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Grazed *Laminaria hyperborea* forest with coralline crusts on upper infralittoral rock

MarLIN – Marine Life Information Network
Marine Evidence-based Sensitivity Assessment (MarESA) Review

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2015-11-30

A report from:

The Marine Life Information Network, Marine Biological Association of the United Kingdom.

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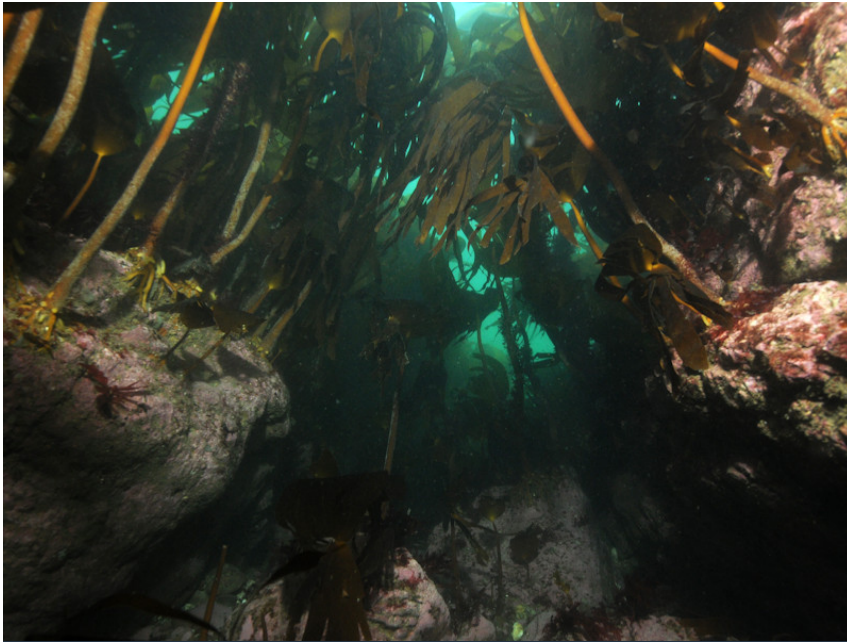
This review can be cited as:

Stamp, T.E. & Hiscock, K. 2015. Grazed [*Laminaria hyperborea*] forest with coralline crusts on upper infralittoral rock. In Tyler-Walters H. and Hiscock K. (eds) *Marine Life Information Network: Biology and Sensitivity Key Information Reviews*, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. DOI <https://dx.doi.org/10.17031/marlinhab.333.1>



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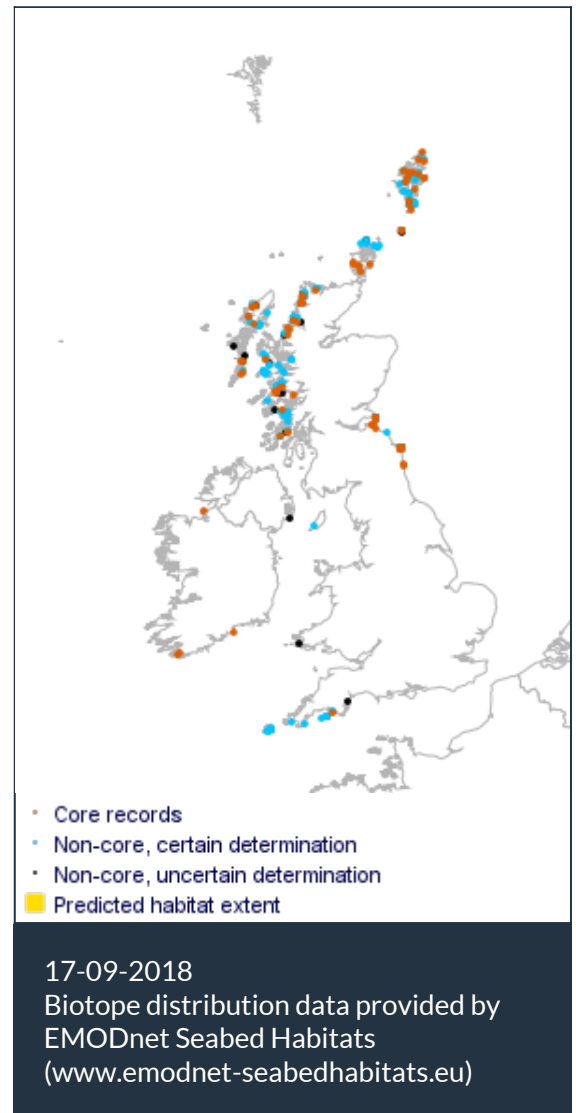
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Grazed *Laminaria hyperborea* forest with coralline crusts on upper infralittoral rock

Photographer: Keith Hiscock

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Researched by Thomas Stamp and Dr Keith Hiscock

Refereed by This information is not refereed.

Summary

☰ UK and Ireland classification

EUNIS 2008 A3.2143

Grazed *Laminaria hyperborea* forest with coralline crusts on upper infralittoral rock

JNCC 2015 IR.MIR.KR.Lhyp.GzFt

Grazed *Laminaria hyperborea* forest with coralline crusts on upper infralittoral rock

JNCC 2004 IR.MIR.KR.Lhyp.GzFt

Grazed *Laminaria hyperborea* forest with coralline crusts on upper infralittoral rock

1997 Biotope IR.MIR.GzK.LhypGz.Ft

Grazed *Laminaria hyperborea* forest with coralline crusts on upper infralittoral rock

🔍 Description

Exposed and moderately exposed kelp forest in some areas is intensely grazed by the urchin *Echinus esculentus*. The rock surface lacks any significant turf of foliose seaweeds and generally

looks bare, though it is covered by coralline algal crusts. The kelp stipes may or may not be grazed; in the most extremely grazed areas, they too are devoid of epiphytic seaweeds. More usually, however, the stipes offer a refuge from grazing, and are characterized by dense turfs of red seaweeds, especially *Phycodrys rubens*, *Palmaria palmata*, *Membranoptera alata* and *Delesseria sanguinea*. The fauna within a grazed kelp forest is also relatively sparse, though some species will survive in cracks and crevices, or other areas that are protected from grazing. In wave-exposed steep rocky areas, the shallowest water may be characterized by a forest of kelp with red seaweeds (EIR.LhypR.Ft), with a grazed kelp forest beneath. This effect may be a result of the increased wave action in shallower water which regularly dislodges the urchins thereby reducing their impact. With increasing depth, the kelp forest grades into a grazed kelp park (MIR.LhypGz.Pk), the lower limit of which is often abrupt, which represents the balance point between urchin grazing pressure and algal growth capabilities.

↓ Depth range

-

Additional information

Survey results are most often referred to one of the sub-biotopes: MIR.LhypGz.Ft (Grazed [Laminaria hyperborea](#) forest with coralline crusts on upper infralittoral rock), or MIR.LhypGz.Pk (Grazed *Laminaria hyperborea* park with coralline crusts on lower infralittoral rock); both of which have been included in research here.

✓ Listed By

- none -

Further information sources

Search on:



Habitat review

🔄 Ecology

Ecological and functional relationships

Kelps are major primary producers. Up to 90% of kelp production enters the detrital food web and kelp is probably a major contributor of organic carbon to surrounding communities (Birkett *et al.*, 1998b). Kelp beds are diverse species rich habitats and over 1,800 species have been recorded in the UK kelp biotopes (Birkett *et al.*, 1998b). Kelp communities and the interaction between kelp, urchins and predators has been studied in Nova Scotia, Norway, southern California and the UK (Kain, 1979; Mann, 1982; Schiel & Foster, 1986; Elner & Vadas, 1990; Vadas & Elner, 1992; Sivertsen, 1997). The following are important ecological relationships.

- Sea-urchins graze rock surfaces including juvenile kelp sporophytes, together with epiphytes and epifauna on laminarian stipes. It is sea urchin grazing that gives the rocks their bare appearance below the kelp. Grazing may prevent potentially dominant species from becoming established and therefore facilitate species richness. Vost (1983) examined the effect of removing grazing *Echinus esculentus* and found that after 6-10 months the patchiness of the understory algae had decreased and the species richness and biomass of epilithic species increased. *Strongylocentrotus droebachiensis* and *Paracentrotus lividus* also graze kelp beds but are less common in the British Isles than *Echinus esculentus*. *Echinus esculentus* grazing probably controls the lower limit of *Laminaria hyperborea* distribution in some locations, e.g. in the Isle of Man (Jones & Kain, 1967; Kain *et al.*, 1975; Kain, 1979).
- Epifauna is more developed on vertical surfaces, under overhangs or boulders and in crevices inaccessible to grazing sea urchins.
- 25 years, If intensive urchin grazing (as seen in Northern Norway) occurs in the UK resilience would be re-assessed as Very Low. However, because of the limited/localised incidence of urchin grazing within the UK, urchin grazing on large scales (as in Northern Norway) has not been included in this general resilience assessment. The introduction of Invasive Non-Indigenous Species (INIS) will also inhibit the recovery of *Laminaria hyperborea* biotopes for an indeterminate amount of time, in these cases resilience would need to be re-assessed as Very Low. Another factor that is beyond the scope of this sensitivity assessment is the presence of multiple concurrent synergistic or cumulative effects, which Smale *et al.*, (2013) suggests could be a more damaging than the individual pressures.

Hydrological Pressures

	Resistance	Resilience	Sensitivity
Temperature increase (local)	Medium Q: High A: High C: High	Medium Q: High A: High C: High	Medium Q: High A: High C: High

Kain (1964) stated that *Laminaria hyperborea* sporophyte growth and reproduction could occur within a temperature range of 0 - 20°C. Upper and lower lethal temperatures have been estimated at between 1-2°C above or below the extremes of this range (Birkett *et al.*, 1988). Above 17°C gamete survival is reduced (Kain, 1964 & 1971) and gametogenesis is inhibited at 21°C (Dieck, 1992). It is, therefore, likely that

Laminaria hyperborea recruitment will be impaired at a sustained temperature increase of above 17°C. Sporophytes, however, can tolerate slightly higher temperatures of 20°C. Temperature tolerances for *Laminaria hyperborea* are also seasonally variable and temperature changes are less tolerated in winter months than summer months (Birkett *et al.*, 1998).

Subtidal red algae are less tolerant of temperature extremes than intertidal red algae, surviving between -2°C and 18-23 °C (Lüning 1990; Kain & Norton, 1990).

Temperature increase may affect growth, recruitment or interfere with reproduction processes. For example, there is some evidence to suggest that blade growth in *Delesseria sanguinea* is delayed until ambient sea temperatures fall below 13 °C. Blade growth is also likely to be intrinsically linked to gametangia development (Kain, 1987), and maintenance of sea temperatures above 13 °C may affect recruitment success.

Increases in sea temperature are also likely to create a northward range contraction of *Laminaria hyperborea* (Brodie *et al.*, 2014), and may inhibit competitive ability at the southern edge of *Laminaria hyperborea*' range. *Laminaria hyperborea* may be out-competed by the Invasive Non-Indigenous Species (INIS) *Undaria pinnatifida* (Brodie *et al.*, 2014; Heiser *et al.*, 2014) and/or its' Lusitanian competitor-*Laminaria ochroleuca* (Smale *et al.*, 2014) along the south coast of the UK (see sub-biotopes IR.HIR.KFaR.LhypR.Loch & IR.LIR.K.LhypLoch). The ecological impacts of such invasions could fundamentally alter *Laminaria hyperborea* habitat structure and limit recovery, however at the time of writing these effects are largely unknown (Brodie *et al.*, 2014; Smale *et al.*, 2014).

Bishop (1985) suggested that *Echinus esculentus* cannot tolerate high temperatures for prolonged periods due to increased respiration rate and resultant metabolic stress. Ursin (1960) reported *Echinus esculentus* occurred at temperatures between 0-18°C in Limfjord, Denmark. Bishop (1985) noted that gametogenesis occurred at 11-19°C however, continued exposure to 19°C disrupted gametogenesis. Embryos and larvae developed abnormally after 24hr exposure to 15°C but normally at 4, 7 and 11°C (Tyler & Young 1998).

Sensitivity assessment. This biotope is distributed throughout the UK (Connor *et al.*, 2004). Northern to southern Sea Surface Temperature (SST) ranges from 8-16°C in summer and 6-13°C in winter (Beszczynska-Möller & Dye, 2013). Overall, a chronic change (2°C for a year) outside the normal range for a year may reduce *Laminaria hyperborea* recruitment and growth, resulting in a minor loss in the population of kelp, especially in winter months or in southern examples of the biotope. However, an acute change (5°C for a month; e.g. from thermal effluent) may result in loss of abundance of kelp or extent of the bed, especially in winter. An increase in sea surface temperature of 2°C for a period of 1 year combined with high temperatures may approach the upper temperature threshold of *Echinus esculentus*. Therefore, resistance to the pressure is considered '**Medium**', and resilience '**Medium**'. The sensitivity of this biotope to increases in temperature has been assessed as '**Medium**'.

Temperature decrease
(local)

High

Q: High A: High C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: High

Kain (1964) stated that *Laminaria hyperborea* sporophyte growth and reproduction could occur within a temperature range of 0 - 20°C. Upper and lower lethal temperatures have been estimated at between 1-2 °C above or below the extremes of this range (Birkett *et al.*, 1988). Subtidal red algae can survive at temperatures between -2 °C and 18-23 °C (Lüning, 1990; Kain & Norton, 1990). *Laminaria hyperborea* is a boreal northern species with a geographic range from mid-Portugal to Northern Norway (Birkett *et al.*, 1998), and a mid range within southern Norway (60°-65° North)(Kain, 1971).

Echinus esculentus has been recorded from the Murmansk Coast, Russia. Due to the high latitude at which *Echinus esculentus* can occur it is unlikely to be affected at the pressure benchmark.

Sensitivity assessment. This biotope is distributed throughout the UK (Connor *et al.*, 2004). Northern to southern Sea Surface Temperature (SST) ranges from 8-16°C in summer and 6-13°C in winter (Beszczynska-Möller & Dye, 2013). The available information suggests the key characterizing species of this biotope would not be affected. Resistance to the pressure is considered '**High**', and resilience '**High**'. The sensitivity of this biotope to decreases in temperature has been assessed as '**Not Sensitive**'.

Salinity increase (local) Low Medium Medium
 Q: Low A: NR C: NR Q: High A: Medium C: High Q: Low A: NR C: NR

Lüning (1990) suggest that 'kelps' are stenohaline, their general tolerance to salinity as a phenotypic group covering 16 - 50 PSU over a 24 hr period. Optimal growth probably occurs between 30-35 PSU (MNCR category- 'Full' salinity) and growth rates are likely to be affected by periodic salinity stress. Birkett *et al.*, (1998) suggested that long-term increases in salinity may affect *Laminaria hyperborea* growth and may result in loss of affected kelp, and, therefore, loss of the biotope.

Echinoderms are generally stenohaline and possess no osmoregulatory organ (Booolootian, 1966). Therefore, an increase in salinity may cause *Echinus esculentus* mortality. *Alcyonium digitatum*' distribution and the depth at which it occurs also suggest it would not likely experience regular salinity fluctuations and therefore not tolerate significant increases in salinity

Sensitivity assessment. Resistance to the pressure is considered '**Low**', and resilience '**Medium**'. The sensitivity of this biotope to an increase in salinity has been assessed as '**Medium**'.

Salinity decrease (local) Low Medium Medium
 Q: Medium A: Medium C: Medium Q: High A: Medium C: High Q: Medium A: Medium C: Medium

Lüning (1990) suggest that 'kelps' are stenohaline, their general tolerance to salinity as a phenotypic group covering 16 - 50 PSU over a 24 hr period. Optimal growth probably occurs between 30-35 PSU (MNCR category-Full Salinity) and growth rates are likely to be affected by periodic salinity stress. Birkett *et al.* (1998) suggest that long-term changes in salinity may result in loss of affected kelp and, therefore, loss of

this biotope.

Hopkin & Kain (1978) tested *Laminaria hyperborea* sporophyte growth at various low salinity treatments. The results showed that *Laminaria hyperborea* sporophytes could grow 'normally' at 19 PSU, growth was reduced at 16 PSU and did not grow at 7 PSU. A decrease in one MNCR salinity scale from 'Full' salinity (30-40psu) to 'Reduced' salinity (18-30 PSU) would result in a decrease of *Laminaria hyperborea* sporophyte growth.

Echinoderms are generally unable to tolerate low salinity (stenohaline) and possess no osmoregulatory organ (Booolootian, 1966). At low salinity, urchins gain weight, and the epidermis loses its pigment as patches are destroyed; prolonged exposure is fatal. However, within *Echinus esculentus*, there is some evidence to suggest intracellular regulation of osmotic pressure due to increased amino acid concentrations. Furthermore, as highlighted the Marine Nature Conservation Review (MNCR) records of 23rd Oct 2014 show *Echinus esculentus* is found within a number of variable and reduced salinity biotopes, e.g. IR.LIR.KVS.SlatPsaVS.

Sensitivity assessment. Resistance to the pressure is considered 'Low', and resilience 'Medium'. The sensitivity of this biotope to decreases in salinity has been assessed as 'Medium'.

Water flow (tidal current) changes (local)

High

Q: High A: High C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: High

Kregting *et al.* (2013) measured *Laminaria hyperborea* blade growth and stipe elongation from an exposed and a sheltered site in Strangford Lough, Ireland, from March 2009-April 2010. Maximal significant wave height (Hm0) was 3.67 & 2m at the exposed and sheltered sites, and maximal water velocity (Velrms) was 0.6 & 0.3m/s at the exposed and sheltered sites respectively. Despite the differences in wave exposure and water velocity, there was no significant difference in *Laminaria hyperborea* growth between the exposed and sheltered sites. Therefore, water flow was found to have no significant effect on *Laminaria hyperborea* growth at the observed range of water velocities.

Biotope structure is, however, different between wave exposed and sheltered sites. Pederson *et al.* (2012) observed *Laminaria hyperborea* biomass, productivity and density increased with an increase in wave exposure. At low wave exposure, *Laminaria hyperborea* canopy forming plants were smaller, had lower densities and had higher mortality rates than at exposed sites. At low wave exposure Pederson *et al.* (2012) suggested that high epiphytic loading on *Laminaria hyperborea* impaired light conditions, nutrient uptake, and increased the drag on the host *Laminaria hyperborea* during extreme storm events.

The morphology of the stipe and blade of kelps vary with water flow. In wave exposed areas, for example, *Laminaria hyperborea* develops a long and flexible stipe and this is probably a functional adaptation to strong water movement (Sjøtun *et al.*, 1998). In addition, the lamina becomes narrower and thinner in strong currents (Sjøtun & Fredriksen, 1995). However, the stipe of *Laminaria hyperborea* is relatively stiff and can snap in strong currents. *Laminaria hyperborea* is usually absent from areas

of high wave action or strong currents, although it is found in the Menai Strait, Wales, where tidal velocities can exceed 4 m/s (NBN, 2015) and in tidal rapids in Norway (J. Jones, pers. comm.) *Laminaria hyperborea* growth can persist in very strong tidal streams (>3 m/s).

Increase water flow rate may also remove or inhibit grazers including *Patella pellucida* and *Echinus esculentus* and remove epiphytic algae growth (Pederson *et al.*, 2012). The associated algal flora and suspension feeding faunal populations change significantly with different water flow regimes. Increased water flow rates may reduce the understory epiflora, to be replaced by an epifauna dominated community (e.g. sponges, anemones and polyclinid ascidians) as in the biotope IR.HIR.KFaR.LhypFa. The composition of the holdfast fauna may also change, e.g. energetic or sheltered water movements favour different species of amphipods (Moore, 1985).

IR.HIR.KFaR.LhypR, IR.HIR.KFaR.LhypFa, IR.MIR.KR.Lhyp, and their associated sub-biotopes are found within strong (1.5-3 m/s)-moderate (0.5-1.5 m/s) tidal streams. A change in peak mean spring bed flow velocity which does not result in a change in tidal streams above or below 0.5-3 m/s is not likely to affect the dominance of *Laminaria hyperborea* within the community, but may cause changes in the understory community. The prominent understory filter feeding community within IR.HIR.KFaR.LhypFa is reliant on high water movement. A decrease in tidal streams may result in a decline of filter feeding fauna and an increase in red seaweeds within the understory community or vice versa with an increase in tidal streams

Echinus esculentus occurred in kelp beds on the west coast of Scotland in currents of about 0.5 m/sec. Outside the beds specimens were occasionally seen being rolled by the current (Comely & Ansell, 1988), which may have been up to 1.4 m/sec. Urchins are removed from the stipe of kelps by wave and current action. *Echinus esculentus* are also displaced by storm action. After disturbance *Echinus esculentus* migrates up the shore, an adaptation to being washed to deeper water by wave action (Lewis & Nichols, 1979). Therefore, increased water flow may remove the population from the affected area; probably to deeper water although individuals would probably not be killed in the process and could recolonize the area quickly.

Sensitivity assessment. A change in peak mean spring bed flow velocity of between 0.1m/s to 0.2m/s for more than 1 year is not likely to affect the dominance of *Laminaria hyperborea*, however, subtle differences in tidal regime may influence the understory community. *Echinus esculentus* may become dislodged but are unlikely to be killed and may recolonize quickly Resistance to the pressure is considered 'High', and resilience 'High'. Hence, the sensitivity of this biotope to changes in peak mean spring bed velocity has been assessed as 'Not Sensitive'.

Emergence regime changes

Low

Q: Low A: NR C: NR

Medium

Q: High A: Low C: High

Medium

Q: Low A: Low C: Low

The upper limit of the *Laminaria hyperborea* bed is determined by wave action and water flow, desiccation, and competition from the more emergence resistant *Laminaria digitata*. *Laminaria hyperborea* exposed at extreme low water are very intolerant of desiccation, the most noticeable effect being bleaching of the frond and subsequent death of the meristem and loss of the plant. An increase in wave exposure

(see below- water flow), as a result of increased emergence, has been found to exclude *Laminaria hyperborea* from shallow waters due to dislodgement of the sporophyte or snapping of the stipe (Birket *et al.*, 1998). Hence, an increase in emergence is likely to lead to mortality of exposed *Laminaria hyperborea* and the associated habitat.

An increase in water depth/decreased emergence (at the benchmark level) may increase the upper depth restriction of *Laminaria hyperborea* forest biotope variants. However, limited light availability at depth will decrease the lower extent of *Laminaria hyperborea*, and may, therefore, result in a shift from forest to park biotope variants at depth. Further increases in depth will cause a community shift to that characterized by circalittoral faunal species, however, this is beyond the scope of the benchmark.

Several mobile species such as sea urchins, brittle stars and feather stars are likely to move away. However, providing that suitable substrata are present, the biotope could re-establish further down the shore within a similar emergence regime to that which existed previously. Similarly, a decrease in emergence may allow the biotope to extend its extent up the shore, however, completion from other species would probably erode its lower extent.

Sensitivity assessment. Resistance to the pressure is considered 'Low', and resilience 'Medium'. The sensitivity of this biotope to changes in tidal emergence has been assessed as 'Medium'.

Wave exposure changes (local)

High

Q: High A: High C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: High

Kregting *et al.*, (2013) measured *Laminaria hyperborea* blade growth and stipe elongation from an exposed and a sheltered site in Strangford Lough, Ireland from March 2009-April 2010. Wave exposure was found to be between 1.1. to 1.6 times greater between the exposed and sheltered sites. Maximal significant wave height (Hm0) was 3.67 & 2 m at the exposed and sheltered sites. Maximal water velocity (Velrms) was 0.6 & 0.3m/s at the exposed and sheltered sites. Despite the differences in wave exposure and water velocity, there was no significant difference in *Laminaria hyperborea* growth between the exposed and sheltered site.

Biotope structure is, however, different between wave exposed and sheltered sites. Pederson *et al.*, (2012) observed *Laminaria hyperborea* biomass, productivity and density increased with an increase in wave exposure. At low wave exposure, *Laminaria hyperborea* canopy forming plants were smaller, had lower densities and had higher mortality rates than at exposed sites. At low wave exposure high epiphytic loading on *Laminaria hyperborea* was theorised to impair light conditions, nutrient uptake, and increase the drag of the host *Laminaria hyperborea* during extreme storm events.

The morphology of the stipe and blade of kelps vary with water flow. In wave exposed areas, for example, *Laminaria hyperborea* develops a long and flexible stipe and this is probably a functional adaptation to strong water movement (Sjötun, 1998). In addition, the lamina becomes narrower and thinner in strong currents (Sjötun & Fredriksen, 1995). However, the stipe of *Laminaria hyperborea* is relatively stiff and

can snap in strong currents. *Laminaria hyperborea* is usually absent from areas of extreme wave action and can be replaced by *Alaria esculenta*. In extreme wave exposures *Alaria esculenta* can dominate the shallow sub-littoral to a depth of 15m (Birket *et al.*, 1998).

Increase water flow rate may also remove or inhibit grazers including *Patella pellucida* and *Echinus esculentus* and remove epiphytic algae growth (Pederson *et al.*, 2012). The associated algal flora and suspension feeding faunal populations change significantly with different water flow regimes. Increased water flow rates may reduce the understory epiflora, to be replaced by an epifauna dominated community (e.g. sponges, anemones and polyclinid ascidians) as in the biotope IR.HIR.KFaR.LhypFa. The composition of the holdfast fauna may also change, e.g. energetic or sheltered water movements favour different species of amphipods (Moore, 1985).

IR.HIR.KFaR.LhypR, IR.HIR.KFaR.LhypFa, IR.MIR.KR.Lhyp, and their associated sub-biotopes are found between extremely exposed to moderate wave exposure. Changes in local wave height above or below that experienced in extremely exposed to moderately exposed sites will affect the dominance of *Laminaria hyperborea*. Smaller changes in local wave height have the potential to cause changes to the understory community. The prominent understory filter feeding community within IR.HIR.KFaR.LhypFa is reliant on wave surge currents. A decrease in wave surge may result in a decline of filter feeding fauna and an increase in red seaweeds within the understory community or vice versa.

Echinus esculentus occurred in kelp beds on the west coast of Scotland in currents of about 0.5 m/sec. Outside the beds specimens were occasionally seen being rolled by the current (Comely & Ansell, 1988), which may have been up to 1.4 m/sec. Urchins are removed from the stipe of kelps by wave and current action. *Echinus esculentus* are also displaced by storm action. After disturbance *Echinus esculentus* migrates up the shore, an adaptation to being washed to deeper water by wave action (Lewis & Nichols, 1979). Keith Hiscock (pers. comm.) reported *Echinus esculentus* occurred in significant numbers as shallow as 15m below low water at the extremely wave exposed site of Rockall, Scotland. Therefore, localised increases in wave height may remove the population from the affected area; probably to deeper water although individuals would probably not be killed in the process and could recolonize the area quickly.

Sensitivity assessment. A change in nearshore significant wave height >3% but <5% is, however, unlikely to have a significant effect. Resistance to the pressure is considered 'High', and resilience 'High'. Hence, the sensitivity of this biotope to changes in local wave height has been assessed as 'Not Sensitive'.

Chemical Pressures

	Resistance	Resilience	Sensitivity
Transition elements & organo-metal contamination	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

This pressure is **Not assessed** but evidence is presented where available.

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. Similarly, Hopkin & Kain (1978) demonstrated sub-lethal effects of heavy metals on *Laminaria hyperborea* gametophytes and sporophytes, including reduced growth and respiration. Sheppard *et al.*, (1980) noted that increasing levels of heavy metal contamination along the west coast of Britain reduced species number and richness in holdfast fauna, except for suspension feeders which became increasingly dominant. Gastropods may be relatively tolerant of heavy metal pollution (Bryan, 1984). *Echinus esculentus* recruitment is likely to be impaired by heavy metal contamination due to the intolerance of its larvae. *Echinus esculentus* are long-lived and poor recruitment may not reduce grazing pressure in the short-term. Although macroalgae species may not be killed, except by high levels of contamination, reduced growth rates may impair the ability of the biotope to recover from other environmental disturbances.

Little is known about the effects of heavy metals on echinoderms. Bryan (1984) reported that early work had shown that echinoderm larvae were sensitive to heavy metals contamination, for example Migliaccio *et al.* (2014) reported exposure of *Paracentrotus lividus* larvae to increased levels of cadmium and manganese caused abnormal larval development and skeletal malformations. Kinne (1984) reported developmental disturbances in *Echinus esculentus* exposed to waters containing 25 µg / l of copper (Cu).

Hydrocarbon & PAH contamination

Not Assessed (NA)
Q: NR A: NR C: NR

Not assessed (NA)
Q: NR A: NR C: NR

Not assessed (NA)
Q: NR A: NR C: NR

This pressure is **Not assessed** but evidence is presented where available.

Laminaria hyperborea fronds, being almost exclusively subtidal, would not come into contact with freshly released oil, but only to sinking emulsified oil and oil adsorbed onto particles (Birket *et al.*, 1998). The mucilaginous slime layer coating of laminarians may protect them from smothering by oil. Hydrocarbons in solution reduce photosynthesis and may be algicidal. However, Holt *et al.* (1995) reported that oil spills in the USA and from the *Torrey Canyon* had little effect on kelp forests. 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). An assessment of holdfast fauna in *Laminaria* showed that although species richness and diversity decreased with increasing proximity to the *Sea Empress* oil spill, overall the holdfasts contained a reasonably rich and diverse fauna, even though oil was present in most samples (Sommerfield & Warwick, 1999). Laboratory studies of the effects of oil and dispersants on several red algae species, including *Delesseria sanguinea* (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. Holt *et al.* (1995) concluded that *Delesseria sanguinea* is probably generally sensitive of chemical contamination. Overall the red algae are likely to be highly intolerant to hydrocarbon contamination. Loss of red algae is likely to reduce the species richness and diversity of the biotope and the understory may become dominated by encrusting corallines; however, red algae are likely to recover relatively quickly.

Echinus esculentus is subtidal and unlikely to be directly exposed to oil spills. However, as with the *Prestige* oil spill rough seas can cause mixing with the oil and the seawater, and therefore subtidal habitats can be affected by the oil spill. Castège *et al.* (2014) recorded the recovery of rocky shore communities following the *Prestige* oil spill which impacted the French Atlantic coast. Rough weather at the time of the spill increased mixing between the oil and seawater, causing sub-tidal communities/habitats to be affected. The urchin *Echinus esculentus* was reported absent after the oil spill however returned after 2-5 years. Large numbers of dead *Echinus esculentus* were found between 5.5 and 14.5 m in the vicinity of Sennen cove, presumably due to a combination of wave exposure and heavy spraying of dispersants following the *Torrey canyon* oil spill (Smith 1968). Smith (1968) also demonstrated that 0.5 -1 ppm of the detergent BP1002 resulted in developmental abnormalities in its echinopluteus larvae. *Echinus esculentus* populations in the vicinity of an oil terminal in A Coruna Bay, Spain, showed developmental abnormalities in the skeleton. The tissues contained high levels of aliphatic hydrocarbons, naphthalenes, pesticides and heavy metals (Zn, Hg, Cd, Pb, and Cu) (Gomez & Miguez-Rodriguez 1999).

Synthetic compound contamination

Not Assessed (NA)
Q: NR A: NR C: NR

Not assessed (NA)
Q: NR A: NR C: NR

Not assessed (NA)
Q: NR A: NR C: NR

This pressure is **Not assessed** but evidence is presented where available.

O'Brian & Dixon (1976) suggested that red algae were the most sensitive group of macrophytes to oil and dispersant contamination (see Smith, 1968). Although *Laminaria hyperborea* sporelings and gametophytes are intolerant of atrazine (and probably other herbicides) overall they may be relatively tolerant of synthetic chemicals (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 than 5 years of age, suggesting that spores and/or early stages were more intolerant (Hoare & Hiscock, 1974). *Patella pellucida* 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. The red alga *Phyllophora membranifolia* was also tolerant of the effluent in Amlwch Bay. Smith (1968) also noted that epiphytic and benthic red algae were intolerant of dispersant or oil contamination due to the Torrey Canyon oil spill; only the epiphytes *Cryptopleura ramosa* and *Spermothamnion repens* and some tufts of *Jania rubens* survived together with *Osmundea pinnatifida*, *Gigartina pistillata* and *Phyllophora crispa* from the sublittoral fringe. *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. Although *Laminaria hyperborea* may be relatively insensitive to synthetic chemical pollution, evidence suggests that grazing gastropods, amphipods and red algae are sensitive. Loss of red algae is likely to reduce the species richness and diversity of the biotope and the understory may become dominated by encrusting corallines; however, red algae are likely to recover relatively quickly.

Large numbers of dead *Echinus esculentus* were found between 5.5 and 14.5 m in the vicinity of Sennen, presumably due to a combination of wave exposure and heavy spraying of dispersants in that area following the *Torrey Canyon* oil spill (Smith 1968). Smith (1968) also demonstrated that 0.5 - 1ppm of the detergent BP1002 resulted in developmental abnormalities in echinopluteus larvae of *Echinus esculentus*. *Echinus esculentus* populations in the vicinity of an oil terminal in A Coruna Bay, Spain, showed developmental abnormalities in the skeleton. The tissues contained high levels of aliphatic hydrocarbons, naphthalenes, pesticides and heavy metals (Zn, Hg, Cd, Pb, and Cu) (Gomez & Miguez-Rodriguez 1999).

Radionuclide contamination	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR
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No evidence was found

Introduction of other substances	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR
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This pressure is **Not assessed**.

De-oxygenation	Medium Q: High A: Medium C: High	High Q: High A: Medium C: High	Low Q: High A: Medium C: High
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Reduced oxygen concentrations have been shown to inhibit both photosynthesis and respiration in macroalgae (Kinne, 1977). Despite this, macroalgae are thought to buffer the environmental conditions of low oxygen, thereby acting as a refuge for organisms in oxygen depleted regions especially if the oxygen depletion is short-term (Frieder *et al.*, 2012). In addition, the biotope occurs in areas of moderate to extreme wave action, so is likely to be continuously aerated. A rapid recovery from a state of low oxygen is expected if the environmental conditions are transient. If levels do drop below 4 mg/l negative effects on these organisms can be expected with adverse effects occurring below 2mg/l (Cole *et al.*, 1999).

In August 1978 a dense bloom of a dinoflagellate, *Gyrodinium aureolum* occurred surrounding Geer reef in Penzance Bay, Cornwall and persisted until September that year. Observations by local divers indicated a decrease in underwater visibility (<1 m) from below 8 m Below Sea Level. It was also noted that many of the faunal species appeared to be affected, e.g. no live *Echinus esculentus* were observed whereas on surveys prior to August were abundant, *Alcyonium sp.* and Bryozoans were also in an impoverished state. During follow-up surveys conducted in early September, *Alcyonium sp.* were noted to be much healthier and feeding. It was suggested the decay of *Gyrodinium aureolum* either reduced oxygen levels or physically clogged faunal feeding mechanisms. Adjacent reefs where also surveyed during the same time period and the effects of the *Gyrodinium aureolum* bloom were less apparent. It was suggested that higher water agitation in shallow water on reefs more exposed to wave action were less effected by the phytoplankton bloom (Griffiths *et al.*, 1979).

Sensitivity Assessment. Reduced oxygen levels are likely to inhibit photosynthesis and respiration but not cause a loss of the macroalgae population directly.

Furthermore, wave exposure is likely to constantly aerate the affected area. While de-oxygenation may not directly affect *Laminaria hyperborea*, small invertebrate epifauna may be lost, causing a reduction in species richness. Therefore, resistance has been assessed as 'Medium' is recorded. Resilience is likely to be 'High', and the biotopes is probably 'Low' at the benchmark level.

Nutrient enrichment	Not relevant (NR)	Not relevant (NR)	Not sensitive
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

This biotope is considered to be 'Not sensitive' at the pressure benchmark that assumes compliance with good status as defined by the WFD.

Holt *et al.* (1995) suggest that *Laminaria hyperborea* may be tolerant of nutrient enrichment since healthy populations are found at ends of sublittoral untreated sewage outfalls in the Isle of Man. Increased nutrient levels e.g. from sewage outfalls, has been associated with increases in abundance, primary biomass and *Laminaria hyperborea* stipe production but with concomitant decreases in species numbers and diversity (Fletcher, 1996).

Increased nutrients may result in phytoplankton blooms that increase turbidity (see water clarity pressure). Increased nutrients may favour sea urchins, e.g. *Echinus esculentus*, due their ability to absorb dissolved organics, and result in increased grazing pressure leading to loss of understorey epiflora/fauna, decreased kelp recruitment and possibly 'urchin barrens'. Therefore, although nutrients may not affect kelps directly, indirect effects such as turbidity, siltation and competition may significantly affect the structure of the biotope.

It was suggested by Comely & Ansell (1988) that *Echinus esculentus* could absorb dissolved organic material for the purposes of nutrition. Nutrient enrichment may encourage the growth of ephemeral and epiphytic algae and therefore increase sea-urchin food availability. Lawrence (1975) reported that sea urchins had persisted over 13 years on barren grounds near sewage outfalls, presumably feeding on dissolved organic material, detritus, plankton and microalgae, although individuals died at an early age.

Organic enrichment	Medium	High	Low
	Q: Medium A: Medium C: Medium	Q: High A: Medium C: High	Q: Medium A: Medium C: Medium

Holt *et al.* (1995) suggest that *Laminaria hyperborea* may be tolerant of organic enrichment since healthy populations are found at ends of sublittoral untreated sewage outfalls in the Isle of Man. Increased nutrient levels e.g. from sewage outfalls, has been associated with increases in abundance, primary biomass and *Laminaria hyperborea* stipe production, but with concomitant decreases in species numbers and diversity (Fletcher, 1996). Increase organic enrichment has also been found to increase the abundance and dominance of suspension feeding fauna within *Laminaria hyperborea* holdfasts (Sheppard *et al.*, 1980). Increase in ephemeral and opportunistic algae are associated with reduced numbers of perennial macrophytes (Fletcher, 1996). Increased nutrients may also result in phytoplankton blooms that increase turbidity. Therefore, although nutrients may not affect kelps directly, indirect effects

such as turbidity and the increased abundance of suspension feeding fauna may affect the structure of *Laminaria hyperborea* biotopes (se

A Physical Pressures

	Resistance	Resilience	Sensitivity
Physical loss (to land or freshwater habitat)	None Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High

All marine habitats and benthic species are considered to have a resistance of 'None' to this pressure and to be unable to recover from a permanent loss of habitat (resilience is 'Very Low'). Sensitivity within the direct spatial footprint of this pressure is therefore 'High'. Although no specific evidence is described confidence in this assessment is 'High', due to the incontrovertible nature of this pressure.

	Resistance	Resilience	Sensitivity
Physical change (to another seabed type)	None Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High

If rock substrata were replaced with sedimentary substrata this would represent a fundamental change in habitat type, which *Laminaria hyperborea* would not be able to tolerate (Birket *et al.*, 1998). The biotope would be lost.

Sensitivity assessment. Resistance to the pressure is considered 'None', and resilience 'Very Low' or 'None'. The sensitivity of this biotope to change from sedimentary or soft rock substrata to hard rock or artificial substrata or vice-versa is assessed as 'High'.

	Resistance	Resilience	Sensitivity
Physical change (to another sediment type)	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

Not relevant

	Resistance	Resilience	Sensitivity
Habitat structure changes - removal of substratum (extraction)	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

Not relevant to rock substrata.

	Resistance	Resilience	Sensitivity
Abrasion/disturbance of the surface of the substratum or seabed	Low Q: High A: High C: High	Medium Q: High A: High C: High	Medium Q: High A: High C: High

Christie *et al.* (1998) observed *Laminaria hyperborea* habitat regeneration following commercial *Laminaria hyperborea* trawling in south Norway. Within the study area, trawling removed all large canopy-forming adult *Laminaria hyperborea*, however, sub-canopy recruits were largely unaffected. In 2-6 years of harvesting, a new canopy had formed 1m off the seabed. The associated holdfast communities recovered in 6 years, however, the epiphytic stipe community did not fully recover within the same time

period. Christie *et al.*, (1998) suggested that kelp habitats were relatively resistant to direct disturbance/removal of *Laminaria hyperborea* canopy.

Recurrent disturbance occurring at a smaller time scale than the recovery period of 2-6 years (stated above) could extend recovery time. Kain (1975) cleared sublittoral blocks of *Laminaria hyperborea* at different times of the year for several years. The first colonizers and succession community differed between blocks and at what time of year the blocks were cleared however within 2 years of clearance the blocks were dominated by *Laminaria hyperborea* (Kain, 1975). Lienaas & Christie (1996) also observed *Laminaria hyperborea* re-colonization of 'urchin barrens', following removal of urchins. The substratum was initially colonized by filamentous macroalgae and *Saccharina latissima* however after 2-4 years *Laminaria hyperborea* dominated the community.

Species with fragile tests, such as *Echinus esculentus* were reported to suffer badly as a result of scallop or queen scallop dredging (Bradshaw *et al.*, 2000; Hall-Spencer & Moore, 2000a & b). Kaiser *et al.* (2000) reported that *Echinus esculentus* were less abundant in areas subject to high trawling disturbance in the Irish Sea. Jenkins *et al.* (2001) conducted experimental scallop trawling in the North Irish sea and recorded the damage caused to several conspicuous megafauna species, both when caught as bi-catch and when left on the seabed. The authors predicted 16.4% of *Echinus esculentus* were crushed/dead, 29.3% would have >50% spine loss/minor cracks, 1.1% would have <50% spine loss and the remaining 53.3% would be in good condition. Sea urchins can rapidly regenerate spines, e.g. *Psammechinus miliaris* were found to re-grow all spines within a period of 2 months (Hobson, 1930).

Sensitivity assessment. Resistance to the pressure is considered '**Low**', and resilience '**Medium**'. The sensitivity of this biotope to damage to seabed surface features is assessed as '**Medium**'.

Penetration or disturbance of the substratum subsurface	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Not Relevant, please refer to pressure "Abrasion/disturbance of the substratum on the surface of the seabed".

Changes in suspended solids (water clarity)	None	Medium	Medium
	Q: High A: High C: High	Q: High A: High C: High	Q: High A: High C: High

Suspended Particle Matter (SPM) concentration has a linear relationship with subsurface light attenuation (Kd) (Devlin *et al.*, 2008). An increase in SPM results in a decrease in sub-surface light attenuation. Light availability and water turbidity are principal factors in determining the depth range of *Laminaria hyperborea* (0-47 m Below Sea Level) (Birkett *et al.*, 1998b). Light penetration influences the maximum depth at which kelp species can grow and it has been reported that Laminarians grow at depths at which the light levels are reduced to 1 percent of incident light at the surface. Maximal depth distribution of laminarians, therefore, varies from 100 m in the Mediterranean to only 6-7 m in the silt-laden German Bight. In Atlantic European

waters, the depth limit is typically 35 m. In very turbid waters the depth at which *Laminaria hyperborea* is found may be reduced to 2.5m (Birkett *et al.* 1998), or in some cases excluded completely (e.g. Severn Estuary), because of the alteration in light attenuation by suspended sediment (Birkett *et al.* 1998; Lüning, 1990).

Laminaria spp. show a decrease of 50% photosynthetic activity when turbidity increases by 0.1/m (light attenuation coefficient =0.1-0.2/m; Staehr & Wernberg, 2009). An increase in water turbidity will likely affect the photosynthetic ability of *Laminaria hyperborea* and decrease *Laminaria hyperborea* abundance and density (see sub biotope-IR.HIR.KFaR.LhypR.Pk). Kain (1964) suggested that early *Laminaria hyperborea* gametophyte development could occur in the absence of light. Furthermore observations from south Norway found that a pool of *Laminaria hyperborea* recruits could persist growing beneath *Laminaria hyperborea* canopies for several years, indicating that sporophytes growth can occur in light limited environments (Christe *et al.*, 1998). However in habitats exposed to high levels of suspended silts *Laminaria hyperborea* is out-competed by *Saccharina latissima*, a silt tolerant species, and thus, a decrease in water clarity is likely to decrease the abundance of *Laminaria hyperborea* in the affected area (Norton, 1978). An absence of this biotope in silt rich environments is therefore expected.

Moore (1977) suggested that *Echinus esculentus* was unaffected by turbid conditions. *Echinus esculentus* is an important grazer of red macro-algae within CR.MCR.EcCr. Increased turbidity and resultant reduced light penetration is likely to negatively affect algal growth. However, *Echinus esculentus* can feed on alternative prey, detritus or dissolved organic material (Lawrence, 1975, Comely & Ansell, 1988)

Sensitivity Assessment. *Echinus esculentus* is unlikely to be affected. However, an increase in water clarity from clear to intermediate (10-100mg/l) represent a change in light attenuation of ca 0.67-6.7 Kd/m, and is likely to result in a greater than 50% reduction in photosynthesis of *Laminaria* spp. Therefore, the dominant kelp species will probably suffer a severe decline, and resistance to this pressure is assessed as 'None'. Resilience to this pressure is assessed as 'Medium' at the benchmark. Hence, this biotope is regarded as having a sensitivity of 'Medium' to this pressure.

Smothering and siltation rate changes (light)

High

Q: Medium A: High C: High

High

Q: High A: Medium C: High

Not sensitive

Q: Medium A: Medium C: High

Smothering by sediment e.g. 5 cm material during a discrete event is unlikely to damage *Laminaria hyperborea* sporophytes but is likely to affect gametophyte survival as well as holdfast fauna, and interfere with zoospore settlement. Given the microscopic size of the gametophyte, 5 cm of sediment could be expected to significantly inhibit growth. However, laboratory studies showed that gametophytes can survive in darkness for between 6 - 16 months at 8 °C and would probably survive smothering by a discrete event. Once returned to normal conditions the gametophytes resumed growth or maturation within 1 month (Dieck, 1993). Intolerance to this factor is likely to be higher during the peak periods of sporulation and/or spore settlement.

If inundation is long lasting then the understory epifauna/flora may be adversely affected, e.g. suspension or filter feeding fauna and/or algal species. This biotope

occurs in high wave exposures and, therefore, deposited sediments are unlikely to remain for more than a few tidal cycles, except in the deepest of rock-pools. Therefore, the effects of depositing 5cm of fine sediment in a discrete event are likely to be transient.

Comely & Ansell (1988) recorded large *Echinus esculentus* from kelp beds on the west coast of Scotland in which the substratum was seasonally covered with "high levels" of silt. This suggests that *Echinus esculentus* is unlikely to be killed by smothering, however, smaller specimens and juveniles may be less resistant. A layer of sediment may interfere with larval settlement. If retained within the host biotope for extended periods a layer of 5cm of the sediment may negatively affect successive recruitment events.

Sensitivity assessment. Resistance to the pressure is considered 'High', and resilience 'High'. The sensitivity of this biotope to light deposition of up to 5cm of fine material added to the seabed in a single discrete event is assessed as 'Note Sensitive'.

Smothering and siltation rate changes (heavy)

Medium

Q: Medium A: High C: High

High

Q: Low A: Medium C: High

Low

Q: Medium A: Medium C: High

Smothering by sediment e.g. 30 cm material during a discrete event is unlikely to damage *Laminaria hyperborea* plants but is likely to affect gametophyte survival, holdfast communities, epiphytic community at the base of the stipe, and interfere with zoospore settlement. Given the microscopic size of the gametophyte, 30 cm of sediment could be expected to significantly inhibit growth. However, laboratory studies showed that gametophytes can survive in darkness for between 6 - 16 months at 8 °C and would probably survive smothering within a discrete event. Once returned to normal conditions the gametophytes resumed growth or maturation within 1 month (Dieck, 1993). Intolerance to this factor is likely to be higher during the peak periods of sporulation and/or spore settlement.

If clearance of deposited sediment occurs rapidly then understory communities are expected to recover quickly. If inundation is long lasting then the understory epifauna/flora may be adversely affected, e.g. suspension or filter feeding fauna and/or algal species. While this biotope occurs in high to moderate energy habitats (due to water flow or wave action) deposition of 30cm of sediment represents a large volume of material that would likely remain for a number of tidal cycles and is expected to damage understory flora/fauna as well as juvenile *Laminaria hyperborea*.

Comely & Ansell (1988) recorded large *Echinus esculentus* from kelp beds on the west coast of Scotland in which the substratum was seasonally covered with "high levels" of silt. This suggests that *Echinus esculentus* is unlikely to be killed by smothering, however, smaller specimens and juveniles may be less resistant. A layer of sediment may interfere with larval settlement. If retained within the host biotope for extended periods a layer of 5cm of the sediment may negatively affect successive recruitment events.

Sensitivity assessment. Resistance to the pressure is considered 'Medium', and resilience 'High'. The sensitivity of this biotope to heavy deposition of up to 30cm of fine material added to the seabed in a single discrete event is assessed as 'Low'.

Litter	Not Assessed (NA)	Not assessed (NA)	Not assessed (NA)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Not assessed.

Electromagnetic changes	Not relevant (NR)	Not relevant (NR)	No evidence (NEv)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

No evidence was found

Underwater noise changes	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Not relevant

Introduction of light or shading	Low	Medium	Medium
	Q: Low A: NR C: NR	Q: Low A: NR C: NR	Q: Low A: Low C: Low

Shading of the biotope (e.g. by construction of a pontoon, pier etc) could adversely affect the biotope in areas where the water clarity is also low, and tip the balance to shade tolerant species, resulting in the loss of the biotope directly within the shaded area, or a reduction in laminarian abundance from forest to park type biotopes.

Sensitivity assessment. Resistance is probably 'Low', with a 'Medium' resilience and a sensitivity of 'Medium', albeit with 'low' confidence due to the lack of direct evidence.

Barrier to species movement	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Not relevant. This pressure is considered applicable to mobile species, e.g. fish and marine mammals rather than seabed habitats. Physical and hydrographic barriers may limit the dispersal of spores. But spore dispersal is not considered under the pressure definition and benchmark.

Death or injury by collision	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Not relevant. Collision from grounding vessels is addressed under abrasion above.

Visual disturbance	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Not relevant



Biological Pressures

Resistance

Resilience

Sensitivity

Genetic modification & translocation of indigenous species	Not relevant (NR)	Not relevant (NR)	No evidence (NEv)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

No evidence regarding the genetic modification or effects of translocation of native kelp populations was found.

Introduction or spread of invasive non-indigenous species	Low	Very Low	High
	Q: High A: High C: High	Q: High A: High C: High	Q: High A: High C: High

Undaria pinnatifida has received a large amount of research attention as a major Invasive Non-Indigenous Species (INIS) which could out-compete native UK kelp habitats (see Farrell & Fletcher, 2006; Thompson & Schiel, 2012, Brodie *et al.*, 2014; Heiser *et al.*, 2014). *Undaria pinnatifida* was first recorded in Plymouth Sound, UK in 2003 (NBN, 2015) subsequent surveys in 2011 have reported that *Undaria pinnatifida* is widespread throughout Plymouth Sound, colonizing rocky reef habitats. Where *Undaria pinnatifida* is present there was a significant decrease in the abundance of other *Laminaria* species, including *Laminaria hyperborea* (Heiser *et al.*, 2014).

In New Zealand, Thompson & Schiel (2012) observed that native furoids could out-compete *U.pinnatifida* and re-dominate the substratum. However, Thompson & Schiel (2012) suggested the furoid recovery was partially due to an annual *Undaria pinnatifida* die back, which as noted by Heiser *et al.*, (2014) did not occur in Plymouth Sound, UK. It is unknown whether *Undaria pinnatifida* will out-compete native macroalgae in the UK. However, from 2003-2011 *Undaria pinnatifida* had spread throughout Plymouth Sound, UK, becoming a visually dominant species at some locations within summer months (Heiser *et al.*, 2014). While *Undaria pinnatifida* may replace *Laminaria hyperborea* in some locations within the UK, at the time of writing there is limited evidence available to assess what ecological impacts this invasion may have on *Laminaria hyperborea* associated communities e.g. red seaweeds.

Undaria pinnatifida was successfully eradicated on a sunken ship in Clatham Islands, New Zealand, by applying a heat treatment of 70 °C (see Wotton *et al.*, 2004) however numerous other eradication attempts have failed, and as noted by Farrell & Fletcher (2006) once established *Undaria pinadifida* resists most attempts of long-term removal. The biotope is unlikely to fully recover until *Undaria pinnatifida* is fully removed from the habitat, which as stated above is unlikely to occur.

Sensitivity assessment. Resistance to the pressure is considered 'Low', and resilience 'Very Low'. The sensitivity of this biotope to the introduction of INIS is assessed as 'High'.

Introduction of microbial pathogens	Medium	High	Low
	Q: Medium A: High C: High	Q: High A: Low C: High	Q: Medium A: High C: Low

Galls on the blade of *Laminaria hyperborea* and spot disease are associated with the endophyte *Streblonema* sp. although the causal agent is unknown (bacteria, virus or endophyte). The resultant damage to the blade and stipe may increase losses in

storms. The endophyte inhibits spore production and, therefore, recruitment and recoverability (Lein *et al.*, 1991).

Echinus esculentus is susceptible to 'Bald-sea-urchin disease', which causes lesions, loss of spines, tube feet, pedicellariae, destruction of the upper layer of skeletal tissue and death. It is thought to be caused by the bacteria *Vibrio anguillarum* and *Aeromonas salmonicida*. Bald sea-urchin disease was recorded from *Echinus esculentus* on the Brittany Coast. Although associated with mass mortalities of *Strongylocentrotus franciscanus* in California and *Paracentrotus lividus* in the French Mediterranean it is not known if the disease induces mass mortality (Bower, 1996).

Sensitivity assessment. Resistance to the pressure is considered '**Medium**', and resilience '**High**'. The sensitivity of this biotope to the introduction of microbial pathogens is assessed as '**Low**'.

Removal of target species

Low

Q: High A: High C: High

Medium

Q: High A: High C: High

Medium

Q: High A: High C: High

Christie *et al.* (1998) observed *Laminaria hyperborea* habitat regeneration following commercial *Laminaria hyperborea* trawling in south Norway. Within the study area trawling removed all large canopy-forming adult *Laminaria hyperborea*, however, sub-canopy recruits were unaffected. Within 2-3 years of harvesting, a new canopy had formed 1 m off the seabed. The associated holdfast communities recovered in 6 years however the epiphytic stipe community did not fully recover within the same time period. Christie *et al.*, (1998) suggested that kelp habitats were relatively resistant to direct disturbance of *Laminaria hyperborea* canopy.

Recurrent disturbance occurring at a smaller time scale than the recovery period of 2-6 years (stated above) could extend recovery time. Kain (1975) cleared sublittoral blocks of *Laminaria hyperborea* at different times of the year for several years. The first colonizers and succession community differed between blocks and at what time of year the blocks were cleared however within 2 years of clearance the blocks were dominated by *Laminaria hyperborea* (Kain, 1975). Lienaas & Christie (1996) also observed *Laminaria hyperborea* re-colonization of 'urchin barrens', following removal of urchins. The substratum was initially colonized by filamentous macroalgae and *Saccharina latissima* however after 2-4 years *Laminaria hyperborea* dominated the community.

Following disturbance or in areas where recurrent rapid disturbance occurs *Laminaria hyperborea* recruitment could also be affected by interspecific competitive interactions with Invasive Non-Indigenous Species or ephemeral algal species (Smale *et al.*, 2013; Brodie *et al.*, 2014), however, evidence for this is limited and thus not included within this assessment. Removal of kelp canopies can also result in the decline of the associated epiphytic and understory red algal species (Hawkins & Harkin, 1985). Removal of *Echinus esculentus* from IR.MIR.KR.Lhyp.GzFt/Pk could also reduce grazing pressure and change the character of the biotope.

Sensitivity assessment. Resistance to the pressure is considered '**Low**', and resilience '**Medium**'. The sensitivity of this biotope to damage to seabed surface features is assessed as '**Medium**'.

Removal of non-target species**Low**

Q: High A: High C: High

Medium

Q: High A: High C: High

Medium

Q: High A: High C: High

Incidental/accidental removal of *Laminaria hyperborea* from extraction of other marine resources, e.g. fisheries or aggregates, is likely to cause similar effects to that of direct harvesting of *Laminaria hyperborea*; hence, the same evidence has been used for both pressure assessments.

Christie *et al.* (1998) observed *Laminaria hyperborea* habitat regeneration following commercial *Laminaria hyperborea* trawling in south Norway. Within the study area trawling removed all large canopy-forming adult *Laminaria hyperborea*, however, sub-canopy recruits were unaffected. Within 2-6 years of harvesting, a new canopy had formed 1m off the seabed. The associated holdfast communities recovered in 6 years however the epiphytic stipe community did not fully recover within the same time period. Christie *et al.*, (1998) suggested that kelp habitats were relatively resistant to direct disturbance of *Laminaria hyperborea* canopy.

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Sensitivity assessment. Resistance to the pressure is considered '**Low**', and resilience '**Medium**'. The sensitivity of this biotope to damage to seabed surface features is assessed as '**Medium**'.

Bibliography

- Arzul, I., Langlade, A., Chollet, B., Robert, M., Ferrand, S., Omnes, E., Lerond, S., Couraleau, Y., Joly, J.P., François, C. & Garcia, C., 2011. Can the protozoan parasite *Bonamia ostreae* infect larvae of flat oysters *Ostrea edulis*? *Veterinary Parasitology*, **179**, 69-76.
- Bayne, B. 1969. The gregarious behaviour of the larvae of *Ostrea edulis* L. at settlement. *Journal of the Marine Biological Association of the United Kingdom*, **49**, 327-356.
- Beszczyńska-Möller, A., & Dye, S.R., 2013. ICES Report on Ocean Climate 2012. In *ICES Cooperative Research Report*, vol. 321 pp. 73.
- Birkett, D.A., Maggs, C.A., Dring, M.J. & Boaden, P.J.S., 1998b. Infralittoral reef biotopes with kelp species: an overview of dynamic and sensitivity characteristics for conservation management of marine SACs. *Natura 2000 report prepared by Scottish Association of Marine Science (SAMS) for the UK Marine SACs Project.*, Scottish Association for Marine Science. (UK Marine SACs Project, vol V.). Available from: <http://www.ukmarinesac.org.uk/publications.htm>
- Birkett, D.A., Maggs, C.A., Dring, M.J., Boaden, P.J.S. & Seed, R., 1998b. Infralittoral reef biotopes with kelp species (volume VII). An overview of dynamic and sensitivity characteristics for conservation management of marine SACs. *Scottish Association of Marine Science (UK Marine SACs Project)*. 174 pp
- Bishop, G.M. & Earll, R., 1984. Studies on the populations of *Echinus esculentus* at the St Abbs and Skomer voluntary Marine Nature Reserves. *Progress in Underwater Science*, **9**, 53-66.
- Bishop, G.M., 1985. *Aspects of the reproductive ecology of the sea urchin Echinus esculentus* L. Ph.D. thesis, University of Exeter, UK.
- Boooloatian, R.A., 1966. *Physiology of Echinodermata*. (Ed. R.A. Boooloatian), pp. 822-822. New York: John Wiley & Sons.
- Bower, S.M., 1996. *Synopsis of Infectious Diseases and Parasites of Commercially Exploited Shellfish: Bald-sea-urchin Disease*. [On-line]. Fisheries and Oceans Canada. [cited 26/01/16]. Available from: <http://www.dfo-mpo.gc.ca/science/aah-saa/diseases-maladies/bsudsu-eng.html>
- Bradshaw, C., Veale, L.O., Hill, A.S. & Brand, A.R., 2000. The effects of scallop dredging on gravelly seabed communities. In: *Effects of fishing on non-target species and habitats* (ed. M.J. Kaiser & de S.J. Groot), pp. 83-104. Oxford: Blackwell Science.
- Brodie J., Williamson, C.J., Smale, D.A., Kamenos, N.A., Mieszkowska, N., Santos, R., Cunliffe, M., Steinke, M., Yesson, C. & Anderson, K.M., 2014. The future of the northeast Atlantic benthic flora in a high CO₂ world. *Ecology and Evolution*, **4** (13), 2787-2798.
- Bryan, G.W., 1984. Pollution due to heavy metals and their compounds. In *Marine Ecology: A Comprehensive, Integrated Treatise on Life in the Oceans and Coastal Waters*, vol. 5. *Ocean Management*, part 3, (ed. O. Kinne), pp.1289-1431. New York: John Wiley & Sons.
- Burrows, M.T., Smale, D., O'Connor, N., Rein, H.V. & Moore, P., 2014. Marine Strategy Framework Directive Indicators for UK Kelp Habitats Part 1: Developing proposals for potential indicators. *Joint Nature Conservation Committee*, Peterborough. Report no. 525.
- Castège, I., Milon, E. & Pautrizel, F., 2014. Response of benthic macrofauna to an oil pollution: Lessons from the "Prestige" oil spill on the rocky shore of Guéthary (south of the Bay of Biscay, France). *Deep Sea Research Part II: Topical Studies in Oceanography*, **106**, 192-197.
- Chadwick, H.C., 1907. *Antedon*. Liverpool Marine Biology Committee Memoirs, vol XV. London: Williams and Norgate.
- Christie, H., Fredriksen, S. & Rinde, E., 1998. Regrowth of kelp and colonization of epiphyte and fauna community after kelp trawling at the coast of Norway. *Hydrobiologia*, **375/376**, 49-58.
- Cole, H. & Knight-Jones, E.W., 1939. Some observations and experiments on the setting behaviour of larvae of *Ostrea edulis*. *Journal du Conseil Permanent International pour L'Exploration de la Mer*, **14**, 86-105.
- Cole, H. & Knight-Jones, E.W., 1949. The setting behaviour of larvae of the European flat oyster, *O. edulis* L. and its influence on methods of cultivation and spat collection. *Ministry of Agriculture, Fisheries and Food, Fisheries Investigations Series II*, **17**, 1-39.
- Cole, S., Codling, I.D., Parr, W. & Zabel, T., 1999. Guidelines for managing water quality impacts within UK European Marine sites. *Natura 2000 report prepared for the UK Marine SACs Project*. 441 pp., Swindon: Water Research Council on behalf of EN, SNH, CCW, JNCC, SAMS and EHS. [UK Marine SACs Project.], <http://www.ukmarinesac.org.uk/>
- Comely, C.A. & Ansell, A.D., 1988. Invertebrate associates of the sea urchin, *Echinus esculentus* L., from the Scottish west coast. *Ophelia*, **28**, 111-137.
- Connell, S.D., 2003. The monopolization of understory habitat by subtidal encrusting coralline algae: a test of the combined effects of canopy-mediated light and sedimentation. *Marine Biology*, **142** (6), 1065-1071.

- Connor, D.W., Allen, J.H., Golding, N., Howell, K.L., Lieberknecht, L.M., Northen, K.O. & Reker, J.B., 2004. The Marine Habitat Classification for Britain and Ireland. Version 04.05. ISBN 1 861 07561 8. In JNCC (2015), *The Marine Habitat Classification for Britain and Ireland Version 15.03*. [2019-07-24]. Joint Nature Conservation Committee, Peterborough. Available from <https://mhc.jncc.gov.uk/>
- Connor, D.W., Dalkin, M.J., Hill, T.O., Holt, R.H.F. & Sanderson, W.G., 1997a. Marine biotope classification for Britain and Ireland. Vol. 2. Sublittoral biotopes. *Joint Nature Conservation Committee, Peterborough, JNCC Report no. 230, Version 97.06.*, *Joint Nature Conservation Committee, Peterborough, JNCC Report no. 230, Version 97.06.*
- Crisp, D.J. (ed.), 1964. The effects of the severe winter of 1962-63 on marine life in Britain. *Journal of Animal Ecology*, **33**, 165-210.
- Devlin, M.J., Barry, J., Mills, D.K., Gowen, R.J., Foden, J., Sivyer, D. & Tett, P., 2008. Relationships between suspended particulate material, light attenuation and Secchi depth in UK marine waters. *Estuarine, Coastal and Shelf Science*, **79** (3), 429-439.
- Dickinson, C.I., 1963. *British seaweeds*. London & Frome: Butler & Tanner Ltd.
- Dieck, T.I., 1992. North Pacific and North Atlantic digitate *Laminaria* species (Phaeophyta): hybridization experiments and temperature responses. *Phycologia*, **31**, 147-163.
- Dieck, T.I., 1993. Temperature tolerance and survival in darkness of kelp gametophytes (Laminariales: Phaeophyta) - ecological and biogeographical implications. *Marine Ecology Progress Series*, **100**, 253-264.
- Dyrinda, P.E.J. & Ryland, J.S., 1982. Reproductive strategies and life histories in the cheilostome marine bryozoans *Chartella papyracea* and *Bugula flabellata*. *Marine Biology*, **71**, 241-256.
- Eckman, J.E., Duggins, D.O., Sewell, A.T., 1989. Ecology of understory kelp environments. I. Effects of kelps on flow and particle transport near the bottom. *Journal of Experimental Marine Biology and Ecology*, **129**, 173-187.
- Edwards, A., 1980. Ecological studies of the kelp *Laminaria hyperborea* and its associated fauna in south-west Ireland. *Ophelia*, **9**, 47-60.
- Edyvean, R.G.J. & Ford, H., 1984b. Population biology of the crustose red alga *Lithophyllum incrustans* Phil. 3. The effects of local environmental variables. *Biological Journal of the Linnean Society*, **23**, 365-374.
- Eggleston, D., 1972a. Patterns of reproduction in marine Ectoprocta off the Isle of Man. *Journal of Natural History*, **6**, 31-38.
- Elnor, R.W. & Vadas, R.L., 1990. Inference in ecology: the sea urchin phenomenon in the northwest Atlantic. *American Naturalist*, **136**, 108-125.
- Erwin, D.G., Picton, B.E., Connor, D.W., Howson, C.M., Gilleece, P. & Bogues, M.J., 1990. Inshore Marine Life of Northern Ireland. *Report of a survey carried out by the diving team of the Botany and Zoology Department of the Ulster Museum in fulfilment of a contract with Conservation Branch of the Department of the Environment (N.I.)*, Ulster Museum, Belfast: HMSO.
- Farrell, P. & Fletcher, R., 2006. An investigation of dispersal of the introduced brown alga *Undaria pinnatifida* (Harvey) Suringar and its competition with some species on the man-made structures of Torquay Marina (Devon, UK). *Journal of Experimental Marine Biology and Ecology*, **334** (2), 236-243.
- Fitt, W.K., Coon, S.L., Walch, M., Weiner, R.M., Colwell, R.R. & Gonar, D.B., 1990. Settlement behaviour and metamorphosis of oyster larvae (*Crassostrea gigas*) in response to bacterial supernatants. *Marine Biology*, **106**, 389-394.
- Fletcher, R.L. & Callow, M.E., 1992. The settlement, attachment and establishment of marine algal spores. *British Phycological Journal*, **27**, 303-329.
- Fletcher, R.L., 1996. The occurrence of 'green tides' - a review. In *Marine Benthic Vegetation. Recent changes and the Effects of Eutrophication* (ed. W. Schramm & P.H. Nienhuis). Berlin Heidelberg: Springer-Verlag. [Ecological Studies, vol. 123].
- Forrest, B.M., Gardner, J.P.A. & Taylor, M.D., 2009. Internal borders for managing invasive marine species. *Journal of Applied Ecology*, **46**, 46-54.
- Fredriksen, S., Sjøtun, K., Lein, T.E. & Rueness, J., 1995. Spore dispersal in *Laminaria hyperborea* (Laminariales, Phaeophyceae). *Sarsia*, **80** (1), 47-53.
- Frieder, C., Nam, S., Martz, T. & Levin, L., 2012. High temporal and spatial variability of dissolved oxygen and pH in a nearshore California kelp forest. *Biogeosciences*, **9** (10), 3917-3930.
- Gage, J.D., 1992a. Growth bands in the sea urchin *Echinus esculentus*: results from tetracycline mark/recapture. *Journal of the Marine Biological Association of the United Kingdom*, **72**, 257-260.
- Gage, J.D., 1992b. Natural growth bands and growth variability in the sea urchin *Echinus esculentus*: results from tetracycline tagging. *Marine Biology*, **114**, 607-616.
- Galtsoff, P., 1964. The American Oyster *Crassostrea virginica* Gmelin. *Fishery Bulletin of the Fish and Wildlife Service*, **64**, 1-480
- Gili, J-M. & Hughes, R.G., 1995. The ecology of marine benthic hydroids. *Oceanography and Marine Biology: an Annual Review*, **33**, 351-426.

- Gomez, J.L.C. & Miguez-Rodriguez, L.J., 1999. Effects of oil pollution on skeleton and tissues of *Echinus esculentus* L. 1758 (Echinodermata, Echinoidea) in a population of A Coruna Bay, Galicia, Spain. In *Echinoderm Research 1998. Proceedings of the Fifth European Conference on Echinoderms, Milan, 7-12 September 1998*, (ed. M.D.C. Carnevali & F. Bonasoro) pp. 439-447. Rotterdam: A.A. Balkema.
- Gordon, D.P., 1972. Biological relationships of an intertidal bryozoan population. *Journal of Natural History*, **6**, 503-514.
- Gorman, T., Bajjouk, J., Populis, M., Vasquez, A. & Ehrhold., 2012. Modeling kelp forest distribution and biomass along temperate rocky coastlines. *Marine Biology*, **160** (2), 209 - 325.
- Grandy, N., 1984. *The effects of oil and dispersants on subtidal red algae*. Ph.D. Thesis. University of Liverpool.
- Gravestock, V., James, F. & Goulden, M., 2014. Solent native oyster (*Ostrea edulis*) restoration - Literature Review & Feasibility Study. *MacAlister Elliot & Partners, On behalf of the Blue Marine Foundation, Report*, no. 2897.
- Griffiths, A.B., Dennis, R. & Potts, G.W., 1979. Mortality associated with a phytoplankton bloom off Penzance in Mount's Bay. *Journal of the Marine Biological Association of the United Kingdom*, **59**, 515-528.
- Hall-Spencer, J.M. & Moore, P.G., 2000a. Impact of scallop dredging on maerl grounds. In *Effects of fishing on non-target species and habitats*. (ed. M.J. Kaiser & S.J., de Groot) 105-117. Oxford: Blackwell Science.
- Hall-Spencer, J.M. & Moore, P.G., 2000c. Scallop dredging has profound, long-term impacts on maerl habitats. *ICES Journal of Marine Science*, **57**, 1407-1415.
- Hammer, L., 1972. Anaerobiosis in marine algae and marine phanerogams. In *Proceedings of the Seventh International Seaweed Symposium, Sapporo, Japan, August 8-12, 1971* (ed. K. Nisizawa, S. Arasaki, Chihara, M., Hirose, H., Nakamura V., Tsuchiya, Y.), pp. 414-419. Tokyo: Tokyo University Press.
- Hansson, H., 1998. NEAT (North East Atlantic Taxa): South Scandinavian marine Echinodermata Check-List. *Tjärnö Marine Biological Association* [On-line] [cited 26/01/16]. Available from: http://www.tmbi.gu.se/libdb/taxon/neat_pdf/NEAT*Echinodermata.pdf
- Hartnoll, R.G., 1985. Growth, sexual maturity and reproductive output. *Crustacean issues*, **3**, 101-128.
- Hartnoll, R.G., 1975. The annual cycle of *Alcyonium digitatum*. *Estuarine and Coastal Marine Science*, **3**, 71-78.
- Hartnoll, R.G., 1983. Substratum. In *Sublittoral ecology. The ecology of the shallow sublittoral benthos* (ed. R. Earll & D.G. Erwin), pp. 97-124. Oxford: Clarendon Press.
- Hartnoll, R.G., 1998. Circalittoral faunal turf biotopes: an overview of dynamics and sensitivity characteristics for conservation management of marine SACs, Volume VIII. *Scottish Association of Marine Sciences, Oban, Scotland*. [UK Marine SAC Project. Natura 2000 reports.]
- Hawkins, L.E., Hutchinson, S. & Askew, C., 2005. Evaluation of some factors affecting native oyster stock regeneration. *Shellfish News*, **19**, 10-12.
- Hawkins, S.J. & Harkin, E., 1985. Preliminary canopy removal experiments in algal dominated communities low on the shore and in the shallow subtidal on the Isle of Man. *Botanica Marina*, **28**, 223-30.
- Hayward, P.J. 1988. *Animals on seaweed*. Richmond, Surrey: Richmond Publishing Co. Ltd. [Naturalists Handbooks 9].
- Hayward, P.J. & Ryland, J.S. 1998. *Cheilostomatous Bryozoa. Part 1. Aeteoidea - Cribrilinoidea*. Shrewsbury: Field Studies Council. [Synopsis of the British Fauna, no. 10. (2nd edition)]
- Heiser, S., Hall-Spencer, J.M. & Hiscock, K., 2014. Assessing the extent of establishment of *Undaria pinnatifida* in Plymouth Sound Special Area of Conservation, UK. *Marine Biodiversity Records*, **7**, e93.
- Hill, A.S., Brand, A.R., Veale, L.O. & Hawkins, S.J., 1997. *Assessment of the effects of scallop dredging on benthic communities. Final Report to MAFF*, Contract CSA 2332, Liverpool: University of Liverpool
- Hiscock, K. & Mitchell, R., 1980. *The Description and Classification of Sublittoral Epibenthic Ecosystems*. In *The Shore Environment, Vol. 2, Ecosystems*, (ed. J.H. Price, D.E.G. Irvine, & W.F. Farnham), 323-370. London and New York: Academic Press. [Systematics Association Special Volume no. 17(b)].
- Hiscock, K., 1983. Water movement. In *Sublittoral ecology. The ecology of shallow sublittoral benthos* (ed. R. Earll & D.G. Erwin), pp. 58-96. Oxford: Clarendon Press.
- Hiscock, K., 1994. Marine communities at Lundy - origins, longevity and change. *Biological Journal of the Linnean Society* **51**, 183-188.
- Hiscock, S., 1986c. Skomer Marine Nature Reserve subtidal monitoring project. Algal results. August 1984 to February 1986. *Nature Conservancy Council, Peterborough, CSD Report no. 620.*, Peterborough, Nature Conservancy Council. (CSD Report No. 620.)
- Hoare, R. & Hiscock, K., 1974. An ecological survey of the rocky coast adjacent to the effluent of a bromine extraction plant. *Estuarine and Coastal Marine Science*, **2** (4), 329-348.
- Hobson, A., 1930. Regeneration of the Spines in Sea-Urchins. *Nature*, **125**, 168.
- Holt, T.J., Jones, D.R., Hawkins, S.J. & Hartnoll, R.G., 1995. The sensitivity of marine communities to man induced change - a scoping report. *Countryside Council for Wales, Bangor, Contract Science Report*, no. 65.

- Hopkin, R. & Kain, J.M., 1978. The effects of some pollutants on the survival, growth and respiration of *Laminaria hyperborea*. *Estuarine and Coastal Marine Science*, **7**, 531-553.
- Hughes, R.G., 1977. Aspects of the biology and life-history of *Nemertesia antennina* (L.) (Hydrozoa: Plumulariidae). *Journal of the Marine Biological Association of the United Kingdom*, **57**, 641-657.
- Irvine, L. M. & Chamberlain, Y. M., 1994. *Seaweeds of the British Isles*, vol. 1. Rhodophyta, Part 2B Corallinales, Hildenbrandiales. London: Her Majesty's Stationery Office.
- Jenkins, S.R., Beukers-Stewart, B.D. & Brand, A.R., 2001. Impact of scallop dredging on benthic megafauna: a comparison of damage levels in captured and non-captured organisms. *Marine Ecology Progress Series*, **215**, 297-301.
- JNCC, 2015. The Marine Habitat Classification for Britain and Ireland Version 15.03. (20/05/2015). Available from <https://mhc.jncc.gov.uk/>
- JNCC (Joint Nature Conservation Committee), 1999. *Marine Environment Resource Mapping And Information Database (MERMAID): Marine Nature Conservation Review Survey Database*. [on-line] <http://www.jncc.gov.uk/mermaid>
- Jones, C.G., Lawton, J.H. & Shachak, M., 1997. Positive and negative effects of organisms as physical ecosystem engineers. *Ecology*, **78** (7), 1946-1957.
- Jones, D.J., 1971. Ecological studies on macro-invertebrate communities associated with polluted kelp forest in the North Sea. *Helgolander Wissenschaftliche Meeresuntersuchungen*, **22**, 417-431.
- Jones, N.S. & Kain, J.M., 1967. Subtidal algal recolonisation following removal of *Echinus*. *Helgolander Wissenschaftliche Meeresuntersuchungen*, **15**, 460-466.
- Kain, J.M., 1964. Aspects of the biology of *Laminaria hyperborea* III. Survival and growth of gametophytes. *Journal of the Marine Biological Association of the United Kingdom*, **44** (2), 415-433.
- Kain, J.M. & Svendsen, P., 1969. A note on the behaviour of *Patina pellucida* in Britain and Norway. *Sarsia*, **38**, 25-30.
- Kain, J.M., 1971a. Synopsis of biological data on *Laminaria hyperborea*. *FAO Fisheries Synopsis*, no. 87.
- Kain, J.M., 1975a. Algal recolonization of some cleared subtidal areas. *Journal of Ecology*, **63**, 739-765.
- Kain, J.M., 1979. A view of the genus *Laminaria*. *Oceanography and Marine Biology: an Annual Review*, **17**, 101-161.
- Kain, J.M., 1987. Photoperiod and temperature as triggers in the seasonality of *Delesseria sanguinea*. *Helgolander Meeresuntersuchungen*, **41**, 355-370.
- Kain, J.M., & Norton, T.A., 1990. Marine Ecology. In *Biology of the Red Algae*, (ed. K.M. Cole & Sheath, R.G.). Cambridge: Cambridge University Press.
- Kain, J.M., Drew, E.A. & Jupp, B.P., 1975. Light and the ecology of *Laminaria hyperborea* II. In *Proceedings of the Sixteenth Symposium of the British Ecological Society, 26-28 March 1974. Light as an Ecological Factor: II* (ed. G.C. Evans, R. Bainbridge & O. Rackham), pp. 63-92. Oxford: Blackwell Scientific Publications.
- Kaiser, M.J., Ramsay, K., Richardson, C.A., Spence, F.E. & Brand, A.R., 2000. Chronic fishing disturbance has changed shelf sea benthic community structure. *Journal of Animal Ecology*, **69**, 494-503.
- Kamphausen, L.M., 2012. *The reproductive processes of a wild population of the European flat oyster Ostrea edulis in the Solent*. UK. Ph.D. thesis. University of Southampton. UK. 153 pp.
- Kennedy, R.J. & Roberts, D., 1999. A survey of the current status of the flat oyster *Ostrea edulis* in Strangford Lough, Northern Ireland, with a view to the restoration of its Oyster Beds.. *Biology and Environment: Proceedings of The Royal Irish Academy*. **99B**, 79-88.
- Kinne, O. (ed.), 1984. *Marine Ecology: A Comprehensive, Integrated Treatise on Life in Oceans and Coastal Waters*. Vol. V. *Ocean Management Part 3: Pollution and Protection of the Seas - Radioactive Materials, Heavy Metals and Oil*. Chichester: John Wiley & Sons.
- Kinne, O., 1977. International Helgoland Symposium "Ecosystem research": summary, conclusions and closing. *Helgoländer Wissenschaftliche Meeresuntersuchungen*, **30**(1-4), 709-727.
- Kregting, L., Blight, A., Elsäßer, B. & Savidge, G., 2013. The influence of water motion on the growth rate of the kelp *Laminaria hyperborea*. *Journal of Experimental Marine Biology and Ecology*, **448**, 337-345.
- Krumhansl, K.A., 2012. *Detrital production in kelp beds*. degree of Doctor of Philosophy, Department of Biology, Dalhousie University, Halifax, Nova Scotia.
- Lancaster, J. (ed), McCallum, S., A.C., L., Taylor, E., A., C. & Pomfret, J., 2014. Development of Detailed Ecological Guidance to Support the Application of the Scottish MPA Selection Guidelines in Scotland's seas. *Scottish Natural Heritage Commissioned Report No.491 (29245)*, Scottish Natural Heritage, Inverness, 40 pp.
- Lang, C. & Mann, K., 1976. Changes in sea urchin populations after the destruction of kelp beds. *Marine Biology*, **36** (4), 321-326.
- Lawrence, J.M., 1975. On the relationships between marine plants and sea urchins. *Oceanography and Marine Biology: An Annual Review*, **13**, 213-286.

- Lein, T.E, Sjutun, K. & Wakili, S., 1991. Mass - occurrence of a brown filamentous endophyte in the lamina of the kelp *Laminaria hyperborea* (Gunnerus) Foslie along the south western coast of Norway *Sarsia*, **76**, 187-193.
- Leinaas, H.P. & Christie, H., 1996. Effects of removing sea urchins (*Strongylocentrotus droebachiensis*): Stability of the barren state and succession of kelp forest recovery in the east Atlantic. *Oecologia*, **105**, 524-536.
- Lewis, G.A. & Nichols, D., 1979a. Colonization of an artificial reef by the sea-urchin *Echinus esculentus*. *Progress in Underwater Science*, **4**, 189-195.
- Lüning, K., 1990. *Seaweeds: their environment, biogeography, and ecophysiology*: John Wiley & Sons.
- MacBride, E.W., 1914. *Textbook of Embryology, Vol. I, Invertebrata*. London: MacMillan & Co.
- Mann, K.H., 1982. Kelp, sea urchins, and predators: a review of strong interactions in rocky subtidal systems of eastern Canada, 1970-1980. *Netherlands Journal of Sea Research*, **16**, 414-423.
- Matthews, A., 1917. The development of *Alcyonium digitatum* with some notes on early colony formation. *Quarterly Journal of Microscopical Science*, **62**, 43-94.
- Mesías-Gansbiller, C., Silva, A., Maneiro, V., Pazos, A., Sánchez, J.L. & Pérez-Parallé, M.L., 2013. Effects of chemical cues on larval settlement of the flat oyster (*Ostrea edulis* L.): A hatchery approach. *Aquaculture*, **376**, 85-89.
- Migliaccio, O., Castellano, I., Romano, G. & Palumbo, A., 2014. Stress response to cadmium and manganese in *Paracentrotus lividus* developing embryos is mediated by nitric oxide. *Aquatic Toxicology*, **156**, 125-134.
- Moore, P.G., 1973a. The kelp fauna of north east Britain I. Function of the physical environment. *Journal of Experimental Marine Biology and Ecology*, **13**, 97-125.
- Moore, P.G., 1973b. The kelp fauna of north east Britain. II. Multivariate classification: turbidity as an ecological factor. *Journal of Experimental Marine Biology and Ecology*, **13**, 127-163.
- Moore, P.G., 1977a. Inorganic particulate suspensions in the sea and their effects on marine animals. *Oceanography and Marine Biology: An Annual Review*, **15**, 225-363.
- Moore, P.G., 1978. Turbidity and kelp holdfast Amphipoda. I. Wales and S.W. England. *Journal of Experimental Marine Biology and Ecology*, **32**, 53-96.
- Moore, P.G., 1985. Levels of heterogeneity and the amphipod fauna of kelp holdfasts. In *The Ecology of Rocky Coasts: essays presented to J.R. Lewis, D.Sc.* (ed. P.G. Moore & R. Seed), 274-289. London: Hodder & Stoughton Ltd.
- Morton, J.E. & Miller, M.C., 1968. *The New Zealand sea shore*. London: Collins
- NBN, 2015. National Biodiversity Network 2015(20/05/2015). <https://data.nbn.org.uk/>
- Nichols, D., 1991. Seasonal reproductive periodicity in the European comatulid crinoid *Antedon bifida* (Pennant). *Proceedings of the Seventh International Echinoderm Conference, Atami, 9-14 September 1990*. In *Biology of Echinodermata* (ed. T. Yanagisawa, I. Yasumasu, C. Oguro, N. Suzuki & T. Motokawa), pp. 241-248. A.A. Balkema. Rotterdam.
- Nichols, D., 1979. A nationwide survey of the British Sea Urchin *Echinus esculentus*. *Progress in Underwater Science*, **4**, 161-187.
- Nichols, D., 1981. The Cornish Sea-urchin Fishery. *Cornish Studies*, **9**, 5-18.
- Nichols, D., 1984. An investigation of the population dynamics of the common edible sea urchin (*Echinus esculentus* L.) in relation to species conservation management. *Report to Department of the Environment and Nature Conservancy Council from the Department of Biological Sciences, University of Exeter*.
- Norderhaug, K., 2004. Use of red algae as hosts by kelp-associated amphipods. *Marine Biology*, **144** (2), 225-230.
- Norderhaug, K.M. & Christie, H., 2011. Secondary production in a *Laminaria hyperborea* kelp forest and variation according to wave exposure. *Estuarine, Coastal and Shelf Science*, **95** (1), 135-144.
- Norderhaug, K.M. & Christie, H.C., 2009. Sea urchin grazing and kelp re-vegetation in the NE Atlantic. *Marine Biology Research*, **5** (6), 515-528.
- Norderhaug, K.M., Christie, H. & Fredriksen, S., 2007. Is habitat size an important factor for faunal abundances on kelp (*Laminaria hyperborea*)? *Journal of Sea Research*, **58** (2), 120-124.
- Norton, T.A., 1978. The factors influencing the distribution of *Saccorhiza polyschides* in the region of Lough Ine. *Journal of the Marine Biological Association of the United Kingdom*, **58**, 527-536.
- Norton, T.A., 1992. Dispersal by macroalgae. *British Phycological Journal*, **27**, 293-301.
- Norton, T.A., Hiscock, K. & Kitching, J.A., 1977. The Ecology of Lough Ine XX. The *Laminaria* forest at Carrigathorna. *Journal of Ecology*, **65**, 919-941.
- O'Brien, P.J. & Dixon, P.S., 1976. Effects of oils and oil components on algae: a review. *British Phycological Journal*, **11**, 115-142.
- Pedersen, M.F., Nejrup, L.B., Fredriksen, S., Christie, H. & Norderhaug, K.M., 2012. Effects of wave exposure on population structure, demography, biomass and productivity of the kelp *Laminaria hyperborea*. *Marine Ecology Progress Series*, **451**, 45-60.
- Penfold, R., Hughson, S., & Boyle, N., 1996. *The potential for a sea urchin fishery in Shetland*.

<http://www.nafc.ac.uk/publish/note5/note5.htm>, 2000-04-14

Philippart, C.J., Anadón, R., Danovaro, R., Dippner, J.W., Drinkwater, K.F., Hawkins, S.J., Oguz, T., O'Sullivan, G. & Reid, P.C., 2011. Impacts of climate change on European marine ecosystems: observations, expectations and indicators. *Journal of Experimental Marine Biology and Ecology*, **400** (1), 52-69.

Raffaelli, D. & Hawkins, S., 1999. *Intertidal Ecology* 2nd edn.. London: Kluwer Academic Publishers.

Rinde, E. & Sjøtun, K., 2005. Demographic variation in the kelp *Laminaria hyperborea* along a latitudinal gradient. *Marine Biology*, **146** (6), 1051-1062.

Rinde, E., Christie, H., Fredriksen, S. & Sivertsen, A., 1992. Ecological consequences of kelp trawling: Importance of the structure of the kelp forest for abundance of fauna in the kelp holdfasts, benthic fauna and epiphytes. *Norsk Institutt for Naturforskning. Oppdragsmelding*, (127), 1-37.

Rostron, D.M. & Bunker, F. St P.D., 1997. An assessment of sublittoral epibenthic communities and species following the *Sea Empress* oil spill. *A report to the Countryside Council for Wales from Marine Seen & Sub-Sea Survey., Countryside Council for Wales, Bangor, CCW Sea Empress Contact Science*, no. 177.

Ryland, J.S., 1970. *Bryozoans*. London: Hutchinson University Library.

Ryland, J.S., 1976. Physiology and ecology of marine bryozoans. *Advances in Marine Biology*, **14**, 285-443.

Ryland, J.S., 1977. Taxes and tropisms of Bryozoans. In *Biology of bryozoans* (ed. R.M. Woollacott & R.L. Zimmer), pp. 411-436.

Schiel, D.R. & Foster, M.S., 1986. The structure of subtidal algal stands in temperate waters. *Oceanography and Marine Biology: an Annual Review*, **24**, 265-307.

Sebens, K.P., 1985. Community ecology of vertical rock walls in the Gulf of Maine: small-scale processes and alternative community states. In *The Ecology of Rocky Coasts: essays presented to J.R. Lewis, D.Sc.* (ed. P.G. Moore & R. Seed), pp. 346-371. London: Hodder & Stoughton Ltd.

Sebens, K.P., 1986. Spatial relationships among encrusting marine organisms in the New England subtidal zone. *Ecological Monographs*, **56**, 73-96.

Sheppard, C.R.C., Bellamy, D.J. & Sheppard, A.L.S., 1980. Study of the fauna inhabiting the holdfasts of *Laminaria hyperborea* (Gunn.) Fosl. along some environmental and geographical gradients. *Marine Environmental Research*, **4**, 25-51.

Sivertsen K., 1991. Harvesting of kelp and kelp regrowth after kelp trawling at Smøla, Møre og Romsdal. *Fisken og Havet*, **1**: 1-44. (in Norwegian with English summary).

Sivertsen, K., 1997. Geographic and environmental factors affecting the distribution of kelp beds and barren grounds and changes in biota associated with kelp reduction at sites along the Norwegian coast. *Canadian Journal of Fisheries and Aquatic Sciences*, **54**, 2872-2887.

Sjøtun, K., Christie, H. & Helge Fosså, J., 2006. The combined effect of canopy shading and sea urchin grazing on recruitment in kelp forest (*Laminaria hyperborea*). *Marine Biology Research*, **2** (1), 24-32.

Sjøtun, K. & Fredriksen, S., 1995. Growth allocation in *Laminaria hyperborea* (Laminariales, Phaeophyceae) in relation to age and wave exposure. *Marine Ecology Progress Series*, **126**, 213-222.

Sjøtun, K., Fredriksen, S. & Rueness, J., 1998. Effect of canopy biomass and wave exposure on growth in *Laminaria hyperborea* (Laminariaceae: Phaeophyta). *European Journal of Phycology*, **33**, 337-343.

Smale, D.A., Burrows, M.T., Moore, P., O'Connor, N. & Hawkins, S.J., 2013. Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. *Ecology and evolution*, **3** (11), 4016-4038.

Smith, J.E. (ed.), 1968. 'Torrey Canyon'. *Pollution and marine life*. Cambridge: Cambridge University Press.

Somerfield, P.J. & Warwick, R.M., 1999. Appraisal of environmental impact and recovery using *Laminaria* holdfast faunas. *Sea Empress, Environmental Evaluation Committee., Countryside Council for Wales, Bangor, CCW Sea Empress Contract Science, Report no. 321*.

Steneck, R.S., Graham, M.H., Bourque, B.J., Corbett, D., Erlandson, J.M., Estes, J.A. & Tegner, M.J., 2002. Kelp forest ecosystems: biodiversity, stability, resilience and future. *Environmental conservation*, **29** (04), 436-459.

Steneck, R.S., Vavrinc, J. & Leland, A.V., 2004. Accelerating trophic-level dysfunction in kelp forest ecosystems of the western North Atlantic. *Ecosystems*, **7** (4), 323-332.

Stickle, W.B. & Diehl, W.J., 1987. Effects of salinity on echinoderms. In *Echinoderm Studies, Vol. 2* (ed. M. Jangoux & J.M. Lawrence), pp. 235-285. A.A. Balkema: Rotterdam.

Stock, J.H., 1988. Lamippidae (Copepoda : Siphonostomatoida) parasitic in *Alcyonium*. *Journal of the Marine Biological Association of the United Kingdom*, **68**, 351-359.

Svendsen, P., 1972. Some observations on commercial harvesting and regrowth of *Laminaria hyperborea*. *Fisken og Havet*, **2**, 33-45.

Thompson, G.A. & Schiel, D.R., 2012. Resistance and facilitation by native algal communities in the invasion success of *Undaria pinnatifida*. *Marine Ecology, Progress Series*, **468**, 95-105.

- Tillin, H.M. & Hull, S.C., 2013g. Tools for Appropriate Assessment of Fishing and Aquaculture Activities in Marine and Coastal Natura 2000 sites. Report VII: Intertidal and Subtidal Reefs. Report No. R.2074. Report by ABPmer for the Marine Institute (Galway).
- Todd, C.D. & Turner, S.J., 1988. Ecology of intertidal and sublittoral cryptic epifaunal assemblages. II. Non-lethal overgrowth of encrusting bryozoans by colonial ascidians. *Journal of Experimental Marine Biology and Ecology*, **115**, 113-126.
- Tritar, S., Prieur, D. & Weiner, R., 1992. Effects of bacterial films on the settlement of the oysters, *Crassostrea gigas* (Thunberg, 1793) and *Ostrea edulis* (Linnaeus, 1750) and the scallop *Pecten maximus* (Linnaeus, 1758). *Journal of Shellfish Research*, **11** (2), 325-330.
- Tubbs, C., 1999. *The Ecology, Conservation and History of the Solent*. Chichester: Packard Publishing Ltd, 179pp.
- Tyler, P.A. & Young, C.M., 1998. Temperature and pressures tolerances in dispersal stages of the genus *Echinus* (Echinodermata: Echinoidea): prerequisites for deep sea invasion and speciation. *Deep Sea Research II*, **45**, 253-277
- Tyler-Walters, H., 2008. *Echinus esculentus*. Edible sea urchin. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. [cited 26/01/16]. Plymouth: Marine Biological Association of the United Kingdom. Available from: <http://www.marlin.ac.uk/species/detail/1311>
- Ursin, E., 1960. A quantitative investigation of the echinoderm fauna of the central North Sea. *Meddelelser fra Danmark Fiskeri-og-Havundersogelser*, **2** (24), pp. 204.
- Vadas, R.L. & Elnor, R.W., 1992. *Plant-animal interactions in the north-west Atlantic*. In *Plant-animal interactions in the marine benthos*, (ed. D.M. John, S.J. Hawkins & J.H. Price), 33-60. Oxford: Clarendon Press. [Systematics Association Special Volume, no. 46].
- Van den Hoek, C., 1982. The distribution of benthic marine algae in relation to the temperature regulation of their life histories. *Biological Journal of the Linnean Society*, **18**, 81-144.
- Vost, L.M., 1983. The influence of *Echinus esculentus* grazing on subtidal algal communities. *British Phycological Journal*, **18**, 211.
- Walker, F. T., 1953. Distribution of Laminariaceae around Scotland. *Journal du Conseil*, **20** (2), 160-166.
- Walne P., 1974. *Culture of Bivalve Molluscs: 50 years' experience at Conwy*. Fishing News Books Ltd (No. Ed. 2), Oxford.
- Wendt, D.E., 1998. Effect of larval swimming duration on growth and reproduction of *Bugula neritina* (Bryozoa) under field conditions. *Biological Bulletin*, **195**, 126-135.
- Whittick, A., 1983. Spatial and temporal distributions of dominant epiphytes on the stipes of *Laminaria hyperborea* (Gunn.) Fosl. (Phaeophyta: Laminariales) in S.E. Scotland. *Journal of Experimental Marine Biology and Ecology*, **73**, 1-10.
- Wilding T. & Hughes D., 2010. A review and assessment of the effects of marine fish farm discharges on Biodiversity Action Plan habitats. *Scottish Association for Marine Science, Scottish Aquaculture Research Forum (SARF)*.
- Wilkinson, M., 1995. Information review on the impact of kelp harvesting. *Scottish Natural Heritage Review*, no. 34, 54 pp.
- Woolmer, A.P., Syvret, M. & Fitzgerald, A., 2011. Restoration of Native Oyster, *Ostrea edulis*, in South Wales: Options and Approaches. *CCW Contract Science Report*, no: 960, pp. 93.
- Wotton, D.M., O'Brien, C., Stuart, M.D. & Fergus, D.J., 2004. Eradication success down under: heat treatment of a sunken trawler to kill the invasive seaweed *Undaria pinnatifida*. *Marine Pollution Bulletin*, **49** (9), 844-849.