	Intermediate
Introduction of non-native species	Insufficient	Insufficient	Not Relevant	Insufficient

	information	information		information
Extraction of this species	Not Relevant	Intermediate	Intermediate	Intermediate
Extraction of other species	Not Relevant	Not Sensitive	Not Relevant	Low

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors				
	Obelia longissima	***Littorina littorea***	***Ulva intestinalis***	***Mytilus edulis***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important other
Substratum Loss	Very high	High	Very high	High
Smothering	Very high	High	Very high	High
Increase in suspended sediment	Very high	High	Very high	Immediate
Decrease in suspended sediment	Immediate	See explanation	Not Relevant	Immediate
Desiccation	Very high	Immediate	Very high	Immediate
Increase in emergence regime	Very high	Immediate	Not Relevant	Very high
Decrease in emergence regime	Not Relevant	See explanation	Very high	Very high
Increase in water flow rate	Very high	High	Very high	Very high
Decrease in water flow rate	Very high	See explanation	Not Relevant	Very high
Increase in temperature	Very high	Immediate	Not Relevant	Very high
Decrease in temperature	Immediate	See explanation	Not Relevant	Very high
Increase in turbidity	Immediate	Very high	Very high	Not Relevant
Decrease in turbidity	Immediate	See explanation	Not Relevant	Not Relevant
Increase in wave exposure	Immediate	High	Very high	High
Decrease in wave exposure	Very high	See explanation	Not Relevant	High
Noise	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Visual Presence	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Abrasion & physical disturbance	Very high	High	Very high	High
Displacement	Very high	Not Relevant	Not Relevant	High
Chemical factors				
	Obelia longissima	***Littorina littorea***	***Ulva intestinalis***	***Mytilus edulis***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important other
Synthetic compound contamination	Very high	Very high	High	High
Heavy metal contamination	Very high	High	Very high	High
Hydrocarbon contamination	Not Relevant	High	Very high	High
Radionuclide contamination	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Changes in nutrient levels	Not Relevant	Not Relevant	Not Relevant	High
Increase in salinity	Not Relevant	Not Relevant	Not Relevant	Very high
Decrease in salinity	Very high	See explanation	Not Relevant	Very high
Changes in oxygenation	Immediate	Very high	Not Relevant	Very high
Biological factors				
	Obelia longissima	***Littorina littorea***	***Ulva intestinalis***	***Mytilus edulis***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important other
Introduction of microbial pathogens/parasites	Immediate	Insufficient information	Not Relevant	High
Introduction of non-native species	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Extraction of this species	Not Relevant	High	Very high	High

Extraction of other species	Not Relevant	Not Relevant	Not Relevant	Very high

Importance

Marine natural heritage importance

National importance	Rare
Habitat Directive feature (Annex 1)	Reefs Large shallow inlets and bays Estuaries

Biotope importance

LR.H is not thought to hold any significant importance for other species although the mussels that may be found in the biotope may be part of large mussel beds (SLR.MytX) which are highly productive, and offer refuge and food for a large variety of organisms. Seed & Suchanek (1992) suggested that in populations of older mussels, productivity may be in the region of 2000-14,500 kJ/m²/yr. The *Mytilus edulis* beds probably also provide secondary productivity in the form of tissue, faeces and pseudofaeces (Seed & Suchanek, 1992; Holt *et al.*, 1998). Larval production represents a significant contribution to the zooplankton, forming an important food source for herring larvae and carnivorous zooplankton (Seed & Suchanek, 1992). Dense beds of bivalve suspension feeders increase turnover of nutrients and organic carbon in estuarine (and presumably coastal) environments by effectively transferring pelagic phytoplanktonic primary production to secondary production (pelagic-benthic coupling) (Dame, 1996).

Exploitation

Both *Littorina littorea* and *Mytilus edulis* are targeted for extraction. *Littorina littorea* is gathered by hand at a number of localities, particularly in Scotland and in Ireland where the industry is valued at around £5 million per year.

Mussels have been harvested for food and bait since early times. British mussel production is relatively small, comprising only 5% of total Europe Community production (Edwards, 1997). Wild mussel fisheries are found in tidal flats of The Wash, Morecambe Bay, Solway and Dornoch Firths in Scotland and river estuaries such as Conwy, North Wales and the Teign and Taw, Devon (Edwards, 1997). Edwards (1997) notes that the commercial development of natural beds is hampered by sporadic and unpredictable recruitment. Extraction of *Mytilus edulis* from LR.H will most likely be by hand on a small scale.

Additional information

No text entered

This Biology and Sensitivity Key Information review can be cited as follows:

Marshall, C.E., 2005. Hydroids, ephemeral seaweeds and Littorina littorea in shallow eulittoral mixed substrata pools. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 21/01/2005]. Available from: <http://www.marlin.ac.uk>

Seaweeds in sediment (sand or gravel)-floored eulittoral rockpools (LR.SwSed)

Key information authored by: Dr Harvey Tyler-Walters

Last updated 25/01/2005

This information is not refereed

Seaweeds in sediment (sand or gravel)-floored eulittoral rockpools. Image width ca XX m.
Image: Tom Mercer / Joint Nature Conservation Committee

Recorded and expected LR.SwSed distribution for Britain and Ireland

Description of biotope

Rockpools with sediment floors support distinct communities of scour-tolerant algae. Deep pools with sediment are similar to LR.FK, and are typically dominated by fucoids and kelps (*Fucus serratus*, *Laminaria digitata*, *Laminaria saccharina* and *Saccorhiza polyschides*). Areas of hard substrata near to the interface with the sediment are, however, characterized by a range of sand-tolerant algae such as *Furcellaria lumbricalis*, *Polyides rotundus*, *Ahnfeltia plicata* and *Rhodothamniella floridula* (compare with LR.F). *Chorda filum* may occur attached to pebbles and shells embedded within the sediment. In pools with large areas of sand, infaunal species such as *Arenicola marina* and *Lanice conchilega* often occur. The sea grass *Zostera* spp. may occur in some pools where stable sand is present. Shallow rockpools with cobble and pebble floors, often with an underlying layer of sediment, support red algal tufts (*Mastocarpus stellatus* mixed with *Ceramium* spp., *Calliblepharis ciliata* and *Cystoclonium purpurea* and green algae). (Information taken from the Marine Biotope Classification for Britain and Ireland, Version 97.06: Connor *et al.*, 1997a, b).

Welsh variation

Although the Welsh examples of many of the biotopes in this report follow the British and Irish classification description closely, some regional variation may exist. Reference should be made to Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

Factors such as pool depth, surface area, volume, orientation to sunlight, shading, internal topography, sediment content and type, together with wave exposure, shore height, and hence flushing rate, and the presence of absence of freshwater runoff, results in large spatial variation in community structure, even between adjacent pools at the same shore height (Ganning, 1971; Metaxas & Scheibling, 1993). Individual rockpools and the communities that occupy them are highly variable. The above biotope description includes a wide variety of rockpool communities, from deep macroalgal dominated pools to shallow sediment filled rockpools that support only a few red algae. As a necessity, therefore, the review that follows is broad in nature.

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Biotope complex	LR.Rkp	Rockpools
Biotope	LR.SwSed	Seaweeds in sediment (sand or gravel)-floored eulittoral rockpools
Similar biotopes:	LR.FK	

Other biotope classification schemes

European Nature Information System (EUNIS) habitat classification - A1.513 - Seaweeds in sediment-floored eulittoral rockpools (Davies & Moss, 1998).

Ecology

Ecological and functional relationships

The rockpool environment varies depending on factors such as pool depth, surface area, volume, orientation to sunlight, shading, internal topography, sediment content and type, together with wave exposure, shore height, and hence flushing rate, and the presence of absence of freshwater runoff. As a result, no two rockpools exhibit exactly the same physio-chemical conditions and exhibit large spatial variation in community structure, even between adjacent pools at the same shore height (Ganning, 1971; Metaxas & Scheibling, 1993; Metaxas *et al.*, 1994). Any given rockpool is effectively unique (Metaxas & Scheibling, 1993). Therefore, while the organisms detailed below have been recorded in this rockpool biotope, not all, or in some case few, of the organisms, and hence the relationships between them, may occur in any one rockpool.

As communities in rockpools remain constantly submerged and the danger of desiccation is absent, it might be expected that rockpools provide an easier environment in which to live for marine life than drying rock surfaces, and that species from regions lower on the shore would be able to extend much further up the shore. However, the rockpool environment differs from that of the surrounding emergent rock surfaces, so that not all species that thrive on the surrounding rock occur abundantly in rockpools and much of the lower shore open rock fauna is absent from rockpools (Lewis, 1964). Rockpools constitute a distinct environment for which physiological adaptations by the flora and fauna may be required (Lewis, 1964; Metaxas & Scheibling, 1993). The following description is based on reviews by Lewis (1964), Ganning (1971) and Metaxas & Scheibling (1993), the species listed in the MNCR database (JNCC, 1999) and additional references as cited.

- Macroalgae such as kelps, fucoids, red and green algae, erect and encrusting corallines provide primary productivity either directly to grazing invertebrates and fish or indirectly, to detritivores and decomposers, in the form of detritus and drift algae or as dissolved organic material and other exudates. Benthic microalgae and phytoplankton (e.g. diatoms) also add to primary productivity.
- Where present, large macroalgae such as *Halidrys siliquosa* and laminarians (e.g. *Laminaria digitata*, *Laminaria saccharina* and *Saccorhiza polyschides*) and fucoids (e.g. *Fucus serratus*, *Fucus vesiculosus*) shade the substratum (depending on density) so that understorey plants tend to be shade tolerant red algae. Understorey algae, by effectively restricting access to the substratum, may also inhibit or restrict recruitment of other species of macroalgae (Hawkins & Harkin, 1985; Hawkins *et al.*, 1992).
- Macroalgae compete for space with sessile invertebrates such as sponges, hydroids, ascidians and bryozoans.
- Macroalgae provide substrata and refuges for a variety of invertebrates and epiphytic algae. The stipes and lamina of *Laminaria* spp. may support bryozoans (e.g. *Membranipora membranipora* or *Electra pilosa*) and grazing blue-rayed limpets (*Helcion pellucida*), while their holdfasts provide additional refuges for meiofauna and small invertebrates. If present, the stipes of *Laminaria hyperborea* may support numerous epiphytes such as *Palmaria palmata*, *Phycodrys rubens* and *Cladophora rupestris* (Goss-Custard *et al.*, 1979). Where present, *Halidrys siliquosa* provide substratum for epiphytes, depending on location, including microflora (e.g. bacteria, blue green algae, diatoms and juvenile larger algae), *Ulothrix* and *Ceramium* sp., hydroids (e.g. *Obelia* spp.), bryozoans (e.g. *Scrupocellaria* spp.), and ascidians (e.g. *Apilidium* spp., *Botryllus schlosseri*, and

Botrylloides leachi) (Lewis, 1964; Moss, 1982; Connor *et al.*, 1997a).

- The macroalgae provide refuges for small invertebrates, such as isopods, amphipods, ostracods and copepods. *Corallina officinalis* provides a substratum for small spirorbids e.g. *Spirorbis corallinae*, which is only found on *Corallina officinalis*. Increasing density of *Spirorbis corallinae* was shown to increase the species richness of the epiphytic fauna (Crisp & Mwaiseje, 1989). The invertebrate fauna of *Corallina officinalis* is detailed in LR.Cor.
- Amphipods, isopods (e.g. *Idotea granulosa*) and other mesoherbivores graze the epiphytic flora and senescent macroalgal tissue, which may benefit the macroalgal host, and may facilitate dispersal of the propagules of some macroalgal species (Brawley, 1992; Williams & Seed, 1992). Mesoherbivores also graze the macroalgae but do not normally adversely affect the canopy (Brawley, 1992).
- Grazers of periphyton (bacteria, blue-green algae and diatoms) or epiphytic algae include harpacticoid copepods, the limpets *Patella vulgata* and *Patella ulyssiponensis*, the blue-rayed limpet *Helcion pellucidum*, and gastropods such as *Gibbula cineraria, Gibbula umbilicalis, Littorina saxatilis, Littorina littorea, Littorina obtusata* and *Rissoa* spp. Limpets and littorinids also graze macroalgal sporelings and green algae especially.
- Coralline algae are probably relatively grazing resistant (Littler & Kauker, 1984) and few species graze the corallines directly except perhaps chitons and limpets of the genus *Tectura*.
- Grazing by littorinids and gammarid amphipods has been shown to significantly affect macroalgal abundance and diversity. For example in cage experiments in littoral fringe pools, Parker *et al.* (1993) found that gammarid amphipods significantly reduced the erect macroalgal canopy, while littorinids grazed microalgae and macroalgal sporelings, and prevented the establishment of erect and encrusting algal canopies. Both groups reduced the species richness of the algal canopy (Parker *et al.*, 1993). In tidepools in Nova Scotia, Chapman (1990) and Chapman & Johnson (1990) reported that grazers (especially littorinids) reduced the abundance of *Fucus* spp. sporelings and juveniles but increased the abundance of ephemeral algae, while having no effect on the encrusting red alga *Hildenbrandia rubra* (Metaxas & Scheibling, 1993). Conversely, Lubchenco (1978) noted that the addition of littorinids to mid-shore pools in Massachusetts decreased the abundance of dominant *Ulva* spp. (as *Enteromorpha* spp.) in favour of *Chondrus crispus* (Metaxas & Scheibling, 1993) a less palatable red alga. Wolfe & Harlin (1988a) noted that Rhode Island tidepools with the highest littorinid densities had the lowest abundance of macroalgae. Similarly, removal of the limpet *Patella vulgata* from high tidal pools at Lough Ine resulted in an increased abundance of *Ulva* (as *Enteromorpha*) sp. (Goss-Custard *et al.*, 1979).
- Where present, suspension feeders include barnacles (e.g. *Semibalanus balanoides*), the mussel *Mytilus edulis*, hydroids, tubeworms (e.g. *Spirorbis* spp. and *Pomatoceros* spp.), ascidians, bryozoans and sponges. However, the abundance of barnacles and mussels in rockpools is usually low (Lewis, 1964), presumably due to heavy predation on juveniles by the dog whelk *Nucella lapillus* and crabs (e.g. *Carcinus maenas* and *Cancer pagurus*).
- The sediment provides habitat for deposit feeding annelids e.g. *Arenicola marina* and terebellids.
- Scavengers include shrimp (e.g. *Palaemon serratus*), brittlestars (e.g. *Amphipholis squamata*), cushion stars (*Asterina gibbosa*) and hermit crabs (e.g. *Pagurus bernhardus*).
- Invertebrate predators include turbellarians and nemerteans feeding on small invertebrates such as copepods and small gastropods. Lower to mid shore rockpools provide refugia for dog whelks *Nucella lapillus* feeding on barnacles and small mussel within the rockpool and /or leaving the rockpool to forage at high tide. Similarly, crabs such as *Carcinus maenas* and *Cancer pagurus* are generalist predators of gastropods (e.g. littorinids) and bivalves as well as scavengers. Passive carnivores include sea anemones such as *Anemonia viridis*, *Actinia equina* and *Urticina felina*. In addition, intertidal fish such as the shanny *Lipophrys pholis* and gobies prey on small invertebrates such as copepods, amphipods and isopods.
- As with grazing, predation pressure is potentially higher in mid to low shore rockpools, since predators can continue feeding irrespective of the state of the tide. For example, in New South Wales, whelks were shown to reduce the abundance of barnacles, tubeworms and limpets (Fairweather, 1987; Metaxas & Scheibling, 1993). Dethier (1984) concluded that harpacticoid copepod abundance in mid to low shore pools was low due to the presence of predators such as fish and to a lesser extent anemones. The reduced abundance of barnacles and mussels observed in rockpools (Lewis, 1964) is probably partly due to increased predation pressure.

Seasonal and longer term change

Conditions within rockpools are the consequence of prolonged separation from the main body of the sea, and physico-chemical parameters within them fluctuate dramatically (Pyefinch, 1943; Ganning, 1971; Daniel & Boyden, 1975; Goss-Custard *et al.*, 1979; Morris & Taylor, 1983; Huggett & Griffiths, 1986; Metaxas & Scheibling, 1993; Metaxas *et al.*, 1994). In general, larger and deep rockpools low on the shore tend to correspond to the sublittoral habitat with a more stable temperature and salinity regime. In contrast, small and shallow pools higher on the shore are especially influenced by insolation, air temperature and rainfall, the effects of which become more significant towards the high shore, where pools may be isolated from the sea for a number of days or weeks (Lewis, 1964).

Weather conditions exert a considerable influence on temperature and salinity. Water temperature in pools follows the temperature of the air more closely than that of the sea.

Temperature
The temperature of pools fluctuates with air temperature and sunlight, and tends to warm throughout the day, especially if in direct sunlight (Daniel & Boyden, 1975; Goss-Custard *et al.*, 1979). Shaded pools exhibit less dramatic changes in temperature (Daniel & Boyden, 1975). For example, the temperature of a high shore pool exposed to direct sunlight rose quickly in the morning to a maximum of 25 °C, while a shaded high shore pool only rose by 1 °C, even though air temperatures reached 20 °C (Daniel & Boyden, 1975). In addition, deeper pools may become stratified, with warmer water near the surface and cooler near the bottom (Daniel & Boyden, 1975), primarily due to sunlight. They noted that pool temperatures remained almost constant at night and suggested that pool temperatures would fluctuate slowly during the day under overcast conditions. In deeper pools, the vertical temperature gradation present in summer, may reverse during winter owing to density stratification, so that ice may form (Naylor & Slinn, 1958). Morris & Taylor (1983) reported warmer water at the bottom of the pools and cooler at the surface, which they attributed to cooling of the surface water by wind. Examples of temperature ranges reported for mid to low shore pools include annual maxima and minima of 1-25 °C and 2-22 °C (Morris & Taylor, 1983), a diurnal range of 24 °C (day) and 13 °C (night) for a mid shore pool (Daniel & Boyden, 1975), and surface water temperature ranges of 14-19.25 °C and 15.5-20.75 °C in mid shore pools (Pyefinch, 1943). Smaller (or shallow pools) are more affected by climatic change in temperature than larger and/or deeper ones (Ganning, 1971). Morris & Taylor (1983) noted that temperature showed the greatest seasonal variation of all the physical parameters examined. In summer, the minimum recorded temperatures were greater than the maximum temperatures recorded in winter, and the daily temperature ranges were greater in summer than in winter, in both high and low shore pools (Morris & Taylor, 1983).

Salinity
High air temperatures cause surface evaporation of water from pools, so that salinity steadily increases, especially in pools not flooded by the tide for several days. Alternatively, high rainfall will reduce pool salinity or create a surface layer of brackish/nearly fresh water for a period. In addition, freezing of surface water increases the salinity of the underlying water (Ganning, 1971; Metaxas & Scheibling, 1993). Daniel & Boyden (1975) and Morris & Taylor (1983) reported little variability in salinity over one tidal cycle, and Ganning (1971) suggested that changes in salinity were of limited importance. However, heavy rain resulted in a layer of low salinity water on the surface of pools. Morris & Taylor (1983) stated that a low salinity layer of 2-10 mm was normal but after one storm the low salinity layer increased in depth, eventually resulting in a homogeneous pool of brackish water. Morris & Taylor (1983) reported an annual salinity range in mid to low shore pools of 26-36.5 ppt.

The extent of temperature and salinity change is affected by the frequency and time of day at which tidal inundation occurs. If high tide occurs in early morning and evening the diurnal temperature follows that of the air, whilst high water at midday suddenly returns the temperature to that of the sea (Pyefinch, 1943). Rockpools in the supralittoral, littoral fringe and upper eulittoral are liable to gradually changing salinities followed by days of fully marine or fluctuating salinity at times of spring tide (Lewis, 1964).

Oxygenation
The biological community directly affects oxygen concentration, carbon dioxide concentration and pH, and are themselves affected by changes in the chemical parameters. Throughout the day, algae photosynthesize and produce oxygen, the concentration of which may rise to three times its saturation value, so that bubbles are released (Pyefinch, 1943; Ganning, 1971; Daniel & Boyden, 1975; Goss-Custard *et al.*, 1979; Morris & Taylor, 1983; Metaxas & Scheibling, 1993). In summer, rockpools are likely to be supersaturated with oxygen during the day (Pyefinch, 1943). For example, the greatest range of oxygen saturation of 101.7%

occurred in a seaweed dominated, sediment floored pool, which reached over 190%saturation on some days (Pyefinch, 1943). Daniel & Boyden (1975) noted that a mid shore, seaweed dominated pool reached 194% saturation (ca 15 mg O_2/l) but that oxygenation was also marked in shaded pools. A pool with dense fauna exhibited a maximum saturation of 210% (Pyefinch, 1943). During photosynthesis algae absorb carbon dioxide and, as concentrations fall, the pH rises. Morris & Taylor (1983) recorded pH values >9 in rockpools on the Isle of Cumbrae.

At night, changes occur in the opposite direction as respiration utilizes much of the available oxygen and pH decreases. Daniel & Boyden (1975) reported oxygen depletion at night, with mid to low shore pools reduced to 8-44% saturation. They noted that the crab *Carcinus maenas* leaves the pools at night, and that other species with the ability to air-breathe could also do so, e.g. limpets, littorinids, and the shanny *Lipophrys pholis*. They also observed that shrimps gathered at the edge of high shore pools at night, presumably to take advantage of the better oxygenated surface layer (Daniel & Boyden, 1975). Daily fluctuation in oxygen concentration and pH also vary seasonally, and with the height of the pool on the shore or pool depth (Daniel & Boyden, 1975; Morris & Taylor, 1983; Metaxas & Scheibling, 1993). Morris & Taylor (1983) noted variation in oxygen concentration with pools with pool depth and proximity to pool algae. Again, inundation by the rising tide causes sudden changes in oxygenation, either sudden drops during the day or increases at night.

Ganning (1971) noted that the temperature of sediment at the bottom of pools showed little variation in temperature, and noted that diurnal fluctuations of greater than 1 °C were rarely observed in bottom sediments of pools deeper than 0.5 m, although a temperature of fall 0.5-1 °C was observed at the water/sediment interface. The presence of sediment in pools increases the risk of scour, which is likely to vary seasonally, increasing in winter storms. In addition, anoxic conditions within the sediment could potentially cause significant and sudden decreases in oxygen levels if the sediment was stirred up by wave action, although no evidence of this effect was found.

Seasonal change in communities

Tidepool community structure has been show to vary markedly over time, particularly with season (Metaxas & Scheibling, 1993). However, most studies have examined tidepools overseas, or different tidepools communities to those that occur in LR.SwSed (Dethier, 1984; Wolf & Harlin, 1988a,b; Kooistra *et al.*, 1989; Metaxas *et al.*, 1994) so that the species concerned are very different. Seasonal changes in macroalgal cover and diversity were associated with changes in water temperature, light intensity and day length, and reduced grazing pressure from littorinids in winter, although the community types were relatively stable over time in Rhode Island pools (Wolfe & Harlin, 1988a,b). Metaxas *et al.* (1994) noted that sheet forming algae (e.g. *Ulva lactuca*) were found throughout the year, filamentous forms (e.g. *Cladophora* and *Ceramium*) were present in late spring and summer (although other studies found them to be present from late spring to late autumn) while thick leathery and encrusting forms did not vary seasonally. However, macroalgal diversity was lowest in summer and autumn, especially in mid shore pools, probably due to grazing. Metaxas *et al.* (1994) also noted that the abundance of mussels, littorinids and whelks in Rhode Island peaked in summer due to recruitment but varied significantly between pools.

Red algae exhibit seasonal variation in growth and reproduction and red algal turf declines in abundance during the winter months, partly due to die back and abrasion during winter storms. Although protected from wave action in deep pools, macroalgae will be particularly susceptible to damage and abrasion by wave action and winter storms in shallow sediment filled pools. For example, maximum growth of *Furcellaria lumbricalis* occurs in March/April (Austin, 1960b) and release of carpospores and tetraspores occurs in December/January (Bird *et al.*, 1991). Reproductive bodies are present on the gametophytes of *Ahnfeltia plicata* between July and January and mature carposporophytes occur between October and July (Maggs & Pueschel, 1989). However, in the Bristol Channel, Bamber & Irving (1993) noted that the biomass of *Corallina officinalis* increased steadily through spring and summer and began to decline after July. *Mastocarpus stellatus* (as *Gigartina stellata*) was reported have a perennial holdfast, losing many erect fronds in winter, which grow back in spring (Dixon & Irvine, 1977). *Osmundea pinnatifida* also shows seasonal variation in growth, expanding its perennial holdfast in June to September, and producing erect fronds from October onwards reaching a maximum in February to May (Maggs & Hommersand, 1993). *Corallina officinalis* may be overgrown by epiphytes, especially during summer. This overgrowth regularly leads to high mortality of fronds due to light reduction (Wiedemann, pers. comm.). The ephemeral green seaweeds *Ulva intestinalis* and *Ulva lactuca* are likely to be more abundant in summer depending on grazing pressure. In summer, erect and encrusting corallines may be bleached (especially in shallow pools) and loose their pink pigment but in some species, e.g. *Phymatolithon* sp., this does not necessarily result in death of the plant and pigment may be re-synthesized (Little & Kitching, 1996).

Habitat structure and complexity

As already noted, no two rockpools exhibit exactly the same physio-chemical conditions and exhibit large spatial variation in community structure, even between adjacent pools at the same shore height (Ganning, 1971; Metaxas & Scheibling, 1993; Metaxas *et al.*, 1994). Habitat complexity will vary with macroalgal cover, the dominant macroalgal species, shore height, pool depth and topography. Deeper pools are likely to be more complex than shallow pools. In this biotope, the influence of sediment and scour on the community is likely to increase with the sediment depth (thickness) and/or with the shallowness of the pool, i.e. shallow pools will exhibit simple communities dominated by sediment resistant red algae. However, a variety of intermediate communities could also be represented by this biotope.

In deep pools the underlying rock is likely to be covered by encrusting corallines. Large macroalgal species (e.g. kelps and fucoids) may dominate the surface of the pool. Their depth within the pool (vertical zonation) is limited by self-shading so that only corallines and red algae occur beneath them. The interface between the bottom sediment and the rock surface is likely to support only sand resistant red algae and fauna, e.g. sand-tolerant algae such as *Furcellaria lumbricalis*, *Polyides rotundus*, *Ahnfeltia plicata*, *Rhodothamniella floridula*, and the anemone *Urticina felina*. The sediment may support infauna such as lugworm (e.g. *Arenicola marina*), the sand mason worm *Lanice conchilega*, terebellids and meiofauna. The upper limit of some species of algae within the pool may be limited by the summer surface water temperatures, and or desiccation after evaporation (e.g. corallines). Grazing intensity due to littorinids may also affect the abundance of fleshy macroalgae, so that the pools may be dominated by less palatable red algae (e.g. *Chondrus crispus* and *Mastocarpus stellatus*). Vertical surfaces within deep pools, and crevices or overhangs present, are likely to be dominated by encrusting fauna e.g. the sponges *Halichondria panicea* and *Hymeniacidon perleve*, tubeworms and anemones. The surface of larger stones and pebbles may support tubeworms and the holdfasts of kelps or *Chorda filum*. The holdfasts of kelps and fucoids, and fronds of filamentous species and erect corallines provide refuges for small invertebrates (e.g. amphipods, isopods and small gastropods) or meiofauna (e.g. copepods) (see ecological relationships above). In addition, the shade of macroalgae provide refuges for shrimps (e.g. *Palaemon* spp.) and intertidal fish (e.g. blennies and gobies), while crevices and underboulder habitats provide additional refuges for crabs.

Rockpool species also display zonation patterns, similar to the emergent species. For example, brown algae and corallines are usually dominant in mid to low shore pools, while green algae tend to dominate high shore pools (Metaxas & Scheibling, 1993). Kooistra *et al.* (1989) noted vertical zonation within pools and found that macroalgal communities could be allocated to different depths within pools in the lower or higher parts of the shore. However, the communities studied in Brittany differed markedly from those found in this biotope. Similarly, zonation patterns have also been reported in flatworms, rotifers, oligochaetes, cladoceans, copepods, ostracods, barnacles, amphipods, isopods, chironomid larvae and fish (see Metaxas & Scheibling, 1993). *Littorina littorea*, mussels, whelks, limpets and sea urchins tend to dominate in lower shore pools, while other littorinids dominate higher on the shore (Metaxas & Scheibling, 1993). Nevertheless, Metaxas *et al.* (1994) noted that horizontal spatial variability between pools within the same shore height appeared to be as great as variability along the intertidal gradient, and suggested that the physical setting of the pool may be of primary importance in determining the macroalgal abundance. Dethier (1984) examined the effect of natural disturbance rockpool communities in the coast of Washington State. She noted that disturbance such as heat stress in summer and wave action in winter occurred regularly (ca 1.6 times per year per pool). The observed disturbances affected dominant species, so that no one dominant species could occupy all the pools within the tidal range at any one time. None of the tidal pool assemblages observed were stable over many generations and disturbances resulted in a mosaic of species assemblages within pools in any one region (Dethier, 1984).

Dominant trophic groups Deposit feeders (detritivores)

Productivity

Although little information on rockpool productivity was found, rocky shore communities are highly productive and are an important source of food and nutrients for members of neighbouring terrestrial and marine ecosystems (Hill *et al.*, 1998; Raffaelli & Hawkins, 1999). Macroalgae exude considerable amounts of dissolved organic carbon which are absorbed readily by bacteria and may even be taken-up directly by some larger invertebrates. Only about 10% of the primary production is directly cropped by herbivores

(Raffaelli & Hawkins, 1999). Dissolved organic carbon, algal fragments and microbial film organisms are continually removed by the sea. This may enter the food chain of local, subtidal ecosystems, or be exported further offshore. Rocky shores make a contribution to the food of many marine species through the production of planktonic larvae and propagules which contribute to pelagic food chains. Accumulations of algal debris are also likely in rockpools and such detrital material contributes to overall productivity.

Information specific to the community was not found but Workman (1983) gave an estimate of primary production by microalgal films on the lower shore in the British Isles to be in the region of 100 g C/m²/yr, much of which will be utilized directly by grazers, while primary productivity for fucoids on sheltered shores was estimated to be 1250 g C/m²/yr (Hawkins *et al.*, 1992) and for encrusting corallines to be 1000 g C/m²/yr (Dawes *et al.*, 1991; Raffaelli & Hawkins, 1999). Ganning & Wulff (1970) reported primary productivity values in terms of gross photosynthesis of between 2 and 3.5 $O_2/m^3/$ hr in brackish water rock pools dominated by green algae. Overall, deep rockpools with abundant macroalgae are likely to be highly productive mesocosms on the shore. However, shallower pools, with only sparse macroalgal cover due to sediment scour are likely to be far less productive.

Major sources of organic carbon	Photosynthesis (macroalgae and/or halophytic plants) Photosynthesis (microalgae)

Recruitment processes

As with the emergent rock surfaces, variation and unpredictability in recruitment of species contributes to the variation in dominant species within rockpool communities and hence spatial variation between rockpools (Dethier, 1984). Recruitment processes of characteristic or dominant species are described here.

Flora

- Vadas *et al.* (1992) reviewed recruitment and mortality of early post settlement stages of benthic algae. They concluded that grazing, canopy and turf effects were the most important but that desiccation and water movement may be as important for the early stages. The review indicated that recruitment is highly variable and episodic and that mortality of algae at this period is high. Chance events during the early post settlement stages are therefore likely to play a large part in survival.
- *Laminaria hyperborea* and *Laminaria digitata* produce vast numbers of spores, however they need to settle and form gametophytes within about 1 mm of each other to ensure fertilization and therefore may suffer from dilution effects over distance. However, Chapman (1981) demonstrated that substantial recruitment of *Laminaria digitata* plants to areas barren of kelp plants was possible up to 600 m away from reproductive plants. *Laminaria saccharina*, is short-lived (2-4 years), reaches maturity quickly and colonizes bare substratum rapidly (ca 6 months) (Kain, 1975; Kain, 1979; Birkett *et al.*, 1998; see *MarLIN* Web site) and may be regarded as relatively opportunistic.
- Settlement of algal spores is partly dependant on their motility (if any) and adhesive properties together with preferences for topography (surface roughness), the chemical nature of the substratum and water movement (Norton 1992; Fletcher & Callow 1992). As with all red algae, the spores of *Ahnfeltia plicata*, *Chondrus crispus*, *Furcellaria lumbricalis* and *Polyides rotundus* are non-flagellate and therefore dispersal is a wholly passive process (Fletcher & Callow, 1992). In general, due to the difficulties of re-entering the benthic boundary layer, it is likely that successful colonization is achieved under conditions of limited dispersal and/or minimum water current activity. Norton (1992) reported that although spores may travel long distances (e.g. *Ulva* sp. 35 km, *Phycodrys rubens* 5 km), the reach of the furthest propagule does not equal useful dispersal range, and most successful recruitment occurs within 10 m of the parent plants. It is expected, therefore, that recruitment of *Ahnfeltia plicata*, *Chondrus crispus*, *Furcellaria lumbricalis*, *Polyides rotundus* and the majority of other macroalgae in the biotope would occur from local populations on the surrounding emergent rock but that establishment and recovery of isolated populations would be patchy and sporadic. Scrosati *et al.* (1994) commented that viability of spores of *Chondrus crispus* was low (<30%) and suggested that reproduction by spores probably does not contribute much to maintenance of the intertidal population in Nova Scotia, compared to vegetative growth of gametophytes. However, macroalgae are highly fecund and widespread in the coastal zone so that recruitment may be still be rapid, especially in the rapid growing ephemeral species such as *Ulva* spp., which reproduce throughout the year with a peak in summer. Similarly, *Ceramium* species produce reproductive propagules throughout the year, while *Mastocarpus stellatus* produce

propagules from February to December, and exhibit distinct reproductive papillae in summer (Dixon & Irvine, 1977; Burrows, 1991; Maggs & Hommersand, 1993).

- *Lithophyllum incrustans*, representing the encrusting corallines in the biotope, it has been calculated that 1 mm x 1mm of reproductive thallus produces 17.5 million bispores per year with average settlement of only 55 sporelings/year (Edyvean & Ford, 1984). Dispersal is likely to be in excess of 5 km and spores will settle and new colonies will arise rapidly on bare substratum, although the growth rate is slow (2-7 mm per annum - see Irvine & Chamberlain 1994). The erect coralline *Corallina officinalis* has isomorphic sexual (gametophyte) and asexual (sporophyte) stages (see *MarLIN* Web site). Settlement and development of fronds is optimal on rough surfaces but settlement can occur on smooth surfaces (Harlin & Lindbergh 1977; Wiedemann, pers comm.). *Corallina officinalis* settled on artificial substrata within 1 week of their placement in the intertidal in New England summer suggesting that recruitment is high (Harlin & Lindbergh 1977).

Fauna

- Gastropods exhibit a variety of reproductive life cycles. The common limpets *Patella vulgata* and *Patella ulyssiponensis*, the top shell *Gibbula umbilicalis*, and *Littorina littorea* have pelagic larvae with a high dispersal potential, although recruitment and settlement is probably variable. However, *Littorina obtusata* lays its eggs on the fronds of fucoids from which hatch crawl-away miniature adults. Similarly, the dog whelk *Nucella lapillus* lays egg capsules on hard substrata in damp places on the shore, from which crawl-always emerge. Therefore, their dispersal potential is limited but probably designed to colonize an abundant food source. In addition, most gastropods are relatively mobile, so that a large proportion of recruitment of available niches would involve migration. *Nucella lapillus* is an exception, as they generally do not move far, averaging 100 mm /tidal cycle, or between 30 cm or 10 m per year when in the vicinity of an abundant food source (see *MarLIN* Web site for details; Fish & Fish, 1996).
- *Arenicola marina* lays its eggs in its burrows, while adjacent males release sperm at the sediment surface, the resultant juveniles developing within the burrows before migrating upshore. Long distance recruitment of lugworm from sedimentary areas is probably sporadic, and reproduction within a rockpool is only likely if both sexes are present within the same pool. However, *Lanice conchilega* produce dispersive planktonic larvae.
- Many species of mobile epifauna have long lived pelagic larvae and/or are highly motile as adults. Gammarid amphipods brood their embryos and offspring but are highly mobile as adults and probably capable of colonizing new habitats from the surrounding area (e.g. see *Hyale prevostii* review on *MarLIN* Web site for example). Similarly, isopods such as *Idotea* species brood their young. *Idotea* species are mobile and active swimmers and probably capable to recruiting to new habitats from the surrounding area by adult migration. Hicks (1985) noted that epiphytic harpacticoid copepods lack planktonic dispersive larval stages but are active swimmers, which is therefore the primary mechanism for dispersal and colonization of available habitats. Some species of harpacticoids are capable to moving between low and mid-water levels on the shore with the tide, while in other colonization rates decrease with increasing distance form resident population. Overall immigration and *in situ* reproduction were thought to maintain equilibrium populations exposed to local extinction, although there may be local spatial variation in abundance (see Hicks, 1985).
- Epiphytic and sessile fauna, such as sponges, hydroids, bryozoans and ascidians, have pelagic but short lived larvae with relatively short effective dispersal ranges, depending on the local hydrography. However, most epiphytic species are widespread and ubiquitous and would probably recruit rapidly from adjacent or nearby populations.

Time for community to reach maturity

Development of the community in this biotope, from bare or denuded rock, is likely to follow a similar successional pattern to emergent sheltered rocky shore communities. The loss of grazing species results in an initial proliferation of ephemeral green then fucoid algae, which then attracts mobile grazers, and encourages settlement of other grazers. Limpet grazing reduces the abundance of fucoids allowing barnacles to colonize the shore. After the *Torrey Canyon* oil spill in March 1967, recovery rates were dependant on local variation in recruitment and mortality so that sites varied in recovery rates, for example maximum cover of fucoids occurred within 1-3 years, barnacle abundance increased in 1-7 years, limpet numbers were still reduced after 6-8 years and species richness was regained in 2 to >10 years (depending on the shore and the degree of disturbance) (Southward & Southward, 1978; Hawkins & Southward, 1992; Raffaelli &

Hawkins, 1999). Where only the rockpool is affected, recruitment is potentially good, especially in motile species. However, variability in rockpool communities and their response to disturbance (recovery) has been attributed to variation and seasonality in recruitment (Metaxas & Scheibling, 1993).

Dethier (1984) noted that few rockpool populations, even of dominant species, remained static over time, based on long-term observations over several years. On the coast of Washington State, partial disturbance (a reduction in abundance or cover) resulted in relatively rapid recovery of the community for example; encrusting corallines recovered in over 2 months, erect corallines attained 87% of their original cover in 2 years. The red algae *Rhodomela* sp. exhibited 39% recovery from total loss after 2 years and *Cladophora* sp. exhibited 77% recovery after total loss. Dethier (1984) concluded that disturbance was a factor that resulted in a mosaic of different communities in rockpools within an area and that, at any point in time, separate rockpool communities were probably in different stages of recovery.

Additional information

None

Habitat preference and distribution

Distribution in Britain and Ireland

Scattered distribution around the coasts of Britain and Ireland.

Habitat preferences

Temperature range preferences	See additional information below
Water clarity preferences	Data deficient
Limiting nutrients	Data deficient
Other preferences	Rockpool

Additional information

This biotope is characterized by rockpools with sediment bottoms, in which the presence of sediment and resultant scour restricts algae at the water/sediment interface to sediment tolerant species. However, the biotope describes a range of biotopes form deep, macroalgal dominated pools to shallow pools with only sparse, sediment tolerant, red algae.

The physical characteristics of the rockpool environment are described under 'Seasonal and longer term change' on the 'Ecology' page.

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	Species name	Common Name
Important characterizing	*Furcellaria lumbricalis*	A red seaweed
Important characterizing	*Ahnfeltia plicata*	A red seaweed
Important characterizing	*Polyides rotundus*	A red seaweed
Important characterizing	*Rhodothamniella floridula*	A red seaweed
Important functional	*Littorina littorea*	Common periwinkle
Important functional	*Amphipoda*	Amphipods

Explanation

This biotope describes a spectrum of rockpools from deep, macroalgal dominated pools to shallow sediment filled pools with sparse sediment tolerant red algae. Therefore, while fucoids, kelps, and green algae may be characterizing species, their abundance and/or presence is likely to vary between pools, and their loss would not herald a loss of an identifiable biotope, although species diversity would be greatly reduced. The most characteristic feature of this rockpool biotope is the presence of sediment, and hence sediment tolerant red algae. Therefore, the red algae *Furcellaria lumbricalis*, *Polyides rotundus*, *Ahnfeltia plicata* and *Rhodothamniella floridula* have been suggested as important characterizing, as examples of sediment tolerant species. However, it should be noted that not all of the above species occur in all records of the biotope, and hence for sensitivity assessment, sediment tolerant algae will be treated as a functional group rather than individually. *Littorina littorea* and amphipods are included as important functional species as grazing pressure affects the macroalgal community.

Species found especially in biotope

No text entered

Additional information

The MNCR database lists 449 species in 58 records of this biotope (JNCC, 1999), although not all species occur in all records of the biotope. The seagrass *Zostera* sp. was recorded from this biotope (see description) and, although no species was given, both *Zostera* species are nationally scarce.

Biotope sensitivity

Physical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	High	Moderate	Major Decline	Low
Smothering	Intermediate	High	Low	Decline	Low
Increase in suspended sediment	Intermediate	High	Low	Decline	Low
Decrease in suspended sediment	High	High	Moderate	Rise	Low
Desiccation	Intermediate	High	Low	Decline	Low
Increase in emergence regime	High	High	Moderate	Decline	Moderate
Decrease in emergence regime	Low	Very high	Very Low	Rise	Low
Increase in water flow rate	Not Relevant	Not Relevant	Not relevant	Not Relevant	Moderate
Decrease in water flow rate	Not Relevant	Not Relevant	Not relevant	Not Relevant	Moderate
Increase in temperature	Low	High	Low	Minor Decline	Low
Decrease in temperature	Tolerant	Not Relevant	Not sensitive	No Change	Low
Increase in turbidity	Low	Very high	Very Low	Decline	Low
Decrease in turbidity	Tolerant	Not Relevant	Not sensitive	Minor Decline	Low
Increase in wave exposure	High	High	Moderate	Decline	Low

Decrease in wave exposure	Intermediate	High	Low	Decline	Low
Noise	Tolerant	Not Relevant	Not sensitive	No Change	High
Visual Presence	Tolerant	Not Relevant	Not sensitive	No Change	High
Abrasion & physical disturbance	Intermediate	High	Low	Decline	Low
Displacement	High	High	Moderate	Major Decline	Low
Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	High	High	Moderate	Major Decline	Moderate
Heavy metal contamination	Intermediate	High	Low	Decline	Low
Hydrocarbon contamination	Intermediate	Moderate	Moderate	Major Decline	Low
Radionuclide contamination	Insufficient information	Not Relevant	Insufficient information	Not Relevant	Not Relevant
Changes in nutrient levels	Intermediate	High	Low	Minor Decline	Low
Increase in salinity	Low	Very high	Very Low	No Change	Low
Decrease in salinity	Tolerant	Not Relevant	Not sensitive	No Change	Low
Changes in oxygenation	Tolerant	Not Relevant	Not sensitive	No Change	Moderate
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Insufficient information	Not Relevant	Insufficient information	Insufficient Information	Not Relevant
Introduction of non-native species	Intermediate	None	Very High	Minor Decline	Low
Extraction of key or important characterizing species	Intermediate	High	Low	Decline	Low
Extraction of important species	Low	Very high	Very Low	Rise	Low

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	Loss of the substratum would involve loss of all the species within the rockpool and hence loss of the biotope. Break up of the rocky substratum (e.g. by a grounded vessel) and or infill of the rockpool would constitute loss of available substratum and hence the habitat. Infilling of the rockpool by permanent material (e.g. by cement) or occlusion by revetment material would constitute a permanent loss of the rockpool and biotope. However, in other instances the species could recolonize the remaining pool and recoverability is likely to be high (see additional information below).
Smothering (see benchmark)	Seapy & Littler (1982) reported a decrease in macroalgal cover from 47.3 to 37.5% on a Californian rocky shore due to sediment deposition on the mid to lower shore following rain and flooding. *Corallina* sp. and *Pelvetia* sp. were the most affected macroalgal species, while associated red algae were only slightly affected by the resultant scour. Macroinvertebrates declined in cover from 15.8% to 6.5% particularly barnacle species. Daly & Mathieson (1977) examined intertidal zonation on a shore affected by sand scour, and noted that fucoids were reduced to small or young plants, while sand tolerant species such as *Ahnfeltia plicata* dominated on areas affected by sediment. Smothering by 5 cm of sediment (see benchmark) is likely to increase scour and be detrimental to macroalgae, especially *Corallina officinalis* and fucoids, and the more fleshy red algae. While red algae such as *Chondrus crispus* and *Ceramium* spp. are large enough not to be smothered completely by 5 cm of sediment, the resultant scour is likely to damage fronds but, in particular, remove juveniles, sporelings and other propagules. In addition, the rockpool environment is likely to be more vulnerable to smothering as sediment is likely to accumulate in, and be retained by the rockpool itself, effectively increasing the depth of the sediment layer in the pool. In wave exposed conditions the sediment may be removed but in sheltered areas it is likely to be retained for longer than indicated by the benchmark. In deep pools, the macroalgae and associated invertebrates are likely to reduce in depth penetration into the pool while sediment tolerant algae increase. In shallow pools, the depth may be further reduced and the macroalgae restricted to sand tolerant species alone. Overall, while the biotope will remain, smothering is likely to reduce the diversity of the pool, exclude grazing littorinids, and smother small epifaunal species such as sponges, bryozoans and ascidians, although large anemones may survive (e.g. *Urticina felina*). Therefore, an intolerance of intermediate has been recorded. Recoverability is likely to be high (see additional information below). However, in extremely high suspended sediment loads, as found in estuaries, rockpools may become completely filled with fine sediment, so that only infaunal species survive.
Increase in suspended sediment (see benchmark)	An increase in suspended sediment could potentially result in increased turbidity (see below), smothering, especially on sheltered shores (see above), and increased scour. The characterizing sediment tolerant red algae are unlikely to be adversely affected by an increase in suspended sediment. However, other macroalgae, and the community they support, are likely to be adversely affected, as shown above (Daly & Mathieson, 1977; Seapy & Littler, 1982). On wave sheltered shores, sediment may accumulate in low to mid shore pools, which again will favour sand tolerant species and infauna. Overall, the biotope is likely to remain but the species diversity decrease (for example see Daly & Mathieson, 1977). Therefore, an intolerance of intermediate has been recorded, although recovery is potentially high (see additional information below). However, in extreme situations deposition of fine sediments may result in smothering of the rockpool (see above).

Decrease in suspended sediment (see benchmark)	The presence of sediment in the rockpool environment, a defining feature of this biotope, suggest occasional or regular sediment supply. Therefore, a decrease in suspended sediment may result in erosion of the sediment from the bottom of pools. Erosion is likely to be greatest in shallow pools or moderately wave exposed shores. The internal topography of the pools will affect the rate of erosion i.e. presence of depressions and crevices may retain sediment longer. A decrease in suspended sediment loads may reduce food availability of suspension feeders within the biotope, however, they would probably feed on plankton within the pools. However, erosion or removal of sediment from the pools would be detrimental for an infauna, and especially sand tolerant algae which are likely to be out-competed by other red algae. Therefore, the character of the pool may change, becoming more like LR.FK. Hence an intolerance of high has been recorded since the biotope may be lost in the long term, although it should be noted that a healthy but different community is likely to remain, potentially of higher species diversity.
Desiccation (see benchmark)	Rockpools are natural refuges from desiccation but may be drained due to slow seepage or due to 'bucketing' by shore users, resulting in a decrease in the water level and hence desiccation exposure. Many members of the biotope are common on the emergent rock surface (e.g. fucoids, red algae, littorinids) and therefore, exhibit relative tolerance of desiccation. However, the presence of the rockpool allows species to occur in niches higher on the shore than they would otherwise. Low shore, sublittoral fringe or sublittoral species within the pool would be particularly intolerant of desiccation, e.g. *Furcellaria lumbricalis* and low shore algae. However, such drainage is likely to be short-lived, and the water level return to normal levels after the next high tide. Therefore, an increase in desiccation at the benchmark level, an increase equivalent to a rise in shore height, is likely to result in a decrease in species richness, although the biotope itself is likely to remain and an intolerance of intermediate has been recorded. Recoverability is likely to be high (see additional information).
Increase in emergence regime (see benchmark)	An increase in emergence is likely to significantly affect physico-chemical environment of the rockpool and its resident community. An increase in emergence will increase the time that the pool is exposed to fluctuating air temperatures, wind, rain and sunlight, all of which will affect the and temperature, salinity regime within the pool. Lower shore pools will come to resemble mid shore pool communities, with a reduction in sublittoral species and species sensitive to extremes of temperature, for example the laminarians (see individual reviews). For example, the upper limit of *Bifurcaria bifurcaria* within rockpools in Roscoff, France was shown to be limited by the summer temperatures where the surface pool water temperatures exceeded 20 °C (Kooistra *et al.*, 1989). Mid shore examples of this biotope are likely to be worst affected. High shore pools tend to support communities of temperature tolerant or opportunistic algae, especially green algae such as *Ulva* spp., and temperature and salinity tolerant species as harpacticoid copepods, ostracods, and small gastropods (for example see LR.G). This biotope would be lost from mid shore areas as a result of an increase in emergence at the benchmark level. Therefore, an intolerance of high has been recorded, although recoverability is potentially high.
Decrease in emergence regime (see benchmark)	A decrease in emergence will reduce the time the pool spends exposed to the air and cut off from the sea. Therefore, the range of temperatures and oxygen levels characteristic of rockpool environments is likely to decrease. Hence the pool communities will come to resemble low shore pools. Low shore pools are characterized by higher abundance of large macroalgae, such as *Halidrys siliquosa*, *Cystoseira* sp. and laminarians, especially deep pools, and a larger diversity of red algae and macrofauna. However, the presence of sediment within the pools will still favour the sand tolerant algae. Therefore, although the community is likely to increase in diversity the biotope is likely to remain. Therefore, an intolerance of low has been recorded to reflect changes in

	community structure.
Increase in water flow rate (see benchmark)	Water flow rate in this biotope is typically only that of the ebb and flood tide speed, which hardly affects intertidal habitats and is far exceeded by the strength of wave action. A change in water flow rate is therefore considered not relevant.
Decrease in water flow rate (see benchmark)	Water flow rate in this biotope is typically only that of the ebb and flood tide speed, which hardly affects intertidal habitats and is far exceeded by the strength of wave action. A change in water flow rate is therefore considered not relevant.
Increase in temperature (see benchmark)	Rockpools experience considerable variation in temperature on a daily and seasonal basis. The range and extremes of temperature change increasing with shore height but also dependent on shading, aspect, topography and depth of the pool (Pyefinch, 1943; Ganning, 1971; Daniel & Boyden, 1975; Goss-Custard *et al.*, 1979; Morris & Taylor, 1983; Huggett & Griffiths, 1986; Metaxas & Scheibling, 1993). For example, reported temperature ranges for mid to low shore pools include annual maxima and minima of 1-25 °C and 2-22 °C (Morris & Taylor, 1983), a diurnal range of 24 °C (day) and 13 °C (night) for a mid shore pool (Daniel & Boyden, 1975), and surface water temperature ranges of 14-19.25 °C and 15.5-20.75 °C in mid shore pools (Pyefinch, 1943). Temperature stratification within pools may result in higher surface temperatures and lower deep water temperatures in sunlight (Daniel & Boyden, 1977) or be reversed due to wind cooling, night or in winter (Naylor & Slinn, 1958; Ganning, 1971; Morris & Taylor, 1983). The temperature range will limit the distribution of sensitive species within the pools, especially normally sublittoral species, e.g. laminarians (see individual reviews). For example, the upper limit of *Bifurcaria bifurcaria* within rockpools in Roscoff, France was shown to be limited by the summer temperatures where the surface pool water temperatures exceeded 20 °C (Kooistra *et al.*, 1989). Therefore, an increase in ambient temperatures is likely to reduce the abundance or vertical extent of sensitive species within the biotope, especially in shallow examples of the biotope. However, the range and extremes of temperature routinely experienced by the biotope are greater than the benchmark level and an intolerance of low has been recorded to represent a potential decrease in species diversity.
Decrease in temperature (see benchmark)	Rockpools experience considerable variation in temperature on a daily and seasonal basis. The range and extremes of temperature change increasing with shore height but also dependent on shading, aspect, topography and depth of the pool (Pyefinch, 1943; Ganning, 1971; Daniel & Boyden, 1975; Goss-Custard *et al.*, 1979; Morris & Taylor, 1983; Huggett & Griffiths, 1986; Metaxas & Scheibling, 1993). For example, reported temperature ranges for mid to low shore pools include annual maxima and minima of 1-25 °C and 2-22 °C (Morris & Taylor, 1983), a diurnal range of 24°C (day) and 13°C (night) for a mid shore pool (Daniel & Boyden, 1975), and surface water temperature ranges of 14-19.25 °C and 15.5-20.75 °C in mid shore pools (Pyefinch, 1943). Temperature stratification within pools may result in higher surface temperatures and lower deep water temperatures in sunlight (Daniel & Boyden, 1977) or be reversed due to wind cooling, or in winter (Naylor & Slinn, 1958; Ganning, 1971; Morris & Taylor, 1983). Morris & Taylor (1983) reported that the surface of an upper shore was seen to freeze one winter night, although that this was a rare event. Freezing is likely to be rare in mid or low shore pools. The pool is likely to represent a buffer from the extreme cold and frosts experienced by fauna and flora on the emergent rock surface. In addition, few macroalgae were damaged as a result of the severe winter of 1962/63 (Crisp, 1964). Overall, the range of temperatures routinely experienced by mid to low shore rock pools is greater than the benchmark level. Therefore, tolerant has been recorded.
Increase in turbidity (see benchmark)	An increase in turbidity will reduce the availability of light for macroalgal growth. Macroalgae near the surface who's fronds float on the water surface will probably

	be unaffected. However, the depth within the pool that large macroalgae can penetrate will be reduced, in favour of shade tolerant red algae. Red algae attract fewer grazers and support fewer mesoherbivores (e.g. amphipods) and meiofauna, so that faunal diversity will decrease. The macroalgal abundance is likely to decrease but the biotope will still be recognizable. Therefore, an intolerance of low has been recorded to represent loss of diversity.
Decrease in turbidity (see benchmark)	A decrease in turbidity will above fucoids and laminarians to grow to greater depths within the pool, in competition with red algae, except at the sediment/ rock surface interface. Overall, fucoid abundance is likely to increase at the expense of some red algae, depending on the depth of the pool, but the biotope will remain. Therefore, tolerant has been reported.
Increase in wave exposure (see benchmark)	This biotope has been recorded from wave exposed to wave sheltered conditions. The effect of increased wave exposure is probably dependant on the depth of the pool. Sediment is unlikely to remain in shallow pools in wave exposed conditions and the biotope is likely to be replaced by coralline pool (LR.Cor). In deep pools, increased wave exposure is likely to result in increased scour, resulting in bare rock at the bottom of the pool, especially where cobbles and pebbles are present. Fine sediments and the infauna they support are likely to be lost. However if the pool is deep enough, the upper levels of the pool are likely to continue to support macroalgae, especially laminarians and erect corallines. For example, an increase in wave exposure from moderately exposed to very exposed is likely to remove the sediment from all but the deepest pools, so that the biotope may come to resemble LR.FK. Overall, the biotope is likely to change and an intolerance of high has been recorded. Recoverability is likely to be high (see additional information below).
Decrease in wave exposure (see benchmark)	This biotope has been recorded from wave exposed to wave sheltered conditions. A decrease in wave exposure from moderately exposed to sheltered is likely to encourage the deposition of sediments and favour sand tolerant red algal species. Therefore, sand tolerant species are likely to increase in abundance. However, a decrease in wave exposure from sheltered to very sheltered is likely to result in smothering of the biotope (see above), and in extremely wave sheltered environments rockpools may fill with sediment and only infauna survive. Overall, an intolerance of intermediate has been recorded at the benchmark level.
Noise (see benchmark)	Few organisms within the biotope are likely to respond to noise or vibration at the benchmark level. Fish may attempt to leave the biotope at high tide but would otherwise be trapped at low tide. Overall, little if any effect on the biotope is expected.
Visual Presence (see benchmark)	Mobile invertebrates and fish are able to react to shading, usually darting to cover in order to avoid a potential predator. However, their visual acuity is low, and they are unlikely to be adversely affected by visual presence.
Abrasion & physical disturbance (see benchmark)	Abrasion by an anchor or mooring may remove some fronds of the large macroalgae, foliose red algae and coralline turf, although most species would grow back from their remaining holdfasts. However, trampling and netting for shrimps or fish may be more damaging. Deep pools and the species they contain are protected by their depth but both small and large shallow pools are probably more vulnerable. No studies of the effects of trampling or netting on rockpools were found but studies of the effects on emergent algal communities are probably indicative. For example, moderate (50 steps per 0.09 sq. metre) or more trampling on intertidal articulated coralline algal turf in New Zealand reduced turf height by up to 50%, and the weight of sand trapped within the turf to about one third of controls. This resulted in declines in densities of the meiofaunal community within two days of trampling. Although the community returned to normal levels within 3 months of

	trampling events, it was suggested that the turf would take longer to recover its previous cover (Brown & Taylor, 1999). Similarly, Schiel & Taylor (1999) noted that trampling had a direct detrimental effect on fucoid algae and coralline turf species on the New Zealand rocky shore. Low trampling intensity (10 tramples) reduced fucoid cover by 25%, while high intensity (200 tramples) reduced fucoid cover by over 90%, although over 97% cover returned within 21 months after spring trampling; autumn treatments took longer to recover due to the delay in recruitment. Coralline bases were seen to peel from the rocks (Schiel & Taylor, 1999) due to increased desiccation caused by loss of the algal canopy. Brosnan & Cumrie (1994) demonstrated that foliose species (e.g. fucoids and *Mastocarpus papillatus*) were the most susceptible to trampling disturbance, while turf forming species were more resistant. Barnacles were also crushed and removed. However, the algae and barnacles recovered in the year following the trampling (Brosnan & Cumrie, 1994). Boalch *et al.* (1974) and Boalch & Jephson (1981) noted a reduction in fucoid cover (especially of *Ascophyllum nodosum*) at Wembury, Devon, when compared with the same transects surveyed 43 years previously. They suggested that the reduction in fucoid cover was due to the large number of visitors and school groups received by the site. Dethier (1984) noted that low shore rockpools on the coast of Washington State, suffered physical disturbance from storms (wave action and wave driven logs) in winter months. The frequency of disturbance ranged from one every 2-5 years, while recovery of dominant to species to its original level ranged from 3 month to over 2 years. As a result, she estimated that ca 20-50% of the populations of dominant pools species were in a state of recovery in her study area. Rockpools form natural mesocosms and so attract considerable attention from the general public, educational events and scientists alike. In addition to trampling within shallow pools and the vicinity of deeper pools, turning of rocks within the pool is likely to disturb underboulder communities (e.g. see MLR.Fser.Fser.Bo). Overall, a proportion of the macroalgal community, and the invertebrates it supports are likely to be removed, depending on trampling intensity, and an intolerance of intermediate has been recorded. Recoverability is likely to be high (see additional information below) once physical disturbance has stopped. However, it should be noted that ongoing trampling is likely to result in a long term reduction in the diversity of affected pools.
Displacement (see benchmark)	The majority of the epiphytic fauna, such as the isopods, amphipods and harpacticoid copepods are highly mobile are unlikely to be adversely affected by displacement. Similarly, gastropods are likely to survive and migrate back to suitable feeding areas. But the dominant macroalgae and sessile epifauna (e.g. barnacles and tubeworms) are permanently attached to the substratum and if removed will be lost. Loss of the red algal species especially will result in loss of the biotope overall. If macroalgal holdfasts and bases are also removed then recovery will be prolonged but still relatively rapid.
Chemical Factors	
Synthetic compound contamination (see benchmark)	O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination, possibly due to the susceptibility of phycoerythrins to destruction. They also suggested that red algae were effective indicators of detergent damage since they undergo colour changes when exposed to relatively low concentration of detergent. Smith (1968) reported that red algae such as *Ahnfeltia plicata*, *Chondrus crispus*, *Furcellaria fastigiata*, *Mastocarpus stellatus*, *Polyides rotundus* and *Osmundea pinnatifida* were amongst the algae least affected by detergents, whereas other species, including *Ceramium* spp., *Cryptopleura ramosa*, *Cladophora rupestris*, *Lomentaria articulata* and *Ulva lactuca* were either killed or unhealthy, although the effects were worst higher on the shore, which had received the most detergents. Laboratory studies of the

effects of oil and dispersants on several red algal species concluded that they were all sensitive to oil/dispersant mixtures, with little difference between adults, sporelings, diploid or haploid life stages (Grandy, 1984; cited in Holt *et al.*, 1995). Smith (1968) reported that oil and detergent dispersants from the *Torrey Canyon* spill affected high water specimens of *Corallina officinalis* more than low shore specimens and some specimens were protected in deep pools. In areas of heavy detergent spraying, however, *Corallina officinalis* was killed, and was affected down to 6m depth at one site, presumably due to wave action and mixing (Smith, 1968). However, regrowth of fronds had begun within 2 months after spraying ceased (Smith, 1968).

Gastropods and amphipods were found to be amongst the most sensitive species to detergents and oils. For example, limpets are extremely intolerant of aromatic solvent based dispersants used in oil spill clean-up. During the clean-up response to the *Torrey Canyon* oil spill nearly all the limpets were killed in areas close to dispersant spraying. Viscous oil will not be readily drawn in under the edge of the shell by ciliary currents in the mantle cavity, whereas detergent, alone or diluted in sea water, would creep in much more readily and be liable to kill the limpet (Smith, 1968). A concentration of 5ppm killed half the limpets tested in 24 hours (Southward & Southward, 1978; Hawkins & Southward, 1992). Toxicity experiments with gastropods demonstrated that 10 ppm of BP1002 was enough to cause the animals to close and stop climbing (Smith, 1968). Smith (1968) noted that over a 100 ppm of BP1002 was required to kill the majority of *Nucella lapillus* in experiments, while different concentrations of BP1002 killed the majority of the following: *Littorina littorea* (100 ppm); *Calliostoma zizyphinum* (10 ppm); *Aplysia punctata* (50 ppm), and *Patella vulgata* (5 ppm) (see individual reviews).

Smith (1968) also noted that after detergent treatment only the beadlet anemone *Actinia equina* and tufts of *Bifurcaria* sp., *Corallina* sp., and other algae were present in a rockpool. The pool had previously supported a community of anemones, gastropods, *Corallina, Lithophyllum, Enteromorpha*, crabs, prawns and fish.

Cole *et al.* (1999) suggested that herbicides were, not surprisingly, very toxic to algae and macrophytes. Hoare & Hiscock (1974) noted that all red algae except *Phyllophora* sp. were excluded from near to an acidified halogenated effluent discharge in Amlwch Bay, Anglesey and that intertidal populations of *Corallina officinalis* occurred in significant amounts only 600 m east of the effluent. Most pesticides and herbicides were suggested to be very toxic for invertebrates, especially crustaceans (amphipods, isopods, mysids, shrimp and crabs) and fish (Cole *et al.*, 1999). For example, Lindane is likely to bioaccumulate significantly and is considered to be highly toxic to fish (Cole *et al.*, 1999). Ebere & Akintonwa (1992) conducted experiments on the toxicity of various pesticides to *Gobius* spp. They found Lindane and Diazinon to be very toxic, with 96 hr LC$_{50}$'s of 0.25 µg/l and 0.04 µg/l respectively. TBT is generally very toxic to algae and fish. However, toxicity of TBT is highly variable with 96-hr LC$_{50}$ ranging from 1.5 to 36 µg/l, with larval stages being more intolerant than adults (Cole *et al.*, 1999). PCBs are highly persistent in the water column and sediments, have the potential to bioaccumulate significantly and can be very toxic to marine invertebrates. However their toxicity to fish was not clear (Cole *et al.*, 1999). The pesticide ivermectin is very toxic to crustaceans, and has been found to be toxic towards some benthic infauna such as *Arenicola marina* (Cole *et al.*, 1999).

Overall, the evidence suggests that, on balance, the characterizing red algae are probably very intolerant to synthetic chemicals, while resident gastropods, crustaceans and fish vary in their sensitivity. Loss of grazing invertebrates will significantly affect community structure. Therefore, biotope intolerance is assessed as high. Rockpools might be expected to accumulate chemical

	contaminants, depending on the rate of flushing, so that mid shore pools may be more vulnerable than low shore examples of the biotope. Recoverability is probably high (see additional information below).
Heavy metal contamination (see benchmark)	Bryan (1984) suggested that the general order for heavy metal toxicity in seaweeds is: organic Hg > inorganic Hg > Cu > Ag > Zn > Cd >Pb. Cole *et al.* (1999) reported that Hg was very toxic to macrophytes. The sub-lethal effects of Hg (organic and inorganic) on the sporelings of an intertidal red algae, *Plumaria elegans*, were reported by Boney (1971). 100% growth inhibition was caused by 1 ppm Hg. Burdin & Bird (1994) reported that both gametophyte and tetrasporophyte forms of *Chondrus crispus* accumulated Cu, Cd, Ni, Zn, Mn and Pb when immersed in 0.5 mg/l solutions for 24 hours. No effects were reported however, and no relationship was detected between hydrocolloid characteristics and heavy metal accumulation. It is generally accepted that adult fucoids are relatively tolerant of heavy metal pollution (Holt *et al.*, 1997). Bryan (1984) suggested that adult gastropod molluscs were relatively tolerant of heavy metal pollution. Cole *et al.* (1999) suggested that Pb, Zn, Ni and As were very toxic to algae, while Cd was very toxic to Crustacea (amphipods, isopods, shrimp, mysids and crabs), and Hg, Cd, Pb, Cr, Zn, Cu, Ni, and As were very toxic to fish. Bryan (1984) reported sublethal effects of heavy metals in crustaceans at low (ppb) levels. In laboratory investigations Hong & Reish (1987) observed 96hr LC_{50} (the concentration which produces 50% mortality) of between 0.19 and 1.83 mg/l in the water column for several species of amphipod. Cd, Hg, Pb, Zn and Cu are highly persistent, have the potential to bioaccumulate significantly and are all considered to be very toxic to fish (Cole *et al.*, 1999). Mueller (1979) found that in *Pomatoschistus* sp., very low concentrations of Cd, Cu and Pb (0.5 g/l Cd^{2+}; 5 g/l Cu^{2+}; 20 g/l Pb^{2+}) brought about changes in activity and an obstruction to the gill epithelia by mucus. This may also be true for other goby species. Inorganic Hg concentrations as low as 30 µg/l (96-h LC_5) are considered to be toxic to fish, whereas organic Hg concentrations are more toxic to marine organisms (WHO, 1989, 1991). Oertzen *et al.* (1988) found that the toxicity of the organic Hg complex exceeded that of $HgCl_2$ by a factor of 30 for the goby *Pomatoschistus microps*. Heavy metal contamination could potentially persist in deep rock pools due to depth and /or the presence of sediments onto which the heavy metals could adsorb. The intolerance of crustaceans and fish to heavy metal contaminants suggests that amphipod and isopod grazers and fish grazers and predators would be lost, allowing rapid growth of opportunistic algae such as *Ulva* spp. However, the presence of sediment will offset the loss of grazers, so that sand tolerant algae are likely to dominate shallow pools and other macroalgae are likely to be little affected. Therefore, an intolerance of intermediate has been recorded to represent the loss of species richness. Recoverability is likely to be high (see additional information below).
Hydrocarbon contamination (see benchmark)	Hydrocarbon contamination, e.g. from spills of fresh crude oil or petroleum products, may cause significant loss of component species in the biotope, through impacts on individual species viability or mortality, and resultant effects on the structure of the community. Rockpools are potentially vulnerable habitats, depending on depth, flushing rate and tidal height. Rockpool organisms may be protected, since oil will float on the pool surface. However, rockpool organisms will be exposed to the water soluble fraction of fresh oils, and a surface film of oil will prevent gaseous exchange and may reduce or exclude light. If exposed to oil the resident sediment is likely to adsorb oil and release it slowly, causing chronic long-term contamination and potentially prolonged recovery. The effects of oil contamination on marine organisms were reviewed by Suchanek (1983) and are summarized below. • Holt *et al.* 1995 reported that oil spills in the USA and from the 'Torrey

	Canyon' had little effect on kelp forest. Similarly, surveys of subtidal communities at a number sites between 1-22.5m below chart datum, including *Laminaria hyperborea* communities, showed no noticeable impacts of the *Sea Empress* oil spill and clean up (Rostron & Bunker, 1997) • *Fucus vesiculosus* shows limited intolerance to oil. After the *Amoco Cadiz* oil spill *Fucus vesiculosus* suffered very little (Floc'h & Diouris, 1980). Indeed, *Fucus vesiculosus* may increase significantly in abundance on a shore where grazing gastropods have been killed by oil, although very heavy fouling could reduce light available for photosynthesis and in Norway a heavy oil spill reduced fucoid cover. • Littoral barnacles (e.g. *Semibalanus balanoides*) have a high resistance to oil (Holt *et al.*, 1995) but may suffer some mortality due to the smothering effects of thick oil (Smith, 1968). • Gastropods (e.g. *Littorina littorea* and *Patella vulgata*) and especially amphipods have been shown to be particularly intolerant of hydrocarbon and oil contamination (see Suchanek, 1993). • The abundance of littorinids decreased after the *Esso Bernica* oil spill in Sullom Voe in December 1978 (Moore *et al.*, 1995). The abundance of *Patella* sp., *Littorina saxatilis, Littorina littorea* and *Littorina neglecta* and *Littorina obtusata* were reduced but had returned to pre-spill levels by May 1979. In heavily impacted sites, subjected to clean-up, where communities were destroyed in the process, *Littorina saxatilis* recovered an abundance similar to pre-spill levels within ca 1 year, while *Littorina littorea* took ca 7 years to recover prior abundance (Moore *et al.*, 1995). • Widdows *et al.* (1981) found *Littorina littorea* surviving in a rockpool, exposed to chronic hydrocarbon contamination due to the presence of oil from the *Esso Bernica* oil spill. • The anemones *Actinia* and *Anthopleura* were reported to survive in waters with severe oil pollution (Smith, 1968; Suchanek, 1993). • Echinoderms are thought to be especially sensitive to oil (Suchanek, 1993). In a survey of rock pool at West Angle Bay, Pembrokeshire, Crump & Emson (1997) noted that limpets, crustaceans (amphipods and *Palaemon*) and the echinoderms *Amphipholis squamata* and rare *Asterina phylactica* were adversely affected. However, the majority of adult *Asterina gibbosa* survived. The macrofauna, except *Asterina phylactica*, had recovered its diversity and abundance within 12 weeks of the spill (Crump & Emson, 1997). Laboratory studies of the effects of oil and dispersants on several red algae species (Grandy 1984 cited in Holt *et al.* 1995) concluded that they were all intolerant of oil/ dispersant mixtures, with little differences between adults, sporelings, diploid or haploid life stages. O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination. However, Smith (1968) noted that ed algae such as *Ahnfeltia plicata*, *Chondrus crispus*, *Furcellaria fastigiata*, *Mastocarpus stellatus*, *Polyides rotundus* and *Osmundea pinnatifida* were amongst the algae least affected by detergents, whereas other species, including *Ceramium* spp., *Cryptopleura ramosa*, *Cladophora rupestris*, *Lomentaria articulata* and *Ulva lactuca* were either killed or unhealthy, although the effects were worst higher on the shore, which had received the most detergents. • The lugworm *Arenicola marina* was driven to the surface by high concentrations of fresh no. 2 fuel oil, and by the presence no. 2 fuel oil in the water column, resulting in death within 3 days (Prouse & Gordon, 1976; Suchanek, 1993). • Cole *et al.* (1999) suggested a moderate to high toxicity of oils and petrochemicals for fish. Bowling *et al.* (1983) found that anthracene, a

	Polyaromatic hydrocarbon (PAH) had a photo-induced toxicity to the bluegill sunfish. They reported that when exposed to sunlight anthracene was at least 400 times more toxic than when no sunlight was present. According to Ankley *et al.* (1997) only a subset of PAH's are phototoxic (fluranthene, anthracene, pyrene etc.). Effects of these compounds are destruction of gill epithelia, erosion of skin layers, hypoxia and asphyxiation (Bowling *et al.*, 1983). In PAH contaminated areas, fish have been observed to develop tumours (GESAMP, 1993). Oil spills were reported to have low acute toxicity to adult fish (GESAMP, 1993), probably since adults can avoid contaminated areas, but that fish kills may occur after exposure to emulsified oil in shallow waters, e.g. after the *Braer* oil spill (GESAMP, 1993). However, in the rockpool environment, fish are unlikely to be able to avoid the water soluble fractions, and may suffer chronic or acute toxicity depending on the oil type and fish species concerned. • Loss of grazing gastropods and mesoherbivores after oil spills results in marked increases in the abundance of ephemeral green algae (e.g. *Ulva* spp.) and fucoids (Southward & Southward, 1978; Hawkins & Southward, 1992; Raffaelli & Hawkins, 1999). Overall, red algae, gastropods, amphipods and other crustaceans, echinoderms and fish within the rockpool community are likely to be adversely affected. However, fucoids and some of the characterizing red algae (e.g. *Ahnfeltia plicata* and *Furcellaria fastigiata*) are likely to survive and the biotope is likely to remain, although with a greatly reduced species richness. Therefore, an intolerance of intermediate has been recorded. The loss of grazers will allow increased growth of ephemeral greens and fucoids, although shade tolerant and sand tolerant red algae should still prevail, as the depth that fucoids penetrate will depend on self-shading and/or the depth of the sediment layer. However, the extent of damage may be exaggerated by the clean-up techniques employed e.g. detergents (see synthetic chemicals above) or high pressure water sprays. High water pressure sprays are likely to denude the rock surface of most life. On wave exposed rocky coasts oil will be removed relatively quickly. Recovery of rocky shore populations was intensively studied after the *Torrey Canyon* oil spill in March 1967. Loss of grazers results in an initial flush of ephemeral green then fucoid algae, followed by recruitment by grazers including limpets, which free space for barnacle colonization. On shores that were not subject to clean-up procedures, the community recovered within ca 3 years. However, on shores treated with dispersants recovery took 5-8 years but was estimated to take up to 15 years on the worst affected shores (Southward & Southward, 1978; Hawkins & Southward, 1992; Raffaelli & Hawkins, 1999). Therefore, the community may take longer to recover, especially if oil is retained within pool bound sediments. Hence, a recoverability of moderate has been recorded (see additional information below).
Radionuclide contamination (see benchmark)	Insufficient information
Changes in nutrient levels (see benchmark)	Little information on the nutrient regime of rockpools was found. Rockpools are cut off from the sea for periods of time, depending on their shore height, and hence nutrients could potentially become limiting (e.g. nitrogen and phosphorous) within the period of emersion. Similarly, pools could also become eutrophic due to the presence of washed up seaweeds and bird droppings and in some cases due to sewage effluents. Increased nutrient may increase growth in fast growing species, especially green algae (e.g. *Ulva* spp., *Cladophora* spp., and *Chaetomorpha* spp.) and some browns (e.g. *Ectocarpus* spp.) (Fletcher, 1996) to the detriment of slower growing and

	perennial species of macroalgae. Red algae such as *Gracilaria* sp. , *Gracilariopsis* sp., *Corallina* sp., *Ceramium* spp., *Gelidium* sp., *Bangia* sp. and in a few instances *Furcellaria lumbricalis* and *Phycodrys rubens* were reported to increase in abundance in eutrophicated waters (Fletcher, 1996). *Fucus vesiculosus* was observed to grow in the vicinity of a sewage outfall (Holt *et al.*, 1997) and is probably not sensitive directly. However, one of the most noticeable changes associated with eutrophication is the decline in abundance of fucoids (e.g. Fucus spp., *Ascophyllum nodulosum*, and *Cystoseira* spp.), possibly due to increased competition with opportunistic tolerant green algae, and associated effects of eutrophication such as suspended sediment levels (Fletcher, 1996). Eutrophication can potentially increase oxygen consumption leading to deoxygenation. However, the rockpool environment normally experience considerable variation in oxygen levels. Overall, the macroalgal community is likely to change, favouring ephemeral green and brown algae, red and coralline algae. However, the sand tolerant species characteristic of the biotope will probably remain. Therefore, an intolerance of intermediate has been recorded to reflect the change in species composition.
Increase in salinity (see benchmark)	High air temperatures cause surface evaporation of water from pools, so that salinity steadily increases, especially in pools not flooded by the tide for several days. However, Daniel & Boyden (1975) and Morris & Taylor (1983) reported little variability in salinity over one tidal cycle, and Ganning (1971) suggested that changes in salinity were of limited importance. Morris & Taylor (1983) reported an annual maximum salinity of 36.5 ppt in the pools studied on the west coast of Scotland. Goss-Custard *et al.* (1979) recorded salinities of 34.8 and 35.05 ppt in mid-shore pools. Therefore, the biotope is probably tolerant of small increases in salinity and an intolerance of low has been recorded. High shore pools exhibit greater variation and higher extremes of salinity (Pyefinch, 1943; Ganning, 1971) and different communities but mid to low shore pools are unlikely to experience such extremes unless the emergence regime is increased (see above) or they are exposed to hypersaline effluents. Therefore, an intolerance of low has been recorded, with a very high recoverability.
Decrease in salinity (see benchmark)	During periods of emersion, high rainfall will reduce pool salinity or create a surface layer of brackish/nearly fresh water for a period. The extremes of salinity experienced will depend on the depth of the pool, shore height and flushing rate, and season. For example, Morris & Taylor (1983) stated that a low salinity layer of 2-10 mm was normal but after one storm the low salinity layer increased in depth, eventually resulting in a homogeneous pool of brackish water. Morris & Taylor (1983) reported an annual salinity range in mid to low shore pools of 26-36.5 ppt. Therefore, decreases in salinity equivalent of a reduction from full to reduced (see benchmark) are likely to be a regular occurrence in rockpool communities. Hence, tolerant has been recorded.
Changes in oxygenation (see benchmark)	During emergence, rockpools are closed systems and gaseous exchange occurs over the air/water interface. In shallow pools the volume to surface area ratio is likely to be high, whereas in deep pools the ratio is likely to be low. In addition, the oxygen concentration is dependant on the community present. During the day, photosynthesis uses up CO_2 and produces O_2, in excess of respiration. However, at night respiration by flora and fauna deplete oxygen levels. As a result rockpool environments exhibit marked variation in oxygen levels. In summer, rockpools are likely to be supersaturated with oxygen during the day (Pyefinch, 1943). For example, the greatest range of oxygen saturation of 101.7% occurred in a seaweed dominated, sediment floored pool, which reach over 190% saturation on some days (Pyefinch, 1943). Daniel & Boyden (1975) noted that a mid shore, seaweed dominated pool reached 194% saturation (ca 15 mg O_2/l) but that oxygenation was also marked in shaded pools. A pool with dense fauna exhibited a maximum

	saturation of 210% (Pyefinch, 1943). During photosynthesis, algae absorb carbon dioxide and as concentrations fall, the pH rises. Morris & Taylor (1983) recorded pH values >9 in rockpools on the Isle of Cumbrae. At night, oxygen levels may fall below 100% saturation and pH will decrease as CO_2 levels increase. Morris & Taylor (1983) noted an annual maximum of oxygen concentration of 400-422 mm Hg (ca 23.4-24.7 mg/l) and an annual minimum of 18-38 mm Hg (ca 1-2.2 mg/l) in mid shore pools (containing *Furcellaria*). Daniel & Boyden (1975) reported oxygen depletion at night, with mid to low shore pools reduced to 8-44% saturation. They noted that the crab *Carcinus maenas* leaves the pools at night, and that other species with the ability to air-breathe could also do so, e.g. limpets, littorinids, and the shanny *Lipophrys pholis*. They also observed that shrimps gathered at the edge of high shore pools at night, presumably to take advantage of the better oxygenated surface layer (Daniel & Boyden, 1975). The range of extremes in oxygen concentration were greater in summer than in winter. On immersion, the rockpool community was exposed to potentially large, sudden fluctuations in oxygen concentrations depending on season and time of day (Morris & Taylor, 1983). Therefore, rockpools communities are probably exposed to variations equivalent to or greater than the benchmark level on a regular basis and tolerant has been recorded.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	Several coralline and non-coralline species are epiphytic on *Corallina officinalis*. Irvine & Chamberlain (1994) cite tissue destruction caused by *Titanoderma corallinae*. However, no information on pathogenic organisms in the British Isles was found. In Rhodophycota, viruses have been identified by means of electron microscopy (Lee, 1971) and they are probably widespread. However, nothing is known of their effects on growth or reproduction in red algae and experimental transfer from an infected to an uninfected specimen has not been achieved (Dixon & Irvine, 1977). Intertidal gastropods often act a secondary hosts for trematode parasites of sea birds. For example, *Nucella lapillus* may be infected by cercaria larvae of the trematode *Parorchis acanthus*. Infestation causes castration and continued growth (Feare, 1970; Kinne, 1980; Crothers, 1985). Overall, a wide variety of pathogens may affect members of the community but no information on associated mortality was found.
Introduction of non-native species (see benchmark)	Several non-native species may occur in this biotope. *Codium fragile* subsp. *tomentosoides* and *Codium fragile* subsp. *atlanticum* were introduced from mainland Europe and Japan respectively and may out-compete the native *Codium tomentosum* (Eno *et al.*, 1997). The non-native harpoon weed *Asparagopsis armata* was first recorded in Ireland in Galway Bay in 1939 and Britain in 1949 at Lundy in the Bristol Channel, and may come to dominate rockpools (Keith Hiscock, pers. comm.), although its effect on other species is not known. *Sargassum muticum* is a non-native macroalgae spreading around the coasts of Britain and Europe (see Eno *et al.*, 1997) and is often found in low to mid shore rockpools in the intertidal in areas it has colonized. Although, no studies on its effects on rockpool species was found studies of its effect on shallow sublittoral macroalgae suggest that it can out-compete fucoids and kelps. For example, Stæhr *et al.* (2000) reported that an increase in the abundance of *Sargassum muticum* in the Limfjorden (Denmark) from 1990 to 1997 was accompanied by a decrease in the abundance of thick, slow growing macroalgae such as *Laminaria saccharina, Codium fragile, Halidrys siliquosa, Fucus vesiculosus*, and *Fucus serratus*, together with other algae such as *Ceramium virgatum* (as *rubrum*) and *Dictyota dichotoma*. In *Sargassum muticum* removal experiments on the coast of Washington State, Britton-Simmonds (2004) concluded that *Sargassum muticum* reduced the abundance of native canopy algae (especially kelps) by 75% and native understorey algae by 50% probably as a result of shading. However, Viejo (1999) noted that mobile epifauna (e.g. amphipods, isopods) successfully

	colonized *Sargassum muticum* which provided additional habitat. Overall, Sargassum muticum can successfully invade rockpools, and would probably out-compete resident fucoids and kelp species, and some red algae. The presence of sediment may still favour sand tolerant red algae, which may be little effected. In addition, mesoherbivores will probably adapt to the new substratum offered by *Sargassum muticum* since they feed primarily on epiphytes. Therefore, the biotope is likely to remain but with a reduced species richness due to the loss of some species of macroalgae, and an intolerance of intermediate has been recorded. Recovery is potentially high but assumes removal of *Sargassum muticum* which is unlikely. Hence, a recoverability of 'none' has been recorded since the modification of the biotope is likely to be permanent, although a viable community will remain.
Extraction of key or important characterizing species (see benchmark)	Several of the characterizing red algae species are subject to harvesting. *Ahnfeltia plicata* is one of the world's principal commercial agarophytes. It is harvested mainly on the Russian coast of the White Sea as a source of high quality, low sulphate agar (Chapman & Chapman, 1980). In Britain and Ireland, however, *Ahnfeltia plicata* does not occur in sufficient quantities to harvest on a commercial scale (Dickinson, 1963). *Chondrus crispus* is extracted commercially in Ireland, but the harvest has declined since its peak in the early 1960s (Pybus, 1977). Mathieson & Burns (1975) described the recovery of *Chondrus crispus* following experimental drag raking (see review) and concluded that control levels of biomass and population structure are probably re-established after 18 months of regrowth. Commercial utilization of Furcellaria lumbricalis is based on the gelling properties of its extracted structural polysaccharide, furcellaran (Bird *et al.*, 1991). Extraction of *Furcellaria lumbricalis* was reviewed by Guiry & Blunden (1991). Plinski & Florczyk (1984) noted that over-exploitation of *Furcellaria lumbricalis* resulted in severe depletion of stocks. However, no commercial harvest as yet occurs in Britain or Ireland. Overall, while rockpool in areas subject to commercial harvesting may be directly affected, most examples of the biotope are unlikely to be affected by commercial harvesting in the UK. However, due to the relative small size of the community, even small scale hand collecting may have a significant effect. Therefore, an intolerance of intermediate has been recorded to represent the loss of a proportion of the macroalgae and the invertebrate community it supports. However, recovery is likely to be rapid since holdfasts and sporelings are likely to remain. Although, *Furcellaria lumbricalis* will recovery slowly, it is only on of the sand tolerant algae characteristic of this biotope.
Extraction of important species (see benchmark)	*Littorina littorea* are subject to harvesting in the UK and limpets in France. Hand collection may reduce the population of *Littorina littorea* within rockpools and hence reduce grazing pressure, resulting in an increase in macroalgal cover, especially of opportunistic green algae and epiphytes. However, the littorinid will probably recover quickly by migration and recruitment. Therefore, an intolerance of low has been recorded, with very high recoverability.

Additional information

Recoverability

Red algae produce non motile spores, dependant on the hydrography and most recruitment is likely to occur within about 10 m of the parent plants (Norton, 1992). Therefore, within a rock pool or a pool surrounded by macroalgae, recruitment is likely to be good. However, recruitment from remote populations is likely to be more protracted and sporadic.

The life history characteristics of *Ahnfeltia plicata* suggest that the species is likely to recover within 5 years if local populations exist (see *MarLIN* Web site). Recovery of a population of *Chondrus crispus* following a perturbation is likely to be largely dependent on whether holdfasts remain, from which new thalli can regenerate (Holt *et al.*, 1995). Following experimental harvesting by drag raking in New Hampshire, USA, populations recovered to 1/3 of their original biomass after 6 months and totally recovered after 12 months

(Mathieson & Burns, 1975). Raking is designed to remove the large fronds but leave the small upright shoots and holdfasts. The authors suggested that control levels of biomass and reproductive capacity are probably re-established after 18 months of regrowth. It was noted however, that time to recovery was much extended if harvesting occurred in the winter, rather than the spring or summer (Mathieson & Burns, 1975). Minchinton *et al.* (1997) documented the recovery of *Chondrus crispus* after a rocky shore in Nova Scotia, Canada, was totally denuded by an ice scouring event. Initial recolonization was dominated by diatoms and ephemeral macroalgae, followed by fucoids and then perennial red seaweeds. After 2 years, *Chondrus crispus* had re-established approximately 50% cover on the lower shore and after 5 years it was the dominant macroalga at this height, with approximately 100% cover. The authors pointed out that although *Chondrus crispus* was a poor colonizer, it was the best competitor.

Kain (1975) examined recolonization of cleared concrete blocks in a subtidal kelp forest. Red algae colonized blocks within 26 weeks in the shallow subtidal (0.8m) and 33 weeks at 4.4m. After about 2.5 years, *Laminaria hyperborea* standing crop, together with an understorey of red algae, was similar to that of virgin forest. Red algae were present throughout the succession increasing from 0.04 to 1.5 percent of the biomass within the first 4 years. Colonizing species varied with time of year, for example blocks cleared in August 1969 were colonized by primarily *Laminaria saccharina* and subsequent colonization by *Laminaria hyperborea* and other laminarians was faster than blocks colonized by *Saccorhiza polyschides*; within 1 year the block was occupied by laminarians and red algae only. Succession was similar at 4.4m, and *Laminaria hyperborea* dominated within about 3 years. Blocks cleared in August 1969 at 4.4m were not colonized by *Saccorhiza polyschides* but were dominated by red algae after 41 weeks, e.g. *Cryptopleura ramosa*. Kain (1975) cleared one group of blocks at two monthly intervals and noted that brown algae were dominant colonists in spring, green algae (solely *%*) in summer and red algae were most important in autumn and winter. Overall, red algae are likely to be able to recolonize and recover abundance with a year in some instances and probably within 5 years. Similarly, laminarians could potentially colonize low shore rockpools within 3-4 years, depending on grazing and competition for space. Fucoids (e.g. *Fucus serratus*) are highly fecund, reproduce throughout the years, are widespread and could potentially recovery quickly. For example, after the *Torrey Canyon*, oil spill fucoids attained maximum cover within 1-3 years (Southward & Southward, 1978; Hawkins & Southward, 1992; Raffaelli & Hawkins, 1999).

Furcellaria lumbricalis is an exception. Although highly fecund (Austin, 1960a), the species grows very slowly compared to other red algae (Bird *et al*., 1991) and takes a long time to reach maturity, typically 5 years (Austin, 1960b). Christensen (1971; cited in Bird *et al.*, 1991) noted that following harvesting of *Furcellaria lumbricalis* forma *aegagropila* in the Baltic Sea, harvestable biomass had not been regained 5 years after the suspension of harvesting. In view of its slow growth, time to maturity and limited dispersal, recovery of *Furcellaria lumbricalis* is likely to take between 5 and 10 years to recover in situations where intolerance to a factor is high. Where a portion of the population remains for vegetative regrowth, recovery is likely to occur within 5 years.

Gastropods and other mobile grazers (e.g. amphipods, isopods) are likely to be attracted by developing microalgae and macroalgae and could return quickly by either migration or larval recruitment. Epifaunal species vary in their recruitment rates. Sebens (1985, 1986) reported that rapid colonizers such as encrusting corallines, encrusting bryozoans, amphipods and tubeworms recolonized cleared rock surfaces within 1-4 months. Ascidians such as *Aplidium* spp. achieved significant cover in less than a year, and, together with *Halichondria panicea*, reached pre-clearance levels of cover after 2 years. Anemones colonized within 4 years (Sebens, 1986) and would probably take longer to reach pre-clearance levels. The anemone *Urticina felina* has poor powers of recoverability due to poor dispersal (Sole-Cava *et al.*, 1994 for the similar *Tealia crassicornis*) and slow growth (Chia & Spaulding, 1972), though populations should recover within 5 years.

Overall, members of the rockpool community could potentially recolonize with a year and a recognizable biotope return within 5 years. However, rockpool recruitment is reported to be sporadic and variable (Metaxas & Scheibling, 1993). Therefore, while a recognizable biotope will return the exact community may differ from that present prior to perturbation.

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors				
	Furcellaria lumbricalis	***Ahnfeltia plicata***	***Rhodothamniella floridula***	***Littorina littorea***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important functional
Substratum Loss	High	High	High	High
Smothering	Intermediate	Intermediate	High	High
Increase in suspended sediment	Intermediate	Intermediate	Intermediate	Intermediate
Decrease in suspended sediment	Not Sensitive	Not Sensitive	Low	See explanation
Desiccation	High	Low	Intermediate	Low
Increase in emergence regime	Intermediate	Intermediate	Intermediate	Low
Decrease in emergence regime	Not Sensitive	Not Sensitive	Not Sensitive	See explanation
Increase in water flow rate	Intermediate	Intermediate	Not Sensitive	Intermediate
Decrease in water flow rate	Not Sensitive	Intermediate	Low	See explanation
Increase in temperature	Low	Low	Low	Low
Decrease in temperature	Not Sensitive	Low	Low	See explanation
Increase in turbidity	Not Sensitive	Intermediate	Intermediate	Low
Decrease in turbidity	Not Sensitive	Not Sensitive*	Not Sensitive	See explanation
Increase in wave exposure	Intermediate	Intermediate	Intermediate	Intermediate
Decrease in wave exposure	Not Sensitive	Low	Not Sensitive	See explanation
Noise	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive
Visual Presence	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive
Abrasion & physical disturbance	Intermediate	Intermediate	Intermediate	Intermediate
Displacement	Low	High	High	Not Sensitive
Chemical factors				
	Furcellaria lumbricalis	***Ahnfeltia plicata***	***Rhodothamniella floridula***	***Littorina littorea***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important functional
Synthetic compound contamination	High	High	High	Low
Heavy metal contamination	Insufficient information	Insufficient information	Insufficient information	Intermediate

Hydrocarbon contamination	High	High	High	High
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	Intermediate	Intermediate	Intermediate	Not Sensitive
Increase in salinity	Low	Not Relevant	Not Relevant	Not Sensitive
Decrease in salinity	Not Sensitive	Low	High	See explanation
Changes in oxygenation	Insufficient information	Insufficient information	Insufficient information	Low
Biological factors				
	Furcellaria lumbricalis	***Ahnfeltia plicata***	***Rhodothamniella floridula***	***Littorina littorea***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important functional
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Introduction of non-native species	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Extraction of this species	High	Not Relevant	Not Relevant	Intermediate
Extraction of other species	Intermediate	Insufficient information	Insufficient information	Not Sensitive

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors				
	Furcellaria lumbricalis	***Ahnfeltia plicata***	***Rhodothamniella floridula***	***Littorina littorea***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important functional
Substratum Loss	Moderate	High	High	High
Smothering	Moderate	High	High	High
Increase in suspended sediment	Moderate	High	Very high	High
Decrease in suspended sediment	Not Relevant	Not Relevant	Very high	See explanation
Desiccation	Moderate	Immediate	Very high	Immediate
Increase in emergence regime	Moderate	High	High	Immediate
Decrease in emergence regime	Not Relevant	Not Relevant	Not Relevant	See explanation
Increase in water flow rate	Moderate	High	Not Relevant	High
Decrease in water flow rate	Not Relevant	High	Very high	See explanation

Increase in temperature	Very high	Very high	Very high	Immediate
Decrease in temperature	Not Relevant	Very high	Very high	See explanation
Increase in turbidity	Not Relevant	High	High	Very high
Decrease in turbidity	Not Relevant	Not Relevant	Not Relevant	See explanation
Increase in wave exposure	Moderate	High	High	High
Decrease in wave exposure	Not Relevant	Very high	Not Relevant	See explanation
Noise	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Visual Presence	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Abrasion & physical disturbance	Moderate	High	High	High
Displacement	Very high	High	High	Not Relevant
Chemical factors				
	Furcellaria lumbricalis	***Ahnfeltia plicata***	***Rhodothamniella floridula***	***Littorina littorea***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important functional
Synthetic compound contamination	Moderate	High	High	Very high
Heavy metal contamination	Not Relevant	Insufficient information	Not Relevant	High
Hydrocarbon contamination	Moderate	High	High	High
Radionuclide contamination	Not Relevant	Insufficient information	Not Relevant	Insufficient information
Changes in nutrient levels	Moderate	High	High	Not Relevant
Increase in salinity	Very high	Not Relevant	Not Relevant	Not Relevant
Decrease in salinity	Not Relevant	Very high	High	See explanation
Changes in oxygenation	Not Relevant	Insufficient information	Not Relevant	Very high
Biological factors				
	Furcellaria lumbricalis	***Ahnfeltia plicata***	***Rhodothamniella floridula***	***Littorina littorea***
Community Importance	Important characterizing	Important characterizing	Important characterizing	Important functional
Introduction of microbial pathogens/parasites	Not Relevant	Insufficient information	Not Relevant	Insufficient information
Introduction of non-native species	Not Relevant	Insufficient information	Not Relevant	Insufficient information
Extraction of this species	Moderate	Not Relevant	Not Relevant	High
Extraction of other species	Moderate	Insufficient information	Insufficient information	Not Relevant

Importance

Marine natural heritage importance

National importance	Common
Habitat Directive feature (Annex 1)	Reefs Large shallow inlets and bays Estuaries

Biotope importance

Little information on the importance of this biotope was found. However, rockpool environments, especially with macroalgal cover in the mid to lower shore, probably provide refuges for juvenile fish species, and juvenile and moulting crabs (e.g. *Cancer pagurus*). Low shore pools provide additional habitat for some sublittoral or sublittoral fringe species, notably the anemones *Urticina felina*, *Corynactis viridis*, *Sagartia elegans* and *Metridium senile*, and the limpet *Patella ulyssiponensis* (Lewis, 1964). Rockpools also allow some sublittoral fringe or lower shore species to extend their range upshore due to the removal of desiccation stress, although not as many species as might be expected, e.g. barnacles are a notably exception (Lewis, 1964). Lewis (1964) noted that deep pools in the lower shore, especially in the southwest, are rich areas for collecting the rarer species of algae. The presence of sediment in this biotope provides a small amount of sedimentary habitat in an otherwise hard substratum environment.

Exploitation

Rockpools are attractive mesocosms, allowing easy investigation of the resident species. Therefore, rockpools receive considerable attention from the public, environmental education schemes and scientists. Inappropriate boulder turning, netting and trampling within the pools may be detrimental (see sensitivity).

Additional information

No text entered

This Biology and Sensitivity Key Information review can be cited as follows:
Tyler-Walters, H., 2005. Seaweeds in sediment (sand or gravel)-floored eulittoral rockpools. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 28/01/2005]. Available from: <http://www.marlin.ac.uk>

Faunal crusts on wave-surged littoral cave walls (LR.FLR.CVOV.FaCr)

Key information authored by: Charlotte Marshall

Last updated 24/01/2005

This information is not refereed.

If you would be willing to supply *MarLIN* with an image of this species/habitat please contact marlin@mba.ac.uk

Recorded and expected LR.FLR.CVOV.FaCr distribution for Britain and Ireland

Description of biotope

The inner walls of caves, predominantly in the mid shore in wave-surged conditions dominated by barnacles *Semibalanus balanoides*, and *Verruca stroemia*, with patches of encrusting sponges such as *Halichondria panicea* and *Grantia compressa* and occasional patches of the mussel *Mytilus edulis*. Increased moisture allows a denser faunal population than LR.FLR.CVOV.ScrFa to develop within the cave. The limpet *Patella vulgata*, the sponge and spirorbid tube-forming polychaetes can be present. The hydroid *Dynamena pumila* and anemones such as *Metridium senile* and *Actinia equina* may occur towards the lower reaches of the cave. Where a dense faunal turf of barnacles or bryozoan crusts cover the cave walls, the biotope can also extend to cover the ceiling and may be accompanied by the bryozoan *Alcyonidium diaphanum*. Variations of this biotope may occur in mid and lower shore scoured caves in south Wales the rock is dominated by dense *Sabellaria alveolata*. In south-west England the rock can be completely covered by the barnacle *Balanus perforatus*. There may be a variation in the species composition from cave to cave, depending on local conditions. (Information taken from the revised Marine Habitat Classification, Version 04.05: Connor *et al.*, 2004.)

Additional information

No text entered

Biotope classification

UK and Ireland Classification

Major habitat	LR	Littoral rock (and other hard substrata)
Biotope	LR.FLR.CVOV.FaCr	Faunal crusts on wave-surged littoral cave walls

Other biotope classification schemes

This biotope code is a new code taken from the revised Marine Habitat Classification, Version 04.05: Connor *et al.*, 2004. A European Union Nature Classification System (EUNIS) habitat classification for this biotope was unavailable.

Ecology

Ecological and functional relationships

This biotope is dominated by species able to withstand the frequent disturbance caused by wave surges. This in itself means that the community is unlikely to be a climax community, but more a transient community dominated by ephemeral, rapidly growing species that are able quickly to dominate spaces created by wave energy. Furthermore, the fauna is likely to vary both spatially, i.e. between caves, and on a temporal basis, depending on the frequency, severity and timing of disturbance. Competition for space may be high where disturbance is less frequent or less severe, for example, on or near the cave floor (if the floor is permanently submerged). Both the flora and fauna are dominated by low lying encrusting forms. The lack of erect and massive species reflects the high energy wave environment. On a sublittoral, vertical rock wall in Maine, Sebens (1985) listed the most rapid colonizers of bare rock to include spirorbid worms, encrusting bryozoans, red crustose algae, and erect hydroids and bryozoans. The assemblage mentioned in Sebens' study is very similar to the community that characterizes this biotope.

- Erect algae are invariably absent in this biotope because they would probably not survive the persistent wave surges. The primary producers, therefore, are mostly represented by encrusting coralline algae, e.g. *Lithophyllum incrustans*
- Suspension feeders are the dominant trophic group although the dominant species is likely to vary between caves and in different geographic areas.
- Active suspension feeders that feed on bacteria, phytoplankton and organic particulates and detritus include sponges, encrusting bryozoans, occasional erect bryozoans and barnacles. The barnacles *Semibalanus balanoides* and *Verruca stroemia* may be abundant, although in the south-west of England, it is the barnacle *Balanus perforatus* which may completely cover the cave walls. *Semibalanus balanoides* suspension feeds both passively and actively, depending on current flow. Patches of encrusting sponge, especially the breadcrumb sponge *Halichondria panicea* and *Grantia compressa* may be found in damper areas of the cave. Damp crevices may give rise to small patches of the common mussel *Mytilus edulis* and anemones (see below). Encrusting bryozoans may form large turf areas and may include species such as *Cryptosula pallasiana* and *Haplopoma graniferum*. Erect bryozoans may be present in the upper reaches of the cave, where the effects of wave surge are reduced, or possibly submerged at the bottom of the cave and might include *Alcyonidium diaphanum* and *Bugula plumosa*, the latter known to be found hanging in caves (Ryland & Hayward, 1977). Other active filter feeders likely to be present are tubeworms, such as *Pomatoceros triqueter* which is an opportunistic species rapidly able to colonize space.
- Passive suspension feeders feed on organic particulates, plankton and other small animals, and may include hydroids such as *Dynamena pumila* and anemones including the plumose anemone *Metridium senile* and the beadlet anemone *Actinia equina*. These anemones can feed on larger prey items and may also be present in the lower and submerged reaches of the cave, providing sand scour is not a significant factor.
- When the floor of the cave if submerged, mobile fish predators may prey upon on the smaller invertebrates. Blennies, for example, will feed on the barnacles.
- The combination of the wave-surged habitat and the lack of easily digestible plant material mean that grazers are uncommon, although the common limpet *Patella vulgata* may be found occasionally as it is capable of feeding on the encrusting red algae.

Competition
Where a dense faunal crust covers the cave walls, space may become a limiting factor and some competition may occur. The anemones *Metridium senile* and *Actinia equina* are unlikely to be grown over (Sebens, 1985). Furthermore, both anemones can sting other anemones (Purcell, 1977; Manuel, 1988) and may therefore be competitively superior to other anemones where space is limited. The breadcrumb sponge *Halichondria panicea* was reportedly overgrown by everything apart from bryozoans in Sebens' (1985) study. This may explain why this sponge, and others, are usually only found in small patches within this biotope. Erect forms such as hydroids and the erect bryozoan *Alcyonidium diaphanum* may escape the immediate effects of competition from encrusting forms by developing vertically rather than laterally (Seed *et al.*, 1983).

Seasonal and longer term change

On wave exposed shores, it is usually the macroalgae that display the most obvious seasonal and temporal changes in abundance. In this biotope, however, it is the invertebrate species that demonstrate such cyclical changes. Some species of bryozoans and hydroids demonstrate seasonal cycles of growth in spring/summer and regression (die back) in late autumn/winter, over wintering as dormant stages or juvenile stages (see Ryland, 1976; Gili & Hughes, 1995; Hayward & Ryland, 1998). Many of the bryozoans and hydroid species are opportunists adapted to rapid growth and reproduction (r-selected), taking advantage of the spring/summer phytoplankton bloom and more favourable (less stormy) conditions (Dyrynda & Ryland, 1982; Gili & Hughes, 1995). Henry (2002) reported a drastic decline in *Dynamena pumila* over the winter months in the Bay of Fundy. The tubeworm *Pomatoceros triqueter* is also an opportunist that can quickly colonize bare rock. In a wave-surged biotope such as this, seasonal changes may be masked by the temporal changes brought about by wave disturbance. Furthermore, the timing of the large disturbances (in terms of time of year) will most likely influence the initial succession of the community. In addition, the community at any given time is likely to vary significantly in terms of abundant species between different caves. As a result of the continual disturbance resulting from wave surges, the community associated with this biotope can not be considered a 'climax' community *per se* and will continually undergo temporal changes.

Habitat structure and complexity

Cave habitats are extremely varied and can be complex in terms of morphology. The most simple cave form may be a cave that has a single entrance and that retreats some distance either into a chamber, tunnel or tapered end of some description. More importantly, there are no holes in the roof of the cave and, therefore, light gradually diminishes with depth into the cave. Invariably, however, cave morphology is not as simplified as this and all caves will vary in terms of:

- the amount of light penetrating into them,
- the depth of the water on the cave floor,
- the height of the cave to the roof,
- the amount of fresh water (if any) entering the cave through seepage or through cracks and fissures etc,
- the length to which the waves penetrate the cave (short caves parallel to the current will obviously experience a greater surge than long caves perpendicular to the current) and
- the extent to which the waves are funneled into the cave, e.g. short and narrow caves will most likely experience a greater surge than deep spacious caves where the waves will be dissipated over the large surface floor area.

The floor of the cave may be submerged at all times and the back of the cave will be damper than at the front. The walls of the cave are likely to have cracks and fissures along which moisture will collect. It is in such microhabitats that animals less adapted to desiccation will be found, for example, plumose anemones. The walls themselves may be vertical or overhanging and there may also be horizontal platforms on which water and sediment may settle. Due to the possibility of sediment settlement and puddles of water, such platforms may again give rise to a community comparably different to the rest of the cave, for example, *Sabellaria alveolata* crusts. The distribution of the flora and fauna within the cave will reflect their ability to withstand various stressors including desiccation, low light levels and sand scour.

Norton *et al.* (1971) studied the distribution of organisms in relation to light in a cave on Bullock Island, Lough Hyne, Ireland. They found that the level of light reaching the organisms was much greater when the cave walls were not entirely immersed. This was because when the cave is only partly immersed, the organisms receive both direct light and reflected light.

Dominant trophic groups	Suspension feeders

Productivity

No information was found concerning the productivity in this biotope but it is expected to be low. Encrusting algae are generally resistant to most grazers and as a consequence, will pass on little in terms of primary production to higher trophic levels. Only their spores and fragments of the algae may enter the food chain of local, subtidal ecosystems, or be exported further offshore. Rocky shores make a contribution to the food of many marine species through the production of planktonic larvae and propagules which contribute to pelagic food chains.

Major sources of organic carbon	Plankton

Recruitment processes

Apart from the encrusting algae, the majority of important 'other' species associated with this biotope produce planktonic larvae and have annual recruitment.

- *Semibalanus balanoides* produce one brood of between 5000 and 10000 eggs per year. The planktotrophic nauplii larvae develop in the surface waters for about two months although settlement and subsequent recruitment is highly variable.
- *Balanus perforatus* releases nauplii into the plankton during the summer and the cyprids settle on the shore during early autumn (Fish & Fish, 1996).
- Sponges may proliferate both asexually and sexually. Most sponges are hermaphroditic but cross-fertilization normally occurs. The process may be oviparous, where there is a mass spawning of gametes through the osculum which enter a neighbouring individual in the inhalant current. Fertilized eggs are discharged into the sea where they develop into a planula larva. However, in the majority development is viviparous, whereby the larva develops within the sponge and is then released. Larvae have a short planktonic life of a few hours to a few weeks, so that dispersal is probably limited and asexual reproduction probably results in clusters of individuals.
- Many anthozoans reproduce both sexually and asexually. The beadlet anemone *Actinia equina* frequently reproduces by viviparity whereby internal fertilization is followed by the release of fully formed young (Manuel, 1988).
- Spawning in *Sabellaria alveolata* occurs each July but subsequent recruitment can vary considerably from year to year. The larvae spend between 6 weeks and 6 months in the plankton. This could enhance the potential for recruitment from external sources, although it is the presence of some remaining adults that will assist in larval settlement as this is the preferred substratum (Wilson, 1929).
- Hayward & Ryland (1995b) and Segrove (1941) suggested that breeding of *Pomatoceros triqueter* probably takes place throughout the year although several authors have suggested that there is a peak in breeding in some areas (see *MarLIN* Web site). Larvae are pelagic for about 2-3 weeks in the summer although this increases to about two months in winter (Hayward & Ryland, 1995b). Settlement is thought to be minimal over the winter months.
- *Lithophyllum incrustans* reproduce annually and it has been calculated that 1 mm² of reproductive thallus produces 17.5 million bispores per year with an average settlement of only 55 sporelings/year (Edyvean & Ford, 1984).
- Dispersal of the hydroid *Dynamena pumila* is restricted to the planula stage which usually settles and starts to metamorphose within 60 hours of release (Orlov, 1996). Seed *et al.* (1981) reported that the reproductive zooids of *Dynamena pumila* were in abundance between May and August in Strangford Lough, Northern Ireland.
- Little information was found concerning recruitment in the ctenostome bryozoan *Alcyonidium diaphanum*. However, Wood & Seed (1992) reported that in populations of *Alcyonidium hirsutum* and *Flustrellidra hispida* (two other common ctenostome bryozoans) in the Menai Strait, larval release occurred over a protracted period. Little growth was observed over the winter months and few survived to their second year. The brooded, lecithotrophic coronate larvae of many bryozoans have a short pelagic life time of several hours to about 12 hours (Ryland, 1976). Recruitment is dependant on the supply of suitable, stable, hard substrata (Eggleston, 1972b; Ryland, 1976; Dyrynda, 1994).

Time for community to reach maturity

Although no information was found concerning temporal changes in this biotope especially, work has been done on similar habitats. Sebens (1985, 1986), for example, studied the succession of a community on the vertical rock walls in the Gulf of Maine. Although the patterns of succession recorded in his work are not entirely relevant here (since his study followed a two year successional period which is unlikely in this biotope given that it is characterized by frequent disturbance), the patterns of recolonization he observed are relevant. This biotope is subjected to frequent small disturbances and the associated community is characterized by relatively short lived and opportunistic species. Furthermore, 'maturity' may well be hard to define for this biotope since the composition of the flora and fauna is likely to change quite dramatically between caves, depending on local environmental conditions. Nonetheless, it is likely that the time taken for the community to reach maturity will be no more than a few years. The spirorbids, encrusting bryozoans, red crustose algae, erect hydroids and bryozoans mentioned in Sebens' study (1985) all covered the cleared areas within 1-4 months in the spring, summer and autumn months. The encrusting algae *Lithothamnion glaciale* took about 3 years to reappear (Sebens, 1985) and the breadcrumb sponge *Halichondria panicea* approached previous cover in about 2 years or more (Sebens, 1985).

Additional information

No text entered

Habitat preference and distribution

Distribution in Britain and Ireland

This biotope is recorded at various locations around the coast of the British Isles. In Wales it has been recorded on the north coast near Colwyn Bay. Around England it has been recorded on Lundy, the Isles of Scilly, on the south coast of Cornwall, St Abbs and near Bridlington. In Scotland it has only been recorded at Stromness on Orkney and in the Moray Firth.

Habitat preferences

Temperature range preferences	Data deficient
Water clarity preferences	Data deficient
Limiting nutrients	Data deficient
Other preferences	Sheltered to exposed coasts.

Additional information

This biotope is found on the vertical walls and ceilings of dark, damp caves. The caves must be damp in order to sustain the various soft bodied faunal and floral crusts.

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	Species name	Common Name
Important other	*Semibalanus balanoides*	An acorn barnacle
Important other	*Balanus perforatus*	An acorn barnacle
Important other	*Sabellaria alveolata*	Honeycomb worm
Important other	*Halichondria panicea*	Breadcrumb sponge
Important other	*Actinia equina*	Beadlet anemone
Important other	*Pomatoceros triqueter*	A tubeworm
Important other	*Lithophyllum incrustans*	An encrusting coralline algae
Important other	*Dynamena pumila*	A hydroid
Important other	*Alcyonidium diaphanum*	An erect bryozoan

Explanation

This biotope is characterized by a transient and ephemeral community that is likely to change both spatially and temporally. As a result, the species chosen as indicative to sensitivity have all been listed as 'important other', since other designations suggest the species plays a permanent central role in the biotope. A representative of the groups of organisms most likely to be found in the biotope at a given time has been selected. Where relevant, species particularly prevalent in certain areas have also been included. For example, the acorn barnacle, *Balanus perforatus*, has been listed because in southwest records of this biotope, this species can reportedly completely cover the rock (Connor *et al.*, 2004). In addition, the honeycomb worm

Sabellaria alveolata may dominate the rock in wave scoured caves in south Wales.

Overall, the acorn barnacle *Semibalanus balanoides* is reported to dominate this biotope (Connor *et al.*, 2004). However, it does not necessarily characterize the biotope as the species composition associated with these cave walls is likely to change from cave to cave. Its presence is likely to competitively exclude other species in terms of space. The remaining six 'important other' species represent a further six phyla and are the representatives of such phyla that are likely to be most frequently associated with this biotope. The encrusting algae and sponge may cover large areas of the rock.

Species found especially in biotope

No text entered

Additional information

A full species list was unavailable for this biotope. However, given the extreme habitat with which it is associated, species diversity is likely to be quite low with a noticeable absence of erect algal species.

Biotope sensitivity

Physical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	High	Moderate	Major Decline	Moderate
Smothering	Tolerant	Not Relevant	Not sensitive	Not Relevant	Moderate
Increase in suspended sediment	Intermediate	High	Low	Minor Decline	Low
Decrease in suspended sediment	Tolerant	Not Relevant	Not sensitive	Not Relevant	Moderate
Desiccation	Intermediate	High	Low	Minor Decline	Low
Increase in emergence regime	High	High	Moderate	Major Decline	Low
Decrease in emergence regime	Tolerant*	Not Relevant	Not sensitive*	Not Relevant	Low
Increase in water flow rate	Not Relevant	Not Relevant	Not relevant	Not Relevant	High
Decrease in water flow rate	Not Relevant	Not Relevant	Not relevant	Not Relevant	High
Increase in temperature	Low	High	Low	Minor Decline	Moderate
Decrease in temperature	Intermediate	High	Low	Decline	Low
Increase in turbidity	Tolerant	Not Relevant	Not sensitive	Not Relevant	Moderate
Decrease in turbidity	Tolerant*	Not Relevant	Not sensitive*	No Change	Moderate
Increase in wave exposure	Intermediate	High	Low	Decline	Low
Decrease in wave exposure	High	High	Moderate	Major Decline	Low
Noise	Tolerant	Not Relevant	Not sensitive	Not Relevant	Low
Visual Presence	Tolerant	Not Relevant	Not sensitive	Not Relevant	Low
Abrasion & physical disturbance	Intermediate	High	Low	Minor Decline	Moderate
Displacement	High	High	Moderate	Major Decline	High

Chemical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence

Synthetic compound contamination	Intermediate	High	Low	Decline	Low
Heavy metal contamination	Low	High	Low	Minor Decline	Low
Hydrocarbon contamination	High	High	Moderate	Major Decline	Moderate
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Changes in nutrient levels	Tolerant*	Not Relevant	Not sensitive*	No Change	Low
Increase in salinity	Not Relevant	Not Relevant	Not relevant	Not Relevant	Moderate
Decrease in salinity	Low	High	Low	No Change	Moderate
Changes in oxygenation	Low	High	Low	No Change	Low
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Insufficient information	Insufficient information	Insufficient information	Insufficient Information	Not Relevant
Introduction of non-native species	Tolerant	Not Relevant	Not sensitive	Not Relevant	Moderate
Extraction of key or important characterizing species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant
Extraction of important species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	All the key and important species associated with this biotope are permanently attached to the substratum and are unable to reattach themselves. Loss of the substratum would result in the loss of the entire biotope and, accordingly, intolerance has been assessed as high. Recoverability is expected to be high as the fauna associated with this biotope are ephemeral and no 'climax community' is known *per se* (see additional information).
Smothering (see benchmark)	This biotope is associated with wave surged areas. Such periodic surges would serve to flush clean the biotope and, therefore, any smothering would be short-lived. Furthermore, most of the substratum will be vertical or overhanging thereby preventing smothering. This biotope is likely to be tolerant to smothering at the benchmark level.
Increase in suspended sediment (see benchmark)	The effect of an increase in the amount of suspended sediment will depend partly on the nature of the sediment. An increase in coarse, sandy sediment, combined with the wave-surged nature of the habitat, could serve to scour species such as hydroids and bryozoans off the rock, especially in the lower reaches of the cave. It may also interfere with the delicate feeding apparatus of the suspension feeders. Furthermore, the feeding activity of suspension feeders on emergent rock, that rely on immersion by wave surges for feeding opportunities, may be prevented altogether if, in that short time, they spend all the time trying to clean their feeding apparatus. At the benchmark level it is likely that, over the course of one month, feeding opportunities will be reduced. This may be reflected in a reduced scope for growth and reproductive potential in the faunal crusts and other species. Delicate or annual species may experience some mortality. In contrast, an increase in the amount of suspended sediment will be beneficial to the establishment of *Sabellaria alveolata* which need the sediment for tube construction. Overall, however, intolerance has

	been assessed as intermediate with a high recovery (see additional information).
Decrease in suspended sediment (see benchmark)	A decrease in suspended sediment could reduce the scour effect of particles on both the floral and faunal components of this biotope. In addition, it is likely that suspension feeding community may become more efficient as there would be fewer inorganic particles to clog and interfere with the feeding apparatus. Assuming that the decrease in suspended sediment refers to inorganic particles, a reduction in ingestion in the suspension feeding component of this biotope is not expected. Therefore, tolerant has been assessed.
Desiccation (see benchmark)	An increase in desiccation at the benchmark level would mean that this biotope change its position by one vertical biological zone on the shore. However, due to that fact that this biotope is found in caves, the effects of such a transition are likely to be reduced since the majority of walls of the cave will remain damp. In addition, the fact that all the species associated with this biotope are intertidal means that they are adapted to some degree of cyclical desiccation. Nevertheless, where the cave walls are exposed to sunshine and wind, such as at the entrance to the caves, some species may experience some mortality. For example, the damp crevices that may otherwise support the beadlet and plumose anemones may become much drier and therefore unsuitable for these two species. *Semibalanus balanoides* has a lower tolerance to desiccation than the chthamalid species, due to a greater permeability of the shell plates, and it is likely that, in some areas, this barnacle may be replaced by other barnacle species over the course of the benchmark. The edges of colonies of the breadcrumb sponge and encrusting algae may experience some bleaching and death. Furthermore, a change in height within the cave may mean that some species are out of reach of the wave surges and will therefore experience reduced feeding opportunities in addition to increased desiccation. However, mass mortality is unlikely and intolerance has been assessed as intermediate. Recoverability is likely to be high (see additional information).
Increase in emergence regime (see benchmark)	Intertidal biotopes such as LR.FLR.CVOV.FaCr are adapted to a certain degree of cyclical immersion and emersion and the associated changes in salinity, desiccation and temperature. In a damp dark cave within which this biotope is found, many of these stresses will be reduced. However, feeding opportunities for much of the suspension feeding community will be reduced. Since many of them are annual species, mortality is likely. For longer living species such as *Pomatoceros triqueter*, *Halichondria panicea* and *Lithophyllum incrustans*, a decrease in abundance may occur. The barnacles are likely to persist since they can respire anaerobically as desiccation increases (Barnes *et al.*, 1963) although the proportion of the various barnacle species may vary as an increase in the period of emersion would cause increased competition from chthamalid barnacles. The upper limit of the biotope is likely to be depressed and, due to the fact that, the biotope may already extend to the cave floor, this reduction may not be counterbalanced by a downward extension of the lower limit. This mean the overall extent of the biotope will be reduced and accordingly, intolerance has been assessed as high but with a high recovery (see additional information).
Decrease in emergence regime (see benchmark)	A decrease in emergence would increase feeding opportunities for all filter feeders, the dominant fauna within this biotope. Both the upper limit of rock covered in faunal crusts and the total area covered may increase. The density of *Pomatoceros triqueter*, anemones, sponges and encrusting algae may increase on the lower reaches of the cave walls. Due to the fact that there is not one particular characteristic community associated with this biotope, it is difficult to assess whether such a change would be 'beneficial'. However, species diversity is likely to increase and therefore tolerant* has been suggested.
Increase in water flow rate (see benchmark)	An increase in water flow rate is not considered relevant as the forces associated with a wave surged environment, such as in this biotope, are likely to be far greater than those that would be experienced by an increase in water flow rate at the

	benchmark level.
Decrease in water flow rate (see benchmark)	A decrease in water flow rate is not considered relevant because the forces associated with a wave surged environment, such as in this biotope, are likely to exceed any caused by water flow.
Increase in temperature (see benchmark)	The geographical distribution of the species associated with this biotope are such that an increase in temperature at the benchmark level is unlikely to adversely affect the majority of them e.g. *Lithophyllum incrustans*, *Halichondria panicea* and *Sabellaria alveolata*. However, *Semibalanus balanoides* is a boreal species, adapted to cool environments. Its southern limits are controlled by high temperatures which prevent final maturation of gametes and mean monthly sea temperature must fall below 7.2 °C in order for the barnacles to breed. In southern occurrences of this biotope where *Semibalanus balanoides* may be rare anyway, it may give way completely to chthamalid barnacles. However, although *Semibalanus balanoides* may experience a decline in abundance, the resultant community would still be typical of this biotope. Therefore, intolerance has been assessed as low. Recovery is expected to be high (see additional information).
Decrease in temperature (see benchmark)	Although many of the species associated with this biotope may be able to tolerate a chronic decrease in temperature, fewer species are likely to be tolerant of an acute drop in temperature. *Sabellaria alveolata* growth is inhibited below 5 °C and below 7 °C, *Pomatoceros triqueter* is unable to build calcareous tubes (Thomas, 1940). These are both temperatures that can reasonably be expected in the intertidal in the British Isles. Crisp (1964) noted frost damage to colonies of *Halichondria panicea* during the severe winter of 1962-63 and other sponges may be similarly affected. In contrast, *Semibalanus balanoides* was not affected during the severe winter of 1962-63 in most areas (Crisp, 1964). *Lithophyllum incrustans* is also likely to be able to tolerate decreased temperature since it occurs in a wide geographical range in temperatures that are much colder (air and water) than in Britain and Ireland. On balance, intolerance has been assessed as intermediate with a high recovery (see additional information).
Increase in turbidity (see benchmark)	An increase in turbidity is not likely to adversely affect the species associated with this biotope. The faunal component will not be affected and the encrusting coralline algae are tolerant of low light levels. At the benchmark level, no adverse affects are expected and accordingly, this biotope has been assessed as being tolerant to turbidity.
Decrease in turbidity (see benchmark)	An increase in turbidity may have the potential to increase phytoplankton production and may also increase light availability for photosynthesis in the encrusting coralline algae. The biotope may therefore benefit from such a reduction and accordingly tolerant* has been suggested.
Increase in wave exposure (see benchmark)	An increase in exposure, in combination with the tunneling effect the cave can have on the wave surges, would result in an extremely high energy environment. Erect bryozoans such as *Alcyonidium diaphanum* would almost certainly be lost. If other filter feeders survived, such as the anemones and hydroids, they may experience feeding difficulties in the powerful surges. Over time this would lead to reduction in ingestion and, therefore, a reduced scope for growth. The barnacle *Semibalanus balanoides* thrives in extremely wave exposed conditions and may come to dominate this biotope over the course of the benchmark. Colonies of *Lithophyllum incrustans* also appear to thrive in conditions exposed to strong water movement. Irvine & Chamberlain (1994) observe that the species is best developed on wave exposed shores. *Sabellaria alveolata* and *Pomatoceros triqueter* can be found in very wave exposed and extremely wave exposed conditions respectively, although the tunneling effects of the surges in the cave may lead to the dislodgement and subsequent loss of parts of the *Sabellaria alveolata* colony. Overall, some mortality among various species is likely and species diversity will probably decline. Therefore, an intolerance of intermediate has been suggested with

	a high recovery.
Decrease in wave exposure (see benchmark)	A decrease in wave exposure could result in the biotope experiencing extremely wave sheltered conditions. This may have a deleterious effect on the biotope community since the dampness sustaining many of the species is reliant on the wave surges to splash the walls and ceiling of the cave. A reduction of wave exposure of this magnitude would mean that the upper reaches of the biotope may be too dry to support the species normally found there and it is likely that the upper limits of the biotope may be suppressed. The reduced upper limit would probably be set by barnacles that may come to dominate the biotope given their ability to competitively outcompete lower shore species in the face of desiccation. Furthermore, without regular and significant wave surges, many of the suspension feeders would be unable to feed and would therefore perish. The biotope would no longer be 'wave surged'. In the lower reaches of the cave, where the walls may be permanently submerged, species more characteristic of sheltered conditions may proliferate. Erect bryozoans may increase in abundance, for example. Competition for space may increase in this area since the biotope will have been 'squeezed' and it is likely that there will be a reduction in the number of species frequently associated with this biotope and an increase in other species. The majority of the biotope coverage is likely to be lost and therefore, intolerance has been assessed as high with a high recovery.
Noise (see benchmark)	The fauna associated with this biotope are unlikely to have effective mechanisms for detecting noise and will most likely be tolerant of noise at the benchmark level.
Visual Presence (see benchmark)	The fauna associated with this biotope are unlikely to have effective mechanisms for detecting visual presence and will most likely be tolerant of visual presence at the benchmark level.
Abrasion & physical disturbance (see benchmark)	Due to the fact that this biotope is associated with cave habitats, abrasion and physical disturbance in this biotope is likely to come in the form of cobbles taken into suspension. Trampling and boats running aground are unlikely. Both the flora and fauna associated with this biotope are characterized by low lying crust forming species and therefore the effects of abrasion will most likely be the removal of, for example, small patches of sponge and bryozoan colonies or encrusting algae. Individual anemones may be killed but mass mortality is unlikely. In a study looking at the compressive strengths of several barnacles (Gubbay, 1983), *Semibalanus balanoides* was found to be weaker than *Balanus perforatus* and repeated physical disturbance in areas where these two co-existed could reduce the abundance of the weaker species thus altering the relative abundances of barnacles. In the lower reaches of the cave, suspended cobbles could scour the walls creating bare patches among the crusts and this area is likely to be more adversely affected than higher up the walls. Intolerance has been recorded as intermediate to reflect some mortality. Due to the fact that a proportion of each species will remain, recoverability is likely to be high.
Displacement (see benchmark)	The majority of key and important species associated with this biotope are permanently attached to the substratum and are unable to reattach themselves if displaced. In contrast, many anemones can reattach themselves once displaced. Wahl (1984) observed that *Metridium senile* detached from the substratum in the Inner Flensburg Fjord may drift away and eventually resettle. However, anemones in isolation are not indicative of LR.FLR.CVOV.FaCr and in general, this factor is thought to have a similar effect to substratum loss. Accordingly, intolerance is likely to be high. Recoverability will be high (see additional information).
Chemical Factors	
Synthetic compound contamination (see benchmark)	Information concerning the effects of synthetic chemicals was not available for all the important species in this biotope and some of the information was conflicting. Hoare & Hiscock (1974) recorded that 'lithothamnia' was absent from the rocky

	shore up to 150 m distance from an acidified halogenated effluent. They also suggested that Polyzoa (Bryozoa) were amongst the most intolerant species to acidified halogenated effluents in Amlwch Bay. However, Soule & Soule (1979) and Holt *et al.*, (1995) reported that bryozoans are common members of the fouling community, and amongst those organisms most resistant to antifouling measures, such as copper containing anti-fouling paints. Barnacles have a low resilience to chemicals such as dispersants, dependant on the concentration and type of chemical involved (Holt *et al.*, 1995). Most *Semibalanus balanoides* were killed in areas treated with dispersants (Smith, 1968). Hawkins & Southward (1992) suggested that the communities on shores heavily treated with dispersants had taken 5-8 years to recover, while some had not recovered after 10 years. Where oil had gone largely untreated, recovery was almost complete within 3 years (Hawkins & Southward, 1992). On balance, it is likely that some species will experience some mortality and, therefore, intolerance has been assessed as intermediate. Recovery is likely to be high (see additional information). The wave surged nature of the habitat may assist in flushing the contaminants from the biotope.
Heavy metal contamination (see benchmark)	Information concerning the effects of heavy metals was not available for all the important species in this biotope. Barnacles accumulate heavy metals and store them as insoluble granules. Clarke (1947) investigated the intolerance of *Semibalanus balanoides* to copper, mercury, zinc and silver. He found that 90% of barnacles died when held in 0.35 mg/l Cu carbonate for two days. Zinc, mercury and silver killed 90 % of barnacles in two days at concentrations of 32 mg/l, 1 mg/l and 0.4 mg/l respectively. Pyefinch & Mott (1948) recorded median lethal concentrations of 0.32 mg/l copper and 0.36 mg/l mercury over 24 hours for this species. Barnacles may tolerate fairly high level of heavy metals in nature, for example they are found in Dulas Bay, Anglesey, where copper reaches concentrations of 24.5 µg/l, due to acid mine waste (Foster *et al.*, 1978). Bryozoans are common members of the fouling community and amongst those organisms most resistant to antifouling measures, such as copper containing anti-fouling paints. Bryozoans were also shown to bioaccumulate heavy metals to a certain extent (Soule & Soule, 1979; Holt *et al.*, 1995). Bryozoans and hydroids may only manifest sublethal effects due to heavy metal contamination. On balance, an intolerance of low has been suggested. Recovery should be high, especially since the wave surged habitat may flush out some contaminants from the biotope.
Hydrocarbon contamination (see benchmark)	The nature of the habitat with which this biotope is associated means that the associated community has the potential to collect oil. For example, if an oil spill was to occur, oil may be splashed onto the walls of the cave. Subsequent splashes of water may be insufficient to wash the oil off the rocks. Littoral barnacles have a high resistance to oil (Holt *et al.*, 1995). However, after the *Torrey Canyon* oil spill, some mortality of barnacles was caused by the oil although most had been able to form a hole in the covering of oil and were 'in good order' (Smith, 1968). Significant reductions in densities of *Semibalanus balanoides* were observed after the *Exxon Valdez* oil spill (1989), especially at high and mid shore (Highsmith *et al.*, 1996). Experimentally, *Semibalanus balanoides* has been found to tolerate exposure to the water-accommodated fraction of diesel oil at 129.4 µg/l for two years (Bokn *et al.*, 1993). Recovery rates appear to be variable. They depend on the level of settlement and the survival rate of spat, both of which vary with a suite of environmental and biological factors. Lightly oiled shores have been observed to take 7 to 9 years to reach the previous normal state and more heavily oiled shores take longer (Holt *et al.*, 1995).

	Where exposed to direct contact with fresh hydrocarbons, encrusting coralline algae appear to have a high intolerance. Crump *et al.* (1999) describe "dramatic and extensive bleaching" of 'Lithothamnia' following the *Sea Empress* oil spill. Observations following the *Don Marika* oil spill (K. Hiscock, own observations) were of rockpools with completely bleached coralline algae. However, Chamberlain (1996) observed that although *Lithophyllum incrustans* was quickly affected by oil during the Sea Empress spill, recovery occurred within about a year. The oil was found to have destroyed about one third of the thallus thickness but regeneration occurred from thallus filaments below the damaged area. *Membranipora* spp. (encrusting bryozoans) and *Bugula* spp. (erect bryozoans) were reported to be lost or excluded from areas subject to oil spills (Mohammad, 1974; Soule & Soule, 1979). Soule & Soule (1979) reported that *Bugula neritina* was lost from breakwater rocks in the vicinity of the 1976 Bunker C oil spill in Los Angeles Harbour, and had not recovered within a year. However, *Bugula neritina* had returned to a nearby area within 5 months even though the area was still affected by sheens of oil. Houghton *et al.* (1996) also reported a reduction in the abundance of intertidal encrusting bryozoans (no species given) at oiled sites after the *Exxon Valdez* oil spill. No information was found concerning the effects of hydrocarbon contamination on the erect bryozoan *Alcyonidium diaphanum*. Very little information has been found about the effects of oil on the sponges associated with this biotope although it appears that *Halichondria panicea* survived in areas affected by the Torrey Canyon oil spill (Smith, 1968), although few observations were made. Overall, an intolerance of high has been suggested. Recoverability will depend on the ability of the habitat to clean itself but it is expected to be high.
Radionuclide contamination (see benchmark)	Insufficient information was available on the effects of radionuclides on the community associated with LR.FLR.CVOV.FaCr.
Changes in nutrient levels (see benchmark)	No information was found concerning the specific effects of nutrient enrichment on the community associated with this biotope. However, it is possible that the suspension feeding community, the dominant trophic group, will benefit. Phytoplankton production may increase thereby increasing the availability of organic particulate matter on which to feed. The risk of oxygen reduction and reduced light, often associated with plankton blooms, are extremely low given the wave surged nature of the habitat. Tolerant* has therefore been suggested.
Increase in salinity (see benchmark)	An increase in salinity is not considered relevant since the biotope is found in variable and full salinity areas. There is no great risk of hypersalinity either considering the walls of the cave will invariably stay damp and there is probably insufficient sunshine and wind to create patches of evaporated salt crust.
Decrease in salinity (see benchmark)	A chronic decrease in salinity at the benchmark level (i.e. down to reduced salinity, 18-30) for one year is unlikely to affect this biotope since it already occurs in areas of variable salinity which can be as low as 18. However, an acute drop in salinity could mean that the biotope experiences salinities less than 18 for one week. There may already be some freshwater penetration into this biotope through seepage and cracks and fissures in the ceiling of the cave and so some species may be tolerant. For example, both the breadcrumb sponge *Halichondria panicea* and the beadlet anemone *Actinia equina* can be found in low salinity conditions. The beadlet anemone is often found in the rills of freshwater that sometimes occur on beaches at low water (Manuel, 1988). Barnacles can survive periodic emersion in freshwater, e.g. from rainfall or fresh water run off, by closing their opercular valves (Foster, 1971). They can also withstand large changes in salinity over moderately long periods of time by falling into a "salt sleep". In this state motor activity ceases and respiration falls, enabling

	animals to survive in freshwater for three weeks (Barnes, 1953). *Semibalanus balanoides* can tolerate salinities down to 12 psu, below which cirral activity ceases (Foster, 1970). *Sabellaria alveolata* and *Pomatoceros triqueter* only occur in fully marine environments any may therefore be intolerant of a sudden decrease in salinity. However, the loss of these two species may not necessarily affect the recognizable biotope. Furthermore, all the species in this biotope are intertidal and will therefore be adapted, to some extent, to short term acute declines in salinity from rainfall and freshwater runoff. Therefore, intolerance has been assessed as low with a high recovery.
Changes in oxygenation (see benchmark)	*Semibalanus balanoides* can respire anaerobically, so it can tolerate some reduction in oxygen concentration (Newell, 1979). When placed in wet nitrogen, where oxygen stress is maximal and desiccation stress is low, *Semibalanus balanoides* has a mean survival time of 5 days (Barnes *et al.*, 1963). Insufficient information was available concerning the effects of reduced oxygen on the other species. However, Cole *et al.* (1999) suggested possible adverse effects on marine species below 4 mg/l and probable adverse effects below 2 mg/l. Given that the benchmark level is exposure to dissolved oxygen concentration of 2mg/l for 1 week, intolerance has been assessed as low with a high recovery.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	Barnacles are parasitised by a variety of organisms and, in particular, the cryptoniscid isopod *Hemioniscus balani*. Heavy infestation can cause castration of the barnacle and, once infected recovery, of an individual barnacle is unlikely. However, levels of infestation within a population vary and the probability of barnacles in this biotope being infected is not known.
Introduction of non-native species (see benchmark)	The Australasian barnacle *Elminius modestus* was introduced to British waters on ships during the second World War. The species does well in estuaries and bays, where it can displace *Semibalanus balanoides*. However, on exposed shores the native species out-compete this invasive species (Raffaelli & Hawkins, 1999). Therefore, tolerant has been assessed.
Extraction of key or important characterizing species (see benchmark)	There are no key or important characterizing species associated with this biotope.
Extraction of important species (see benchmark)	*Sabellaria alveolata* is occasionally collected for bait although the intertidal cave habitats in this biotope are such that exploitation is likely to be minimal. Furthermore, this species is only associated with variations of this biotope in south Wales and this factor is, therefore, not considered to be relevant.

Additional information

Recoverability

The community associated with this biotope is dominated by ephemeral and fast growing species that can colonize rapidly space created by wave energy. For this reason, the progression of recoverability will depend on what time of year disturbances occur. However, as mentioned previously, the LR.FLR.CVOV.FaCr community will vary both spatially and temporally and it is therefore difficulty to identify a ‘climax’ community as such. Furthermore, because there are no key functional, structural or characterizing species, any combination of faunal crust species could, theoretically, determine the biotope community. Nevertheless, the majority of the flora and fauna normally associated with LR.FLR.CVOV.FaCr will recolonize the areas within a year or two and recoverability is expected to be high.

In Sebens' study of recolonization of vertical rock wall in Maine (Sebens, 1986), epifaunal and algal crust species were shown to re-colonize cleared areas quickly. For example encrusting bryozoans, tubeworms, tubicolous amphipods and worms, erect hydroids and bryozoans were reported to cover cleared areas within 1-

4 months in spring, summer and autumn (Sebens, 1986). *Pomatoceros triqueter* is fairly widespread, reaches sexual maturity within 4 months (Hayward & Ryland, 1995b; Dons, 1927) and longevity has been recorded to be between 1.5 and 4 years (Hayward & Ryland, 1995b; Castric-Fey, 1983; Dons, 1927). Larvae are pelagic for about 2-3 weeks in the summer and about 2 months in the winter (Hayward & Ryland, 1995b), enabling them to disperse widely. Recovery is therefore likely to be high. *Actinia equina* is also likely to recover fairly rapidly from surrounding areas.

The remaining species associated with this biotope may take longer to recover although it should still be within about three years. Bennell (1981) observed that, after barnacles were scraped off the surface rock in a barge accident at Amlwch in North Wales, barnacle populations returned to pre-accident levels within 3 years. However, barnacle recruitment can be very variable because it is dependent on a suite of environmental and biological factors. Jenkins *et al.* (2000) reported variation in settlement and recruitment of *Semibalanus balanoides* at all spatial scales studied (10s, 1000s of metres and 100s of km) in Sweden, the Isle of Man, southwest Ireland and southwest England and between 2 years, 1997 and 1998. Substantial variation in settlement and recruitment occurred between sites and variation in settlement explained 29 -99% of variation in recruitment across all sites, although not all variation in recruitment was explained by settlement at all sites.

Sebens (1985) reported that *Halichondria panicea* had reached previous cover within two or more years. It was slow to recolonize the cleared areas, only appearing after about a year, although it is relatively fast growing.

Sabellaria alveolata spawning occurs each July but actual recruitment levels vary considerably from year to year so recovery could take several years. The presence of some remaining adults will assist in larval settlement as this is the preferred substratum (Wilson, 1929). However, this species is only dominant south Wales and not the majority of records of this biotope.

Encrusting coralline algae (e.g. *Lithothamnion* and *Phytomatolithon* took 1-2 years to recolonize cleared areas (Sebens, 1985; 1986) and with their slow growth rates probably take many years to recover their original abundance. Recoverability of *Lithophyllum incrustans* will be slow because although spores will settle and new colonies will arise rapidly on bare substratum, growth rate is slow (2-7 mm per annum - see Irvine & Chamberlain 1994).

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors					
	Semibalanus balanoides	***Sabellaria alveolata***	***Halichondria panicea***	***Pomatoceros triqueter***	***Lithophyllum incrustans***
Community Importance	Important other	Important other	Important other	Important other	Important other
Substratum Loss	High	High	High	High	High
Smothering	Intermediate	Low	High	High	Low
Increase in suspended sediment	Low	Low	Low	Low	Low
Decrease in suspended sediment	See explanation	See explanation	Not Sensitive	Low	Not Sensitive*
Desiccation	Intermediate	Intermediate	Intermediate	Intermediate	High
Increase in emergence regime	High	Intermediate	Intermediate	Intermediate	High
Decrease in emergence regime	See explanation	See explanation	Not Sensitive	Not Sensitive*	Not Sensitive
Increase in water flow rate	Low	Intermediate	Intermediate	Not Sensitive*	Low
Decrease in water flow rate	See explanation	See explanation	Low	Not Sensitive	Low
Increase in temperature	Intermediate	Intermediate	Low	Not Sensitive*	Not Sensitive

Decrease in temperature	See explanation	See explanation	Low	Intermediate	Not Sensitive
Increase in turbidity	Low	Not Sensitive	Not Sensitive	Not Sensitive	Low
Decrease in turbidity	See explanation	See explanation	Not Sensitive	Not Sensitive	Not Sensitive*
Increase in wave exposure	Low	Intermediate	Intermediate	Low	Not Sensitive
Decrease in wave exposure	See explanation	See explanation	Low	Not Sensitive	Low
Noise	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive
Visual Presence	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive
Abrasion & physical disturbance	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate
Displacement	High	High	High	Low	Low
Chemical factors					
	Semibalanus balanoides	***Sabellaria alveolata***	***Halichondria panicea***	***Pomatoceros triqueter***	***Lithophyllum incrustans***
Community Importance	Important other	Important other	Important other	Important other	Important other
Synthetic compound contamination	Intermediate	Insufficient information	Insufficient information	Insufficient information	High
Heavy metal contamination	Low	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Hydrocarbon contamination	Intermediate	Insufficient information	Low	Insufficient information	High
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient levels	Intermediate	Insufficient information	Insufficient information	Insufficient information	Low
Increase in salinity	Low	Intermediate	Low	Not Sensitive	Insufficient information
Decrease in salinity	See explanation	See explanation	Low	High	Intermediate
Changes in oxygenation	Intermediate	Intermediate	Intermediate	Insufficient information	Insufficient information
Biological factors					
	Semibalanus balanoides	***Sabellaria alveolata***	***Halichondria panicea***	***Pomatoceros triqueter***	***Lithophyllum incrustans***
Community Importance	Important other	Important other	Important other	Important other	Important other
Introduction of microbial pathogens/parasites	Intermediate	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Introduction of non-native species	Intermediate	Insufficient information	Insufficient information	Not Sensitive	Insufficient information
Extraction of this species	Not Relevant	Intermediate	Not Relevant	Not Relevant	Not Relevant
Extraction of other species	Intermediate	Intermediate	High	Not Relevant	Intermediate

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors					
	Semibalanus balanoides	***Sabellaria alveolata***	***Halichondria panicea***	***Pomatoceros triqueter***	***Lithophyllum incrustans***
Community Importance	Important other	Important other	Important other	Important other	Important other
Substratum Loss	High	Moderate	High	High	Low

Smothering	High	Immediate	High	High	Very high
Increase in suspended sediment	Very high	Very high	Immediate	High	Very high
Decrease in suspended sediment	See explanation	See explanation	Not Relevant	High	Not Relevant
Desiccation	High	High	Very high	High	Low
Increase in emergence regime	High	High	Very high	High	Low
Decrease in emergence regime	See explanation	See explanation	Not Relevant	Not Relevant	Not Relevant
Increase in water flow rate	Very high	High	Very high	Not Relevant	Very high
Decrease in water flow rate	See explanation	See explanation	Immediate	Not Relevant	Very high
Increase in temperature	High	High	Very high	Not Relevant	Not Relevant
Decrease in temperature	See explanation	See explanation	Very high	High	Not Relevant
Increase in turbidity	Very high	Not Relevant	Not Relevant	Not Relevant	Very high
Decrease in turbidity	See explanation	See explanation	Not Relevant	Not Relevant	Not Relevant
Increase in wave exposure	High	High	Very high	High	Not Relevant
Decrease in wave exposure	See explanation	See explanation	Very high	Not Relevant	Immediate
Noise	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Visual Presence	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Abrasion & physical disturbance	High	High	High	Immediate	High
Displacement	High	Moderate	High	High	Very high
Chemical factors					
	Semibalanus balanoides	***Sabellaria alveolata***	***Halichondria panicea***	***Pomatoceros triqueter***	***Lithophyllum incrustans***
Community Importance	Important other	Important other	Important other	Important other	Important other
Synthetic compound contamination	Moderate	Insufficient information	Not Relevant	Not Relevant	Low
Heavy metal contamination	High	Insufficient information	Not Relevant	Not Relevant	Not Relevant
Hydrocarbon contamination	Moderate	Insufficient information	High	Not Relevant	High
Radionuclide contamination	Not Relevant	Insufficient information	Not Relevant	Not Relevant	Not Relevant
Changes in nutrient levels	High	Insufficient information	Not Relevant	Not Relevant	High
Increase in salinity	High	High	High	Not Relevant	Not Relevant
Decrease in salinity	See explanation	See explanation	High	High	High
Changes in oxygenation	High	High	High	Not Relevant	Not Relevant
Biological factors					
	Semibalanus balanoides	***Sabellaria alveolata***	***Halichondria panicea***	***Pomatoceros triqueter***	***Lithophyllum incrustans***
Community Importance	Important other	Important other	Important other	Important other	Important other
Introduction of microbial pathogens/parasites	High	Insufficient information	Not Relevant	Not Relevant	Not Relevant
Introduction of non-native species	High	Insufficient information	Not Relevant	Not Relevant	Not Relevant
Extraction of this species	Not Relevant	High	Not Relevant	Not Relevant	Not Relevant
Extraction of other species	High	High	High	Not Relevant	High

Importance

Marine natural heritage importance

National importance Not available

Biotope importance

It is unlikely that this biotope holds any significant importance for other species. Epifaunal habitats are dominated by suspension feeding invertebrates and probably have an important role in marine food webs by transferring primary productivity from the photic zone and the plankton or shallow coastal water macroalgae to the benthos, so called termed 'benthic-pelagic' coupling (Gili & Hughes, 1995).

Exploitation

None of the species frequently associated with this biotope are targeted for extraction apart from *Sabellaria alveolata*. These worms are occasionally collected for bait although the intertidal cave habitats in this biotope are such that exploitation is likely to be minimal, if any.

Additional information

The honeycomb worm *Sabellaria alveolata* is covered by a Habitat Action Plan in its reef form. However, in this biotope, the species will simply form a low lying crust on the rock as opposed to massive, reef forms.

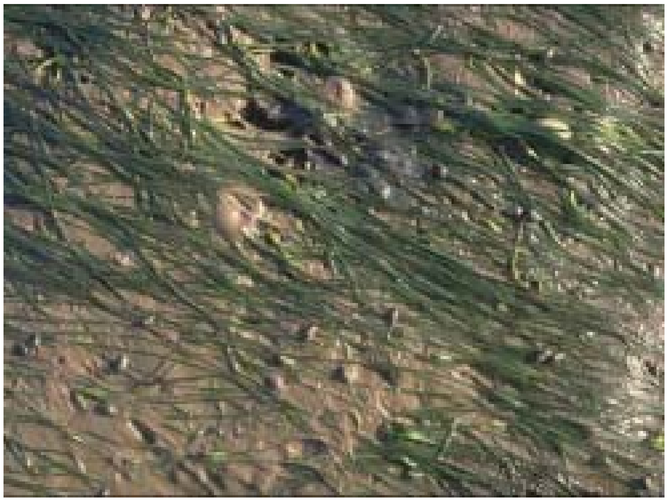
This Biology and Sensitivity Key Information review can be cited as follows:
Marshall, C.E., 2005. Faunal crusts on wave-surged littoral cave walls. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 25/01/2005]. Available from: <http://www.marlin.ac.uk>

Zostera noltii beds in upper to mid shore muddy sand (LMS.Znol)

Key information authored by: Dr Harvey Tyler-Walters

Last updated 17/11/2004

Refereed by: Dr Leigh Jones


A bed of *Zostera noltii* with *Hydrobia ulvae* visible on the mud surface. Image width ca 40 cm.
Image: Mark Davies / Joint Nature Conservation Committee


Recorded and expected LMS.Znol distribution for Britain and Ireland

Description of biotope

Mid and upper shore wave-sheltered muddy fine sand or sandy mud with narrow-leafed eel grass *Zostera noltii* at an abundance of frequent or above. This is similar to polychaetes and *Cerastoderma edule* (LMS.PCer) since it is most frequently found on lower estuary and sheltered coastal muddy sands with a similar infauna. Exactly what determines the distribution of the *Zostera noltii* is, however, not entirely clear. *Zostera noltii* is often found in small lagoons and pools, remaining permanently submerged, and on sediment shores where the muddiness of the sediment retains water and stops the roots from drying out. A black layer is usually present below 5 cm sediment depth. The infaunal community is characterized by polychaetes *Pygospio elegans* and *Arenicola marina*, mud amphipods *Corophium volutator* and bivalves *Cerastoderma edule*, *Macoma balthica* and *Scrobicularia plana*. Typically an epifaunal community is found that includes the mud snail *Hydrobia ulvae*, shore crabs *Carcinus maenas* and the green alga *Ulva* sp. This biotope should not be confused with IMS.Zmar which is a *Zostera marina* bed on the lower shore or shallow sublittoral clean or muddy sand. (Information taken from the Marine Biotope Classification for Britain and Ireland, Version 97.06: Connor *et al.*, 1997a, b).

Welsh Variation

Some seagrass beds exist in Wales, e.g. the Severn Estuary, where *Zostera noltii* and *Zostera marina* occur together. In these seagrass beds, *Zostera marina* is found in the wet channels and *Zostera noltii* is found on the raised beds (between the small channels) that dry between tides. Kay (1998) suggested that the distribution of *Zostera noltii* in Wales has been severely underestimated as a result of confusion with *Zostera angustifolia.* See Rohan Holt (in prep.) for details. Alternatively, contact the CCW Marine Monitoring Team.

Additional information

No text entered

Biotope classification

UK and Ireland Classification

Major habitat	LS	Littoral sediments
Habitat complex	LMS	Littoral muddy sands
Biotope complex	LMS.Zos	Littoral *Zostera* (seagrass) beds
Biotope	LMS.Znol	*Zostera noltii* beds in upper to mid shore muddy sand
Similar biotopes:	LMS.Pcer	

Other biotope classification schemes

European Union Natural Information System (EUNIS): A2.71/B-LMS.Zos.Znol. *Zostera noltii* beds in upper to mid shore muddy sand (Davies & Moss, 1998).
Wadden Sea classification: 05.02.01. Intertidal seagrass beds (von Nordheim *et al.*, 1996).
France (ZNIEFF-MER): II.3.3. Herbiers de *Zostera marina*, *Zostera noltii* (= *Z. nana* pro parte) du mediolittoral inferieur. France (ZNIEFF-MER): III.3.7. Biocenose des sables vaseux superficiels de mode calme (SVMC) (Dauvin *et al.,* 1994).

Ecology

Ecological and functional relationships

- *Zostera noltii* provides shelter or substratum for a wide range of species, especially epiphytes and periphyton.
- Leaves slow currents and water flow rates under the canopy and encourage settlement of fine sediments, detritus and larvae (Orth, 1992).
- Seagrass rhizomes stabilize the sediment and protect against wave disturbance and favour sedentary species that require stable substrata and may, therefore, increase species diversity (Orth, 1992; Davison & Hughes, 1998).
- The transport of oxygen to the roots and rhizomes produces an oxygenated microzone around them and increasing the penetration of oxygen into the sediment.
- *Zostera* sp. support numerous epiphytes and periphyton, e.g. the leaves may be colonized by microphytobenthos such as diatoms and blue green algae, the brown algae *Halothrix lumbricalis* and *Leblondiella densa* are only found on *Zostera* leaves and *Cladosiphon contortus* occurs primarily on the rhizomes of *Zostera* sp.
- The algal epiphytes on the leaves are grazed by small prosobranch molluscs, for example, *Rissoa* spp., *Hydrobia* spp. and *Littorina littorea*.
- The sediment supports a diverse infauna, including deposit feeders such as, *Arenicola marina*, *Pygospio elegans*, *Scrobicularia plana*, *Macoma balthica*, and *Corophium volutator*; as well as suspension feeders such as *Cerastoderma edule* (Connor *et al.*, 1997b; Davison & Hughes, 1998).
- *Zostera noltii* leaves and seeds have been reported to be eaten by *Hediste diversicolor* (Hughes *et al.*, 2000).
- The epifauna and infauna are probably prone to predation by intertidal fish, and shore crabs (*Carcinus maenas*) at high tide.
- Since the decline of *Zostera marina* beds *Zostera noltii* has become the preferred food for dark-bellied Brent geese (*Branta bernicla*).
- Intertidal *Zostera noltii* beds are heavily grazed by over-wintering wildfowl and are an important food source for Brent geese (*Branta bernicla*), wigeon (*Anas penelope*), mute and whooper swans (*Cygnus olor* and *Cygnus cygnus*).

Seasonal and longer term change

Zostera beds are naturally dynamic and may show marked seasonal changes. The leaves are shed in winter, although *Zostera noltii* retains its leaves longer than *Zostera marina*. Leaf growth stops in September/October (Brown, 1990). Leaves are lost, or removed by grazing or wave action over-winter. For example, in the Wadden Sea, Nacken & Reise (2000) noted that 50% of leaves fell off, while Brent geese removed 63% of the plant biomass. *Zostera noltii* over-winters as rhizome and shoot fragments, resulting in 'recruitment' of several cohorts in the following spring (Marta *et al.*, 1996). However, Nacken & Reise (2000) noted that the *Zostera noltii* beds recovered normal shoot density and that grazing wildfowl helped to maintain a balance between accretion and erosion within the bed, without which recovery was inhibited. The rhizome of *Zostera noltii* has limited carbohydrate storage capability, and Marta *et al.* (1996) and Dawes & Guiry (1992) regarded this species as ephemeral, taking advantage of seasonal increases in nutrients and light especially to grow rapidly in spring and early summer.

Where present *Arenicola marina* spawns synchronously either once or twice a year, the precise timing depending on location (Howie, 1959; Clay, 1967; Bentley & Pacey, 1992). *Cerastoderma edule* spawning between March - August with a peak in summer, while *Macoma balthica* spawns in February - March with another peak autumn and *Scrobicularia plana* spawns in summer (Fish & Fish, 1996). Settlement of spat in intertidal bivalves is generally sporadic (see *Cerastoderma edule* for review). While *Macoma balthica* may be protected from low winter temperatures by its depth in the sediment, *Cerastoderma edule* is vulnerable to low temperatures in winter, especially in severe winters. Therefore, cockle mortality is likely over winter due to low temperatures, lack of food and predation, especially from wildfowl such as the oystercatcher (*Haematopus ostralegus*). Further mortality is likely in year one cockles due to exhausted energy reserves and predation by the shore crab *Carcinus maenas*. Epifaunal species, such as *Littorina littorea* and *Hydrobia ulvae* may suffer additional predation over winter without the refuge provided by *Zostera noltii* leaves, especially from wildfowl, however they are mobile and able to ingest alternative food sources.

Habitat structure and complexity

Seagrasses provide shelter and hiding places. Leaves and rhizomes provide substrata for periphyton and epiphytic species. These epiphytic species may be grazed by other species (Davison & Hughes, 1998). The sediment supports a rich infauna of polychaetes, bivalve molluscs and the mud amphipod *Corophium volutator*. *Hydrobia ulvae* and *Littorina littorea* are mobile epifauna in seagrass beds, grazing on epiphytes, periphyton and other algae such as *Ulva* sp. Cockle beds (*Cerastoderma edule*) are often associated with intertidal seagrass beds. The sediment also includes a diverse meiofauna, for example many species of free-living turbellarians, ostracods and copepods (Asmus & Asmus, 2000b). In addition the intertidal seagrass beds are visited by several fish species when immersed.

Dominant trophic groups	Photoautotrophs Herbivores (grazers)

Productivity

Seagrass beds are characterized by high productivity and biodiversity and are considered to be of great ecological and economic importance (Davison & Hughes, 1998; Asmus & Asmus, 2000b). Within seagrass ecosystems primary production is derived from phytoplankton, microphytobenthos and *Zostera* sp. In addition, organic carbon is derived from the input of detritus into the system (for estimates of g C/m²/year see Asmus & Asmus, 2000b). Asmus & Asmus (2000b) reported that seagrass beds are sediment traps and nutrient sinks, which under storm conditions may become nutrient sources for the surrounding ecosystems, and are, therefore, important for the material flux in the ecosystem. For example, in the Sylt-Rømø Bight, Asmus & Asmus (2000b) estimated that the seagrass beds contributed significantly to material flux within the total intertidal system even though the seagrass beds only covered 12% of the intertidal area. Periphyton contributes significantly to the above ground biomass and Philippart (1995b) estimated that by May on an intertidal mudflat off Terschelling, the Netherlands, periphyton biomass equaled *Zostera noltii* biomass, declining to 20% of the total above ground biomass by the end of September.

Detritus food chains within the seagrass beds are driven by bacterial decomposition of dead seagrass tissue and other detritus. Dissolved organic matter (DOM) leaching from seagrass and bacterial decomposition supports high numbers of heterotrophic protists. Seagrass detritus is rich in micro-organisms, e.g. 1 g (dry weight) may support on average 9 mg of bacteria and protists, including heterotrophic flagellates and ciliates (Davison & Hughes, 1998). Dead seagrass leaves can be transported by currents to great depths or washed up on the shore, hence supporting detritus based food chains and communities in distant areas of the coast (Davison & Hughes, 1998).

Although primary production is high, secondary production is similar in un-vegetated areas and seagrass beds (Asmus & Asmus, 2000b). Asmus and Asmus (2000b) presented a general food web for intertidal *Zostera* spp. beds, and noted that loss of intertidal seagrass beds resulted in profound changes in the food web of the total ecosystem.

Major sources of organic carbon	Photosynthesis (macroalgae and/or halophytic plants) Photosynthesis (microalgae) Detritus

Recruitment processes

Zostera sp. are perennials but may be annuals under stressful conditions. Seedlings rarely occur in seagrass beds except in areas cleared by storms, blow-out or excessive herbivory (Phillips & Menez, 1988). Seed mortality is very high (Phillips & Menez, 1988; Fishman & Orth, 1996). Seed may be dispersed through the gut of wildfowl (Fishman & Orth, 1996), or float long distances (up to 200 m in some cases) on attached gas bubbles. The generative stalk may be released and can also float long distances. If displaced pieces of shoot or rhizome float and may root if they settle on suitable substrata. However, vegetative reproduction probably exceeds seedling recruitment except in areas of sediment disturbance (Phillips & Menez, 1988; Reusch *et al.*, 1998).

Hootsmans *et al*. (1987) noted that potential recruitment was maximal (32% of seeds) at 30 °C and 10 psu, and no recruitment occurred at 30 psu and they estimated that, in 1983 <5% of *Zostera noltii* plants in their study area in the Zandkreek originated from seed. Recruitment of *Zostera noltii* is, therefore, most likely to occur by dispersal of shoots and rhizomes rather than seed.

However, potential recruitment may be hampered by competition with infauna such as the ragworm *Hediste diversicolor* or blow lug *Arenicola marina* (Philippart, 1994a; Hughes *et al.*, 2000). Hughes *et al.* (2000) noted that *Hediste diversicolor* consumed leaves of *Zostera noltii* by pulling them into their burrow and also consumed their seeds, and reduced the survival of transplanted seedlings in the field. They concluded that the distribution of *Zostera noltii* was probably restricted by burrowing infauna such as *Hediste diversicolor*. However, the rhizome mat of the seagrass probably inhibits burrowing and therefore colonization of the seagrass bed by *Hediste diversicolor* (Hughes *et al.*, 2000). Similarly *Corophium volutator* has been reported to inhibit colonization of mud by *Salicornia* sp. (Hughes *et al.*, 2000) and, where present may also inhibit *Zostera noltii* recruitment.

Philippart (1994a) reported a distinct, marked transition between a bed of *Zostera noltii* and *Arenicola marina* dominated sediment in the Wadden Sea. She suggested that bioturbation by the blow lug inhibited colonization by *Zostera noltii*. Experimental transplantation suggested that the seagrass beds were unlikely to survive invasion by *Arenicola marina* and she concluded that the blow lug populations in the Wadden Sea may have contributed to the decline in the *Zostera noltii* beds over the previous 25 years. However, it should be noted that low densities of blow lug may be beneficial because they increase nutrient flux and oxygenation in the sediment, and that *Arenicola marina* is a characterizing species in this biotope, albeit at moderate density.

While *Zostera noltii* has been reported to recover from seasonal grazing and loss of leaf biomass over-winter (Nacken & Reise, 2000), *Zostera noltii* beds have continued to decline in the Wadden Sea (Philippart, 1994b) and its scarce distribution in the UK suggests that recovery or recruitment is slow and in the region of 5-10 years (Holt *et al.*, 1997; Davison & Hughes, 1998). Epifaunal species such as *Hydrobia ulvae* are widely distributed, mobile, occur at high densities, and have a planktonic life cycle suggesting that they would recruit rapidly. Similarly *Littorina littorea* is likely to recruit rapidly.

Development of both *Arenicola marina* and *Pygospio elegans* starts in the female's tube. Larvae of *Pygospio elegans* becoming pelagic while *Arenicola marina* larvae migrate up the shore. However, recruitment in *Arenicola marina* is rapid, especially where there are adjacent populations present.

Recruitment in infaunal bivalve populations is sporadic due to variation in larval supply and post-settlement mortality. For instance, in *Cerastoderma edule* although recruitment is likely to occur annually, significant recruitment to the population may take up to five years.

Time for community to reach maturity

Nacken & Reise (2000) noted that *Zostera noltii* beds had returned to previous abundance within a year following leaf loss and grazing by wildfowl. The majority of species associated with intertidal seagrass beds are not restricted to the biotope (Asmus & Asmus, 2000b), with the exception of *Zostera* sp. Specific epiphytes, and are likely to be present in the sediment or migrate into the developing bed. *Zostera noltii* was regarded as a relatively ephemeral species by Dawes & Guiry (1992).

Additional information

No text entered.

Habitat preference and distribution

Distribution in Britain and Ireland

This biotope is sparsely distributed around the UK, with particularly extensive stands in Cromarty Firth, and along the Essex and north Kent coasts.

Habitat preferences

Temperature range preferences	5 -30 °C
Water clarity preferences	Medium clarity / Medium turbidity Low clarity / High turbidity
Limiting nutrients	Nitrogen (nitrates) Phosphorus (phosphates)
Other preferences	No text entered

Additional information

Populations of *Zostera noltii* occur from the Mediterranean to southern Norway and *Zostera* sp. are regarded as tolerant of sea temperatures between about 5 - 30 °C. Therefore, they may not be sensitive to the range of temperatures likely in the British Isles (Davison & Hughes, 1998). Intertidal populations may be damaged by frost (den Hartog, 1987) and Covey & Hocking (1987) reported defoliation of *Zostera noltii* in the upper reaches of mudflats in Helford River due to ice formation in the exceptionally cold winter of 1987. However, the rhizomes survived and leaves are lost at this time of year due to shedding, storms or grazing with little apparent effect (Nacken & Reise, 2000).

Seagrass requires a particular light regime to net photosynthesize and grow. The intertidal is likely to be more turbid than the shallow subtidal occupied by *Zostera marina* due to runoff and re-suspension of sediment by wave and tidal action. Turbidity decreases light penetration and reduces the time available for net photosynthesis. However, intertidal *Zostera noltii* 'escapes' this turbidity since it is able to take advantage of the high light intensities at low tide (Vermaat *et al.*, 1996).

Seagrass beds act as sinks for nutrients (Asmus & Asmus, 2000b) and as such, nitrogen may not be limiting in sparse intertidal seagrass beds. In sandy sediments phosphate may be limiting where it is adsorbed onto particles (Short, 1987; Jones *et al.*, 2000).

The presence of *Zostera noltii* does not always indicate the presence of LMS.Znol. However, Kay (1998) provides a detailed account of the distribution of *Zostera noltii* in Wales.

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	Species name	Common Name
Key structural	*Zostera noltii*	Dwarf eelgrass
Important functional	*Hydrobia ulvae*	Laver spire shell
Important functional	*Littorina littorea*	Common periwinkle
Important other	*Cerastoderma edule*	Common cockle

Important other	*Arenicola marina*	Blow lug

Explanation

Zostera noltii stabilizes the substratum, promotes sedimentation of particulates and detritus, and provides substratum for epiphytes and refugia for other species. It is also a significant source of primary production and detritus. *Hydrobia ulvae* and *Littorina littorea* have been considered important functional species because they graze periphyton and epiphytes, which could otherwise reduce the light and nutrients available for *Zostera noltii* and may smother the seagrass. For example, Philippart (1995a, b) estimated that periphyton could reduce light incident on *Zostera noltii* blades by 10 -90% reducing the time available for net photosynthesis in the seagrass by 2-80%. She estimated the *Hydrobia ulvae* population was able to ingest 25 -100% of the standing crop of periphyton and microphytobenthos on a daily basis. She also suggested that the potential decline in *Zostera noltii* beds in the Wadden Sea due to shading by epiphytes had been offset by an increase in the *Hydrobia ulvae* population in the 1970s-1980s and noted that a previous decline in the mudsnail population in the early 1970s coincided with abnormally high fouling of the leaves of seagrass (Philippart, 1995a & b). *Arenicola marina* has been included as 'important other', partly to represent the sensitivity of polychaete species and because it has been shown to compete with *Zostera noltii*, potentially limiting the distribution and recruitment of *Zostera noltii* (Philippart, 1994a). *Cerastoderma edule* has been included as important other to represent the sensitivity of the bivalves.

Species found especially in biotope

Rhodophysema georgii An epiphytic seaweed
Halothrix lumbricalis An epiphytic seaweed
Leblondiella densa An epiphytic seaweed
Myrionema magnusii An epiphytic seaweed
Cladosiphon zosterae An epiphytic seaweed
Punctaria crispata An epiphytic seaweed

Rare or scarce species associated with this biotope

Nationally rare	*Halothrix lumbricalis*
Nationally rare	*Leblondiella densa*

Additional information

The MNCR survey recorded 185 species from this biotope. Asmus & Asmus (2000b, Table 1 and Figure 8) review species diversity in intertidal seagrass beds in the Sylt-Rømø. Davison & Hughes (1998) list representative and characteristic species of *Zostera* sp. beds. Species lists for major eelgrass beds are available for the Helford Passage (Sutton & Tompsett, 2000). Species lists are likely to underestimate the total number of species present, especially with respect to microalgal epiphytes, bacteria and meiofauna. Asmus & Asmus (2000b) noted that ostracods and copepods and fish were under estimated. However, many of the species found in intertidal seagrass beds are not specific to the community (Asmus & Asmus, 2000b). Therefore, although intertidal seagrass beds make a major contribution to primary and secondary production within the intertidal sedimentary ecosystem, loss of the seagrass beds would have a minor effect on species richness, especially with respect to the infaunal community (Asmus & Asmus, 2000b).

Biotope sensitivity

Physical Factors

	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	Low	High	Major Decline	High
Smothering	High	Low	High	Major Decline	Moderate
Change in suspended sediment	Intermediate	Moderate	Moderate	Minor Decline	High

Desiccation	Intermediate	Moderate	Moderate	Minor Decline	Moderate
Change in emergence regime	Intermediate	Moderate	Moderate	Minor Decline	Low
Change in water flow rate	Intermediate	Moderate	Moderate	Minor Decline	Low
Change in temperature	Low	Very high	Very Low	No Change	Moderate
Change in turbidity	Intermediate	Moderate	Moderate	Minor Decline	Moderate
Change in wave exposure	High	Very low	Very High	Major Decline	Low
Noise	Tolerant	Not Relevant	Tolerant	NR	Moderate
Visual Presence	Tolerant	Not Relevant	Tolerant	NR	Moderate
Abrasion & physical disturbance	Intermediate	Moderate	Moderate	Minor Decline	Moderate
Displacement	High	Very low	Very High	Major Decline	Moderate
Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Synthetic compound contamination	Intermediate	Moderate	Moderate	Minor Decline	Low
Heavy metal contamination	Intermediate	Very high	Low	Minor Decline	Moderate
Hydrocarbon contamination	Intermediate	Moderate	Moderate	Minor Decline	Moderate
Radionuclide contamination	Insufficient information	Not Relevant	Insufficient information	Insufficient Information	Not Relevant
Changes in nutrient levels	High	Very low	Very High	Major Decline	High
Change in salinity	Low	Very high	Very Low	No Change	Moderate
Changes in oxygenation	Intermediate	High	Low	Minor Decline	Low
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Intermediate	Moderate	Moderate	Minor Decline	High
Introduction of non-native species	Intermediate	Low	High	Minor Decline	Low
Extraction of key or important characterizing species	Intermediate	High	Low	Minor Decline	Moderate
Extraction of important species	High	Very low	Very High	Major Decline	High

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	The rhizome occupies the top 20 cm of the substratum. Substratum loss will result in the loss of the shoots, rhizome and probably the seed bank together with the other species within the biotope. Recoverability of *Zostera noltii* will depend on recruitment from other populations. Although *Zostera* sp. seed dispersal may occur over large distances, high seedling mortality and seed predation may

	significantly reduce effective recruitment. Holt *et al.* (1997) suggested that recovery would take between 5-10 years, but in many cases longer. *Zostera noltii* populations are considered to be in decline (Philippart, 1994b; Jones *et al.*, 2000). Polychaetes such as *Arenicola marina* may recolonize the sediment relatively quickly from the surrounding area or from planktonic larvae. Gastropods such as *Hydrobia ulvae* and *Littorina littorea* are common and mobile with planktonic larvae and also likely to recover quickly. However, recruitment in the bivalve macrofauna is sporadic e.g. *Cerastoderma edule* and may take longer to recover (1 -5 years). It should be noted that recolonization by *Arenicola marina* at high abundance before *Zostera noltii* may inhibit recolonization by the seagrass (Philippart, 1994a). Loss of *Zostera noltii* would result in loss of the biotope.
Smothering (see benchmark)	Sediment disturbance, siltation, erosion and turbidity resulting from coastal engineering and dredging activities have been implicated in the decline of seagrass beds world wide (Holt *et al.*, 1997; Davison & Hughes, 1998). Seagrasses are intolerant of smothering and typically bend over with addition of sediment and are buried in a few centimetres of sediment (Fonseca, 1992). *Zostera* sp. are highly intolerant of smothering by epiphytes or algal mats (see nutrients), as are infauna, especially due to deoxygenation caused by death and decomposition of the algae (see oxygenation). Surface dwelling epifauna such as *Littorina littorea* is highly intolerant of smothering, although *Hydrobia ulvae* is less so. Burrowing deposit feeding polychaetes are probably not sensitive to smothering by 5 cm of sediment. However, *Cerastoderma edule* can burrow upwards more readily through sandy sediment than muddy sediment (Jackson & James, 1979) and some mortality is likely due to smothering by 5 cm of sediment. Recoverability of *Zostera noltii* will depend on recruitment from other populations. Although *Zostera* sp. seed dispersal may occur over large distances, high seedling mortality and seed predation may significantly reduce effective recruitment. Holt *et al.* (1997) suggested that recovery would take between 5-10 years, but in many cases longer. *Zostera noltii* populations are considered to be in decline (Philippart, 1994b; Jones *et al.*, 2000). Polychaetes such as *Arenicola marina* may recolonize the sediment relatively quickly from the surrounding area or from planktonic larvae. Gastropods such as *Hydrobia ulvae* and *Littorina littorea* are common and mobile with planktonic larvae and also likely to recover quickly. However, recruitment in the bivalve macrofauna is sporadic e.g. *Cerastoderma edule* and may take longer to recover (1 -5 years). It should be noted that recolonization by *Arenicola marina* at high abundance before *Zostera noltii* may inhibit recolonization by the seagrass (Philippart, 1994a). Loss of *Zostera noltii* would result in loss of the biotope.
Change in suspended sediment (see benchmark)	Increased sediment erosion or accretion has been associated with loss of seagrass beds in the Australia, the Mediterranean, the Wadden Sea, and USA. Sediment dynamics and hydrodynamics are key factors in seagrass systems (Holt *et al.*, 1997; Davison & Hughes, 1998; Asmus & Asmus, 2000a, b). Seagrass beds demonstrate a balance of sediment accretion and erosion (Davison & Hughes, 1998). Increased sediment availability may result in raised eelgrass beds or smothering of the leaves. Decreased sedimentation is likely to result in erosion and loss of the eelgrass beds. Sediment deposited during summer months may be lost again due to winter storms, resuspension by grazing wildfowl, and increased erosion due to die back of leaves and shoots in autumn and winter. The grazing and digging activity of brent geese and wigeon may increase erosion of intertidal beds, but in doing so compensate for the sediment deposited during summer months, which may be beneficial to growth of *Zostera noltii* beds (Nacken & Reise, 2000). The rhizome of Mediterranean *Zostera noltii* was able to grow upward, through 2 cm of substratum in 4 months (Vermaat *et al.*, 1996). Changes to the sediment regime due to coastal engineering works has been implicated in the decline of *Zostera* sp. beds, e.g. due to the coffer dam during construction of the second Severn crossing (Davison & Hughes, 1998), and dock construction and channel widening in the Solent (Butcher, 1941). Seagrass beds should be

	considered intolerant of any activity that changes the sediment regime where the change is greater than expected due to natural events or long term. Increased suspended sediment concentrations will also decrease light penetration (see turbidity).
Desiccation (see benchmark)	*Zostera noltii* is more tolerant of desiccation than other *Zostera* species, due to its intertidal position and ability to colonize well draining sediment. In well -drained areas *Zostera noltii* may dry out completely between tides (Davison & Hughes, 1998). However, little information on desiccation tolerance in this species was found. Epifaunal species such as gastropods are mobile and many exhibit physiological and behavioural adaptations to desiccation stress, e.g. burrowing in *Hydrobia ulvae*. Infaunal species a partly protected from desiccation due to the water content of the sediment and depths of their burrows, with perhaps the exception of *Cerastoderma edule* since it dwells in the top few cm of the sediment. The upper extent of the biotope is most likely to be vulnerable to desiccation. Therefore, increased desiccation equivalent to raising the population from mid to high water is likely to reduce the upper extent of the biotope, especially *Zostera noltii* and *Cerastoderma edule*.
Change in emergence regime (see benchmark)	Philippart (1995b) noted that although tolerant of high light intensities, its upper shore extent was limited by desiccation tolerance, and the optimal intertidal position of *Zostera noltii* on a tidal flat near Terschelling, Wadden Sea, was 50% emersion. Mobile epifauna such as gastropods are mobile and unlikely to be adversely affected, however, increased emergence is likely to reduce the time available for feeding by infauna and the risk of hypoxia in burrows. A long term change in the emergence regime is likely to increase or reduce the extent of the population in the intertidal. An increase in emergence is likely to reduce its upper extent of the biotope although this may be compensated for increased growth lower on the shore. Decreased emergence is likely to enable the biotope to expand further up the shore. However, expansion depends on available habitat and competition in infaunal dominated sediments (e.g. *Hediste diversicolor* or *Arenicola marina* (Philippart, 1994a; Hughes *et al.*, 2000). A decrease in emersion, possible due to sea level rise, may reduce the available intertidal habitat and therefore reduce the extent of this biotope.
Change in water flow rate (see benchmark)	Seagrasses require sheltered environments, with gentle long shore currents and tidal flux. Where populations are found in moderately strong currents they are smaller, patchy and vulnerable to storm damage and blow outs. Increased water flow rates may destabilize the bed and increase the risk of 'blow outs' within the seagrass beds, deposit coarser sediments and erode fine sediments resulting in loss of suitable substrata for the species within this biotope. Epifauna may be removed or 'washed' to unsuitable substrata at high water flow rates. Conversely reduced water flow may increase the deposition of fine muds which are unsuitable for some members of the infauna, e.g. *Cerastoderma edule* and *Arenicola marina* (see siltation). Nacken & Reise (2000) noted that where sediment was allowed to accumulate in parts of a *Zostera noltii* beds from which wildfowl (and hence their eroding effects) were excluded, the seagrass did not grow as profusely as in areas in which the wildfowl actively fed. Populations present in moderately strong currents may benefit from decreased water flow rates. Davison & Hughes (1998) point out that *Zostera* sp. beds probably exist in areas with defined rates of summer accretion and winter erosion, too much sediment deposition resulting in smothering (see emergence regime).
Change in temperature (see benchmark)	Populations of *Zostera noltii* occur from the Mediterranean to southern Norway and *Zostera* sp. are regarded as tolerant between about 5 - 30 °C. Therefore, they may not be intolerant of the range of temperatures likely in the British Isles (Davison & Hughes, 1998). Intertidal populations may be damaged by frost (den Hartog, 1987) and Covey & Hocking (1987) reported defoliation of *Zostera noltii*

	in the upper reaches of mudflats in Helford River due to ice formation in the exceptionally cold winter of 1987. However, the rhizomes survived and leaves are usually lost at this time of year due to shedding, storms or grazing with little apparent effect (Nacken & Reise, 2000). The infauna are partly protected from short term acute temperature change by their position in the sediment. *Cerastoderma edule* is more vulnerable since it occupies the top few centimetres of sediment, however, it is relatively tolerant of temperature change, especially temperature increases. The epifaunal gastropods are also relatively tolerant of temperature change. However, increases in temperature are likely to stimulate bacterial activity and oxygen consumption resulting in hypoxia which may affect infauna indirectly. Increased temperatures may also stimulate growth of ephemeral algae, e.g. *Ulva* spp. and epiphytes which, while potentially detrimental to *Zostera noltii* may be beneficial for epifaunal grazing gastropods. However, although the infauna may be adversely affected by long term temperature change, *Zostera noltii* is tolerant of a wide range of temperatures and will probably be little affected and therefore, the biotope as a whole will be little affected.
Change in turbidity (see benchmark)	Increased turbidity will reduce the light available for photosynthesis, the time available for net photosynthesis and, therefore, growth. However, *Zostera noltii* is tolerant of high light intensities and can take advantage of the light available at low tide (Vermaat *et al.*, 1996). Furthermore, *Zostera noltii* can store and mobilize carbohydrates and has been reported to be able to tolerate acute light reductions (below 2% of surface irradiance for two weeks) (Peralta *et al.*, 2002). However, *Zostera noltii* are likely to be more intolerant to chronic increases in turbidity. This biotope may benefit form decreased turbidity. Philippart (1994b) suggested that the decline in *Zostera noltii* beds in the Wadden Sea probably occurred in beds at low water. Permanently submerged brackish water populations may be more vulnerable to increased turbidity. Most other species in the biotope, e.g. infauna and epifauna will probably not be adversely affected by changes in turbidity.
Change in wave exposure (see benchmark)	Seagrasses require sheltered environments, with gentle long shore currents and tidal flux. Where populations are found in moderately strong currents they are smaller, patchy and vulnerable to storm damage and blow outs. Increased wave exposure may also increase sediment erosion (see siltation above). Populations present in moderately strong currents may benefit from decreased water flow rates. Small patchy populations or recently established population and seedling may be highly intolerant of increased wave action since they lack an extensive rhizome system.
Noise (see benchmark)	It is unlikely that noise will have an adverse effect on *Zostera noltii* or other species within the biotope. Wildfowl, however, are intolerant of disturbance from noise from e.g. shooting (Madsen, 1988) and from coastal recreation, industry and engineering works. For example, Percival & Evans (1997) reported that wigeon were very intolerant of human disturbance and, where wildfowling was popular, wigeon avoided *Zostera noltii* beds at the top of the shore, preferring *Zostera marina* and *Zostera angustifolia* beds lower on the shore, until the lower shore beds were exhausted. Reduced grazing pressure may benefit *Zostera* sp. beds. However, Nacken & Reise (2000) noted that where wildfowl were excluded from grazing experimental plots, the *Zostera noltii* beds summer regrowth was inhibited. They suggested that grazing was important for the persistence of *Zostera noltii* beds, at least in their study area.
Visual Presence (see benchmark)	*Zostera noltii* or other species within the biotope are unlikely to be affected by visual disturbance. Wildfowl, however, are intolerant of disturbance from noise from e.g. shooting (Madsen, 1988) and from coastal recreation, industry and engineering works. Disturbance is species dependant, some species habituating to noise and visual disturbance while others become more nervous. For example, brent geese, redshank, bar-tailed godwit and curlew are more 'nervous' than oyster catcher, turnstone and dunlin (Elliott *et al.*, 1998). Turnstones will often tolerate

	one person within 5-10 m. However, one person on a tidal flat can cause birds to stop feeding or fly off affecting ca. 5 ha for gulls, ca.13 ha for dunlin, and up to 50 ha for curlew (Smit & Visser, 1993). Industrial and urban development may exclude 'nervous' species from adjacent tidal flats. Reduced grazing pressure may benefit *Zostera* sp. beds. However, Nacken & Reise (2000) noted that where wildfowl were excluded from grazing experimental plots, the *Zostera noltii* beds summer regrowth was inhibited. They suggested that grazing was important for the persistence of *Zostera noltii* beds, at least in their study area.
Abrasion & physical disturbance (see benchmark)	Seagrass rhizomes are easily damaged by trampling, anchoring, dredging and other activities that disturb the sediment (Holt *et al.*, 1997; Davison & Hughes, 1998). Small scale sediment disturbance may actually stimulate growth and small patches of sediment allow recolonization by seedlings. Rhizomes are likely to be damaged, leaf blades removed and seeds buried too deep to germinate, by activities such as trampling, anchoring, digging, dredging, power boat and jet-ski wash. For example, damage after the *Sea Empress* oil spill was reported as limited to the ruts left by clean up vehicles, especially in the intertidal (Jones *et al.*, 2000). However, wildfowl grazing of intertidal seagrass beds results in significant physical disturbance. Brent geese feed on shoots, rhizomes and roots, reworking the top centimetre of sediment (8 times in 3 months), and in the process dig pits 3-10 cm deep by trampling. As a result, in the Wadden Sea from Sept-Dec (the over-wintering period) Brent geese removed 63% of the plant biomass and pitted 12% of the seagrass bed. However, the bed of *Zostera noltii* recovered by the following year, and the authors suggested that grazing and bioturbation was necessary for the persistence of the intertidal seagrass beds (Nacken & Reise, 2000). Similarly, several authors have suggested that *Zostera* sp. can recover from 'normal' levels of wildfowl grazing (Davison & Hughes, 1998). Nevertheless, physical disturbance may be detrimental where ‘normal’ levels of physical disturbance caused by grazing birds are augmented by physical disturbance from human activities. Epifaunal gastropods, such as *Littorina littorea* and bivalves, such as *Cerastoderma edule* living near the surface may be damaged by abrasion, and infaunal polychaetes may be damaged by physical disturbance to the sediment. Therefore, an intolerance of intermediate is reported. Recoverability has been assessed as moderate (see additional information below). Physical disturbance caused by fishing activities e.g. for cockles is greater than the benchmark, and is discussed under 'extraction' (see below).
Displacement (see benchmark)	The majority of the epifauna are unlikely to be significantly affected by displacement since they are mobile species capable of migrating from adjacent areas with a wide range of habitat preferences. Similarly most infauna can re-burrow if displaced, although predation risk while on the surface will be high, especially if displacement coincides with low tide. However, the seagrass bed is unlikely to survive displacement. Seagrass rhizomes are easily damaged by trampling, anchoring, dredging and other activities that disturb the sediment such as storms. Although rhizomes and shoots can root and re-establish themselves if they settle on sediment long enough (Phillips & Menez, 1988) displacement is likely to result in loss of the seagrass and its associated biotope.
Chemical Factors	
Synthetic compound contamination (see benchmark)	Little information concerning *Zostera noltii*, the key species in this biotope, was found. *Zostera marina* is known to accumulate TBT but no damage was observable in the field (Williams *et al.*, 1994). Naphthalene, pentachlorophenol, Aldicarb and Kepone reduce nitrogen fixation and may affect *Zostera marina* viability. Triazine herbicides (e.g. Irgarol) inhibit photosynthesis and sublethal effects have been detected. Terrestrial herbicides may damage seagrass beds in the marine environment. For example, the herbicide Atrazine is reported to cause

	growth inhibition and 50 percent mortality in *Zostera marina* exposed to 100 ppb (ng/ l) Atrazine for 21 days (Davison & Hughes, 1998). Bester (2000) noted a correlation between raised concentrations of 4 triazine herbicides and areas where *Zostera* sp. had been lost. TBT contamination is likely to adversely affect grazing gastropods resulting in increased algal growth, reduced primary productivity and potential smothering of the biotope, e.g. Philippart (1995a) suggested that the decline in *Zostera noltii* beds in the Wadden Sea in the 1970s due to eutrophication was exacerbated by a simultaneous decline in the mud-snail (*Hydrobia ulvae*) population, although mud-snail populations have increased subsequently. Bryan & Gibbs (1991) suggested that TBT may cause reproductive failure or larval mortality in bivalve molluscs, e.g. *Pecten maximus* at ca. 50ng/l TBT, however little information on the effect of TBT on polychaetes was available. Overall, terrestrial herbicides are likely to adversely affect seagrass beds, and loss of grazing gastropods due to TBT or other synthetic chemicals is likely to result in smothering and potential reduction in the extent of the seagrass. Therefore, an intolerance of intermediate has been reported.
Heavy metal contamination (see benchmark)	Little information was found regarding the effect of heavy metal concentrations on *Zostera noltii* however, the following information was found for *Zostera marina*. The concentration and toxicity of heavy metals in salt marsh plants, including *Zostera marina* was reviewed by Williams *et al.* (1994). Growth of *Zostera marina* is inhibited by 0.32 mg/l Cu and 10 mg/l Hg, but Cd, Zn, Cr and Pb had measurable but less toxic effects (Williams *et al.*, 1994). Davison & Hughes (1998) report that Hg, Ni and Pb reduce nitrogen fixation which may affect viability. However, leaves and rhizomes accumulate heavy metals, especially in winter. Williams *et al.* (1994) did not observe any damage to *Zostera marina* in the field. Bryan (1984) suggested that polychaetes were fairly resistant to heavy metals, while the larval and embryonic stages of bivalve molluscs were the most intolerant. Mercury was the most toxic to bivalves whereas Cu, Cd, and Zn probably caused the most problems in the field. Bryan (1984) concluded that gastropods were relatively tolerant of heavy metals, in part due to the protection afforded by their shell. However, the viability and reproductive potential of the polychaetes, and molluscs is probably reduced by heavy metal contamination. Given the potential effects of heavy metals on *Zostera* spp., heavy metal contamination could lead to reduction in the extent or abundance of the seagrass and an intolerance rank of intermediate was reported
Hydrocarbon contamination (see benchmark)	Intertidal seagrass beds are likely to be more vulnerable to direct oil contamination and the sheltered conditions in which they occur suggests that any oil will weather slowly (Davison & Hughes, 1998; Jones *et al.*, 2000). However, several studies on seagrass beds after oil spills and in the vicinity of long term, low level hydrocarbon effluents suggest that *Zostera* sp. are little effected by hydrocarbon contamination (Jacobs, 1980; Hiscock, K.,1987; Davison & Hughes, 1998; Jones *et al.*, 2000). However, pre-mixed oil and dispersant were found to cause rapid death and significant reduction in cover of *Zostera noltii*, and led to the authors recommending that dispersants should be avoided (Holden & Baker, 1980; Howard *et al.*, 1989; Davison & Hughes, 1998). The removal of oil intolerant grazers, e.g. gastropods and amphipods, however, is likely to indirectly affect the seagrass bed, resulting in unchecked growth of periphyton, epiphytes and ephemeral algae and smothering of the seagrass (see nutrients). Suchanek (1993) reviewed the effects of oil spills on marine invertebrates and concluded that, in general in soft sediment habitats, infaunal polychaetes, bivalves and amphipods were particularly affected. For example, evidence from oil spills suggested that gastropods such as *Hydrobia ulvae* and especially *Littorina littorea* were intolerant of oil spills (Jacobs, 1980). Large numbers of dead or moribund *Cerastoderma edule* were washed ashore after the

	Sea Empress oil spill. Similarly, the abundance of *Arenicola marina* populations were adversely affected by oil or oil:dispersant mixtures, and seawater oil concentrations of 5 mg/l caused the lugworms to leave the sediment (Levell, 1976; Prouse & Gordon, 1976). Therefore, hydrocarbon contamination is likely to adversely affect epifaunal and infaunal species within the biotope, and although *Zostera noltii* may not be adversely affected directly the loss of grazers is likely to result in smothering and potential loss of areas of seagrass bed.
Radionuclide contamination (see benchmark)	Insufficient information.
Changes in nutrient levels (see benchmark)	Increased nutrient concentrations (nitrates and phosphates) have been implicated in the continued decline of seagrass beds world-wide, either directly or due to eutrophication (Phillips & Menez, 1988; Philippart, 1994b; Vermaat *et al.*, 1996; Philippart, 1995a, b; Davison & Hughes, 1998; Asmus & Asmus, 2000a, b). The following effects on *Zostera* sp. have been attributed to nutrients and eutrophication. • High nitrate concentrations implicated in decline of *Zostera marina.* Burkholder *et al.* (1992) demonstrated that nitrate enrichment could cause decline of *Zostera marina* in poorly flushed areas. In addition they noted that increasing or high temperatures associated with spring exacerbated the adverse effects of nitrate enrichment and that growth and survival were significantly reduced by nutrient enrichment levels of between 3.5 and 35µM nitrate/day with the most rapid decline (weeks) at high nitrate levels. Plant loss resulted from death of the meristem tissue. • van Katwijk *et al.* (1999) noted that adverse effects of nitrate were dependant on salinity. Estuarine *Zostera marina* plants were more intolerant of high nitrate concentration than marine *Zostera marina* plants at high (30 psu) salinity than at lower salinities (23 psu) and that both populations benefited from nitrate enrichment (0-4 to 6.3 µM nitrate per day) at 23 or 26 psu. • Increased growth of epiphytes or blanketing algae, for example: o Den Hartog (1994) reported the growth of a dense blanket of *Ulva radiata* in Langstone Harbour in 1991 that resulted in the loss of 10ha of *Zostera marina* and *Zostera noltii*, and by summer 1992 the *Zostera* sp. were absent, however this may have been exacerbated by grazing by Brent geese o Philippart (1995b) reported that shading by periphyton reduced incident light reaching the leaves of *Zostera noltii* by 10-90% and reduced the period of time that net photosynthesis could occur by 2-80% depending on location. o Philippart (1995b) estimated that the mud-snail *Hydrobia ulvae* could remove 25-100% of the periphyton and microphytobenthos, and suggested that the decline of *Zostera noltii* in the Wadden Sea in the 1970s was in part due to increased periphyton growth due to eutrophication, and a simultaneous decline of the mud-snail population (although mud-snail populations have increased subsequently) (Philippart, 1995a). • Encouragement of phytoplankton blooms which increase turbidity and reduce light penetration, although this may be of less significance for intertidal *Zostera noltii* populations (see above) (Davison & Hughes, 1998). • The levels of phenolic compounds in *Zostera* sp. (involved in disease resistance) are reduced under nutrient enrichment and may increase their susceptibility to infection by wasting disease (Buchsbaum *et al.*, 1990; Burkholder *et al.*, 1992).

	Increased nutrients may benefit deposit feeding polychaetes, such as *Arenicola marina* and grazing gastropods may also benefit from the bloom of ephemeral and epiphytic algae. However, loss or reduction of the *Zostera noltii* bed will necessitate loss or reduction of the biotope itself.
Change in salinity (see benchmark)	*Zostera* sp. have a wide tolerance of salinity from 10 - 39 ppt (Davison & Hughes, 1998), although den Hartog (1970) suggested a lower salinity tolerance of 5 psu for *Zostera* sp. Den Hartog (1970) stated that *Zostera noltii* was a euryhaline species, penetrating estuaries and the Baltic Sea to the average annual isohaline of 9-10 psu. *Zostera noltii* is probably more tolerant of extremes of salinity than its congeners due to its intertidal habitat. Most of the other intertidal species present in the biotope are probably tolerant of a wide range of salinities, e.g. *Hydrobia ulvae* and *Littorina littorea*. Similarly both *Cerastoderma edule* and *Arenicola marina* are tolerant of a wide range of salinities, however, both have been reported to be susceptible to low salinities after heavy rains at low tide.
Changes in oxygenation (see benchmark)	The effects of oxygen concentration on the growth and survivability of *Zostera noltii* are not reported in the literature. *Zostera* sp. leaves contain air spaces (lacunae) and oxygen is transported to the roots where it permeates into the sediment, resulting in an oxygenated microzone. This enhances the uptake of nitrogen. The presence of air spaces suggests that seagrass may be tolerant of low oxygen levels in the short term, however, prolonged deoxygenation, especially if combined with low light penetration and hence reduced photosynthesis may have an effect. Epifaunal gastropods may be tolerant of hypoxic conditions, especially *Littorina littorea* and *Hydrobia ulvae*. Infaunal species are likely to be exposed to hypoxic conditions, especially at low tide when they can no longer irrigate their burrows e.g. *Arenicola marina* can survive for 9 days without oxygen (Hayward, 1994). Conversely, possibly since it occupies the top few centimetres of sediment, *Cerastoderma edule* may be adversely affected by anoxia and would probably be killed by exposure to 2mg/l oxygen for a week. Smothering of the seagrass beds by epiphytes and ephemeral algae (see nutrients) may indirectly result in anoxic conditions as the algae die and decompose. Therefore, given the potential intolerance of *Zostera noltii* to deoxygenation, an overall intolerance of intermediate has been reported.
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	A major outbreak of wasting disease resulted in significant declines of *Zostera* beds on both sides of the Atlantic in 1920s to 1930s, primarily *Zostera marina* in the subtidal. Wasting disease is thought to be caused by the marine fungus, *Labyrinthula macrocystis*. However, *Zostera noltii* was little affected (Rasmussen, 1977; Davison & Hughes, 1998). Decline of intertidal *Zostera marina* and *Zostera noltii* beds in the Wadden Sea began in the 1960s and a marked decline in *Zostera noltii* occurred between 1965 and 1975, presumably due to anthropogenic change (Philippart, 1994b). Intertidal gastropods and bivalves often act an intermediary host for trematode parasites of wildfowl and sea birds. In many cases the trematode cercariae accumulate in the gut and gonad tissue resulting in castration of infected individuals, and hence reducing the reproductive capability of the host population. The significance of this form of parasitism varies with species. However, mass mortalities of *Hydrobia ulvae* have been reported, due to the mass development of larval digenean trematodes as a result of high temperatures (Huxham *et al.*, 1995). Therefore, given the importance of *Hydrobia ulvae* in controlling periphyton and epiphytes (see nutrients above; Philippart, 1995a). An intolerance of intermediate has been reported.

Introduction of non-native species (see benchmark)	*Spartina anglica* (a cord grass) is an invasive pioneer species, a hybrid of introduced and native cord grass species. Its rapid growth consolidates sediment, raises mudflats and reduces sediment availability elsewhere. It has been implicated in the reduction of *Zostera* sp. cover in Lindisfarne, Northumberland due to encroachment and changes in sediment dynamics (Davison & Hughes, 1998). Wireweed (*Sargassum muticum*) invades open substratum and may prevent recolonization of areas of seagrass beds left open by disturbance (Davison & Hughes, 1998). Intertidal seagrass beds may be particularly vulnerable. However, evidence for competition is conflicting and requires further research. If the invasive species prevent recolonization then the recoverability from other factors will be reduced.
Extraction of key or important characterizing species (see benchmark)	Wildfowl grazing can consume significant amounts of seagrass and reduce cover mainly in autumn and winter. Grazing is probably part of the natural seasonal fluctuation in seagrass cover and *Zostera* sp. can recover from normal grazing (Davison & Hughes, 1998; Naken & Reise, 2000). *Zostera noltii* is the preferred food of the dark-bellied Brent goose (*Branta bernicla*). Brent geese feed on shoots, rhizomes and roots, reworking the top centimetre of sediment (8 times in 3 months), and in the process dig pits 3-10 cm deep. As a result, in the Wadden Sea from Sept-Dec (the over-wintering period) Brent geese removed 63% of the plant biomass and pitted 12% of the seagrass bed. However, the bed of *Zostera noltii* recovered by the following year, and the authors suggested that grazing and bioturbation was necessary for the persistence of the intertidal seagrass beds (Nacken & Reise, 2000). However, where a bed is stressed by other factors it may not be able to withstand grazing (Holt *et al*,. 1997; Davison & Hughes, 1998). Eelgrass rhizomes are easily damaged by trampling, anchoring, dredging and other activities that disturb the sediment. The seagrass bed is unlikely to survive displacement or extraction. However, Phillips & Menez (1988) reported that rhizomes and shoots can root and re-establish themselves if they settle on sediment long enough
Extraction of important species (see benchmark)	*Zostera* sp. are regarded as very intolerant of hydraulic bivalve fishing in the UK and Wadden Sea (Philippart, 1994b; Holt *et al*., 1997; Davison & Hughes, 1998). Cockles and *Zostera noltii* are frequently associated and intertidal beds may be more vulnerable (Holt *et al*., 1997). Hydraulic dredging is likely to break up and remove rhizomes. It was suggested that hydraulic harvesting of cockles in the Solway Firth could cause widespread damage or eradicate *Zostera* sp. from the bay (Perkins, 1988). Furthermore, tractor dredging reduced the density of cover in *Zostera* beds from 75% to 5% (Hawker, 1994). Digging and dredging for the American hard-shell clam (*Mercenaria mercenaria* had a significant effect on the eelgrass beds (Cox, 1991; Eno *et al*., 1997). In the Dutch Wadden Sea seagrass is hardly found where cockles are normally fished (Dankers & de Vlas, 1992). Recovery was severely restricted especially where no rhizomes and roots were left in the sediment (de Jong & de Jong, 1992; Philippart, 1994b). Hand gathering is likely to have a similarly adverse affect to bait digging, especially if vehicular access is used. Extraction of grazing epifauna, e.g. by foraging wildfowl such as shelduck could result in increased leaves of smothering, especially during the summer months. Given the intolerance of intertidal seagrass beds to hydraulic dredging and the associated decline in seagrass beds, an intolerance of high has been reported.

Additional information

No text entered

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors					
	Zostera noltii	***Hydrobia ulvae***	***Littorina littorea***	***Cerastoderma edule***	***Arenicola marina***
Community Importance	Key structural	Important functional	Important functional	Important other	Important other
Substratum Loss	High	High	High	High	High
Smothering	High	Intermediate	High	Intermediate	Not Sensitive
Increase in suspended sediment	Intermediate	Not Sensitive	Intermediate	Low	Low
Decrease in suspended sediment	See explanation	See explanation	See explanation	See explanation	See explanation
Desiccation	Low	Low	Low	Intermediate	Not Relevant
Increase in emergence regime	Intermediate	Low	Low	Intermediate	Intermediate
Decrease in emergence regime	See explanation	See explanation	See explanation	See explanation	See explanation
Increase in water flow rate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate
Decrease in water flow rate	See explanation	See explanation	See explanation	See explanation	See explanation
Increase in temperature	Not Sensitive	Intermediate	Low	Intermediate	Intermediate
Decrease in temperature	See explanation	See explanation	See explanation	See explanation	See explanation
Increase in turbidity	Intermediate	Not Sensitive	Low	Not Sensitive	Low
Decrease in turbidity	See explanation	See explanation	See explanation	See explanation	See explanation
Increase in wave exposure	High	High	Intermediate	Intermediate	Intermediate
Decrease in wave exposure	See explanation	See explanation	See explanation	See explanation	See explanation
Noise	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive
Visual Presence	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive	Not Sensitive
Abrasion & physical disturbance	Intermediate	Low	Intermediate	Intermediate	Intermediate
Displacement	Intermediate	Not Sensitive	Not Sensitive	Low	Low
Chemical factors					
	Zostera noltii	***Hydrobia ulvae***	***Littorina littorea***	***Cerastoderma edule***	***Arenicola marina***
Community Importance	Key structural	Important functional	Important functional	Important other	Important other
Synthetic compound contamination	Intermediate	Low	Low	Intermediate	High
Heavy metal contamination	Low	Insufficient information	Intermediate	Intermediate	Low
Hydrocarbon contamination	High	Intermediate	High	Intermediate	Intermediate
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Changes in nutrient	Intermediate	Low	Not Sensitive	Intermediate	Intermediate

levels	🟨	🟦	🟦	🟨	🟨
Increase in salinity	Low	Not Sensitive	Not Sensitive	Low	Low
Decrease in salinity	See explanation	See explanation	See explanation	See explanation	See explanation
Changes in oxygenation	Low	Intermediate	Low	High	Low
Biological factors					
	Zostera noltii	***Hydrobia ulvae***	***Littorina littorea***	***Cerastoderma edule***	***Arenicola marina***
Community Importance	Key structural	Important functional	Important functional	Important other	Important other
Introduction of microbial pathogens/parasites	Intermediate	High	Insufficient information	Intermediate	Insufficient information
Introduction of non-native species	Intermediate	Insufficient information	Insufficient information	Insufficient information	Insufficient information
Extraction of this species	Intermediate	Not Relevant	Intermediate	Intermediate	Intermediate
Extraction of other species	High	Not Sensitive	Not Sensitive	High	Intermediate

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors					
	Zostera noltii	***Hydrobia ulvae***	***Littorina littorea***	***Cerastoderma edule***	***Arenicola marina***
Community Importance	Key structural	Important functional	Important functional	Important other	Important other
Substratum Loss	Low	High	High	High	High
Smothering	Low	Very high	High	High	Not Relevant
Increase in suspended sediment	High	Not Relevant	High	Immediate	Immediate
Decrease in suspended sediment	See explanation	See explanation	See explanation	See explanation	See explanation
Desiccation	Very high	Immediate	Immediate	High	Not Relevant
Increase in emergence regime	High	Immediate	Immediate	High	Very high
Decrease in emergence regime	See explanation	See explanation	See explanation	See explanation	See explanation
Increase in water flow rate	High	Very high	High	High	Very high
Decrease in water flow rate	See explanation	See explanation	See explanation	See explanation	See explanation
Increase in temperature	Not Relevant	Immediate	Immediate	High	Very high
Decrease in temperature	See explanation	See explanation	See explanation	See explanation	See explanation
Increase in turbidity	High	Not Relevant	Very high	Not Relevant	Immediate
Decrease in turbidity	See explanation	See explanation	See explanation	See explanation	See explanation
Increase in wave exposure	Low	High	High	High	Very high
Decrease in wave exposure	See explanation	See explanation	See explanation	See explanation	See explanation
Noise	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Visual Presence	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant
Abrasion & physical disturbance	High	Very high	High	High	Very high

Displacement	High	Not Relevant	Not Relevant	High	Immediate
Chemical factors					
	Zostera noltii	***Hydrobia ulvae***	***Littorina littorea***	***Cerastoderma edule***	***Arenicola marina***
Community Importance	Key structural	Important functional	Important functional	Important other	Important other
Synthetic compound contamination	High	Immediate	Very high	High	High
Heavy metal contamination	Very high	Insufficient information	High	High	Very high
Hydrocarbon contamination	High	Very high	High	High	High
Radionuclide contamination	Not Relevant	Insufficient information	Insufficient information	Insufficient information	Not Relevant
Changes in nutrient levels	High	Immediate	Not Relevant	High	High
Increase in salinity	Very high	Not Relevant	Not Relevant	Very high	Immediate
Decrease in salinity	See explanation	See explanation	See explanation	See explanation	See explanation
Changes in oxygenation	Very high	Very high	Very high	High	Immediate
Biological factors					
	Zostera noltii	***Hydrobia ulvae***	***Littorina littorea***	***Cerastoderma edule***	***Arenicola marina***
Community Importance	Key structural	Important functional	Important functional	Important other	Important other
Introduction of microbial pathogens/parasites	Very high	High	Insufficient information	High	Not Relevant
Introduction of non-native species	Low	Insufficient information	Insufficient information	Insufficient information	Not Relevant
Extraction of this species	High	Not Relevant	High	High	Very high
Extraction of other species	Low	Not Relevant	Not Relevant	High	Very high

Importance

Marine natural heritage importance

Listed under:	**UK Biodiversity Action Plan** **EC Habitats Directive**
National importance	Scarce
Habitat Directive feature (Annex 1)	Mudflats and sandflats not covered by seawater at low tide Large shallow inlets and bays Estuaries Lagoons
UK Biodiversity Action Plan habitat	Seagrass beds Saline lagoons Littoral sediment (broad habitat statement)
OSPAR Priority Habitat	*Zostera* beds

Biotope importance

The following algal species have been recorded only from seagrass leaves: *Halothrix lumbricalis*; *Leblondiella densa*; *Myrionema magnusii*; *Cladosiphon zosterae*; *Punctaria crispata* and *Cladosiphon contortus*, which is larger and found primarily on *Zostera* sp. rhizomes. The decline of *Zostera marina* beds in Europe and North America due to wasting disease in the 1920s -30s caused Brent geese (*Branta bernicla*) to shift their preferences to *Zostera noltii*, which is now their preferred food (Davison & Hughes, 1998;

Jones *et al.*, 2000). In Europe, the decline in the dark-bellied Brent geese population to about 25% of its pre-1930s level strongly paralleled the decline in *Zostera* sp. (Ogilvie & Matthews, 1969). In the 1950s and 60s dark-bellied Brent geese on the Essex coast fed primarily on *Zostera noltii* and *Ulva* sp. (Burton, 1961). Wigeon numbers have declined dramatically in recent years, presumably due to the shift from *Zostera marina* to *Zostera noltii*. Wigeon tend to graze lower on the shore, switching to *Zostera noltii* once the supplies of *Zostera marina* or *Zostera angustifolia* (Percival & Evans, 1997). The majority of species associated with the biotope are not specific to the community (Asmus & Asmus, 2000b). However, loss of the biotope would engender a reduction in the material flux within the local ecosystem and loss of a major source of primary production and detritus. For example, Asmus & Asmus (2000b) estimated that loss of intertidal seagrass beds would probably result in a 9% reduction in aerobic microbial turnover, a 7% reduction in anaerobic microbial turnover, a reduction in predatory macrobenthos such as *Carcinus maenas*, and a 30 % reduction in the average biomass of benthic grazers such as *Hydrobia ulvae* and *Littorina littorea*. They estimated that secondary productivity, by macrobenthic infauna, was not significantly reduced.

Exploitation

- Seagrass beds are often associated with cockle beds. Suction dredging for bivalves, such as cockles and *Mercenaria* sp., has been reported to damage eelgrass beds (see 'extraction'; Davison & Hughes, 1998).
- The decline in seagrass beds in the 1920s and1930s together with their importance in coastal processes has resulted in scientific research use and experimental management studies.
- Seagrasses are considered to be of great ecological and economic importance (Asmus & Asmus, 2000a, b) and act a nutrient and sediment sinks.
- Seagrass promote the accumulation of sediment and their rhizomes bind the sediment. Therefore, they absorb a proportion of incident wave energy and may form a natural coastal defence.
- In the past seagrasses have been put to a number of uses world-wide, for example, sound-proofing, insulation, roofing thatch, binding soil, packaging, basket weaving and in the manufacture of 'coir' matting (see Kuelan, 1999 for review).

Additional information

Zostera noltii has not yet been found in lagoons in Wales.

This Biology and Sensitivity Key Information review can be cited as follows:
Tyler-Walters, H., 2004. *Zostera noltii* beds in upper to mid shore muddy sand. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 25/01/2005]. Available from: <http://www.marlin.ac.uk>

Cirratulids and *Cerastoderma edule* in littoral mixed sediment (LS.LMX.MX.CirCer)

Key information authored by: Charlotte Marshall

Last updated 29/11/2004

This information is not refereed.

If you would be willing to supply *MarLIN* with an image of this species/habitat please contact marlin@mba.ac.uk

Recorded and expected LS.LMX.MX.CirCer distribution for Britain and Ireland

Description of biotope

Sheltered mixed sediments, usually subject to variable salinity conditions. Banks of shell may be present. The infauna is very diverse, dominated by a range of polychaetes including *Exogone naidina*, *Sphaerosyllis taylori*, *Pygospio elegans*, *Chaetozone gibber*, *Cirriformia tentaculata*, *Aphelochaeta marioni*, *Capitella capitata*, *Mediomastus fragilis*, and *Melinna palmata*. The oligochaetes *Tubificoides benedii* and *Tubificoides pseudogaster* are abundant, as is the cockle *Cerastoderma edule*. A large range of amphipods may occur, including *Melita palmata*, *Microprotopus maculatus*, *Aora gracilis* and *Corophium volutator*. The bivalves *Abra alba* and *Abra nitida* may occur. The barnacle *Elminius modestus* can be abundant where the sediment has stones on the surface. Epifaunal algae may occur attached to stable cobbles on the sediment surface. (Information taken from the revised Marine Habitat Classification, Version 04.05: Connor *et al*., 2004.).

Additional information

No text entered

Biotope classification

UK and Ireland Classification

Major habitat	LS	Littoral sediments
Biotope	LS.LMX.MX.CirCer	Cirratulids and *Cerastoderma edule* in littoral mixed sediment
Similar biotopes:	LS.LMX.GVMU.HedMx	

Other biotope classification schemes

This biotope code is a new code taken from the revised Marine Habitat Classification, Version 04.05 (Connor *et al*., 2004). A European Union Nature Classification System (EUNIS) habitat classification for this biotope was unavailable.

Ecology

Ecological and functional relationships

- Deposit feeders including the cirratulids *Aphelochaeta marioni*, *Chaetozone gibber*, *Cirriformia tentaculata* and other polychaete worms such as *Pygospio elegans*, *Capitella capitata* and *Melinna palmata* are the dominant trophic group in the biotope. These species feed on organic debris, diatoms and detrital matter within the sediment. The oligochaetes *Tubificoides benedii* and *Tubificoides pseudogaster* are also abundant deposit feeders, feeding on detrital material and bacteria.
- Suspension feeders, represented mainly by the common cockle *Cerastoderma edule*, an important characterizing species in this biotope, are another important trophic group. Other associated suspension feeders may include the barnacle *Elminius modestus* and the bivalves *Abra alba* and *Abra nitida* although these bivalves are also deposit feeders. The polychaete *Pygospio elegans*, although principally a surface deposit feeder, can also filter feed (Fauchald & Jumars, 1979).
- A range of amphipods including *Corophium volutator* may occur. This species is capable of both deposit feeding and suspension feeding and alternates between the two depending on the state of the tide. Only when immersed can it filter feed. It feeds on particulate organic matter, bacteria and diatoms.
- The catworm *Nephtys hombergii* and phyllodocid polychaete *Anaitides mucosa* are carnivorous polychaetes and feed mostly on other polychaete species. Combined, they may represent significant predators on the other polychaetes in the biotope.
- Birds and fish are likely to represent the most important large mobile predators, with the birds exerting more predation pressure at low tide and *vice versa*. Hayward (1994) proposed that the major marine predators of sand infauna are fish such as the sand goby *Pomatoschistus minutus*, sole *Solea solea* and plaice *Pleuronectes platessa*. Gobies were said to feed mainly on polychaetes whereas sole and plaice feed on polychaetes and small bivalves (Hayward, 1994). The diet of the redshank *Tringa totanus* includes *Hydrobia ulvae*, *Nephtys hombergii* and *Corophium volutator*, the latter representing its preferred prey (Goss-Custard, 1977a,b).
- The epifaunal algae which may occur attached to stable cobbles on the sediment may provide shelter for the laver spire shell *Hydrobia ulvae.*

Density dependent effects on community structure

- Assemblages of cockles can have a significant influence on the structure of the macrobenthic community. For example, Flach (1996) reported that the presence of *Cerastoderma edule* significantly reduced the densities of juvenile *Pygospio elegans*, *Anaitides* spp., *Nephtys hombergii*, *Aphelochaeta marioni* (studied as *Tharyx marioni*), *Corophium volutator* and *Cerastoderma edule* juveniles themselves. Following a dramatic decline in numbers of *Cerastoderma edule* after eutrophic episodes in the Bay of Somme, France, the abundance of *Pygospio elegans* increased dramatically to almost 200,000 individuals / m² where there had previously only been several tens per m² (Desprez *et al.*, 1992). By 1987, when the cockles had returned, *Pygospio elegans* had all but disappeared.
- Flach (1996) also looked at the effects that the abundance of cockles had on the abundance of several other species on the tidal flats of Balgzand, Wadden Sea. When comparing the abundance of species on plots with no cockles to those where cockles occupied 16% of the plot, he found a negative density dependent effect. For example, the abundances of *Corophium volutator* were 144 and 1648 / m², *Nephtys hombergii* were 196 and 817 / m² and *Pygospio elegans* were 7023 and 30001 / m² for the cockle-occupied plots and control plots respectively. The negative effects on *Corophium volutator* are thought to result from the movement of the cockles that destroys the tubes of the amphipod. This causes the amphipod to move away, therefore increasing chances of predation (Flach, 1996).
- The presence of the gastropod *Hydrobia ulvae* in some areas on the German Bight has been implicated as the cause behind low numbers of *Aphelochaeta marioni* (studied as *Tharyx marioni*), (Farke, 1979). *Corophium volutator* and *Peloscolex benedeni* have also been suggested as competitors for food and space with *Aphelochaeta marioni* (Farke, 1979).

Seasonal and longer term change

- The abundance of the associated polychaete species is likely to show significant peaks throughout the year concomitant with their respective breeding periods. A peak in abundance in the cirratulid *Cirriformia tentaculata*, for example, was seen over the summer months on Hamble Spit in Southampton (George, 1964b). In August 1960, more than 300 individuals were present in a 16 cm² quadrat whereas in April only 100 or so were counted in the same area (George, 1964b). In *Aphelochaeta marioni* (studied as *Tharyx marioni*), abundance was highest in winter in Stonehouse Pool, a muddy sandy habitat at the very seaward end of the Tamar estuary in Plymouth (Gibbs, 1971). At this time population numbers were almost 100,000 / m², representing the brood of the previous spring and summer, and abundance decreased continually from February to July (Gibbs, 1971; Farke, 1979).
- Cockle beds are periodically decimated by severe winter weather and these high mortalities in winter are often followed by an exceptionally high spring spatfall (Hayward, 1994). The post larval cockles then grow rapidly to occupy space on sand within a year (Hayward, 1994). However, settlement and subsequent recruitment is highly sporadic and varies with geographic location, year, season, reproductive condition of the adults, climatic variation, intra and interspecific mortality and predation. Nevertheless, *Cerastoderma edule* are likely to experience a peak in abundance over the summer and autumn months. Due to the negative effects the presence of this species has on other associated fauna, increased abundance of some fauna e.g. polychaetes and amphipods may be observed over winter. Jensen (1985) found that following a winter mortality of cockles, *Corophium volutator* moved into sandy low-shore areas where it did not normally occur (normally being in silty areas of sand unsuitable for cockles) (Hayward, 1994).
- Fluctuating numbers of birds and fish throughout the year may affect the level of predation pressure on invertebrates in this biotope. These changes will be superimposed on any cyclical changes the invertebrates themselves experience throughout the year.
- Macroalgae populations are also likely to exhibit some seasonal differences with a general decline in abundance / biomass over winter.

Habitat structure and complexity

The sediment itself, being a mixture of sand, gravel and mud, provides heterogeneity to the biotope and increases the number of potential habitats. The common cockle *Cerastoderma edule* contributes to the complexity of the habitat in two ways:

- The broken and empty shells of cockles provide some heterogeneity in terms of substratum type. Apart from the cobbles that may be present on the surface on the substratum, the shells probably represent the largest structural element within this biotope. In laboratory flume experiments, Thompson & Amos (2002) reported that the addition of even a single *Cerastoderma edule* shell (studied as *Cerastoderma edulis*) caused the significant erosion of a clay bed.
- The crawling and shaking behaviour of the cockles disturbs the surrounding sediment and can leave shallow trough-like depressions in it. Flach (1996) reported that cockles with a shell length greater than 4 cm can disturb more than 10 cm² of sediment in one week by shaking alone. The same size cockle was able to disturb almost 30 cm² by crawling over a distance of 4 cm in a week. Such disturbance can significantly affect the abundance of other benthic species and dense assemblages of cockles have a strong influence on the structure of the macrobenthic community (see ecological relationships above).

On a smaller scale, the burrows and tubes built by polychaete worms result in an uneven sediment surface. This partly explains the highly diverse fauna associated with this biotope. Stones and cobbles may be found on the sediment surface and several of the polychaete species can be found underneath them, for example, *Cirriformia tentaculata*. It is likely that the stones and cobbles offer the worms some protection from desiccation during tidal emersion.

Dominant trophic groups Deposit feeders (detritivores)

Productivity

- Little information concerning the productivity of this biotope specifically was found. However, productivity in the muddy fine sand *Abra alba* - *Melinna palmata* community in the Bay of Morlaix in France ranged from just under 5,000 to over 25,000 g / m² / year (Dauvin, 2000). This community is also dominated by a polychaete and bivalve combination, has similar sediment characteristics and is possibly representative of productivity in this biotope.

- Secondary production accounts for almost all of the productivity within this biotope with the deposit feeders contributing the most to this. *Tubificoides benedii* (studied as *Tubificoides benedeni*) accounted for over 92% of the biomass of mud fauna in the Forth estuary and production values or this species ranged from 14.2-27.1 g (wet weight) per m² per year (Bagheri & McLusky, 1984). Overall, the oligochaetes and small polychaetes in this estuary accounted for about half of the total invertebrate production.
- The small amount of epifaunal algae that may be occur in this biotope will contribute some dissolved organic carbon to the biotope. Algal fragments and microbial film organisms are continually removed by the sea and may enter the food chain of local, subtidal ecosystems or perhaps exported further offshore.

Major sources of organic carbon	Detritus Plankton

Recruitment processes

Recruitment in this biotope is characterized by a variety of reproductive mechanisms. Recruitment does not usually occur through dispersive larval phases as many of the species do not produce planktonic larvae. In such cases, recruitment to the biotope via larval dispersal is unlikely and will probably depend on adult immigration. Due to the limited mobility of the characterizing species in this biotope however, this immigration is likely to be primarily through passive mechanisms such as dislodgement during storms or tidal action and 'bed-load' transport. Coffen-Smout & Rees (1999), for example, reported that cockles could be distributed by flood and ebb tides by rolling around on the surface.

Recruitment in the major groups present is summarized below.

- Egg production in cirratulids, for example *Cirriformia tentaculata* and *Aphelochaeta marioni*, often varies with location. In addition, many cirratulids are thought to have direct development, which has obvious limitations with regards to dispersal.
- Breeding in the cirratulid *Cirriformia tentaculata* occurs in 'bursts' between March and September in Southampton, although the main breeding period runs from April to August (George, 1964a). Petersen (1999) stated that *Cirriformia tentaculata* may have a brief planktonic stage although none have ever been observed in the plankton. However, behavioural differences were found between the larval stages of *Cirriformia tentaculata* from Drake's Island in Plymouth and those from Southampton (George, 1963). In the former, the larvae were found to pass through a strongly swimming trochophore phase for about one week, whereas larvae from Southampton were entirely benthic. Recruitment and dispersal in this species could, therefore, vary depending on the geographical location of the biotope.
- The cirratulid *Aphelochaeta marioni* breeds in April in the Thames estuary and Chalkwell in Essex, from September to October in the Tamar Estuary (Petersen, 1999) and from late October to early November in Stonehouse Pool, a muddy sandy habitat at the very seaward end of the Tamar estuary in Plymouth (studied as *Tharyx marioni*, Gibbs, 1971). At this time population numbers were almost 100,000 / m², representing the brood of the previous spring and summer, and abundance decreased continually from February to July (Gibbs, 1971; Farke, 1979). The larvae of *Aphelochaeta marioni* are non-pelagic and bottom living (Gibbs, 1971). The larvae burrow immediately after hatching therefore dispersal though larval stages is unlikely. Large females only produce about 1000-1500 eggs (Dales, 1951).
- Recruitment in *Cerastoderma edule* populations is highly variable. In the Schelde estuary, large fluctuations were observed in the year-to-year biomass of *Cerastoderma edule* with contribution to biomass ranging between 19-72% in the middle region over 6 years. *Cerastoderma edule* first mature and spawn in their second summer, at about 18 months old and 15-20 mm in length, however, large cockles (>15 mm) may mature in their first year suggesting that size and maturity are linked (Orton, 1926; Hancock & Franklin, 1972; Seed & Brown, 1977). Most adults spawn in a short peak period over summer with remaining adults spawning over a protracted period, resulting in a short (ca. 3 month) period of peak settlement followed by generally declining numbers of recruits (Hancock, 1967; Seed & Brown, 1977). Spawning generally occurs between March - August in the UK followed by peak spatfall between May and September, however the exact dates vary between sites in the UK and Europe (Seed & Brown, 1977; Newell & Bayne, 1980).

Settlement and subsequent recruitment is sporadic and varies with geographic location, year, season, reproductive condition of the adults, climatic variation, intra and interspecific mortality and predation. Ducrotoy *et al*. (1991; Figure 14) identified, 'crisis', 'recovery', 'upholding', and 'decline' phases in dynamics of *Cerastoderma edule* populations (see *MarLIN* Web site).

- In terms of other characterizing species, a planktonic larval stage is usually absent in the polychaete *Pygospio elegans* as well (Rostron, 1998). However, recruitment in this species can be good. In a study focusing on the establishment of zoobenthic communities in seagrass beds, Boström & Bonsdorff (2000) found that *Pygospio elegans* colonized artificial seagrass patches rapidly. Densities of the *Pygospio elegans* in the experimental trays were comparable to those in *Zostera marina* meadows within nine weeks. The oligochaete *Tubificoides benedii* is sluggish and does not posses the capability to liberate large numbers of planktonic larvae for dispersal either (Barnett, 1983). Breeding of *Nephtys hombergii* was intermittent and prone to failure in the North East of England (Olive & Morgan, 1991).
- Female *Corophium volutator* brood their eggs until they hatch at which time the young crawl from the parent burrow (Eltringham, 1971). This means that dispersal relies entirely on the movement by the adult members of the population. However, dispersal on small scales (tens of square metres) is very good and *Corophium volutator* can rapidly colonize by immigration and recruitment of juveniles from immigrants (see *MarLIN* Web site). *Capitella capitata* has planktonic larvae which can be present all year thus increasing its chances of successful colonization of new areas and distribution. Benthic larvae can also be produced which enables the rapid exploitation of concentrations of organic matter (Rostron, 1998). *Capitella capitata* can reach maturity within about 40 days and therefore has a high potential to recolonize an area.

Overall, the major species in this biotope have a limited dispersal potential and recruitment is subject to significant influence from a variety of factors.

Time for community to reach maturity

Little information was found concerning community development, or indeed the development of populations of all of the characterizing species. Some of the species associated with this biotope are considered 'opportunistic' and may be able to re-establish themselves relatively quickly. However, these 'opportunistic' species such as *Capitella capitata*, although commonly associated with this biotope, are not considered to be important characterizing species (see 'Species Composition'). *Capitella capitata* has planktonic larvae which can be present all year thus increasing its chances of successful colonization of new areas and distribution. Benthic larvae can also be produced which enables the rapid exploitation of concentrations of organic matter (Rostron, 1998).

Cirriformia tentaculata has been found to produce both benthic and planktonic larvae (George, 1963). The significance of this is that these two apparently different 'physiological races' will have entirely different dispersal potential and thus varying chances of successful recolonization of areas. George (1968) discussed possible recolonization in the two cirratulids *Cirratulus cirratus* and *Cirriformia tentaculata* in the British Isles. He postulated that if the lower limit of a population extended to the subtidal, recolonization of intertidal areas would be rapid, taking at most 1-2 years. However, both the species he studied were intertidal. *Cirratulus cirratus* disappeared from Sussex following the severe winter of 1962/63 and had not reappeared by 1968. He suggested that it existed subtidally in such small numbers that it could not maintain itself once replenishment from the shore population had ceased. With regards to *Cirriformia tentaculata*, it was concluded that recolonization by this species would take place by marginal dispersal rather than remote dispersal (Crisp, 1958, cited in George, 1968) and that it was likely to take several decades with mild winters before its distribution returned to that prior to 1962/63 (George, 1968). Farke (1979) implied that *Aphelochaeta marioni* (studied as *Tharyx marioni*) became dominant in areas of the German Bight where it was previously absent in only a few years.

Recruitment in the cockle *Cerastoderma edule* is highly variable. In the Schelde estuary, large fluctuations were observed in the year-to-year biomass of *Cerastoderma edule* with contribution to biomass ranging between 19-72% in the middle region over 6 years. However, evidence suggests that recolonization and population development is fairly rapid. Following the Sea Empress oil spill in Angle Bay, Milford Haven, the presence of juvenile *Cerastoderma edule* on the lower shore shortly after the spill enabled the re-establishment of adult populations on the middle shore within about six months (Rostron, 1998). Hall & Harding (1997) found that *Cerastoderma edule* abundance had returned to control levels within about 56 days after significant mortality due to suction dredging, and Moore (1991) also suggested that recovery was rapid. Recovery is dependant on recruitment of spat or migration (active or passive) from the surrounding substratum. For example, Coffen-Smout & Rees (1999) reported that cockles could be distributed by flood and ebb tides, but especially flood tides (by rolling around the surface) up to 0.45 m on neap tides or between 94 m and 164 m on spring tides and could colonize cleared areas at a rate of 2.2 -12 individuals / m² / 14 days. Cockle beds are periodically decimated by severe winter weather and these high mortalities at winter are often followed by an exceptionally high spring spatfall (Hayward, 1994). The post larval cockles then grow rapidly to occupy space on sand within a year (Hayward, 1994).

Additional information

No text entered

Habitat preference and distribution

Distribution in Britain and Ireland

This biotope has been recorded in Milford Haven in Wales, the Solent in Hampshire and in the Fal Estuary, Cornwall.

Habitat preferences

Temperature range preferences	Data deficient.
Water clarity preferences	Data deficient
Limiting nutrients	Data deficient
Other preferences	Sheltered to very sheltered habitats.

Additional information

Species composition within this biotope is likely to be greatly influenced by sediment type and height on the shore. Due to the sheltered and tidally influenced nature of the habitat, finer particles may be found higher up the shore with a higher proportion of sand and gravel lower down. This change in substratum may also lead to a general transition from deposit feeders to suspension feeders.

In Stonehouse Pool, a muddy sandy habitat at the seaward end of the Tamar estuary in Devon, *Aphelochaeta marioni* (studied as *Tharyx marioni*) was found to occupy a similar niche to *Cirriformia tentaculata* and *Cirratulus cirratus* but at different heights on the shore (Gibbs, 1971). The former densely populated the shore from the low water mark down whereas the latter two species were found from this point up to mid-tide level.

Species composition

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3). The biology of other component species of the biotope is also taken into account wherever information is known to the researcher.

Community Importance	Species name	Common Name
Important characterizing	*Aphelochaeta marioni*	A bristleworm
Important characterizing	*Chaetozone gibber*	A bristleworm
Important characterizing	*Cirriformia tentaculata*	A bristleworm
Important characterizing	*Tubificoides benedii*	A sludge-worm
Important characterizing	*Tubificoides pseudogaster*	An oligochaete worm
Important characterizing	*Cerastoderma edule*	Common cockle
Important characterizing	*Pygospio elegans*	A bristleworm

Important characterizing	*Melinna palmata*	A polychaete worm
Important other	*Corophium volutator*	A mud shrimp

Explanation

This biotope is characterized by a diverse infauna, dominated by a range of polychaetes. The cirratulid polychaetes *Aphelochaeta marioni*, *Chaetozone gibber* and *Cirriformia tentaculata* and the common cockle *Cerastoderma edule* give the biotope its name and are all important characterizing species. The polychaetes *Pygospio elegans* and *Melinna palmata* and the oligochaetes *Tubificoides benedii* and *Tubificoides pseudogaster* are all abundant and have therefore also been listed as important characterizing species. *Corophium volutator* is listed to represent the large range of amphipods that may occur.

Species found especially in biotope

No text entered

Additional information

No text entered

Biotope sensitivity

Physical Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Substratum Loss	High	Moderate	Moderate	Major Decline	High
Smothering	Intermediate	High	Low	Minor Decline	Moderate
Increase in suspended sediment	Intermediate	High	Low	Minor Decline	Moderate
Decrease in suspended sediment	Low	High	Low	No Change	Low
Desiccation	Intermediate	High	Low	No Change	Low
Increase in emergence regime	Intermediate	High	Low	No Change	Moderate
Decrease in emergence regime	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Increase in water flow rate	High	Moderate	Moderate	Major Decline	Moderate
Decrease in water flow rate	Intermediate	High	Low	No Change	Low
Increase in temperature	Low	High	Low	Minor Decline	Low
Decrease in temperature	High	Moderate	Moderate	Decline	Moderate
Increase in turbidity	Low	High	Low	No Change	Very low
Decrease in turbidity	Tolerant*	Not Relevant	Not sensitive*	Not Relevant	Not Relevant
Increase in wave exposure	High	Moderate	Moderate	Major Decline	Low
Decrease in wave exposure	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Noise	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Visual Presence	Low	High	Low	No Change	Low
Abrasion & physical disturbance	Intermediate	High	Low	Decline	Low
Displacement	Intermediate	High	Low	Minor Decline	Moderate
Chemical Factors					
	Intolerance	Recoverability	Sensitivity	Species	Evidence /

				Richness	Confidence
Synthetic compound contamination	Insufficient information	Not Relevant	Insufficient information	Insufficient Information	Not Relevant
Heavy metal contamination	High	High	Moderate	Decline	Moderate
Hydrocarbon contamination	High	High	Moderate	Major Decline	Moderate
Radionuclide contamination	Insufficient information	Not Relevant	Insufficient information	Insufficient Information	Not Relevant
Changes in nutrient levels	Intermediate	High	Low	Decline	Moderate
Increase in salinity	Tolerant	Not Relevant	Not sensitive	Not Relevant	Not Relevant
Decrease in salinity	Intermediate	High	Low	Minor Decline	Moderate
Changes in oxygenation	Intermediate	High	Low	Minor Decline	Moderate
Biological Factors					
	Intolerance	Recoverability	Sensitivity	Species Richness	Evidence / Confidence
Introduction of microbial pathogens/parasites	Intermediate	High	Low	Minor Decline	Moderate
Introduction of non-native species	Insufficient information	Not Relevant	Insufficient information	Insufficient Information	Not Relevant
Extraction of key or important characterizing species	Intermediate	High	Low	Decline	Moderate
Extraction of important species	Not Relevant	Not Relevant	Not relevant	Not Relevant	Not Relevant

Explanation of sensitivity and recoverability

Physical Factors	
Substratum Loss (see benchmark)	All the characterizing species within this species live on the surface of or within the top few centimetres of substratum. Loss of the substratum will result in loss of these species and loss of the biotope and therefore, an intolerance of high has been recorded. Recoverability is likely to be moderate (see additional information).
Smothering (see benchmark)	The cirratulids *Aphelochaeta marioni*, *Chaetozone gibber* and *Cirriformia tentaculata* all live buried in the top few centimetres of sediment and are therefore unlikely to be adversely affected by smothering. Maurer *et al.* (1986) studied the effects of dredged material on the vertical migration and mortality of four species of benthic invertebrates (including two polychaetes) and reported that the intolerance of species to smothering was influenced by the nature of the sediment. They predicted that some individuals of both the polychaete species studied (*Nereis succinea* and *Scoloplos fragilis*) would be capable of vertical migration through 0.9 m of sediment if that sediment was indigenous to their usual habitat. In a study in the Santa Catalina Basin (1240 m depth) off the California coast, Kukert & Smith (1992) reported that subsurface deposit feeders appeared to be the least susceptible to smothering when buried under 5-6 cm of sediment. All four trophic groups studied (surface-deposit feeders, sub-surface deposit feeders, omnivores and others) and both domicile groups (tube-dwellers and non-tube dwellers) were significantly reduced in absolute abundance four days after disturbance when compared to the background community. However, the macrobenthos had reached background levels within 11 months although community succession continued for 23 months. Burrowing was found to be a significant dispersal mode. The cirratulids would need to be able to reposition themselves in order to resume feeding at the surface and therefore smothering by heavy impermeable substances such as tar would result in an increased

	intolerance. *Cerastoderma edule* has short siphons and needs to keep in contact with the surface of the sediment. Jackson & James (1979) reported that few *Cerastoderma edule* buried to 10 cm in sediment were able to burrow to the surface whereas most buried to a depth of 5 cm could reach the surface. In another experiment *Cerastoderma edule* buried 10 cm in sandy substrate was able to burrow near to the surface, but still suffered 83% mortality in 6 days, whereas in muddy substrates all cockles died between 3 and 6 days. Therefore, cockles are probably of intermediate intolerance to smothering by 5 cm of sediment although smaller individuals may be more intolerant. *Melinna palmata* lives in a mucous-lined tube covered in sediment that projects obliquely above the sediment (Fauchald & Jumars, 1979). In general, mucus tube feeders and labial palp deposit feeders were most intolerant to burial (Maurer *et al*., 1986). Smothering may result in this tube being broken which may result in the displacement or mortality of some individuals. It is not known whether other important characterizing fauna including the oligochaetes *Tubificoides benedii, Tubificoides pseudogaster* and the polychaete *Pygospio elegans* would be adversely affected by smothering but their mobility may enable them to dig back up through the sediment to the surface. On balance, an intolerance of intermediate with a high recoverability has been recorded following the evidence on the cockles (see additional information).
Increase in suspended sediment (see benchmark)	An increase in the amount of suspended sediment could potentially increase the amount of food available to deposit feeders, the major trophic group within this biotope. However, this would only be true if the proportion of organic material within the suspended sediment increased. With regard to suspension feeders, increasing total particulate concentrations have been shown to decrease clearance rates and increase pseudofaeces production in *Cerastoderma edule* (Navarro *et al.* 1992; Navarro & Widdows, 1997). Furthermore, due to the sheltered nature of the habitat, siltation is likely. The increase in suspended sediment is likely to increase the proportion of mud, to the detriment of *Cerastoderma edule*. Therefore, an intolerance of intermediate has been recorded. Recovery is expected to be high (see additional information).
Decrease in suspended sediment (see benchmark)	A decrease in suspended sediment is likely to reduce the amount of available food for both suspension feeders and deposit feeders although at the benchmark level this is unlikely to cause mortality. Navarro & Widdows (1997) suggested that *Cerastoderma edule* was able to compensate for decrease in particulate quality (i.e. proportion of organic to inorganic seston) between 1.6 to 300 mg/l. Over the benchmark period the associated fauna may experience a temporary deleterious effect on growth and fecundity and accordingly an intolerance of low has been recorded. On resumption of normal levels of suspended sediment, recoverability is expected to be high.
Desiccation (see benchmark)	This biotope is found on the lower and mid shore and the associated fauna are likely to be tolerant of a certain degree of desiccation. In addition, the majority of important characterizing species are infaunal and are therefore protected from major changes in aerial exposure. Boyden (1972) reported that *Cerastoderma edule* survived 42.9% water loss. However, increased desiccation, equivalent to raising the biotope from mid to high water, is likely to reduce the abundance of this some associated fauna, especially those that don't build tubes such as the polychaetes *Exogone naidina* and *Sphaerosyllis taylori*. If the branchiae of the cirratulid *Cirriformia tentaculata* are exposed they will either be withdrawn into the burrow of the worm or clump together and stop functioning properly (Dales & Warren, 1980). Overall, an intolerance of intermediate has been recorded. Recoverability is expected to be high since a proportion of each population is likely to remain (see additional information).

Increase in emergence regime (see benchmark)	An increase in emergence, equivalent to one hour not covered by the sea, will render the biotope more susceptible to desiccation, extremes of temperature and predation pressure from shore birds. If the branchiae of the cirratulid *Cirriformia tentaculata* are exposed they will either be withdrawn into the burrow of the worm or clump together and stop functioning properly (Dales & Warren, 1980). *Aphelochaeta marioni*, another cirratulid, can only feed when immersed and therefore will experience reduced feeding opportunities. Over the course of a year the resultant energetic cost is likely to cause some mortality and the upper limit of the biotope will be reduced. An intolerance of intermediate has been recorded to reflect this mortality. Recoverability has been assessed as high because some proportion of each population are likely to remain (see additional information).
Decrease in emergence regime (see benchmark)	A decrease in emergence will reduce the tidally induced stresses of desiccation, hypersalinity, extremes of temperature and predation by shore birds. Predation by fish may increase but so may the extent of the lower limit of the population provided a suitable substratum remained. Therefore, tolerant has been recorded.
Increase in water flow rate (see benchmark)	The biotope is associated with weak and very weak tidal streams and is therefore likely to be adversely affected by an increase in water flow rate at the benchmark level. The increased flow rate will change the sediment characteristics in which the species lives and essentially, the habitat could be lost. Finer sediment particles such as silt and mud are likely to be lost. Less than half of the sediment in this biotope is mud but it is the preferred habitat for some important characterizing species. The cirratulid *Aphelochaeta marioni*, for example, prefers a habitat with a high silt content (Gibbs, 1969). Therefore, the species would be outside its habitat preference and mortality would be likely. Additionally, the consequent lack of deposition of particulate matter at the sediment surface would greatly reduce food availability for all deposit feeders. Over the course of a year this is likely to adversely affect growth rates and fecundity. George (1964b) found that particle size was negatively correlated with the density of *Cirriformia tentaculata* in Hamble Spit, Southampton. However, he suggested that this was probably as much to do with availability of organic matter, it being generally lower in the areas with higher grain sizes. There was a positive correlation between the amount of organic matter and the number of worms. *Nephtys* are one of the few polychaetes that are able to live in shifting sand and can penetrate and move through sand very efficiently (Truman & Ansell, 1969). *Nephtys hombergii* is a predatory polychaete and if this species can tolerate an increased water flow rate whilst other polychaetes are suffering then mortality is expected to further increase. An increased water flow rate may also interfere with the delicate feeding apparatus of suspension feeders such as *Cerastoderma edule* leading to a reduced food consumption. Increasing water flow may remove adult *Cerastoderma edule* from the sediment surface and carry them to unfavourable substratum or deep water, where they may be lost from the population. Coffen-Smout & Rees (1999) reported that cockles could be distributed by flood and ebb tides, but especially flood tides (by rolling around the surface) up to 0.45m on neap tides or between 94 m and 164 m on spring tides. Newly settled spat and juveniles (<4.8mm) are capable of bysso-pelagic dispersal. Therefore, water flow rates probably affect the distribution and dispersal of juveniles and adults. An increase in water flow rate at the benchmark level is likely to have a similar effect to substratum loss and accordingly, an intolerance of high has been suggested. Recoverability is expected to be moderate (see additional information).
Decrease in water flow rate (see benchmark)	The biotope is associated with weak and very weak tidal streams and is therefore unlikely to be adversely affected by a decrease in water flow rate. Decreasing water flow rate may increase siltation and change the proportions of sand and gravel in the sediment to favour muddy substrates. Such substrata are unsuitable

	for *Cerastoderma edule* and Boyden & Russell (1972) suggested that lack of tidal flow may exclude *Cerastoderma edule* possibly due to reduced food availability as suggested by Brock (1979). An intolerance of intermediate has been recorded to reflect cockle mortality. Recoverability is likely to be high.
Increase in temperature (see benchmark)	This biotope occurs intertidally and is therefore likely to be relatively tolerant of changes in temperature as experienced during cyclical periods of immersion and emersion. The cirratulid *Aphelochaeta marioni* (studied as *Tharyx marioni*) has been recorded from the Baltic to the Indian Ocean and so it probably has some degree of adaptation or tolerance to a range of temperatures (Hartmann-Schroder, 1974 and Rogall, 1977, cited in Farke, 1979). However, acute rises in temperature may have a more deleterious effect. George (1964a) reported that a rapid rise or fall in temperature of 3 °C was sufficient to induce spawning in 25% of mature *Cirriformia tentaculata*. If this occurred at a time of year that was not suitable for larval survival then larval mortality could be high. The upper lethal limits for *Cirriformia tentaculata* from the Hamble were reported to be of 32 °C and 29 °C for 5-6 day old and adult *Cirriformia tentaculata* respectively (George, 1964b). The upper temperature tolerance (that killed half of the test organisms after 96 hours) of the oligochaete *Tubificoides benedii* (studied as *Peloscolex benedeni*) was reported to be 28.5 °C (Diaz, 1980). However, temperatures of this magnitude are unlikely to be experienced by this intertidal biotope. *Cirriformia tentaculata* is reported to be near its northern limit in the British Isles (George, 1968) and an increase in temperature may lead to the extension of its upper distribution range. An increase in temperature could also serve to decrease the length of time spent in the larval phase and so reduce the risk of predation. The rate of larval growth in *Cirriformia tentaculata* was found to be twice as fast at 20 °C than at 8 °C. Much work has been done on the temperature tolerances in *Cerastoderma edule* (see *MarLIN* Web site). Kristensen (1958) reported that *Cerastoderma edule* from the Dutch Wadden Sea had an upper temperature tolerance of 31 °C for 24 hrs, but that spat (3-6 mm) were more tolerant. Ansell *et al.* (1981) reported an upper median lethal temperature of 35 °C after 24 hrs (29 °C after 96 hrs exposure). Wilson (1981) noted that *Cerastoderma edule* had limited ability to acclimate. However, Newell & Bayne (1980) stated that *Cerastoderma edule* was able to acclimate to a temperature change of 10 °C and regulate its metabolic rate in response to rising spring temperatures. Temperature tolerance in the above studies was dependant on the environmental temperature, i.e. specimens collected in summer or areas of higher average temperature tolerated higher temperatures than specimens collected in winter and/or at lower average temperatures. Therefore, the intolerance of *Cerastoderma edule* to temperature change will be dependant on season. Rapid increases in temperature during the spawning season may initiate spawning (Ducrotoy *et al.*, 1991). Wilson (1993) concluded that *Cerastoderma edule* was probably tolerant of a long-term temperature rise of 2 °C associated with climate change. On balance, it is unlikely that an increase in temperature similar to that of the benchmark will cause significant mortality within the biotope. An intolerance of low has been recorded, reflecting some physiological stress in less tolerant species but with a low confidence. Recoverability has been assessed as high (see additional information).
Decrease in temperature (see benchmark)	This biotope occurs intertidally and is therefore likely to be relatively tolerant of changes in temperature as experienced during cyclical periods of immersion and emersion. *Aphelochaeta marioni* (studied as *Tharyx marioni*) has been recorded from the Baltic to the Indian Ocean and so it probably has some degree of

	adaptation or tolerance to a range of temperatures (Hartmann-Schroder, 1974 and Rogall, 1977, cited in Farke, 1979). Short periods of severe frost in November 1973 were not reported to have affected the population of *Aphelochaeta marioni* (studied as *Tharyx marioni*) in the German Bight (Farke, 1979). Acute falls in temperature may have a more deleterious effect. George (1964a) reported that a rapid rise or fall in temperature of 3 °C was sufficient to induce spawning in 25% of mature *Cirriformia tentaculata*. If this occurred at a time of year that was not suitable for larval survival then larval mortality could be high. However, George (1964b) noted that although in Southampton the incoming tide incurred a drop of 6 °C in five minutes, such rapid changes in temperature had no significant effect on the mortality of either juvenile of adult *Cirriformia tentaculata* in the laboratory. The larvae of this species grow twice as slow at 8 °C as they do at 20 °C (George, 1964a). Any increase in the length of time spent in the larval phase will increase the risk of predation. In adults, field data suggests that growth ceases at 6 °C (George, 1964a). On the Hamble, lower lethal limits of -6 °C (by extrapolation) and 2 °C have been reported for 5-6 day old and adult *Cirriformia tentaculata* respectively (George, 1964b). These are temperatures that can reasonably be expected in winter in this intertidal biotope and so some mortality is likely. Furthermore, *Cirriformia tentaculata* is reported to be near its northern limit in the British Isles (George, 1968) and a long term chronic decrease in temperature could serve to exclude this species from the northern extent of its distribution. George (1968) reported several major changes and a major reduction in the distribution range of *Cirriformia tentaculata* following the severe winter of 1962/3. In temperature tolerance experiments, no *Cirriformia tentaculata* survived even a brief exposure to -2 °C or 96 hours at 0 °C. The cirratulid *Cirratulus cirratus* was found to be tolerant to lower temperatures and it is possible that this species will become more prevalent in this biotope if the temperature falls. George (1968) reported that the ciliary feeding mechanisms of *Cirriformia tentaculata* became so inefficient at low temperatures that, over long periods, the animal may die of starvation. George (1968) also mentioned that the animal does not withdraw its branchiae in cold weather. Due to their delicate nature, the branchiae may subsequently freeze on the surface. In such a case, the animal would be living under anaerobic conditions and so emerges from the burrow to enable them to respire through their body surface. This emergence would increase both risk of predation and of freezing. High mortalities of cockle populations due to severe winters have been reported by many authors. Kristensen (1958) reported that the sediment froze to a depth of 10 cm and 15 cm, resulting in death of cockles in areas of the Wadden Sea in the severe winter of 1954. Hancock & Urquhart (1964) report almost 100% mortality of cockles in Llanrhidian Sands, Burry Inlet and high mortalities of cockles in other areas around the UK after the winter of 1962/63. Beukema (1990) considered *Cerastoderma edule* to be intolerant of cold winters. Kristensen (1958) reported that *Cerastoderma edule* from the Dutch Wadden Sea died within 24 hrs at -1.9 °C. Smaal *et al.* (1997) stated that *Cerastoderma edule* is unable to acclimate to low temperatures. No specific information concerning the effects of a decrease in temperature on the other important characterizing species was found but an intolerance of high has been recorded to reflect mortality in the studies mentioned above. Providing some part of the affected species' population survived, recoverability is expected to be moderate.
Increase in turbidity (see benchmark)	An increase in turbidity will mean that primary production in the water column may suffer from increased light attenuation. The photosynthetic capabilities of epifaunal algae within the biotope may also decrease. Plankton drifting in from other areas will dampen the effect of a reduction in food availability for the suspension and deposit feeders but over the course of a year the species are likely

	to experience some reduced feeding and fecundity. Therefore a low intolerance has been recorded with a high recoverability.
Decrease in turbidity (see benchmark)	A decrease in turbidity may stimulate further primary production in the water column. This would increase food availability for the suspension feeders and also the amount of organic material reaching the sediment surface. Therefore tolerant* has been recorded.
Increase in wave exposure (see benchmark)	This biotope occurs in very sheltered and extremely sheltered habitats and is therefore likely to be highly sensitive to an increase in wave exposure similar to that of the benchmark. Species on the sediment surface including cockles and tube building polychaetes are likely to be washed away and may end up in unfavourable habitats. Infauna may also be dislodged if the top layers centimetres of sediment are removed. This will render the worms more susceptible to predation. Rough seas in March 1960 were found to wash away young *Cirriformia tentaculata* from the top surface layers of mud at Hamble Spit, Southampton (George, 1964b). Polychaetes living further down in the sediment may be saved from dislodgement but the biotope *per se* will be lost. Therefore, intolerance has been assessed as high. This factor is likely to have a similar effect to substratum loss and accordingly, recoverability has been assessed as moderate.
Decrease in wave exposure (see benchmark)	This biotope occurs in very sheltered and extremely sheltered habitats and therefore is therefore likely to be tolerant of a decrease in wave exposure.
Noise (see benchmark)	*Cerastoderma edule* can probably detect the vibration caused by predators and will withdraw its siphons. However, little information was found concerning the effect of noise or vibration on cockle populations. The polychaetes and other worms are unlikely to have the ability to detect noise and other associated fauna are also unlikely to be adversely affected. Shore birds are highly sensitive to noise and may be scared away. This would decrease the predation pressure on the fauna in this biotope from this source and, therefore, tolerant has been recorded.
Visual Presence (see benchmark)	*Aphelochaeta marioni* is only active at night and Farke (1979) noted their intolerance to visual disturbance in a microsystem in the laboratory. In order to observe feeding and breeding in the microsystem, the animals had to be gradually acclimated to lamp light. Even then, additional disturbance, such as an electronic flash, caused the retraction of palps and cirri and cessation of all activity for some minutes. Visual disturbance, in the form of direct illumination during the species' active period at night, may therefore result in loss of feeding opportunities, which may compromise growth and reproduction. *Cerastoderma edule* has well developed eyes on the sensory tentacles of the inhalant and exhalent tentacles (Charles, 1966). These probably enable the cockle to response to shadowing by predators and withdraw the siphons. However its visual acuity is probably limited and it is unlikely to be sensitive to visual presence. No information was found on the sensitivity to visual presence of other important characterizing species. However, shore birds are highly sensitive to visual presence and may be scared away. This would decrease the predation pressure on the fauna in this biotope from birds. However, in respect of the evidence for *Aphelochaeta marioni*, an intolerance of low has been recorded.
Abrasion & physical disturbance (see benchmark)	The majority of species within this biotope are soft bodied organisms which feed on the surface of the substratum or at least expose part of their body to the surface whilst feeding. Physical disturbance, such as cockle dredging or dragging an anchor, would be likely to penetrate the upper few centimetres of the sediment and cause physical damage to many of the important characterizing species. Birds and

	fish would be attracted to the site of disturbance and the fauna would be at greater risk of predation. Coffen-Smout (1998) studied simulated fisheries impacts on *Cerastoderma edule* and reported that the cockle shell withstood between 12.9 and 171.4 newtons (N) of force depending on shell size and position of load (a 1 kg weight exerts about 10 N). Cockles are often damaged during mechanical harvesting and Picket (1973) found that 20% were too damaged to be processed after hydraulic dredging. Physical disturbance equivalent to a passing scallop dredge is likely to cause a similar degree of damage. However, only a proportion of the population is likely to be affected (see extraction of key or important characterizing species) and, on balance, an intolerance of intermediate has been recorded with a high recoverability.
Displacement (see benchmark)	Farke (1979) noted the effects of displacement on *Aphelochaeta marioni* (studied as *Tharyx marioni*) while performing experiments on intolerance to salinity changes. It was observed that when an individual was removed from its habitat and displaced to a similar habitat, it took approximately one minute to dig itself into the sediment. Cockles are capable of burrowing rapidly into the substratum and more than 50% burrowed into the substratum within 1 hour in experimental trials (Coffen-Smout & Rees, 1999), although this rate was inhibited by prior disturbance. Brock (1979) reported that 80% began to burrow within 60 min and 50% had successfully burrowed into sediment within 60 min. He also noted that young cockles could burrow quickly, and were nearly buried within 5 min. Disturbance and displacement may also reduce the growth rates (Orton, 1926) or interfere with the reproductive cycle (Hummel & Bogaards, 1989). Populations of cockles are probably moved, buried or displaced naturally by storms and once exposed can burrow relatively quickly into suitable sediment, and therefore are probably adapted to being displaced. Reduction in the local population density may enable good recruitment in following years, dependent on larval supply. Animals that have been displaced onto the sediment surface are at an increased risk of predation and some may not be able to reburrow rapidly, if at all. *Pygospio elegans* can build new tubes if necessary (Rostron, 1998) and it is possible that other species may be able to do the same. Overall, an intolerance of intermediate has been recorded to reflect the mortality that is likely to arise from predation. Recoverability is likely to be high.
Chemical Factors	
Synthetic compound contamination (see benchmark)	The close association of benthic invertebrates with contaminated sediments may cause some sub-lethal effects and in the long term could interfere with reproductive potential (Rostron, 1998). *Cerastoderma edule* is known to accumulate PCBs (see *MarLIN* Web site) but no specific information concerning the actual effects that contamination with synthetic chemicals has on this species or on other characterizing species within the biotope was found. *Corophium volutator* is considered to have an intermediate intolerance to synthetic chemicals (see *MarLIN* Web site). However, this is not a characterizing species and its loss would not adversely affect the recognizable biotope.
Heavy metal contamination (see benchmark)	Bryan (1984) suggested that many polychaetes were resistant to heavy metals and evidence from the work of Bryan & Gibbs (1983) in the metal polluted Fal estuary supports this view. Bivalves, on the other hand, displayed a much lower tolerance and were found to be the most obvious absentees from the polluted Restronguet Creek area of the Fal (Bryan & Gibbs, 1983). The following information is taken from Bryan & Gibbs (1983). • *Aphelochaeta marioni* (studied as *Tharyx marioni*) was found to contain exceptionally high concentrations of arsenic (> 2000 µg / gram dry body weight) without obvious adverse effects.

	• *Pygospio elegans* appear to have adapted to the high concentrations of copper and zinc in Restronguet Creek and the larvae are subjected to widely fluctuating conditions of salinity and relatively high metal concentrations. • Increased tolerance of copper was found in the amphipod *Corophium volutator* and the polychaete *Nephtys hombergii* in the creek. • Adult *Cerastoderma edule* were found to be more tolerant to metal toxicity than the juvenile or larval stages which appear unable to withstand the high concentrations of copper and zinc. However, transplantation of *Cerastoderma edule* into Restronguet Creek (highly polluted by heavy metals) resulted in 10-15% mortality within 63 days but 100% within about four months. The toxic body-burden of copper to *Cerastoderma edule* was found to be ca. 250 µg / g with zinc being less toxic. Bryan & Gibbs (1983) stated that *Cerastoderma edule* takes up heavy metals mainly from solution rather than from sediment and that it was excluded from Restronguet Creek by the high levels of Cu and Zn. Given the evidence for the cockles, an intolerance of high has been recorded because loss of cockles would result in loss of the recognizable biotope. A recoverability of high has been suggested (see additional information below).
Hydrocarbon contamination (see benchmark)	The impacts of hydrocarbon contamination on sediment shores were well documented by Rostron (1998) following the *Sea Empress* oil spill in Milford Haven, Wales and the information in the following section is taken mainly from that report including the references therein. • High mortalities of the cockles *Cerastoderma edule* were reported. In Angle Bay, the presence of juveniles lower down the shore shortly after the spill enabled the reestablishment of adult populations on the middle shore within about six months. • Additional species recorded at Sandy Haven in the summer following the spill included the polychaetes *Pygospio elegans* and *Capitella capitata* and the oligochaete *Tubificoides benedii*. The abundance of *Capitella capitata* increased dramatically at one site. • At one station in Sandy Haven, the amphipod *Corophium volutator* disappeared completely following the *Sea Empress* oil spill. Indeed, Chasse & Morvan (1978, cited in Rostron 1998) calculated that only 10% of these amphipods survived the *Amoco Cadiz* oil spill. • At Angle Bay, a sheltered bay with mixed sandy mud and mud, the cirratulid *Chaetozone gibber* showed a dramatic increase after the spill. However, this success was short lived and the numbers had fallen significantly by the following year. • Populations of *Nephtys hombergii* declined after the oil spill but had recovered by the following year. The decline was probably due to the timing of the breeding season which is late summer in this species. Cirratulids appeared to Suchanek (1993) to be mostly immune to oil spills because their feeding tentacles are protected by a heavy secretion of mucus. This immunity is supported by observations of *Aphelochaeta marioni* following the *Amoco Cadiz* oil spill in March, 1978 (Dauvin, 1982, 2000). Prior to the spill, *Aphelochaeta marioni* (studied as *Tharyx marioni*) was present in very low numbers in the Bay of Morlaix, western English Channel. Following the spill, the level of hydrocarbons in the sediment increased from 10 mg/kg dry sediment to 1443 mg/kg dry sediment 6 months afterwards. In the same period, *Aphelochaeta marioni* increased in abundance to a mean of 76 individuals per m², which placed it among the top five dominant species in the faunal assemblage. It was suggested that the population explosion occurred due to the increased food availability because of accumulation of organic matter resulting from high mortality of browsers. Six years later, abundance of *Aphelochaeta marioni* began to fall away

	again, accompanied by gradual decontamination of the sediments. In light of the evidence for *Cerastoderma edule* and other species, an intolerance of high has been given. Species richness associated with this biotope is likely to decline, albeit temporarily. The loss of the cockles will result in the loss of the biotope but an explosion of opportunistic species may be seen. Recoverability is likely to be high (see additional information).
Radionuclide contamination (see benchmark)	No information concerning the effects of radionuclide contamination on this biotope was found.
Changes in nutrient levels (see benchmark)	Nutrient enrichment may result in increased primary productivity that could increase the amount of food available to both suspension feeders and deposit feeders. However, nutrient enrichment often culminates in eutrophic episodes which usually lead to increased light attenuation (see turbidity) and reduced oxygen concentration (see oxygenation); and increased algal growth often culminates in mats of algae covering the sediment surface. Desprez *et al*. (1992) implicated a eutrophication-induced plankton bloom as the cause behind the decline of *Cerastoderma edule* populations in the Bay of Somme, France. Prior to the event in 1982, densities were several 1000 / m² but by 1982 this had fallen to just a few hundred individuals / m². By 1987, the cockle population had returned. Rosenberg & Loo (1988) suggested that the mass mortalities of *Cerastoderma edule* observed in Laholm Bay, western Sweden during the 1980s were correlated with increased nutrient levels and the associated decrease in oxygen levels during this period. However, no direct causal link was established. Some authors have reported a decline in the abundance of *Cerastoderma edule* under algal mats (Raffaelli *et al*., 1998). Raman & Ganapati (1983) studied the distribution of *Aphelochaeta marioni* (studied as *Tharyx marioni*) in relation to a sewage outfall in Visakhaptnam Harbour, Bay of Bengal. *Aphelochaeta marioni* was found to be dominant in the 'semi-healthy zone' characterized by high dissolved oxygen (median 7.2 mg/l), low biological oxygen demand (9.6 mg/l) and low nutrients (nitrate 0.02 mg/l, phosphate 0.88 mg/l). *Aphelochaeta marioni* was not found in high numbers in the polluted zone close to the sewage outfall, characterized by low dissolved oxygen (median 6.0 mg/l), high biological oxygen demand (14-60 mg/l) and high nutrients (nitrate 0.042-0.105 mg/l, phosphate 2.35-3.76 mg/l). This would suggest that *Aphelochaeta marioni* is intolerant of eutrophication. The oligochaete *Tubificoides benedii* can be found living in abundance under algal mats (Nubilier *et al*., 1997). It is opportunistic and responds to organic pollution by increasing the size of the population (Diaz, 1977, cited in Diaz, 1980). Oligochaetes often become the dominant benthic fauna under algal mats (Raffaelli *et al*., 1998). Estuarine oligochaetes tend to become more abundant in areas where pollution or other physical factors result in a reduced habitat diversity and stressful conditions, concomitant with a decrease in polychaetes species (Diaz, 1980). Barnett (1983) found the maximum abundance of the oligochaete *Tubificoides benedii* at a site which received a significant input of both industrial and domestic effluent, including raw sewage, in the Humber estuary. *Capitella capitata* is often associated with areas of high nutrient enrichment and is generally considered to be tolerant of increased nutrient load (see *MarLIN* Web site). *Corophium volutator* experienced a dramatic decline in abundance under experimental algal mats and it is thought that the mats interfere with its feeding behaviour (Raffaelli *et al*., 1998). However, these amphipods recovered completely following the loss of the mats. Furthermore, *Corophium volutator* are not a characterizing species and their disappearance would not adversely affect the

	recognizable biotope. Overall, it is likely that there will be some mortality within the biotope and an intolerance of intermediate has been suggested accordingly. Recoverability, as evidenced in the French studies above, is considered to high.
Increase in salinity (see benchmark)	Studies on *Cirriformia tentaculata* from Hamble Spit in Southampton recorded that the upper and lower lethal salinities were 52 and 14 ‰ respectively (George, 1964b). In the same study, salinity changes in the top centimetre of mud were found to vary drastically when compared to sediment at a depth of 6-8 cm. For example, the salinity of interstitial water after five and a half hours of hot and sunny weather was 45 ‰ in the top centimetre but almost the same as the surrounding seawater (35 ‰) at 6-8 cm. Similarly, the salinity of interstitial seawater was about 24 ‰ after five hours of heavy rain whereas it was only 33 ‰ at 6-8 cm. Considering many of the polychaetes in this biotope are buried below the top centimetre of sediment or live within tubes above the surface it is likely that they will, to some degree, be buffered against large fluctuations. The fact that this biotope is intertidal also means that the associated fauna have some inherent tolerance to fluctuating salinities to a certain degree. The salinity tolerance of *Tubificoides benedii* (as *Peloscolex benedeni*) ranged from 2.8 to > 34 ‰ at 5 °C and salinity was considered to the primary factor influencing its distribution (Diaz, 1980). Some species within this biotope can tolerate a wide range of salinities including *Cerastoderma edule* (see *MarLIN* Web site) and *Corophium volutator*. *Corophium volutator* has been reported to be able to survive a salinity of 50 ‰ although normal functioning is impaired above 30 ‰ (McLusky, 1967, 1968). Due to the fact that this biotope occurs in variable salinities (ranging from 18-40 psu), an increase in salinity similar to that in the benchmark is unlikely to adversely affect the viability of the associated fauna and tolerant has been recorded.
Decrease in salinity (see benchmark)	Studies on *Cirriformia tentaculata* from Hamble Spit in Southampton found that the upper and lower lethal salinities were 52 and 14 ‰ respectively (George, 1964b). In the same study, salinity changes in the top centimetre of mud were found to vary greatly when compared to sediment at a depth of 6-8 cm. For example, the salinity of interstitial water after five and a half hours of hot and sunny weather was 45 ‰ in the top centimetre but almost the same as the surrounding seawater (35 ‰) at 6-8 cm. Similarly, the salinity of interstitial seawater was about 24 ‰ after five hours of heavy rain whereas it was only 33 ‰ at 6-8 cm. Considering many of the polychaetes in this biotope are buried below the top centimetre of sediment or live within tubes above the surface it is likely that they will, to some degree, be buffered against large fluctuations. The fact that this biotope is intertidal also means that the associated fauna have some inherent tolerance to fluctuating salinities to a certain degree. The salinity tolerance of *Tubificoides benedii* (as *Peloscolex benedeni*) was recorded as ranging from 2.8 to > 34 ‰ at 5 °C and salinity was considered to the primary factor influencing its distribution (Diaz, 1980). Some species within this biotope can tolerate a wide range of salinities including *Cerastoderma edule* (see *MarLIN* Web site) and *Corophium volutator*. *Corophium volutator* is tolerant of a wide range of salinities and it can survive in fresh water for several days (Eltringham, 1971). *Cirratulus cirratus* has a greater tolerance of low salinities than *Cirriformia tentaculata* and is found in areas of lower salinities (George, unpublished, cited in George, 1968). It is possible that over time, if low salinity conditions persisted, the cirratulids may be dominated by *Cirratulus cirratus* instead. Farke (1979) reported that *Aphelochaeta marioni* (studied as *Tharyx marioni*) penetrated into areas exposed to salinities of 4 psu in the German Bight during short periods at low tide when the freshwater discharge from rivers was high. Interestingly, *Aphelochaeta marioni* was found to be more

	tolerant to changing salinities when in sediment but highly intolerant when outside the burrow (Farke, 1979). In the laboratory, transfer of the worm from a Petri dish onto a sediment surface with a difference in salinity of 3-5 ‰ initiated random digging movements. The worms failed to penetrate the substratum and died on the surface within a few hours (Farke, 1979). An acute change in salinity similar to that in the benchmark could therefore cause some mortality, particularly of the less tolerant species, and an intolerance of intermediate has been recorded.
Changes in oxygenation (see benchmark)	Connor *et al.* (1997) described sediments in which the cirratulid *Aphelochaeta marioni* is commonly found as usually having a "black anoxic layer close to the sediment surface". Broom *et al.* (1991) considered *Aphelochaeta marioni* (studied as *Tharyx marioni*) to be characteristic of faunal assemblage of very poorly oxygenated mud in the Severn Estuary. They found that it dominated sediments where the redox potential at 4 cm sediment depth was 56 mV and, therefore, concluded that the species was tolerant of very low oxygen tensions. Thierman *et al.* (1996) studied the distribution of *Aphelochaeta marioni* in relation to hydrogen sulphide concentrations. The species was found to be abundant at low sulphide concentrations (less than 50 µM) but only occasional at concentrations from 75-125 µM. They concluded that *Aphelochaeta marioni* does not display a massively adverse reaction to sulphidic conditions and is able to tolerate a low amount of sulphide. The evidence suggests that *Aphelochaeta marioni* is capable of tolerating hypoxia but it is difficult to determine to what degree. The cirratulid *Cirriformia tentaculata* is reported to have several metabolic adaptations to the hypoxic conditions to which it is periodically subjected (Dales & Warren, 1980; Bestwick *et al*., 1989). The sediment around their burrows is often hydrogen-sulphide rich and therefore a sink for oxygen (Bestwick *et al*., 1989). The adaptations are, firstly, the filamentous branchiae of the worm, that are spread out over the surface of the substratum, are very thin and oxygen uptake can continue during tidal emersion providing the branchiae are covered by a film of water (Bestwick *et al*., 1989). If the branchiae are exposed they may be withdrawn into the burrow at which point the gaseous exchange occurring across the branchial epithelium starts to fall. Secondly, the haemoglobin has an extremely high affinity for oxygen and as the internal oxygen pressure falls, oxygen is released from the haemoglobin store (Dales & Warren, 1980). At an external oxygen pressure of 0.88 mg/l, oxygen uptake stops and the species cannot tolerate anoxia for more than three days (Dales & Warren, 1980). The oligochaete *Tubificoides benedii* also inhabits sulfide rich environments and has a high capacity to tolerate anoxic conditions (Nubilier *et al*., 1997; Giere *et al*., 1999). *Tubificoides benedii* is often buried up to 10 cm deep and so has no contact with the surface but has a highly specialized adaptive physiology that allows it to maintain some oxygen consumption even at 2% (approximately 0.18 mg/l) oxygen saturation of the surrounding environment on the Isle of Sylt. The critical oxygen saturation for *Capitella capitata* is about 7.5 mg/l (Gamenick, 1996, cited in Giere *et al*., 1999). It has been suggested that tolerance to anoxia may be influenced by temperature. *Tubificoides benedii* (studied as *Peloscolex benedeni*) was found to be less tolerant to anoxia as temperature increased (Diaz, 1980). At 20 °C, it took almost 60 hours for half the worms to be killed but at 30 °C it took less than 18 hours. Boyden (1972) reported that when emersed, air breathing *Cerastoderma edule* had a median lethal survival time of 129 hrs, whereas specimens unable to 'breathe' air (i.e. those that had been clamped) or those in an oxygen free environment, had median lethal times of 69 and 75 hrs respectively, indicating that *Cerastoderma edule* was capable of anaerobic respiration. Rosenberg *et al.* (1991) reported 100% mortality of *Cerastoderma edule* exposed to 0.7 - 1.4 mg/l oxygen for 43 days and 98% mortality after 32 days. *Cerastoderma edule* migrated to the

	surface of the sediment in response to decreased oxygen concentrations. Theede *et al.* (1969) reported 50% mortality after 4.25 days at 2.1 mg/l oxygen. Theede *et al.* (1969) also noted that *Cerastoderma edule* only survived 4 days exposure to 0.0-6.1 cm^3 per litre of hydrogen sulphide, which is associated with anoxic conditions. This suggests that *Cerastoderma edule* could survive several days anoxia but it is likely that continued exposure to 2 mg/l oxygen for a week would be lethal. Therefore, despite the tolerance of many of the polychaete species in this biotope to hypoxia, an intolerance of intermediate has been recorded to reflect likely mortality in the cockles. Recoverability is expected to be high (see additional information).
Biological Factors	
Introduction of microbial pathogens/parasites (see benchmark)	Nearly all *Aphelochaeta marioni* (as *Tharyx marioni* individuals from Stonehouse Pool in Plymouth were infected with a sporozoan parasite of the *Gonospora* genus but no evidence was found that the animal was adversely affected by its presence (Gibbs, 1971). Several parasitic species have been associated with the common cockle *Cerastoderma edule* and some are known to cause mortality (see *MarLIN*) review. Boyden (1972) reported castration of 13% of the cockle population in the River Couch estuary due to infestation with larval digenetic trematodes. Therefore, an intolerance of intermediate has been assessed.
Introduction of non-native species (see benchmark)	No information regarding alien species likely to compete or displace any of the species in this biotope was found.
Extraction of key or important characterizing species (see benchmark)	The cockle *Cerastoderma edule* is probably the most widely exploited of all intertidal species harvested by mechanical means (Hall & Harding, 1997). In just one year between 1987 and 1988, landings of *Cerastoderma edule* in the Solway Firth had increased from 234 to 3548 tonnes (Hall & Harding, 1997). Hall & Harding (1997) investigated the effects of mechanical harvesting of cockles on non-target species. Overall, the faunal structure in disturbed plots recovered within 56 days following suction dredging although a 30% decline in the number of species and a 50% decline in the number of individuals of some species was observed. In Burry Inlet, Wales, tractor towed cockle harvesting led to a reduction in density of *Pygospio elegans* (Ferns *et al.*, 2000). In this study, numbers of *Pygospio elegans* and *Hydrobia ulvae* remained significantly reduced for more than 100 days after harvesting and *Nephtys hombergii* for more than 50 days. The effects of the harvesting were found to vary between muddy sand and clean sand with clean sand recovering more quickly in general, due to the higher abundance of mobile species there. *Nephtys hombergii* for example, had recovered back to its previous abundance 56 days after harvesting in the clean sand whereas in the muddy sand the abundance was still only about a third after the same time period. Similar effects were seen in *Pygospio elegans*, *Hydrobia ulvae* and *Cerastoderma edule* but none of these three species had fully recovered more than six months after the dredging. *Capitella capitata* had almost trebled its abundance within the 56 days in the clean sandy area. Experimental bait digging resulted in a significant mortality of *Cerastoderma edule* in dug areas compared to undug areas (48% mortality in 9 days to a maximum of 85% after 11 days) probably due to smothering (Jackson & James, 1979). Smaller individuals were more likely to die than larger ones. Fowler (1999) reported 90% mortality of cockles in areas affected by bait digging, recolonization occurring three months after bait digging, although the cockle population was still different from undisturbed areas. Jackson & James (1979) pointed out that bait digging disturbs sediment to a depth of 30-40 cm and probably buries many cockles below 10 cm and surface exposure of others that are then taken by predators. They suggested that bait digging was involved in the decline in the cockle fishery on the north Norfolk Coast in the 1950s and 60s.

	Therefore, cockles are probably of intermediate intolerance to bait digging although smaller individuals may be more intolerant. In years of good recruitment recovery may occur within a year, however, recruitment is sporadic (see reproduction) and may take longer in 'bad' years.
Extraction of important species (see benchmark)	There are no species within this biotope that are considered to be important structural or functional species and this section is therefore not relevant.

Additional information

Recoverability

Many cirratulids are thought to have direct development so that dispersal is likely to be low (see section on recruitment processes). George (1968) discussed possible recolonization in the two cirratulids *Cirratulus cirratus* and *Cirriformia tentaculata* in the British Isles. Following the disappearance of this species from Sussex after the severe winter of 1962-63, he suggested that *Cirratulus cirratus* probably existed subtidally in such small numbers that it could not maintain itself once replenishment from the shore population had ceased. With regards to *Cirriformia tentaculata*, it was concluded that recolonization by this species will take place by marginal dispersal rather than remote dispersal (Crisp, 1958, cited in George, 1968) and that it was likely to take several decades with mild winters before its distribution returns to that prior to 1962/63 (George, 1968). Farke (1979) implied that *Aphelochaeta marioni* (studied as *Tharyx marioni*) became dominant in areas of the German Bight, where it was previously absent, in only a few years. On balance, however, the recoverability of cirratulids is therefore likely to be low.

Cockle recruitment is known to be sporadic and highly variable. *Cerastoderma edule* first matures and spawn in its second summer (see section on recruitment processes). Settlement and subsequent recruitment is sporadic and varies with geographic location, year, season, reproductive condition of the adults and climatic variation, intra and interspecific mortality and predation. Recovery is dependant on recruitment of spat or migration (active or passive) from the surrounding substratum. In Angle Bay, Milford Haven, the presence of juvenile *Cerastoderma edule* on the lower shore shortly after the *Sea Empress* oil spill enabled the re-establishment of adult populations on the middle shore within about six months (Rostron, 1998). Coffen-Smout & Rees (1999) reported that cockles could be distributed by flood and ebb tides and could colonize cleared areas at a rate of 2.2 -12 individuals/m² /14 days. Hall & Harding (1997) found that *Cerastoderma edule* abundance had returned to control levels within about 56 days after significant mortality due to suction dredging, and Moore (1991) also suggested that recovery was rapid. It seems likely therefore that the population could recover within a year, however, given the sporadic nature of recruitment in *Cerastoderma edule*, recovery may be more protracted.

With regard to the recovery of other important characterizing species, little information was found. However, it is known that *Pygospio elegans* normally omit the planktonic larval stage (Rostron, 1998) and *Tubificoides benedii* is sluggish and does not posses the capability to liberate large numbers of planktonic larvae for dispersal (Barnett, 1983).

On balance, recoverability of some of the characterizing species, especially the cirratulids, may be low whereas others may be high. Providing some local populations of cirratulids remained then recovery, from impacts to which the biotope is highly sensitive, should occur within 10 years. The recovery of some other fauna, including *Cerastoderma edule* (albeit sporadic) is considered to be more rapid and where such species are intolerant to certain factors and experience loss of some of the population, recovery is likely to remain high.

Species used to indicate biotope intolerance

To assess the sensitivity of the biotope, the sensitivity of component species is reviewed. Those species that are considered to be particularly indicative of the sensitivity of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors			
	Aphelochaeta marioni	***Cerastoderma edule***	***Corophium volutator***
Community Importance	Important characterizing	Important characterizing	Important other
Substratum Loss	High	High	High
Smothering	Low	Intermediate	High
Increase in suspended sediment	Not Sensitive*	Low	Intermediate
Decrease in suspended sediment	Low	See explanation	Not Sensitive
Desiccation	Not Relevant	Intermediate	Not Sensitive
Increase in emergence regime	Intermediate	Intermediate	Intermediate
Decrease in emergence regime	Not Sensitive	See explanation	Not Sensitive
Increase in water flow rate	Intermediate	Intermediate	High
Decrease in water flow rate	Not Sensitive*	See explanation	Not Relevant
Increase in temperature	Low	Intermediate	Low
Decrease in temperature	Low	See explanation	Low
Increase in turbidity	Low	Not Sensitive	Not Sensitive
Decrease in turbidity	Not Sensitive	See explanation	Not Sensitive
Increase in wave exposure	High	Intermediate	Intermediate
Decrease in wave exposure	Not Sensitive	See explanation	Not Sensitive
Noise	Not Sensitive	Not Sensitive	Not Sensitive
Visual Presence	Low	Not Sensitive	Not Relevant
Abrasion & physical disturbance	Intermediate	Intermediate	Intermediate
Displacement	Not Sensitive	Low	Not Sensitive
Chemical factors			
	Aphelochaeta marioni	***Cerastoderma edule***	***Corophium volutator***
Community Importance	Important characterizing	Important characterizing	Important other
Synthetic compound contamination	High	Intermediate	High
Heavy metal contamination	Low	Intermediate	High
Hydrocarbon contamination	Not Sensitive*	Intermediate	High
Radionuclide contamination	Insufficient information	Insufficient information	Low
Changes in nutrient levels	Intermediate	Intermediate	High
Increase in salinity	Not Sensitive	Low	Not Sensitive
Decrease in salinity	Not Sensitive	See explanation	Not Sensitive
Changes in oxygenation	Low	High	High
Biological factors			
	Aphelochaeta marioni	***Cerastoderma edule***	***Corophium volutator***
Community Importance	Important characterizing	Important characterizing	Important other
Introduction of microbial pathogens/parasites	Low	Intermediate	Insufficient information
Introduction of non-native species	Insufficient information	Insufficient information	Insufficient information
Extraction of this species	Not Relevant	Intermediate	Not Relevant
Extraction of other species	Intermediate	High	Intermediate

Species used to indicate biotope recoverability

To assess the recoverability of the biotope, the recoverability of component species is reviewed. Those species that are considered to be particularly indicative of the recoverability of the biotope, and for which research has been undertaken in detail are shown below (See Appendix 3).

Physical factors			
	Aphelochaeta marioni	***Cerastoderma edule***	***Corophium volutator***
Community Importance	Important characterizing	Important characterizing	Important other
Substratum Loss	High	High	High
Smothering	Immediate	High	High
Increase in suspended sediment	Not Relevant	Immediate	High
Decrease in suspended sediment	Immediate	See explanation	Not Relevant
Desiccation	Not Relevant	High	Not Relevant
Increase in emergence regime	High	High	Very high
Decrease in emergence regime	Not Relevant	See explanation	Not Relevant
Increase in water flow rate	High	High	High
Decrease in water flow rate	Not Relevant	See explanation	Not Relevant
Increase in temperature	Very high	High	Very high
Decrease in temperature	Very high	See explanation	Very high
Increase in turbidity	Very high	Not Relevant	Not Relevant
Decrease in turbidity	Not Relevant	See explanation	Not Relevant
Increase in wave exposure	High	High	High
Decrease in wave exposure	Not Relevant	See explanation	Not Relevant
Noise	Not Relevant	Not Relevant	Not Relevant
Visual Presence	Immediate	Not Relevant	Not Relevant
Abrasion & physical disturbance	High	High	Very high
Displacement	Not Relevant	High	Not Relevant
Chemical factors			
	Aphelochaeta marioni	***Cerastoderma edule***	***Corophium volutator***
Community Importance	Important characterizing	Important characterizing	Important other
Synthetic compound contamination	High	High	Very high
Heavy metal contamination	Very high	High	High
Hydrocarbon contamination	Not Relevant	High	High
Radionuclide contamination	Not Relevant	Insufficient information	Very high
Changes in nutrient levels	High	High	Very high
Increase in salinity	Not Relevant	Very high	None
Decrease in salinity	Not Relevant	See explanation	Not Relevant
Changes in oxygenation	Very high	High	Very high
Biological factors			
	Aphelochaeta marioni	***Cerastoderma edule***	***Corophium volutator***
Community Importance	Important characterizing	Important characterizing	Important other
Introduction of microbial pathogens/parasites	Very high	High	Insufficient information
Introduction of non-native species	Not Relevant	Insufficient information	Insufficient information
Extraction of this species	Not Relevant	High	Not Relevant
Extraction of other species	High	High	Very high

Importance

Marine natural heritage importance

National importance Rare

Biotope importance

The polychaetes and bivalves that dominate this biotope provide an important food source for several species of fish, including the sand goby *Pomatoschistus minutus*, sole *Solea solea* and plaice *Pleuronectes platessa* (Hayward, 1994). The associated fauna are also likely to provide food for many species or waders and over-wintering birds. The redshank *Tringa totanus*, for example, feeds on *Hydrobia ulvae*, *Nephtys hombergii* and *Corophium volutator*, the latter representing its preferred prey (Goss-Custard, 1977a,b).

Exploitation

The cockle *Cerastoderma edule* is probably the most widely exploited of all intertidal species harvested by mechanical means (Hall & Harding, 1997). In just one year between 1987and 1988, landings of *Cerastoderma edule* in the Solway Firth had increased from 234 to 3548 tonnes (Hall & Harding, 1997). Cockle beds are usually highly accessible which makes them even more vulnerable to exploitation. Cockles can be taken by mechanical means, such as suction dredging or tractor dredging, or by hand and their collection often has an impact on non-target species (see sensitivity).

Additional information

No text entered

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