



MarLIN

Marine Information Network

Information on the species and habitats around the coasts and sea of the British Isles

Cirratulids and *Cerastoderma edule* in littoral mixed sediment

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

Dr Heidi Tillin & Charlotte Marshall

2016-07-12

A report from:

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

Please note. This MarESA report is a dated version of the online review. Please refer to the website for the most up-to-date version [<https://www.marlin.ac.uk/habitats/detail/372>]. All terms and the MarESA methodology are outlined on the website (<https://www.marlin.ac.uk>)

This review can be cited as:

Tillin, H.M. & Marshall, C.M., 2016. Cirratulids and [*Cerastoderma edule*] in littoral mixed sediment. 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.372.1>

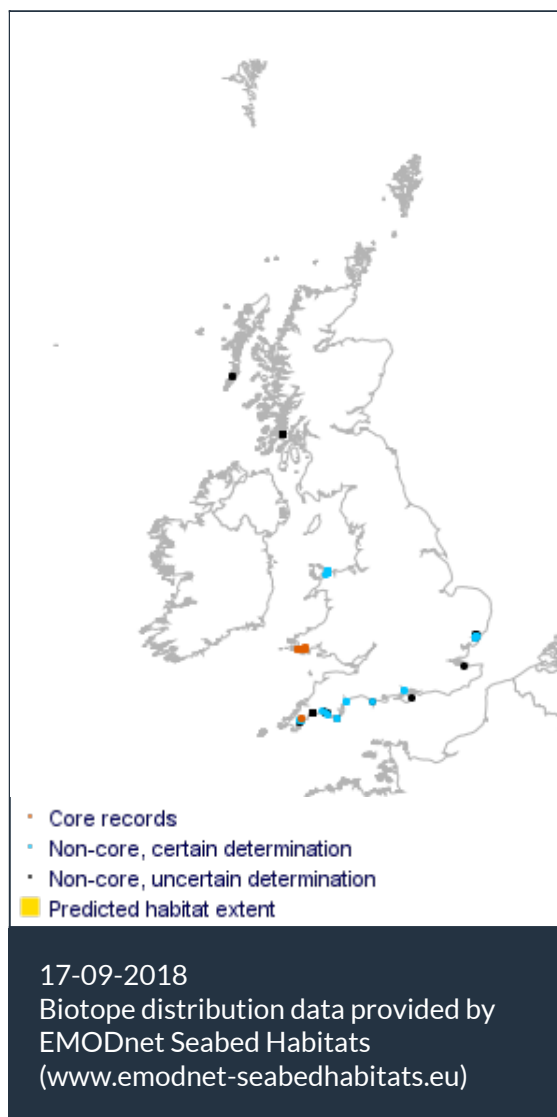


The information (TEXT ONLY) provided by the Marine Life Information Network (MarLIN) is licensed under a Creative Commons Attribution-Non-Commercial-Share Alike 2.0 UK: England & Wales License. Note that images and other media featured on this page are each governed by their own terms and conditions and they may or may not be available for reuse. Permissions beyond the scope of this license are available [here](#). Based on a work at www.marlin.ac.uk

(page left blank)



Cirratulids and *Cerastoderma edule* in littoral mixed sediment
 Photographer: Paul Brazier
 Copyright: Joint Nature Conservation Committee (JNCC)



Researched by Dr Heidi Tillin & Charlotte Marshall

Refereed by This information is not refereed.

Summary

☰ UK and Ireland classification

EUNIS 2008	A2.421	Cirratulids and <i>Cerastoderma edule</i> in littoral mixed sediment
JNCC 2015	LS.LMx.Mx.CirCer	Cirratulids and <i>Cerastoderma edule</i> in littoral mixed sediment
JNCC 2004	LS.LMx.Mx.CirCer	Cirratulids and <i>Cerastoderma edule</i> in littoral mixed sediment
1997 Biotope		

🔍 Description

Sheltered mixed sediments, usually subject to variable salinity conditions. Banks of shell may be present. The infauna is very diverse, dominated by a range of polychaetes including *Exogone naidina*, *Sphaerosyllis taylori*, *Pygospio elegans*, *Chaetozone gibber*, *Cirriformia tentaculata*, *Aphelochaeta marioni*, *Capitella capitata*, *Mediomastus fragilis*, and *Melinna palmata*. The oligochaetes *Tubificoides benedii* and *Tubificoides pseudogaster* are abundant, as is the cockle *Cerastoderma edule*. A large range of amphipods may occur, including *Melita palmata*, *Microtopopus maculatus*, *Aora*

gracilis and *Corophium volutator*. The bivalves *Abra alba* and *Abra nitida* may occur. The barnacle *Elminius modestus* can be abundant where the sediment has stones on the surface. Epifaunal algae may occur attached to stable cobbles on the sediment surface. (Information from Connor *et al.*, 2004; JNCC, 2015).

↓ Depth range

-

Additional information

-

✓ Listed By

- none -

Further information sources

Search on:



Habitat review

🔄 Ecology

Ecological and functional relationships

- Deposit feeders including the cirratulids *Aphelochaeta marioni*, *Chaetozone gibber*, *Cirriformia tentaculata* and other polychaete worms such as *Pygospio elegans*, *Capitella capitata* and *Melinna palmata* are the dominant trophic group in the biotope. These species feed on organic debris, diatoms and detrital matter within the sediment. The oligochaetes *Tubificoides benedii* and *Tubificoides pseudogaster* are also abundant deposit feeders, feeding on detrital material and bacteria.
- Suspension feeders, represented mainly by the common cockle *Cerastoderma edule*, an important characterizing species in this biotope, are another important trophic group. Other associated suspension feeders may include the barnacle *Elminius modestus* and the bivalves *Abra alba* and *Abra nitida* although these bivalves are also deposit feeders. The polychaete *Pygospio elegans*, although principally a surface deposit feeder, can also filter feed (Fauchald & Jumars, 1979).
- A range of amphipods including *Corophium volutator* may occur. This species is capable of both deposit feeding and suspension feeding and alternates between the two depending on the state of the tide. Only when immersed can it filter feed. It feeds on particulate organic matter, bacteria and diatoms.
- The catworm *Nephtys hombergii* and phyllodocid polychaete *Anaitides mucosa* are carnivorous polychaetes and feed mostly on other polychaete species. Combined, they may represent significant predators on the other polychaetes in the biotope.
- Birds and fish are likely to represent the most important large mobile predators, with the birds exerting more predation pressure at low tide and *vice versa*. Hayward (1994) proposed that the major marine predators of sand infauna are fish such as the sand goby *Pomatoschistus minutus*, sole *Solea solea* and plaice *Pleuronectes platessa*. Gobies were said to feed mainly on polychaetes whereas sole and plaice feed on polychaetes and small bivalves (Hayward, 1994). The diet of the redshank *Tringa totanus* includes *Hydrobia ulvae*, *Nephtys hombergii* and *Corophium volutator*, the latter representing its preferred prey (Goss-Custard, 1977a,b).
- The epifaunal algae which may occur attached to stable cobbles on the sediment may provide shelter for the laver spire shell *Hydrobia ulvae*.

Density dependent effects on community structure

- Assemblages of cockles can have a significant influence on the structure of the macrobenthic community. For example, Flach (1996) reported that the presence of *Cerastoderma edule* significantly reduced the densities of juvenile *Pygospio elegans*, *Anaitides* spp., *Nephtys hombergii*, *Aphelochaeta marioni* (studied as *Tharyx marioni*), *Corophium volutator* and *Cerastoderma edule* juveniles themselves. Following a dramatic decline in numbers of *Cerastoderma edule* after eutrophic episodes in the Bay of Somme, France, the abundance of *Pygospio elegans* increased dramatically to almost 200,000 individuals / m² where there had previously only been several tens per m² (Desprez *et al.*, 1992). By 1987, when the cockles had returned, *Pygospio elegans* had all but disappeared.
- Flach (1996) also looked at the effects that the abundance of cockles had on the abundance of several other species on the tidal flats of Balgzand, Wadden Sea. When comparing the abundance of species on plots with no cockles to those where cockles

occupied 16% of the plot, he found a negative density dependent effect. For example, the abundances of *Corophium volutator* were 144 and 1648 / m², *Nephtys hombergii* were 196 and 817 / m² and *Pygospio elegans* were 7023 and 30001 / m² for the cockle-occupied plots and control plots respectively. The negative effects on *Corophium volutator* are thought to result from the movement of the cockles that destroys the tubes of the amphipod. This causes the amphipod to move away, therefore increasing chances of predation (Flach, 1996).

- The presence of the gastropod *Hydrobia ulvae* in some areas on the German Bight has been implicated as the cause behind low numbers of *Aphelochaeta marioni* (studied as *Tharyx marioni*), (Farke, 1979). *Corophium volutator* and *Pelosclex benedeni* have also been suggested as competitors for food and space with *Aphelochaeta marioni* (Farke, 1979).

Seasonal and longer term change

- The abundance of the associated polychaete species is likely to show significant peaks throughout the year concomitant with their respective breeding periods. A peak in abundance in the cirratulid *Cirriformia tentaculata*, for example, was seen over the summer months on Hamble Spit in Southampton (George, 1964b). In August 1960, more than 300 individuals were present in a 16 cm² quadrat whereas in April only 100 or so were counted in the same area (George, 1964). In *Aphelochaeta marioni* (studied as *Tharyx marioni*), abundance was highest in winter in Stonehouse Pool, a muddy sandy habitat at the very seaward end of the Tamar estuary in Plymouth (Gibbs, 1971). At this time population numbers were almost 100,000 / m², representing the brood of the previous spring and summer, and abundance decreased continually from February to July (Gibbs, 1971; Farke, 1979).
- Cockle beds are periodically decimated by severe winter weather and these high mortalities in winter are often followed by an exceptionally high spring spatfall (Hayward, 1994). The post larval cockles then grow rapidly to occupy space on sand within a year (Hayward, 1994). However, settlement and subsequent recruitment is highly sporadic and varies with geographic location, year, season, reproductive condition of the adults, climatic variation, intra and interspecific mortality and predation. Nevertheless, *Cerastoderma edule* are likely to experience a peak in abundance over the summer and autumn months. Due to the negative effects the presence of this species has on other associated fauna, increased abundance of some fauna e.g. polychaetes and amphipods may be observed over winter. Jensen (1985) found that following a winter mortality of cockles, *Corophium volutator* moved into sandy low-shore areas where it did not normally occur (normally being in silty areas of sand unsuitable for cockles) (Hayward, 1994).
- Fluctuating numbers of birds and fish throughout the year may affect the level of predation pressure on invertebrates in this biotope. These changes will be superimposed on any cyclical changes the invertebrates themselves experience throughout the year.
- Macroalgae populations are also likely to exhibit some seasonal differences with a general decline in abundance / biomass over winter.

Habitat structure and complexity

The sediment itself, being a mixture of sand, gravel and mud, provides heterogeneity to the biotope and increases the number of potential habitats. The common cockle *Cerastoderma edule* contributes to the complexity of the habitat in two ways:

- The broken and empty shells of cockles provide some heterogeneity in terms of

substratum type. Apart from the cobbles that may be present on the surface on the substratum, the shells probably represent the largest structural element within this biotope. In laboratory flume experiments, Thompson & Amos (2002) reported that the addition of even a single *Cerastoderma edule* shell (studied as *Cerastoderma edulis*) caused the significant erosion of a clay bed.

- The crawling and shaking behaviour of the cockles disturbs the surrounding sediment and can leave shallow trough-like depressions in it. Flach (1996) reported that cockles with a shell length greater than 4 cm can disturb more than 10 cm³ of sediment in one week by shaking alone. The same size cockle was able to disturb almost 30 cm³ by crawling over a distance of 4 cm in a week. Such disturbance can significantly affect the abundance of other benthic species and dense assemblages of cockles have a strong influence on the structure of the macrobenthic community (see ecological relationships above).

On a smaller scale, the burrows and tubes built by polychaete worms result in an uneven sediment surface. This partly explains the highly diverse fauna associated with this biotope. Stones and cobbles may be found on the sediment surface and several of the polychaete species can be found underneath them, for example, *Cirriformia tentaculata*. It is likely that the stones and cobbles offer the worms some protection from desiccation during tidal emersion.

Productivity

- Little information concerning the productivity of this biotope specifically was found. However, productivity in the muddy fine sand *Abra alba* - *Melinna palmata* community in the Bay of Morlaix in France ranged from just under 5,000 to over 25,000 g / m² / year (Dauvin, 2000). This community is also dominated by a polychaete and bivalve combination, has similar sediment characteristics and is possibly representative of productivity in this biotope.
- Secondary production accounts for almost all of the productivity within this biotope with the deposit feeders contributing the most to this. *Tubificoides benedii* (studied as *Tubificoides benedeni*) accounted for over 92% of the biomass of mud fauna in the Forth estuary and production values of this species ranged from 14.2-27.1 g (wet weight) per m² per year (Bagheri & McLusky, 1984). Overall, the oligochaetes and small polychaetes in this estuary accounted for about half of the total invertebrate production.
- The small amount of epifaunal algae that may occur in this biotope will contribute some dissolved organic carbon to the biotope. Algal fragments and microbial film organisms are continually removed by the sea and may enter the food chain of local, subtidal ecosystems or perhaps exported further offshore.

Recruitment processes

Recruitment in this biotope is characterized by a variety of reproductive mechanisms. Recruitment does not usually occur through dispersive larval phases as many of the species do not produce planktonic larvae. In such cases, recruitment to the biotope via larval dispersal is unlikely and will probably depend on adult immigration. Due to the limited mobility of the characterizing species in this biotope however, this immigration is likely to be primarily through passive mechanisms such as dislodgement during storms or tidal action and 'bed-load' transport. Coffen-Smout & Rees (1999), for example, reported that cockles could be distributed by flood and ebb tides by rolling around on the surface.

Recruitment in the major groups present is summarized below.

- Egg production in cirratulids, for example *Cirriformia tentaculata* and *Aphelochaeta marioni*, often varies with location. In addition, many cirratulids are thought to have direct development, which has obvious limitations with regards to dispersal.
- Breeding in the cirratulid *Cirriformia tentaculata* occurs in 'bursts' between March and September in Southampton, although the main breeding period runs from April to August (George, 1964a). Petersen (1999) stated that *Cirriformia tentaculata* may have a brief planktonic stage although none have ever been observed in the plankton. However, behavioural differences were found between the larval stages of *Cirriformia tentaculata* from Drake's Island in Plymouth and those from Southampton (George, 1963). In the former, the larvae were found to pass through a strongly swimming trochophore phase for about one week, whereas larvae from Southampton were entirely benthic. Recruitment and dispersal in this species could, therefore, vary depending on the geographical location of the biotope.
- The cirratulid *Aphelochaeta marioni* breeds in April in the Thames estuary and Chalkwell in Essex, from September to October in the Tamar Estuary (Petersen, 1999) and from late October to early November in Stonehouse Pool, a muddy sandy habitat at the very seaward end of the Tamar estuary in Plymouth (studied as *Tharyx marioni*, Gibbs, 1971). At this time population numbers were almost 100,000 / m², representing the brood of the previous spring and summer, and abundance decreased continually from February to July (Gibbs, 1971; Farke, 1979). The larvae of *Aphelochaeta marioni* are non-pelagic and bottom living (Gibbs, 1971). The larvae burrow immediately after hatching therefore dispersal though larval stages is unlikely. Large females only produce about 1000-1500 eggs (Dales, 1951).
- Recruitment in *Cerastoderma edule* populations is highly variable. In the Schelde estuary, large fluctuations were observed in the year-to-year biomass of *Cerastoderma edule* with contribution to biomass ranging between 19-72% in the middle region over 6 years. *Cerastoderma edule* first mature and spawn in their second summer, at about 18 months old and 15-20 mm in length, however, large cockles (>15 mm) may mature in their first year suggesting that size and maturity are linked (Orton, 1926; Hancock & Franklin, 1972; Seed & Brown, 1977). Most adults spawn in a short peak period over summer with remaining adults spawning over a protracted period, resulting in a short (ca. 3 month) period of peak settlement followed by generally declining numbers of recruits (Hancock, 1967; Seed & Brown, 1977). Spawning generally occurs between March - August in the UK followed by peak spatfall between May and September, however the exact dates vary between sites in the UK and Europe (Seed & Brown, 1977; Newell & Bayne, 1980). Settlement and subsequent recruitment is sporadic and varies with geographic location, year, season, reproductive condition of the adults, climatic variation, intra and interspecific mortality and predation. Ducrotoy *et al.* (1991; Figure 14) identified, 'crisis', 'recovery', 'upholding', and 'decline' phases in dynamics of *Cerastoderma edule* populations (see MarLIN review).
- In terms of other characterizing species, a planktonic larval stage is usually absent in the polychaete *Pygospio elegans* as well (Rostron, 1998). However, recruitment in this species can be good. In a study focusing on the establishment of zoobenthic communities in seagrass beds, Boström & Bonsdorff (2000) found that *Pygospio elegans* colonized artificial seagrass patches rapidly. Densities of the *Pygospio elegans* in the experimental trays were comparable to those in *Zostera marina* meadows within nine weeks. The oligochaete *Tubificoides benedii* is sluggish and does not possess the capability to liberate large numbers of planktonic larvae for dispersal either (Barnett, 1983). Breeding of *Nephtys hombergii* was intermittent and prone to failure in the North East of England (Olive & Morgan, 1991).

- Female *Corophium volutator* brood their eggs until they hatch at which time the young crawl from the parent burrow (Eltringham, 1971). This means that dispersal relies entirely on the movement by the adult members of the population. However, dispersal on small scales (tens of square metres) is very good and *Corophium volutator* can rapidly colonize by immigration and recruitment of juveniles from immigrants (see MarLIN review). *Capitella capitata* has planktonic larvae which can be present all year thus increasing its chances of successful colonization of new areas and distribution. Benthic larvae can also be produced which enables the rapid exploitation of concentrations of organic matter (Rostron, 1998). *Capitella capitata* can reach maturity within about 40 days and therefore has a high potential to recolonize an area.

Overall, the major species in this biotope have a limited dispersal potential and recruitment is subject to significant influence from a variety of factors.

Time for community to reach maturity

Little information was found concerning community development, or indeed the development of populations of all of the characterizing species. Some of the species associated with this biotope are considered 'opportunistic' and may be able to re-establish themselves relatively quickly. However, these 'opportunistic' species such as *Capitella capitata*, although commonly associated with this biotope, are not considered to be important characterizing species (see 'Species Composition'). *Capitella capitata* has planktonic larvae which can be present all year thus increasing its chances of successful colonization of new areas and distribution. Benthic larvae can also be produced which enables the rapid exploitation of concentrations of organic matter (Rostron, 1998).

Cirriiformia tentaculata has been found to produce both benthic and planktonic larvae (George, 1963). The significance of this is that these two apparently different 'physiological races' will have entirely different dispersal potential and thus varying chances of successful recolonization of areas. George (1968) discussed possible recolonization in the two cirratulids *Cirratulus cirratus* and *Cirriiformia tentaculata* in the British Isles. He postulated that if the lower limit of a population extended to the subtidal, recolonization of intertidal areas would be rapid, taking at most 1-2 years. However, both the species he studied were intertidal. *Cirratulus cirratus* disappeared from Sussex following the severe winter of 1962/63 and had not reappeared by 1968. He suggested that it existed subtidally in such small numbers that it could not maintain itself once replenishment from the shore population had ceased. With regards to *Cirriiformia tentaculata*, it was concluded that recolonization by this species would take place by marginal dispersal rather than remote dispersal (Crisp, 1958; cited in George, 1968) and that it was likely to take several decades with mild winters before its distribution returned to that prior to 1962/63 (George, 1968). Farke (1979) implied that *Aphelochaeta marioni* (studied as *Tharyx marioni*) became dominant in areas of the German Bight where it was previously absent in only a few years.

Recruitment in the cockle *Cerastoderma edule* is highly variable. In the Schelde estuary, large fluctuations were observed in the year-to-year biomass of *Cerastoderma edule* with contribution to biomass ranging between 19-72% in the middle region over 6 years. However, evidence suggests that recolonization and population development is fairly rapid. Following the Sea Empress oil spill in Angle Bay, Milford Haven, the presence of juvenile *Cerastoderma edule* on the lower shore shortly after the spill enabled the re-establishment of adult populations on the middle shore within about six months (Rostron, 1998). Hall & Harding (1997) found that *Cerastoderma edule* abundance had returned to control levels within about 56 days after significant mortality due to suction dredging, and Moore (1991) also suggested that recovery was rapid. Recovery is dependant on

recruitment of spat or migration (active or passive) from the surrounding substratum. For example, Coffen-Smout & Rees (1999) reported that cockles could be distributed by flood and ebb tides, but especially flood tides (by rolling around the surface) up to 0.45 m on neap tides or between 94 m and 164 m on spring tides and could colonize cleared areas at a rate of 2.2 -12 individuals / m / 14 days. Cockle beds are periodically decimated by severe winter weather and these high mortalities at winter are often followed by an exceptionally high spring spatfall (Hayward, 1994). The post larval cockles then grow rapidly to occupy space on sand within a year (Hayward, 1994).

Additional information

-

Preferences & Distribution

Habitat preferences

Depth Range

[Water clarity preferences](#)

Limiting Nutrients Data deficient

Salinity preferences

Physiographic preferences

Biological zone preferences

Substratum/habitat preferences

Tidal strength preferences

Wave exposure preferences

Other preferences Sheltered to very sheltered habitats.

Additional Information

Species composition within this biotope is likely to be greatly influenced by sediment type and height on the shore. Due to the sheltered and tidally influenced nature of the habitat, finer particles may be found higher up the shore with a higher proportion of sand and gravel lower down. This change in substratum may also lead to a general transition from deposit feeders to suspension feeders.

In Stonehouse Pool, a muddy sandy habitat at the seaward end of the Tamar estuary in Devon, [Aphelochaeta marioni](#) (studied as *Tharyx marioni*) was found to occupy a similar niche to *Cirriformia tentaculata* and *Cirratulus cirratus* but at different heights on the shore (Gibbs, 1971). The former densely populated the shore from the low water mark down whereas the latter two species were found from this point up to mid-tide level.

Species composition

Species found especially in this biotope

Rare or scarce species associated with this biotope

-

Additional information

Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

The biotope description and characterizing and associated species are taken from (JNCC, 2015). The biotope is associated with sheltered mixed sediments, usually subject to variable salinity conditions. The infauna is very diverse and is dominated by a range of polychaetes, from a range of taxonomic groups including the cirratulids. *Aphelochaeta marioni*, *Chaetozone gibber*, *Cirriformia tentaculata*; the syllids *Exogone naidina*, *Sphaerosyllis taylori*, the suspension feeding spionids *Pygospio elegans*, the capitellids, *Capitella capitata*, *Mediomastus fragilis*, and the ampharetid *Melinna palmata*.

The species named in the biotope title (the cirratulids *Aphelochaeta marioni*, *Chaetozone gibber*, *Cirriformia tentaculata* and *Cerastoderma edule*) are considered to be key characterizing species and are considered specifically in the sensitivity assessments. The other infaunal species present contribute to species richness and ecosystem function and are considered generally in the assessments.

The oligochaetes *Tubificoides benedii* and *Tubificoides pseudogaster* are abundant, as is the cockle *Cerastoderma edule*. A large range of amphipods may occur, including *Melita palmata*, *Microprotopus maculatus*, *Aora gracilis* and *Corophium volutator*. The bivalves *Abra alba* and *Abra nitida* may occur.

The barnacle *Elminius modestus* can be abundant where the sediment has stones on the surface and epifaunal algae may occur attached to stable cobbles on the sediment surface: these species are not considered to characterize the biotope although they contribute to species richness and ecosystem function and are not considered specifically in the assessments

Resilience and recovery rates of habitat

Areas of dense cockles support recreational and commercial fisheries and are an important food source for some shore-birds. There has, therefore, been considerable interest in the population dynamics of *Cerastoderma edule* and the effects of harvesting and this species is well-studied compared with many of the other soft-sediment species found in this biotope. Cockle beds undergo natural variations in density between years with periods of population stability and high densities interspersed with periods of mass mortality or more gradual decline and recovery (Ducrotoy *et al.*, 1991). The duration of the cycle of decline and recovery varies between 1 and 10 years (Ducrotoy *et al.*, 1991).

Cerastoderma edule reaches sexual maturity between 1 and 2 years may live for as long as 13 years (although most individuals live for 3-4 years). Cockles spawn annually, generally in Spring in the UK (Boyden, 1971) and fertilization is external. Males may release about 15 million sperm per second while females release about 1900 eggs per second. Gamete viability is short and fertilization is reduced 50% in 2 hrs; no fertilization occurs after 4-8 hrs. André and Lindegarth (1995) noted that fertilization efficiency was dependent on sperm concentration, so that at high water flow rates fertilisation was only likely between close individuals. However, this may be compensated for by high population densities and synchronous spawning of a large proportion of the population. The planktotrophic larvae can live in the water column for up to 5 weeks (Jonsson *et al.*, 1991). The larvae therefore have the potential for long-distance (10s-100s of km) transport (Coscia *et al.*, 2013), supporting recruitment where local populations are removed. However, the degree of connectivity will depend on hydrodynamics (Coscia *et al.*, 2013). Following settlement, the larvae

of *Cerastoderma edule* can disperse again through 'byssio-pelagic' dispersal (drifting on byssal threads), (de Montaudouin, 1997; Bouma et al. 2001; Huxham & Richards, 2003; Beukema & de Vlas, 1989).

Coffen-Smout and Rees (1999) reported that cockles that had been displaced from the sediment and had not reburied could be distributed by flood and ebb tides, but especially flood tides (by rolling around the surface). *Cerastoderma edule* adults were observed to colonize cleared plots (7.65 m²) at a mean rate of 2.2 individuals/m²/14 days. Flach (1996) About 7% of a cockle population move each week (Flach, 1996; Schuitema, 1970), furrows caused by crawling cockles in aquaria during immersion were up to 50 cm in length (Richardson et al 1993, although on intertidal flats smaller movements of a few centimetres were observed (Flach, 1996; Schuitema, 1970). Exposed cockles on the surface may be moved much greater distances by tidal flows (Coffen-Smout & Rees, 1999). It seems likely that small depopulated patches within beds could rapidly recover through adult migration. Other mobile species associated with this biotope may actively migrate into disturbed patches although more sedentary species such as the tube dwelling *Pygospio elegans* will depend on larval recolonization rather than active migration (although some water transport of adults may occur).

No evidence was found that *Cerastoderma edule* can repair significant damage and it is likely that damaged individuals will suffer predation from birds, crabs, whelks and other species. However some species within the biotope can regenerate following extensive injury. Like other polychaetes and molluscs *Pygospio elegans* may suffer from predation by fish and birds on exposed parts of the body and can rapidly repair this (repair takes between 9-12 days, Lindsay et al., 2007).

Recovery of the biotope following large scale depopulation of *Cerastoderma edule* depends on episodes of good recruitment where suitable habitats remain. In The Wash, long-term time studies suggest that over the last 100 years spatfall of cockle is adequate or good in half of years; with the most recent decade studied (1990-1999) no different from previous years. This pattern of episodic recruitment is observed throughout Europe (Beukema et al., 1993; Beukema & Dekker, 2005). A number of factors have been identified that affect larval supply and recruitment to the adult population. Survival during the first few months of life appears to be the decisive factor for recruitment success (Beukema & Dekker, 2005). Post-settlement mortalities are high and result from intra- and inter-specific competition and predation by shore crabs and other species (Strasser & Gunther 2001; Sanchez-Salazar et al. 1987a; Montaudouin & Bachelet, 1996; André et al. 1993; Guillou & Tartu, 1994). High densities of adult *Cerastoderma edule* and other suspension feeders may reduce settlement by ingestion of settling larvae and juveniles or smothering by sediment displaced in burrowing and feeding (Montaudouin & Bachelet, 1996). André et al. (1993) observed that adults inhaled 75% of larvae at 380 adults/m², which were also ingested. However, Montaudouin and Bachelet (1996) noted that adults that inhaled juveniles, rejected them and closed their siphons but that rejected juveniles usually died. High levels of juvenile recruitment have been observed where previous severe winters with heavy storm surges have reduced the population density of adults and reduced numbers of infaunal predators (Ducrotoy et al., 1991). In areas of the Wadden Sea with a high biomass of the shrimp *Crangon crangon*, (a predator of bivalve post-larvae) annual recruitment of *Cerastoderma edule* was negatively related to shrimp biomass at the time of settlement (Beukema & Dekker, 2005). Bivalve recruitment appears to be enhanced following severe winters that reduce populations of predators such as the shore crab *Carcinus maenas*.

Resilience of associated species

The polychaetes *Capitella capitata* and *Pygospio elegans* have many characteristics that allow rapid colonization and population increase in disturbed and defaunated patches where there is little competition from other species (Grassle & Grassle 1974; McCall 1977). *Capitella capitata* and *Pygospio elegans* exhibit a number of reproductive strategies (a trait known as poecilogony). Larvae may develop directly allowing rapid population increase in suitable patches, or they may have a planktonic stage (allowing colonization of new habitats). Experimental studies using defaunated sediments have shown that on small scales *Capitella* can recolonize to background densities within 12 days (Grassle & Grassle 1974; McCall 1977). *Capitella capitata* had almost trebled in abundance within 56 days following disturbance from tractor dredging in a clean sandy area (Ferns et al., 2000). Experimental defaunation studies have shown an increase in *Pygospio elegans*, higher than background abundances within 2 months, reaching maximum abundance within 100 days (Colen et al. 2008). Following a period of anoxia in the Bay of Somme (north France) that removed cockles, *Pygospio elegans* increased rapidly but then decreased as cockle abundance recovered and sediments were disturbed by cockle movement (Desprez et al., 1992; Rybarczyk et al., 1996). Recovery will depend on the lack of stronger competitors and the supply of larvae and hence the season of disturbance will moderate recovery time. In general recovery is predicted to occur within 6 months. However, where conditions are stable these species are likely to be replaced by competitive dominants, particularly bivalves such as cockles, *Limecola balthica* or *Tellina tenuis*.

Many cirratulids are thought to have direct development so that dispersal is likely to be low. George (1968) discussed possible recolonization in the two cirratulids *Cirratulus cirratus* and *Cirriiformia tentaculata* in the British Isles. Following the disappearance of this species from Sussex after the severe winter of 1962-63, he suggested that *Cirratulus cirratus* probably existed subtidally in such small numbers that it could not maintain itself once replenishment from the shore population had ceased. With regards to *Cirriiformia tentaculata*, it was concluded that recolonization by this species will take place by marginal dispersal rather than remote dispersal (Crisp, 1958, cited in George, 1968) and that it was likely to take several decades with mild winters before its distribution returns to that prior to 1962/63 (George, 1968). Under stable conditions, adult and juvenile *Aphelochaeta marioni* disperse by burrowing (Farke, 1979). Farke (1979) reported that *Aphelochaeta marioni* (studied as *Tharyx marioni*) was capable of swimming but only did so under abnormal circumstances, e.g. when removed from the sediment. Farke (1979) suggested that as there was no pelagic stage, dispersal and immigration to new areas must mainly occur during periods of erosion when animals are carried away from their habitat by water currents. Therefore, if adjacent populations are available recovery will be rapid. However where the affected population is isolated or severely reduced, recovery may be extended.

The lifecycle of *Aphelochaeta marioni* varies according to environmental conditions. In Stonehouse Pool, Plymouth Sound, *Aphelochaeta marioni* (studied as *Tharyx marioni*) spawned in October and November (Gibbs, 1971) whereas in the Wadden Sea, Netherlands, spawning occurred from May to July (Farke, 1979). Spawning, which occurs at night, was observed in a microsystem in the laboratory by Farke (1979). The female rose up into the water column with the tail end remaining in the burrow. The eggs were shed within a few seconds and sank to form puddles on the sediment. The female then returned to the burrow and resumed feeding within half an hour. Fertilization was not observed, probably because the male does not leave the burrow. The embryos developed lecithotrophically and hatched in about 10 days (Farke, 1979). The newly hatched juveniles were ca 0.25 mm in length with a flattened, oval body shape, and had no pigment, chaetae, cirri or palps. Immediately after hatching, the juveniles dug into the sediment. Where the sediment depth was not sufficient for digging, the juveniles swam or crawled in search of a suitable substratum (Farke, 1979). In the microsystem, juvenile mortality was high (ca 10% per month) and most animals survived for less than a year (Farke, 1979). In the Wadden Sea, the majority of the cohort reached

maturity and spawned at the end of their first year, although some slower developers did not spawn until the end of their second year (Farke, 1979). However, the population of *Aphelochaeta marioni* in Stonehouse Pool spawned for the first time at the end of the second year of life (Gibbs, 1971). There was no evidence of a major post-spawning mortality and it was suggested that individuals may survive to spawn over several years. Gibbs (1971) found that the number of eggs laid varied from 24-539 (mean=197) and was correlated with the female's number of genital segments, and hence, female size and age. Farke (1979) implied that *Aphelochaeta marioni* (studied as *Tharyx marioni*) became dominant in areas of the German Bight, where it was previously absent, in only a few years. On balance, however, the recoverability of cirratulids is therefore likely to be low.

The longevity of *Tubificoides* is two years at which point the worm is sexually mature. It is hermaphrodite & reproduces throughout the year. Fertilisation is internal & the larvae are hatched after about 15 days in a cocoon. The worm can form dense communities, but the dispersal potential is very low. (MES Ltd, 2010) suggests this genus has a low recoverability. However the species exhibits many of the traits of opportunistic species.

Guillou & Hily (1983) tracked the recovery of *Melinna palmata* following dredging in the Harbour of Brest (France). Settlement began after 8 months *Melinna palmata* colonized the dredged area in two ways: by settlement of juveniles in autumn and by probable immigration of young and adults in May. The population increased in number and biomass from the end of dredging (August, 1978) to June 1981 and decreased after this period. Following experimental beam trawl disturbance in an area that had previously been closed to fishing populations of *Melinna palmata* increased by 41% (Tuck *et al.*, 1998). The area was repeatedly disturbed over an 18 month period and recovery tracked for a further 18 months. The recoverability of this species is therefore considered to be 'High'.

Resilience assessment. On balance, recoverability of some of the characterizing species, especially the cirratulids, may be low whereas others may be high. Providing some local populations of cirratulids remained then recovery, from impacts to which the biotope has 'Low-No' resistance, should occur within 10 years. The recovery of some other fauna, including *Cerastoderma edule* (albeit episodic) may be more rapid and adult migration may support rapid recovery of small disturbed patches. When resistance to an impact is assessed as 'High' resilience is, therefore, assessed as 'High' by default. When resistance is assessed as 'Medium' (25% of population or habitat removed or severely impacted), resilience is assessed as 'High' based on migration and recovery from adjacent sediments of the characterizing species and local supply of larvae for species with direct development (where the habitat remains suitable). As recruitment in *Cerastoderma edule* is episodic and cirratulids have low dispersal, resilience is assessed as 'Medium' (2-10 years) when resistance is 'Low' (loss of 25-75% of populations and/or habitat) or None (>75% of population removed or habitat impacted).

NB: The resilience and the ability to recover from human induced pressures is a combination of the environmental conditions of the site, the frequency (repeated disturbances versus a one-off event) and the intensity of the disturbance. Recovery of impacted populations will always be mediated by stochastic events and processes acting over different scales including, but not limited to, local habitat conditions, further impacts and processes such as larval-supply and recruitment between populations. Full recovery is defined as the return to the state of the habitat that existed prior to impact. This does not necessarily mean that every component species has returned to its prior condition, abundance or extent but that the relevant functional components are present and the habitat is structurally and functionally recognisable as the initial habitat of interest. It should be

noted that the recovery rates are only indicative of the recovery potential.

Hydrological Pressures

	Resistance	Resilience	Sensitivity
Temperature increase (local)	High Q: High A: High C: Medium	High Q: High A: High C: High	Not sensitive Q: High A: High C: High

This biotope occurs intertidally and is therefore likely to be relatively tolerant of rapid changes in temperature as experienced during cyclical periods of immersion and emersion. Examples of distribution and thermal tolerances tested in laboratory experiments are provided as evidence to support the sensitivity assessment. In general, populations can acclimate to prevailing conditions which can alter tolerance thresholds and care should, therefore, be used when interpreting reported tolerances.

The key characterizing species *Cerastoderma edule* is found from Norway to Mauritania (Honkoop et al., 2008) and through the Baltic, Mediterranean and Black Sea (Longshaw & Malham, 2013). The eastern border of distribution is the Murmansk coast of the Barents sea (Genelt-Yanovskiy et al., 2010). The species is therefore likely to be exposed to warmer and colder water and air temperatures than experienced in the UK over its geographic range.

Kristensen (1958) reported that *Cerastoderma edule* from the Dutch Wadden Sea have an upper temperature tolerance of 31°C for 24 hrs, but that spat (3-6 mm) were more tolerant. All cockles died after 6 min at 36°C. Ansell et al. (1981) reported an upper median lethal temperature of 35°C after 24hrs (29°C after 96 hrs exposure), and Wilson (1981) reported an upper lethal temperature of 42.5°C. These temperatures are likely to exceed the pressure benchmark.

Wilson (1981) noted that *Cerastoderma edule* had limited ability to acclimate and Smaal et al. (1997) stated that *Cerastoderma edule* is unable to acclimate to low temperatures. However, Newell & Bayne (1980) stated that *Cerastoderma edule* was able to acclimate to a temperature change of 10°C and regulate its metabolic rate in response to rising spring temperatures. Temperature tolerance in the above studies was dependant on the environmental temperature, i.e. specimens collected in summer or areas of higher average temperature tolerated higher temperatures than specimens collected in winter and/or at lower average temperatures.

Kingston (1974) reared artificially fertilized *Cerastoderma edule* (as *Cardium edule*) in the laboratory in the temperature range 10-20°C (fertilization did not occur at 5°C). Larval growth was 'poor' at 10°C, optimal between 15 and 20°C and most larvae grew poorly and died before metamorphosing at 30°C. No larval growth occurred at 35 °C and all larvae held at this temperature were dead within 4 days of the start of the experiment. Honkoop and Van Der Meer (1998) found that winter temperatures influenced egg production by *Cerastoderma edule*, individuals kept in warmer waters produced smaller eggs.

Wilson (1993) concluded that *Cerastoderma edule* was probably tolerant of a long-term temperature rise of 2°C associated with climate change. Warmer temperatures during winter result in increased metabolic rate and hence depletion of energy reserves in a time of low food availability and may contribute to post winter mortality of adult cockles (Wilson & Elkaim, 1991). Therefore, the tolerance of *Cerastoderma edule* to temperature change will be dependent on season, an acute, short-term temperature rise in summer or decrease in winter may be detrimental.

Rapid increases in temperature during the spawning season may initiate spawning (Ducrotoy et al. 1991). High shore populations are likely to be more vulnerable to extremes of temperatures due to their longer emergence time (see emergence). However, Wilson (1981) showed that *Cerastoderma edule* had the highest upper lethal temperature of the species he studied, presumably due to acclimation from its close contact with the sediment surface. The upper lethal temperature of 42.8°C is unlikely to occur on mudflats except in extremely hot summers.

Changes in temperature may also lead to indirect ecological consequences. Experiments demonstrated that predation on *Cerastoderma edule* by shore crabs (*Carcinus maenas*) increases as temperature increases (Sanchez-Salazar et al., 1987a). Experiments were run at 6.0, 9.5, and 15.5 °C, representing the annual range of sea surface temperatures within the Menai Strait (north Wales). (Sanchez-Salazar et al., 1987a). Mild winters that enhance predator survival are likely to result in increased predation of spat the following spring (Bukema & Dekker, 2005),

The cirratulid *Aphelochaeta marioni* (studied as *Tharyx marioni*) has been recorded from the Baltic to the Indian Ocean and so it probably has some degree of adaptation or tolerance to a range of temperatures (Hartmann-Schroder, 1974 and Rogall, 1977, cited in Farke, 1979). However, acute rises in temperature may have a more deleterious effect. George (1964a) reported that a rapid rise or fall in temperature of 3 °C was sufficient to induce spawning in 25% of mature *Cirriformia tentaculata*. If this occurred at a time of year that was not suitable for larval survival then larval mortality could be high.

The upper lethal limits for *Cirriformia tentaculata* from the Hamble were reported to be of 32 °C and 29 °C for 5-6 day old and adult *Cirriformia tentaculata* respectively (George, 1964b). The upper temperature tolerance (that killed half of the test organisms after 96 hours) of the oligochaete *Tubificoides benedii* (studied as *Pelosclex benedeni*) was reported to be 28.5 °C (Diaz, 1980). However, temperatures of this magnitude are unlikely to be experienced by this intertidal biotope.

Cirriformia tentaculata is reported to be near its northern limit in the British Isles (George, 1968) and an increase in temperature may lead to the extension of its upper distribution range. An increase in temperature could also serve to decrease the length of time spent in the larval phase and so reduce the risk of predation. The rate of larval growth in *Cirriformia tentaculata* was found to be twice as fast at 20 °C than at 8 °C.

Capitella capitata were a dominant species in mud sediments receiving effluents that were typically 8-12°C warmer than the receiving waters (Bamber & Spencer, 1984) and are considered to be tolerant to this pressure at the benchmark. *Eteone longa* and *Pygospio elegans* were summer visitors to the same effluent exposed habitats and these three species are considered tolerant of acute and chronic increases in temperature.

Sensitivity assessment. Typical surface water temperatures around the UK coast vary, seasonally from 4-19°C (Huthnance, 2010). The characterizing and associated species are considered likely to be tolerant of acute and chronic increases in temperature at the pressure benchmark.

Cerastoderma edule has a wide geographic range and as experiments suggest that individuals can survive sudden increases in temperature. As an intertidal species, with some populations occurring above mid-shore, *Cerastoderma edule* experiences rapid fluctuations in temperature over the tidal cycle. The lack of evidence for mass mortalities in very hot summers (compared with reports for low winter temperatures suggest that this species is likely to tolerate a chronic increase at the pressure benchmark (2°C for one year). An acute increase in temperature for one month may lead

to changes in reproductive success and predation, particularly on spat and juveniles. Adults may, however survive. Biotope resistance is therefore assessed as 'High' and residence is 'High' (by default), the biotope is therefore considered to be 'Not sensitive'.

Temperature decrease (local)

Low

Q: High A: High C: Medium

Medium

Q: High A: Low C: Medium

Medium

Q: High A: Low C: Medium

This biotope occurs intertidally and is therefore likely to be relatively tolerant of rapid changes in temperature as experienced during cyclical periods of immersion and emersion. Examples of distribution and thermal tolerances tested in laboratory experiments are provided as evidence to support the sensitivity assessment. In general, populations can acclimate to prevailing conditions which can alter tolerance thresholds and care should, therefore, be used when interpreting reported tolerances.

The key characterizing species *Cerastoderma edule* is found from Norway to Mauritania (Honkoop *et al.*, 2008) and through the Baltic, Mediterranean and Black Sea (Longshaw & Malham, 2013). The eastern border of distribution is the Murmansk coast of the Barents sea (Genelt-Yanovskiy *et al.*, 2010). Populations at the Barents sea may experience annual water temperatures from 3-8°C but are exposed to air temperatures of -30°C. These populations are present between mid to low shore and although acclimated to lower temperatures are present in low densities compared to more central parts of the range (Genelt-Yanovskiy *et al.*, 2010). The low densities may be due to thermal tolerances or restrictions on feeding and growth or other factors.

High mortalities of cockle populations due to severe winters have been reported by many authors (Kristensen, 1958; Hancock & Urquhart, 1964; Beukema, 1979, 1985, 1990; Ducrotoy *et al.*, 1991, Strasser *et al.*, 2001). Kristensen (1957) showed a direct influence of temperatures below about -2 °C on cockle survival (cited from Beukema, 1979). Kristensen (1958) reported that the sediment froze to a depth of 10 cm and 15 cm, resulting in death of cockles in areas of the Wadden Sea in the severe winter of 1954. Hancock & Urquhart (1964) report almost 100% mortality of cockles in Llanrhidian Sands, Burry Inlet and high mortalities of cockles in other areas around the UK after the winter of 1962/63. However, enhanced recruitment of bivalves, including *Cerastoderma edule* and *Limecola balthica* has been observed in European estuaries after colder winters while densities following milder winters are lower (Beukema 1991, Walker & Dare, 1993, Young *et al.*, 1996). The factors indirectly responsible for this pattern may be changes in reproductive success (Honkoop & Van Der Meer, 1998), changes in the spring phytoplankton bloom, predation (Beukema & Dekker, 2005), removal of larvae by off-shore currents and removal of adults (enhancing recruitment via reduced ingestion of larvae (André *et al.*, 1993) and reduced competition between adults and juveniles).

Aphelocheata marioni (studied as *Tharyx marioni*) has been recorded from the Baltic to the Indian Ocean and so it probably has some degree of adaptation or tolerance to a range of temperatures (Hartmann-Schroder, 1974 and Rogall, 1977, cited in Farke, 1979). Short periods of severe frost in November 1973 were not reported to have affected the population of *Aphelocheata marioni* (studied as *Tharyx marioni*) in the German Bight (Farke, 1979).

Acute falls in temperature may have a more deleterious effect. George (1964a) reported that a rapid rise or fall in temperature of 3 °C was sufficient to induce spawning in 25% of mature *Cirriformia tentaculata*. If this occurred at a time of year that was not suitable for larval survival then larval mortality could be high. However, George (1964b) noted that although in Southampton the incoming tide incurred a drop of 6 °C in five minutes, such rapid changes in temperature had no

significant effect on the mortality of either juvenile or adult *Cirriiformia tentaculata* in the laboratory. The larvae of this species grow twice as slow at 8 °C than they do at 20 °C (George, 1964). Any increase in the length of time spent in the larval phase will increase the risk of predation. In adults, field data suggests that growth ceases at 6 °C (George, 1964). On the Hamble, lower lethal limits of -6 °C (by extrapolation) and 2 °C have been reported for 5-6 day old and adult *Cirriiformia tentaculata* respectively (George, 1964b). These are temperatures that can reasonably be expected in winter in this intertidal biotope and so some mortality is likely. Furthermore, *Cirriiformia tentaculata* is reported to be near its northern limit in the British Isles (George, 1968) and a long-term chronic decrease in temperature could serve to exclude this species from the northern extent of its distribution. George (1968) reported several major changes and a major reduction in the distribution range of *Cirriiformia tentaculata* following the severe winter of 1962/3. In temperature tolerance experiments, no *Cirriiformia tentaculata* survived even a brief exposure to -2 °C or 96 hours at 0 °C.

The cirratulid *Cirratulus cirratus* was found to be tolerant to lower temperatures and it is possible that this species will become more prevalent in this biotope if the temperature falls. George (1968) reported that the ciliary feeding mechanisms of *Cirriiformia tentaculata* became so inefficient at low temperatures that, over long periods, the animal may die of starvation. George (1968) also mentioned that the animal does not withdraw its branchiae in cold weather. Due to their delicate nature, the branchiae may subsequently freeze on the surface. In such a case, the animal would be living under anaerobic conditions and so emerges from the burrow to enable them to respire through their body surface. This emergence would increase both risk of predation and of freezing.

Sensitivity assessment. Typical surface water temperatures around the UK coast vary, seasonally from 4-19°C (Huthnance, 2010). The biotope is considered to tolerate a chronic change at the pressure benchmark (2°C decrease in temperature for a year). An acute reduction in temperature may be tolerated by adults and spat outside of winter (although acclimation to warmer temperatures means that impacts on spawning and growth may occur). An acute reduction in temperature during winter may exceed thermal tolerances, biotope resistance (based on *Cerastoderma edule* evidence) is therefore assessed as 'Low' and resistance is assessed as 'Medium'. Biotope sensitivity is therefore judged to be 'Medium', this precautionary assessment is presented in the table.

Salinity increase (local)

Low

Q: High A: Medium C: Medium

Medium

Q: High A: Low C: Medium

Medium

Q: High A: Low C: Medium

This biotope is reported to occur in variable (18-35 ppt) salinity (JNCC, 2015). A change at the pressure benchmark is considered to represent an increase to full salinity.

Boyden & Russell (1972) stated that *Cerastoderma edule* prefers salinities between 15 and 35 psu. Russell & Peterson (1973) reported lower median salinity limits of 12.5 psu and upper median salinity limits of 38.5 psu. Rygg (1970) noted that *Cerastoderma edule* did not survive 23 days exposure to <10 psu or at 60 psu, although they did survive at 46 psu. Rygg (1970) also demonstrated that salinity tolerance was temperature dependant (after 3 days, 100% survival at 33 psu and 35-38°C, but 50% mortality occurred at 20 psu and 37°C and 100% mortality at 13 psu and 37°C). Wilson (1984) noted that *Cerastoderma edule* remained open during 1 hour exposure to salinities between 13.3 and 59.3 psu. It should be noted that the tolerances reported above depend on the duration of the experiment.

Kingston (1974) found that *Cerastoderma edule* larvae grew optimally at 30 and 35 psu, and grew

well at 40 psu but the growth increment declined at 45 psu and larvae did not metamorphose. He noted that *Cerastoderma edule* larvae survived between 20 -50 psu, but died after 11 days at 55 psu or 10 days at 10 psu.

Populations of *Aphelochaeta marioni* inhabit the open coast where seawater is at full salinity. They are clearly capable of thriving in fully saline conditions and hence probably relatively tolerant of increases in salinity. No information was found concerning the reaction to hypersaline conditions (>40psu). Farke (1979) studied the effects of changing salinity on *Aphelochaeta marioni* (studied as *Tharyx marioni*) in a microsystem in the laboratory. Over several weeks, the salinity in the microsystem was increased from 25-40 psu and no adverse reaction was noted. However, when individuals were removed from the sediment and displaced to a new habitat, they only dug into their new substratum if the salinities in the two habitats were similar. If the salinities differed by 3-5 psu, the worms carried out random digging movements, failed to penetrate the sediment and died at the substratum surface after a few hours. This would suggest that *Aphelochaeta marioni* can tolerate salinity changes when living infaunally but is far more intolerant when removed from its habitat.

Sensitivity assessment. Little evidence was found to assess this pressure at the benchmark. Although species within the biotope are likely to tolerate short-term increases in salinity in sediment surface layers between tidal cycles a longer change is likely to exceed salinity tolerances of adult *Cerastoderma edule* and larvae. Biotope resistance is assessed as 'Low' as the results of Rygg (1970) suggest some adults may survive and acclimate. Biotope resilience (following a return to suitable habitat conditions) is assessed as 'Medium' and sensitivity is assessed as 'Medium'.

Salinity decrease (local)

High

Q: High A: Medium C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: Medium C: High

This biotope is reported to occur in full (30-35 ppt) salinity (JNCC, 2015). As the characterizing species *Cerastoderma edule* is found in biotopes in both full and variable salinity habitats, the biotope is considered 'Not sensitive' to a decrease in salinity from full to reduced or variable.

The available studies indicate that *Cerastoderma edule* larvae and adults show a wide tolerance range of salinity for both adults and larvae, in accordance with the intertidal distribution. Kristensen (1958), however, reported the death of young spat (1-2 mm) in the Dutch Wadden Sea due to heavy rain, whereas the adults were able to dig deeper into the sediment, reducing exposure.

Boyden & Russell (1972) stated that *Cerastoderma edule* prefers salinities between 15 and 35 psu. Russell & Peterson (1973) reported lower median salinity limits of 12.5 psu and upper median salinity limits of 38.5 psu. Rygg (1970) noted that *Cerastoderma edule* did not survive 23 days exposure to <10 psu. Rygg (1970) also demonstrated that salinity tolerance was temperature dependant (after 3 days, 100% survival at 33 psu and 35-38°C, but 50% mortality occurred at 20 psu and 37°C and 100% mortality at 13 psu and 37°C). Wilson (1984) noted that *Cerastoderma edule* remained open during 1 hour exposure to salinities between 13.3 and 59.3 psu. It should be noted that the tolerances reported above depend on the duration of the experiment.

Russell (1969) found that the optimum salinity for the survival of an adult cockle varies with the mean environmental salinity and suggested that the different salinity tolerance, demonstrated for various populations of *Cerastoderma edule* are not inherent interspecific differences, but a result of localized environmental acclimation. It is possible that larvae settling in regions of low salinity

could have developed elsewhere, under more favourable conditions, and have become gradually acclimatized to the low salinity conditions; alternatively, the larvae produced by parents from a low salinity environment might be adapted to lower salinities than those produced by populations from higher salinity (Russell, 1969).

In the Severn Estuary, *Aphelochaeta marioni* (studied as *Tharyx marioni*) characterized the faunal assemblage of very poorly oxygenated, poorly sorted mud with relatively high interstitial salinity (Broom *et al.*, 1991). *Aphelochaeta marioni* can tolerate lower salinities range. Wolff (1973) recorded *Aphelochaeta marioni* (studied as *Tharyx marioni*) from brackish inland waters in the Netherlands with a salinity of 16 psu, but not in areas permanently exposed to lower salinities. Farke (1979) reported that the species also penetrated into areas exposed to salinities of 4 psu during short periods at low tide when the freshwater discharge from rivers was high.

Sensitivity assessment. The available evidence and distribution in estuaries indicates that adult *Cerastoderma edule* and other characterizing species may survive a reduction in salinity to reduced or variable and populations may become locally acclimated to reduced salinities. Biotope resistance is therefore assessed as 'High' and resilience as 'High', so that the biotope is assessed as 'Not sensitive'.

Water flow (tidal current) changes (local)

Medium

Q: High A: Medium C: Medium

High

Q: High A: Low C: Medium

Low

Q: High A: Low C: Medium

The biotope is associated with weak tidal streams (<0.5 m/s) and a change at the pressure benchmark (increase or decrease may affect the sediments and biological assemblage). Depending on site specific hydrodynamics an increase in water flow rate at the benchmark level may remove fine silts and organic matter. Although *Cerastoderma edule* and *Abra nitida* are found in coarser sediments (muddy sands) the cirratulid *Aphelochaeta marioni*, prefers a habitat with a high silt content (Gibbs, 1969). George (1964b) found that particle size was negatively correlated with the density of *Cirriformia tentaculata* in Hamble Spit, Southampton. However, he suggested that this was probably as much to do with availability of organic matter, it being generally lower in the areas with higher grain sizes. There was a positive correlation between the amount of organic matter and abundance.

Cockles are dependent on water flow to deliver suspended food particles and are abundant in biotopes that experience stronger tidal streams than the biotope considered. Decreasing water flow rate in sheltered habitats may increase siltation and favour muddy substrates that are less suitable for *Cerastoderma edule*. Boyden and Russell (1972) suggested that lack of tidal flow may exclude *Cerastoderma edule* possibly due to reduced food availability as suggested by Brock (1979). According to regression models developed by Ysebaert *et al.* (2002), *Cerastoderma edule* occurs in environments subject to flow velocities of up to 0.8 m/s, having a maximum predicted probability of occurrence at flow velocities around 0.35 m/s. Experimental studies of water velocity and clearance rate in *Cerastoderma edule* have produced a range of results which may be due to genetic or phenotypic differences in test populations (Widdows & Navarro, 2007). Wildish & Miyares (1990) recorded a reduction in flume experiments found that feeding efficiency was greatest at 0.15 m/s and gradually declined to 0.45 m/s, there was no significant difference in feeding rate between current velocities of 0.05 and 0.35 m/s (Widdows & Navarro, 2007). As this biotope occurs in sheltered areas and is characterized by muddy mixed sediments, water flows are already likely to be low and a further decrease may reduce habitat suitability for *Cerastoderma edule*.

Increasing water flow may remove adult *Cerastoderma edule* from the sediment surface and carry

them to unfavourable substratum or deep water, where they may be lost from the population. Coffen-Smout & Rees (1999) reported that cockles could be distributed by flood and ebb tides, but especially flood tides (by rolling around the surface) up to 0.45 m on neap tides or between 94 m and 164 m on spring tides. Newly settled spat and juveniles (<4.8mm) are capable of bysso-pelagic dispersal. Therefore, water flow rates probably affect the distribution and dispersal of juveniles and adults but these changes are unlikely at the pressure benchmark.

Additionally, an increase in water flow that reduced the deposition of particulate matter at the sediment surface would reduce food availability for all deposit feeders. . At the pressure benchmark, increased water flow may enhance food supply to the suspension feeding *Cerastoderma edule*, an increase in habitat suitability for this species may lead to changes in the biological assemblage as cockles can exclude other species by occupying more space and disturbing sediments leading to organic matter re-suspension and reduction in habitat suitability for deposit feeders.

Sensitivity assessment. The cirratulids are considered to be tolerant of a reduction in water flow at the pressure benchmark, as these are found in accreting environments with high mud content and are deposit feeders, benefitting from increased deposition of organic matter. Increased siltation will reduce habitat suitability for ephemeral algae and the barnacle *Elminius modestus* if small stones and other suitable attachment surfaces become covered with silts. The characterizing *Cerastoderma edule* is considered to have some resistance to this pressure as they are found within a range of flow speeds and can feed at a range of flow speeds. However decreased flow rates (at the pressure benchmark) in sheltered habitats may reduce food supply and enhance sediment deposition leading to replacement by deposit feeders. At the pressure benchmark some biotopes may be affected by an increase or decrease in water flow through effects on sediment and organic matter and delivery of suspended food; biotope resistance is assessed as 'Medium' and resilience is assessed as 'High'

Emergence regime changes

Low

Q: High A: High C: Medium

Medium

Q: High A: Low C: Medium

Medium

Q: High A: Low C: Medium

This biotope is found on the lower and mid shore (JNCC, 2015) and the associated fauna are likely to be tolerant of a certain degree of desiccation. In addition, the majority of important characterizing species are infaunal and are therefore protected from major changes in aerial exposure.

Boyden (1972) reported that *Cerastoderma edule* survived 42.9% water loss. However, increased desiccation, equivalent to raising the biotope from mid to high water, is likely to reduce the abundance of this some associated fauna, especially those that don't build tubes such as the polychaetes *Exogone naidina* and *Sphaerosyllis taylori*. If the branchiae of the cirratulid *Cirriformia tentaculata* are exposed they will either be withdrawn into the burrow of the worm or clump together and stop functioning properly (Dales & Warren, 1980). If the branchiae of the cirratulid *Cirriformia tentaculata* are exposed they will either be withdrawn into the burrow of the worm or clump together and stop functioning properly (Dales & Warren, 1980). *Aphelochaeta marioni*, another cirratulid, can only feed when immersed and therefore will experience reduced feeding opportunities, reducing growth.

Cockle dominated biotopes can range from mean high water springs (Sanchez-Salazar *et al.*, 1987b) to the sublittoral (JNCC, 2015). Shore height influences a number of factors that affect cockle condition and survival and the size and age structure of populations can vary significantly

with shore height (Sanchez-Salazar *et al.*, 1987b), hence this biotope is likely to be sensitive to changes in emergence (both increase and decrease).

At lower shore levels predation by shore crabs and fish may structure populations by removing smaller individuals and may set the lower distribution limit, while at higher shore levels predation by oyster-catchers targets larger size classes (Sanchez-Salazar *et al.*, 1987b). Higher shore populations are exposed to air temperatures for longer that may be warmer and colder than seawater creating thermal shocks, higher shore individuals also have less time to feed, resulting in reduced growth (Jensen, 1992) body condition which may increase susceptibility to parasites and other factors (Wegeberg & Jensen, 2003). Dense populations lower on the shore may also deplete the available suspended food, reducing the supply to higher shore populations (Peterson & Black, 1987, 1991; Kamermans 1993).

DeMontadouin and Bachelet (1996) manipulated low and high population densities (160-2000 adults/m² and tidal elevation (low and mid-water levels of *Cerastoderma edule* at Arcachon bay, SW France to test the influence of adult densities and emersion time on growth, settlement and survival. Growth rates were affected by tidal height with higher growth rates at low water levels.

Sensitivity assessment. A change in emersion (particularly increase) is likely to alter the habitat suitability for *Cerastoderma edule* and associated species, resulting in changes in growth rates, predation and assemblage structure, biotope resistance is therefore assessed as 'Low' and resilience is assessed as 'Medium' following a return to previous habitat condition

Wave exposure changes (local)

High

Q: High A: Low C: Medium

High

Q: High A: High C: High

Not sensitive

Q: High A: Low C: Medium

This biotope occurs in very sheltered habitats (JNCC, 2015) and is considered to be tolerant of a decrease in wave exposure at the pressure benchmark.

Increases in wave exposure greater than the pressure benchmark are likely to have marked effects on the sediment dynamics of the shore. Species on the sediment surface including cockles and tube building polychaetes are likely to be washed away and may end up in unfavourable habitats. Infauna may also be dislodged if the top layers centimetres of sediment are removed. This will render the worms more susceptible to predation. Rough seas in March 1960 were found to wash away young *Cirriformia tentaculata* from the top surface layers of mud at Hamble Spit, Southampton (George, 1964b). Polychaetes living further down in the sediment may be saved from dislodgement but the biotope per se will be lost. Increased exposure could also result in increased grain size or erosion of the sediment, while decreased exposure will lead to increased siltation and reduced grain size (muddy sediment). In both cases the sediment may become unsuitable for *Cerastoderma edule* populations resulting in a reduction of the extent or abundance of the population (see physical change pressures). Increased wave action during storms may also remove adult cockles from the sediment surface which may be subsequently lost from the population. These changes are not assessed in this section as they are considered to be the result of changes in wave action that exceeds the pressure benchmark.

Sensitivity assessment. At the pressure benchmark the biotope is considered to have 'High' resistance and 'High' resilience (by default) to changes (increase or decrease) in wave action at the pressure benchmark.

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.

The species present in the biotope may, however, be sensitive to increases in contaminants greater than the pressure benchmark. Studies of *Cerastoderma edule* populations from polluted and uncontaminated sites in Southampton Water showed that tissue heavy metal concentrations were lower in summer than winter/spring, tissue heavy metal concentrations decreased with size of the cockle, and that cockles in sediments contaminated with metals and hydrocarbons had lower life expectancies, growth rates and body condition index (Savari *et al.* 1991(a), (b)).

Bryan (1984) suggested that many polychaetes were resistant to heavy metals and evidence from the work of Bryan & Gibbs (1983) in the metal polluted Fal estuary supports this view. Bivalves, on the other hand, including *Cerastoderma edule* displayed a much lower tolerance and were found to be the most obvious absentees from the polluted Restrouguet Creek area of the Fal (Bryan & Gibbs, 1983). The following information is taken from Bryan & Gibbs (1983).

- *Aphelochaeta marioni* (studied as *Tharyx marioni*) was found to contain exceptionally high concentrations of arsenic (> 2000 µg / gram dry body weight) without obvious adverse effects.
- *Pygospio elegans* appear to have adapted to the high concentrations of copper and zinc in Restrouguet Creek and the larvae are subjected to widely fluctuating conditions of salinity and relatively high metal concentrations.
- Increased tolerance of copper was found in the amphipod *Corophium volutator* in the creek.
- Adult *Cerastoderma edule* were found to be more tolerant to metal toxicity than the juvenile or larval stages which appear unable to withstand the high concentrations of copper and zinc. However, transplantation of *Cerastoderma edule* into Restrouguet Creek (highly polluted by heavy metals) resulted in 10-15% mortality within 63 days but 100% within about four months. The toxic body-burden of copper to *Cerastoderma edule* was found to be ca. 250 µg / g with zinc being less toxic. Bryan & Gibbs (1983) stated that *Cerastoderma edule* takes up heavy metals mainly from solution rather than from sediment and that it was excluded from Restrouguet Creek by the high levels of Cu and Zn.

A 2-year microcosm experiment was undertaken to investigate the impact of Cu on the benthic fauna of the lower Tyne Estuary (UK) by Hall and Frid (1995). During a 1-year simulated contamination period, 1 mg l⁻¹ Cu was supplied at 2-weekly 30% water changes, at the end of which the sediment concentrations of Cu in contaminated microcosms reached 411 µg g⁻¹. Toxicity effects reduced populations of the four dominant taxa, including *Capitella capitata*. When Cu dosage was ceased and clean water supplied, sediment Cu concentrations fell by 50% in less than 4 days, but faunal recovery took up to 1 year, with the pattern varying between taxa. Since the Cu leach rate was so rapid it is concluded that after remediation, contaminated sediments show rapid improvements in chemical concentrations, but faunal recovery may be delayed with experiments in microcosms showing faunal recovery taking up to a year.

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.

The species present in the biotope may, however, be sensitive to increases in contaminants greater than the pressure benchmark. The impacts of hydrocarbon contamination on sediment shores were well documented by Rostron (1998) following the Sea Empress oil spill in Milford Haven, Wales and the information in the following section is taken mainly from that report including the references therein.

- High mortalities of the cockles *Cerastoderma edule* were reported. In Angle Bay, the presence of juveniles lower down the shore shortly after the spill enabled the reestablishment of adult populations on the middle shore within about six months.
- Additional species recorded at Sandy Haven in the summer following the spill included the polychaetes *Pygospio elegans* and *Capitella capitata* and the oligochaete *Tubificoides benedii*. The abundance of *Capitella capitata* increased dramatically at one site.
- At one station in Sandy Haven, the amphipod *Corophium volutator* disappeared completely following the Sea Empress oil spill. Indeed, Chasse & Morvan (1978, cited in Rostron 1998) calculated that only 10% of these amphipods survived the Amoco Cadiz oil spill.
- At Angle Bay, a sheltered bay with mixed sandy mud and mud, the cirratulid *Chaetozone gibber* showed a dramatic increase after the spill. However, this success was short lived and the numbers had fallen significantly by the following year.

Cirratulids appeared to Suchanek (1993) to be mostly immune to oil spills because their feeding tentacles are protected by a heavy secretion of mucus. This immunity is supported by observations of *Aphelocheata marioni* following the Amoco Cadiz oil spill in March, 1978 (Dauvin, 1982, 2000). Prior to the spill, *Aphelocheata marioni* (studied as *Tharyx marioni*) was present in very low numbers in the Bay of Morlaix, western English Channel. Following the spill, the level of hydrocarbons in the sediment increased from 10 mg/kg dry sediment to 1443 mg/kg dry sediment 6 months afterwards. In the same period, *Aphelocheata marioni* increased in abundance to a mean of 76 individuals per m², which placed it among the top five dominant species in the faunal assemblage. It was suggested that the population explosion occurred due to the increased food availability because of accumulation of organic matter resulting from high mortality of browsers. Six years later, abundance of *Aphelocheata marioni* began to fall away again, accompanied by gradual decontamination of the sediments.

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.

The species present in the biotope may, however, be sensitive to increases in contaminants greater than the pressure benchmark. The close association of benthic invertebrates with contaminated sediments may cause some sub-lethal effects and in the long-term could interfere with reproductive potential (Rostron, 1998). *Cerastoderma edule* is known to accumulate PCBs (see MarLIN review) but no specific information concerning the actual effects that contamination with

synthetic chemicals has on this species or on other characterizing species within the biotope was found.

Beaumont *et al.* (1989) investigated the effects of tri-butyl tin (TBT) on benthic organisms. At concentrations of 1-3 µg/l there was no significant effect on the abundance of *Cirratulus cirratus* (family Cirratulidae) 9 weeks in a microcosm. However, no juvenile polychaetes were retrieved from the substratum and hence there is some evidence that TBT had an effect on the larval and/or juvenile stages of the polychaetes.

Radionuclide contamination

No evidence (NEv)

Q: NR A: NR C: NR

No evidence (NEv)

Q: NR A: NR C: NR

No evidence (NEv)

Q: NR A: NR C: NR

No evidence.

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

This pressure is **Not assessed**.

De-oxygenation

Medium

Q: High A: High C: High

High

Q: High A: Low C: Medium

Low

Q: High A: Low C: Medium

A number of animals have behavioural strategies to survive periodic events of reduced dissolved oxygen. These include avoidance by mobile species such as crustaceans, shell closure and reduced metabolic rate in bivalve molluscs and either decreased burrowing depth or emergence from burrows for sediment dwelling crustaceans, molluscs and annelids. The sensitivity to reduced oxygen and recovery from episodes of hypoxia and anoxia varies between the characterizing and associated species of this biotope. The available evidence suggests that *Cerastoderma edule* is more sensitive to this pressure than polychaete species.

Rosenberg *et al.* (1991) reported 100% mortality of *Cerastoderma edule* exposed to 0.5-1.0ml/l oxygen for 43 days and 98% mortality after 32 days. *Cerastoderma edule* migrated to the surface of the sediment in response to decreased oxygen concentrations. Theede *et al.* (1969) reported 50% mortality after 4.25 days at 1.5 mg/l oxygen. Theede *et al.* (1969) also noted that *Cerastoderma edule* only survived 4 days exposure to 0.0-6.1 cm³/l of hydrogen sulphide, which is associated with anoxic conditions. This suggests that *Cerastoderma edule* could survive short periods of anoxia but it is likely that continued exposure to 2 mg/l oxygen for a week would be lethal.

Fifty percent (LT50) of cockles in anoxic seawater died after 3.5 days (Babarro & de Zwaan, 2001) The anoxic survival time of *Cerastoderma edule* from two different ecosystems and differing anoxia tolerances was studied in static (closed) and flow-through systems. The antibiotics chloramphenicol, penicillin and polymyxin were added, and molybdate (a specific inhibitor of the process of sulfate reduction). Median mortality times were 2.7 and 2.9 days for *Cerastoderma* for static and flow-through incubations, respectively. The addition of chloramphenicol increased strongly survival time in both systems with corresponding values of 6.4 and 6.5 days for *Cerastoderma*. Overall the results indicate that proliferation of anaerobic pathogenic bacteria, associated with the bivalves, is a main cause of death besides the lack of oxygen. Bacterial damage is probably caused by injury of the tissues of the clams and not by the release of noxious

compounds to the medium (de Zwaan et al. 2002).

Connor et al. (1997b) described sediments in which the cirratulid *Aphelochaeta marioni* is commonly found as usually having a "black anoxic layer close to the sediment surface". Broom et al. (1991) considered *Aphelochaeta marioni* (studied as *Tharyx marioni*) to be characteristic of faunal assemblage of very poorly oxygenated mud in the Severn Estuary. They found that it dominated sediments where the redox potential at 4 cm sediment depth was 56 mV and, therefore, concluded that the species was tolerant of very low oxygen tensions. Thierman et al. (1996) studied the distribution of *Aphelochaeta marioni* in relation to hydrogen sulphide concentrations. The species was found to be abundant at low sulphide concentrations (less than 50 μM) but only occasional at concentrations from 75-125 μM . They concluded that *Aphelochaeta marioni* does not display a massively adverse reaction to sulphidic conditions and is able to tolerate a low amount of sulphide. The evidence suggests that *Aphelochaeta marioni* is capable of tolerating hypoxia but it is difficult to determine to what degree.

The cirratulid *Cirriformia tentaculata* is reported to have several metabolic adaptations to the hypoxic conditions to which it is periodically subjected (Dales & Warren, 1980; Bestwick et al., 1989). The sediment around their burrows is often hydrogen-sulphide rich and therefore a sink for oxygen (Bestwick et al., 1989). The adaptations are, firstly, the filamentous branchiae of the worm, that are spread out over the surface of the substratum, are very thin and oxygen uptake can continue during tidal emersion providing the branchiae are covered by a film of water (Bestwick et al., 1989). If the branchiae are exposed they may be withdrawn into the burrow at which point the gaseous exchange occurring across the branchial epithelium starts to fall. Secondly, the haemoglobin has an extremely high affinity for oxygen and as the internal oxygen pressure falls, oxygen is released from the haemoglobin store (Dales & Warren, 1980). At an external oxygen pressure of 0.88 mg/l, oxygen uptake stops and the species cannot tolerate anoxia for more than three days (Dales & Warren, 1980).

The oligochaete *Tubificoides benedii* also inhabits sulfide rich environments and has a high capacity to tolerate anoxic conditions (Nubilier *et al.*, 1997; Giere *et al.*, 1999). *Tubificoides benedii* is often buried up to 10 cm deep and so has no contact with the surface but has a highly specialized adaptive physiology that allows it to maintain some oxygen consumption even at 2% (approximately 0.18 mg/l) oxygen saturation of the surrounding environment on the Isle of Sylt. The critical oxygen saturation for *Capitella capitata* is about 7.5 mg/l (Gamenick, 1996, cited in Giere *et al.*, 1999). It has been suggested that tolerance to anoxia may be influenced by temperature. *Tubificoides benedii* (studied as *Pelosclex benedeni*) was found to be less tolerant to anoxia as temperature increased (Diaz, 1980). At 20 °C, it took almost 60 hours for half the worms to be killed but at 30 °C it took less than 18 hours.

Dense *Capitella capitata* populations are frequently located in areas with greatly elevated organic content, even though eutrophic sediments are often anoxic and highly sulfidic (Tenore 1977; Warren 1977; Tenore & Chesney 1985; Bridges et al. 1994). The polychaetes *Capitella capitata*, *Pygospio elegans* and *Scoloplos armiger* have all been reported to recolonize habitats following periods of anoxia and hypoxia. Following a period of anoxia in the Bay of Somme (north France) that removed cockles, *Pygospio elegans* increased rapidly but then decreased as cockle abundance recovered (Desprez et al., 1992; Rybarczyk et al., 1996).

Sensitivity assessment. Decreased oxygen levels, could lead to an alteration in sediment chemistry, including the production of hydrogen sulphides that would alter habitat conditions and is likely to lead to mortality of *Cerastoderma edule* although other species present are likely to be more tolerant. Based on Theede *et al.*, 1996, the sensitivity of the biotope (based on *Cerastoderma edule*) is 'Medium' as periodic emersion would reoxygenate sediments and exposure is likely to be short-term, limiting mortality. Resilience is assessed as 'high' and sensitivity is assessed as 'Low'.

Nutrient enrichment

High

Q: High A: Medium C: Medium

High

Q: High A: High C: High

Not sensitive

Q: High A: Medium C: Medium

Nutrient enrichment may result in increased primary productivity that could increase the amount of food available to both suspension feeders and deposit feeders. However, nutrient enrichment often culminates in eutrophic episodes which usually lead to increased light attenuation (see turbidity) and reduced oxygen concentration (see oxygenation); and increased algal growth often culminates in mats of algae covering the sediment surface.

Desprez *et al.* (1992) implicated a eutrophication-induced plankton bloom as the cause behind the decline of *Cerastoderma edule* populations in the Bay of Somme, France. Prior to the event in 1982, densities were several 1000 / m² but by 1982 this had fallen to just a few hundred individuals / m². By 1987, the cockle population had returned. Rosenberg & Loo (1988) suggested that the mass mortalities of *Cerastoderma edule* observed in Laholm Bay, western Sweden during the 1980s were correlated with increased nutrient levels, and the associated decrease in oxygen levels during this period. However, no direct causal link was established. Some authors have reported a decline in the abundance of *Cerastoderma edule* under algal mats (Raffaelli *et al.*, 1998).

Raman & Ganapati (1983) studied the distribution of *Aphelocheata marioni* (studied as *Tharyx marioni*) in relation to a sewage outfall in Visakhapatnam Harbour, Bay of Bengal. *Aphelocheata marioni* was found to be dominant in the 'semi-healthy zone' characterized by high dissolved oxygen (median 7.2 mg/l), low biological oxygen demand (9.6 mg/l) and low nutrients (nitrate 0.02 mg/l, phosphate 0.88 mg/l). *Aphelocheata marioni* was not found in high numbers in the polluted zone close to the sewage outfall, characterized by low dissolved oxygen (median 6.0 mg/l), high biological oxygen demand (14-60 mg/l) and high nutrients (nitrate 0.042-0.105 mg/l, phosphate 2.35-3.76 mg/l). This would suggest that *Aphelocheata marioni* is intolerant of eutrophication.

The oligochaete *Tubificoides benedii* can be found living in abundance under algal mats (Nubilier *et al.*, 1997). It is opportunistic and responds to organic pollution by increasing the size of the population (Diaz, 1977, cited in Diaz, 1980). Oligochaetes often become the dominant benthic fauna under algal mats (Raffaelli *et al.*, 1998). Estuarine oligochaetes tend to become more abundant in areas where pollution or other physical factors result in a reduced habitat diversity and stressful conditions, concomitant with a decrease in polychaetes species (Diaz, 1980). Barnett (1983) found the maximum abundance of the oligochaete *Tubificoides benedii* at a site which received a significant input of both industrial and domestic effluent, including raw sewage, in the Humber estuary.

Capitella capitata is often associated with areas of high nutrient enrichment and is generally considered to be tolerant of increased nutrient load.

Sensitivity assessment. As *Cerastoderma edule* and other characterizing species in the biotope are not primary producers they are not considered directly sensitive to an increase or decrease in plant nutrients in the water column. Phytoplankton and algal detritus may be utilised as food

by *Cerastoderma edule* and deposit feeders but supply is not considered to be affected at the pressure benchmark level. The biotope is therefore considered to be 'Not Sensitive' to this pressure. Resistance is therefore assessed as 'High' and resilience as 'High' (by default).

Organic enrichment	High	High	Not sensitive
	Q: High A: High C: High	Q: High A: High C: High	Q: High A: High C: High

Benthic responses to organic enrichment have been described by Pearson & Rosenberg (1978) and Gray (1981). Moderate enrichment increases food supply enhancing productivity and abundance.

Cerastoderma edule has been categorised through expert judgement and literature review as AMBI Group III- species tolerant to excess organic matter enrichment. These species may occur under normal conditions, but their populations are stimulated by organic enrichment (slight unbalance situations). They are surface deposit feeding species (Borja *et al.*, 2000, validated by Gittenberger & van Loon, 2011).

Organic enrichment beneath oyster cultivation trestles and mussel cultivation sites and fish cages has led to community replacement/dominance by cirratulid, capitellid and spionid polychaetes, in mudflats, that characterize disturbed areas enriched in organic matter (Pearson & Rosenberg 1978, Samuelson 2001, Bouchet & Saurier 2008). The associated cirratulids within the biotope are therefore, likely to benefit from organic enrichment at the pressure benchmark.

Sensitivity assessment. Areas with significant mud contents are likely to be rich in organic matter and low oxygen penetration coupled with high levels of bacterial activity means sediments are anoxic a short distance below the surface. Given their adaptation to these habitat conditions the characterizing *Cerastoderma edule* and other characterizing species are not considered sensitive to organic enrichment. The deposit feeding cirratulids are likely to benefit from the additional food source. The biotope is considered 'Not sensitive' to this pressure based on 'High' resistance and 'High' recovery (by default). Gross organic pollution (greater than the pressure benchmark would be likely to lead to detrimental effects depending on the level of the pressure).

A Physical Pressures

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

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

This biotope is found on muddy sands (Connor *et al.*, 2004). A change to natural or artificial hard substratum would remove this sedimentary biotope and the species. If pockets of fine sediment

accumulate in pockets within the substrata then these areas may be re-colonised by species associated with this biotope but these pockets of sediment would not be equivalent to the biotope. Recovery will depend on the re-instatement of suitable habitat.

Sensitivity assessment. Based on the loss of suitable habitat, biotope resistance to this pressure is assessed as 'None'. Resilience is assessed as 'Very low' as the pressure benchmark refers to a permanent change. Biotope sensitivity is therefore 'High'.

Physical change (to another sediment type)

None

Q: High A: High C: High

Very Low

Q: High A: High C: High

High

Q: High A: High C: High

The benchmark for this pressure refers to a change in one Folk class. The pressure benchmark originally developed by Tillin *et al.*, (2010) used the modified Folk triangle developed by Long (2006) which simplified sediment types into four categories: mud and sandy mud, sand and muddy sand, mixed sediments and coarse sediments. The change referred to is therefore a change in sediment classification rather than a change in the finer-scale original Folk categories (Folk, 1954). The change in one Folk class is considered to relate to a change in classification to adjacent categories in the modified Folk triangle (Long, 2006). As this biotope is characterized by mud and gravelly mud (JNCC, 2015), the change at the pressure benchmark refers to a potential change to coarse sediments and sands.

The particle size of sediments and correlated physical and chemical factors (such as, organic matter content and hydrodynamic regime), is a key determinant of the structure of benthic invertebrate assemblages (Van Hoey *et al.*, 2004; Yates *et al.*, 1993). A change to coarse sediments would result in loss of characterizing and associated species, resulting in biotope reclassification..

A study in the intertidal of the Dutch Wadden Sea showed that suction-dredging for cockles (*Cerastoderma edule*) led to a significant long-term reduction in settlement and stocks of the target bivalve species (Piersma *et al.*, 2001). Analysis of sediment characteristics before and after dredging showed an increase in median grain size and a reduction of silt content, and that these changes were most pronounced in the area dredged for cockles. Sediment characteristics only returned to pre-impact conditions 8-11 years after the suction dredging. The authors concluded that suction dredging of *Cerastoderma edule* had long lasting effects on the recruitment of bivalves (particularly the target species *Cerastoderma edule*, but also *Limecola balthica*) in sandy parts of the Wadden Sea basin.

Sensitivity assessment. The character of the habitat is largely determined by the sediment type, changes to this would lead to habitat re-classification. A change to coarse or sand sediment without a high proportion of mud would be unsuitable for the characterizing species and would lead to the development of a different habitat type. Changes in sediment characteristics can lead to changes in community structure. An increase in coarse sediments would lead to the development of a community typical of mixed sediments, clean sands and/or gravels depending on the degree of change. In general an increase to very coarse sediments may favour some amphipod species rather than *Cerastoderma edule*, and the associated species. This change would alter the character of the biotope present leading to re-classification. Biotope resistance is assessed as 'None', as a change at the pressure benchmark would result in loss of the habitat. Biotope recovery is assessed as 'Very low' as the change at the pressure benchmark is considered to be permanent. Sensitivity is therefore assessed as 'High'

Habitat structure changes - removal of substratum (extraction)

None

Q: High A: High C: NR

Medium

Q: High A: Low C: Medium

Medium

Q: High A: Low C: Low

Sedimentary communities are likely to be highly intolerant of substratum removal, which will lead to partial or complete defaunation, expose underlying sediment which may be anoxic and/or of a different character or bedrock and lead to changes in the topography of the area (Dernie *et al.*, 2003). Recovery by infilling will depend on local factors including the mobility of sediments, sediment supply, hydrodynamics and the spatial scale of the area affected (Van Hoey *et al.* 2008). The extraction of sediment to 30 cm (the pressure benchmark) would remove the characterizing species and associated species present.

Sensitivity assessment. Extraction of 30 cm of sediment will remove the characterizing biological component of the biotope and sediments. The resistance of the habitat to extraction is assessed as 'None' as sediment is removed: the depth of remaining sediments and their character will be site-specific. Recovery will depend on local factors including hydrodynamics, sediment supply and sediment mobility and the spatial scale affected. Resilience is assessed as 'Medium' as sediment infilling may be rapid in intertidal areas, however, recruitment of the characterizing *Cerastoderma edule* is episodic (see resilience section). Biotope sensitivity is therefore assessed as 'Medium'. If sediments do not return to the previous condition, larval recolonization may be inhibited (see physical change pressures).

Abrasion/disturbance of the surface of the substratum or seabed

Medium

Q: High A: High C: High

High

Q: High A: Low C: Medium

Low

Q: High A: Low C: Medium

Sediment cohesion provides some sediment stabilisation to resist erosion following surface disturbance. Species associated with muddy sands/sandy muds are infaunal and hence have some protection against surface disturbance, although siphons and other body parts extended to the surface for respiration and/or feeding may be damaged. *Cerastoderma edule* has short siphons and requires contact with the surface for respiration and feeding and may be damaged by abrasion at the surface, *Abra nitida* however may be more deeply buried (ref). Surface compaction can collapse burrows and reduce the pore space between particles, decreasing penetrability and reducing stability and oxygen content (Sheehan, 2007). Trampling (3 times a week for 1 month) associated with bait digging reduced the abundance and diversity of infauna (Sheehan, 2007; intertidal muds and sands). However, Cooke *et al.* (2002) found that trampling associated with bait digging had little effect on infaunal species composition (intertidal muddy sands).

Rossi *et al.* (2007) conducted experimental trampling on a mudflat (5 people, 3-5 hours, twice a month between March and September). Mobile fauna were not affected; however, the abundance of adult *Cerastoderma edule* was sharply reduced, probably due to the trampling directly killing or burying the animals, resulting in asphyxia. However, no effect was observed on small (<12 mm) individuals of *Cerastoderma edule*. The authors suggested that this was because the experiment was conducted in the reproductive season for these species and hence there were juveniles present in the water column to replace individuals displaced by trampling. The lack of observed effect was therefore due to continuous recruitment and replacement of impacted individuals.

Sensitivity assessment. Abrasion at the surface is likely to damage a proportion of the population shallow buried bivalves (*Cerastoderma edule* and soft-bodied species that live on or very close to

the surface (*examples*). The level of damage and mortality will depend on the force exerted. Biotope resistance is assessed as 'Medium' and resilience is assessed as 'High' so that biotope sensitivity is therefore assessed as 'Low'

Penetration or disturbance of the substratum subsurface

Low

Q: High A: High C: High

Medium

Q: High A: High C: High

Medium

Q: High A: High C: High

The characterizing species *Cerastoderma edule*, the cirratulids *Aphelochaeta marioni*, *Chaetozone gibber* and *Cirriformia tentaculata* all live buried in the top few centimetres of sediment and are therefore likely to be damaged by physical disturbance that penetrates the upper few centimetres of the sediment. Birds and fish could be attracted to the site of disturbance to feed on exposed and damaged individuals.

In the Burry Inlet, Wales, intertidal tractor towed cockle harvesting led mechanical cockle harvesting in muddy sand reduced the abundance of *Cerastoderma edule* by ca 34%. Populations of *Cerastoderma edule* had not recovered their original abundance after 174 days (Ferns *et al.*, 2000). Hall and Harding (1997) studied the effect of suction and tractor dredging for cockles on non-target benthic fauna in the Solway Firth, Scotland where sediments contained 60-90% silt/clay in the more sheltered areas. The results showed that suction dredging resulted in significantly lower mean species numbers (by up to 30%) and mean numbers of individuals (up to 50%) and in the abundance of 3 of the 5 dominant species. The faunal structure of the dredged plots recovered (i.e. approached that of the undisturbed control plots) by 56 days. The results of the tractor dredge experiments showed fewer effects than the suction dredging (no significant effect on the number of species or individuals). The authors concluded that mechanical harvesting methods imposed high levels of mortality on non-target benthic fauna but that the recovery of disturbed sites was rapid and that the overall effects on populations were low. Although the results suggested that tractor dredging had less impact than suction dredging the authors proposed this may have been due to differences in the timing of the experiments (May-July suction dredging; July-September tractor dredging). They concluded that although significant mortality of *Cerastoderma edule* and other infauna occurred, recovery was rapid and the overall effects on populations were low. Hall & Harding (1997) found that abundance had returned to control levels within about 56 days and Moore (1991) also suggested that recovery was rapid. Rostron (1995) carried out experimental dredging of sandflats with mechanical cockle dredge. Two distinct sites were sampled; Site A: poorly sorted fine sand with small pools and *Arenicola marina* casts with some algal growth, and Site B: well sorted fairly coarse sand, surface sediment well drained and rippled as a result of wave activity. At both sites, *Cerastoderma edule* reduced after dredging but recovery was rapid at Site B (no difference between control and experimental plots after 14 days), whilst at Site A significant reduction in numbers compared with the control were still apparent up to six months post-dredging.

A number of studies have found that the abundance of the polychaete *Pygospio elegans* is reduced by simulated cockle dredging (Hall & Harding, 1998; Moore, 1990; Ferns *et al.*, 2000; Rostron, 1995). Ferns *et al.* (2000) found that tractor-towed cockle harvesting, removed 83% of *Pygospio elegans* (initial density 1850/ m²). In muddy sand habitats, *Pygospio elegans* had not recovered to the original abundance after 174 days (Ferns *et al.*, 2000). Rostron (1995) also found that *Pygospio elegans* had not recovered to pre-dredging numbers after six months. Conversely, Hall & Harding, (1998) found that abundance of *Pygospio elegans* increased significantly over 56 days following suction dredging. *Pygospio elegans* inhabits a fragile tube that projects above the sediment surface

and is probably more vulnerable to physical disturbance and abrasion than other, more deeply buried, infaunal species. Other species may recover more rapidly *Capitella capitata* had almost trebled its abundance within the 56 days in a clean sandy area (Ferns *et al.* 2000). Following experimental beam trawl disturbance in an area that had previously been closed to fishing populations of *Melinna palmata* increased by 41% (Tuck *et al.* 1998). The area was repeatedly disturbed over an 18 month period and recovery tracked for a further 18 months.

With respect to displacement, cockles are capable of burrowing rapidly into the substratum and >50% burrowed into the substratum within 1 hour in experimental trials (Coffen-Smout & Rees, 1999), although this rate was inhibited by prior disturbance. Brock (1979) reported that 80% began to burrow within 60 min and 50% had successfully burrowed into sediment within 60 min. He also noted that young cockles could burrow quickly, and were nearly buried within 5 min. Hand-raking for cockles was shown not to influence the re-burial rate of cockles in Strangford Lough, Northern Ireland (McLaughlin *et al.* 2007).

Sensitivity assessment. The available evidence indicates that small patches of physical disturbance are likely to be in-filled by adult cockle movement, large patches will recover through larval recruitment, which again is subject to many factors, and may be improved by the removal of adult cockles. Biotope resistance is assessed as 'Low' based on loss of characterizing species *Cerastoderma edule* and associated species. Resilience is assessed as 'Medium' to take account of recruitment variability and return of normal age structure. Sensitivity is therefore categorized as 'Medium'

Changes in suspended solids (water clarity)

High

Q: High A: Medium C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: Medium C: High

An increase in the amount of suspended sediment could potentially increase the amount of food available to deposit feeders, the major trophic group within this biotope. However, this would only occur if the proportion of organic material within the suspended sediment increased. With regard to suspension feeders, increasing total particulate concentrations have been shown to decrease clearance rates and increase pseudofaeces production in *Cerastoderma edule* (Navarro *et al.*, 1992; Navarro & Widdows, 1997). Furthermore, due to the sheltered nature of the habitat, siltation is likely. The increase in suspended sediment is likely to increase the proportion of mud, to the detriment of *Cerastoderma edule*.

A decrease in suspended sediment is likely to reduce the amount of available food for both suspension feeders and deposit feeders although at the benchmark level this is unlikely to cause mortality. Navarro & Widdows (1997) suggested that *Cerastoderma edule* was able to compensate for decrease in particulate quality (i.e. proportion of organic to inorganic seston) between 1.6 to 300 mg/l. Over the benchmark period the associated fauna may experience reduction in growth. On resumption of normal levels of suspended sediment. An increase in turbidity will mean that primary production in the water column may suffer from increased light attenuation.

Sensitivity assessment. A decrease in turbidity and hence increased light penetration may result in increased phytoplankton production and hence increased food availability for suspension feeders, including *Cerastoderma edule*. Therefore, reduced turbidity may be beneficial. In areas of high

suspended sediment, a decrease may result in improved condition and recruitment due to a reduction in the clogging of filtration apparatus of suspension feeders and an increase in the relative proportion of organic particulates. However, a decrease in suspended organic particles in some areas may reduce food availability for deposit feeders resulting in lower growth or reduced energy for reproduction. Where increased turbidity results from organic particles then subsequent deposition may enhance food supply for deposit feeders within the biotope such as the cirratulids and oligochaetes. Alternatively, if turbidity results from an increase in suspended inorganic particles then energetic costs may be imposed on these species as sorting and feeding becomes less efficient reducing growth rates and reproductive success. Lethal effects are considered unlikely given the occurrence of *Cerastoderma edule* and other associated species in estuaries where turbidity is frequently high from suspended organic and inorganic matter. Resistance and resilience are therefore assessed as 'High' and the biotope is considered to be 'Not sensitive'.

Smothering and siltation rate changes (light)

Medium

Q: High A: High C: High

High

Q: High A: High C: High

Low

Q: High A: High C: High

Cerastoderma edule has short siphons and needs to keep in contact with the surface of the sediment. Bait digging (for large polychaete worms) disturbs the sediment down to a depth of 30cm (Jackson & James, 1979). Intensification of bait digging on intertidal flats on the north Norfolk coast for lugworm (*Arenicola marina*) and rag worm (*Hediste diversicolor*) was associated with declines in the *Cerastoderma edule* populations (Jackson & James, 1979). Experimental simulation of bait digging (sediment dug over to a depth of 30cm with a garden fork) led to high mortalities of cockles in dug areas rather than undug areas (48% mortality in 9 days to a maximum of 85% after 11 days) probably due to smothering (Jackson & James, 1979). The observation was texted experimentally in the laboratory by burying 3 size-classes of cockles at 0, 5 or 10cm depth in a mix of oxidated and deeper anoxic sands (mixed as a ratio of 3:1) was used as the sediment. Movements were recorded after 24, 48 and 72 hours. When buried to 5 cm depth most cockles returned to the surface but few were able to reposition to the surface if buried at 10cm depth. None had died after 72 hours. Additional burial experiments under 10 cm of sediment assessed movement and survival after 3, 6 and 9 days in two sediment types (a mix of surface mud and sand in two ratios 9:1 and 1:9). Movement towards the surface was slower in the predominantly muddy sediment and all cockles died between 3 and 6 days. Substantial mortality resulted in the predominantly sandy mixture although some cockles were able to move towards the surface and survive for 9 days.

Cerastoderma edule have been categorised through expert and literature review as AMBI sedimentation Group II – species sensitive to high sedimentation. They prefer to live in areas with some sedimentation, but don't easily recover from strong fluctuations in sedimentation (Gittenberger & van Loon 2011).

The associated species *Pygospio elegans* is limited by high sedimentation rates (Nugues *et al.*, 1996) and the species does not appear to be well adapted to oyster culture areas where there are high rates of accumulation of faeces and pseudo faeces (Sornin *et al.*, 1983; Deslous-Paoli *et al.*, 1992; Mitchell, 2006 and Bouchet & Sauriau 2008). *Pygospio elegans* is known to decline in areas following re-deposition of very fine particulate matter (Rhoads & Young, 1971; Brenchley, 1981). Experimental relaying of mussels on intertidal fine sands led to the absence of *Pygospio elegans* compared to adjacent control plots. The increase in fine sediment fraction from increased sediment deposition and biodeposition alongside possible organic enrichment and decline in

sediment oxygen levels was thought to account for this (Ragnarsson & Rafaelli, 1999).

Mobile and/or burrowing species (including molluscs and polychaetes such as *Hydrobia ulvae*, *Eteone longa* and *Scoloplos armiger*) are generally considered to be able to reposition following periodic siltation events or low levels of chronic siltation. Field experiments where 10 cm of sediment were placed on intertidal sediments to investigate the effects of the beneficial use of dredged materials found that the abundance of *H. ulvae* had returned to ambient levels within 1 week (Bolam et al. 2004). However, survival depends on several factors. The snail can only burrow up through certain sorts of sediment. If the silt content of the smothering sediment is high and the water content low then it is unlikely that the surface will be regained from 5 cm down. Looser sediment with high water and low silt content can be negotiated quite rapidly. The surface is generally regained within a day. If the surface cannot be regained then *Hydrobia ulvae* can survive burial for quite extended periods although this is highly temperature dependent. Temperatures of 20°C result in all individuals dying after 10 days. Survival is much better at lower temperatures. It is thought that oxygen stress is the cause of mortality (Jackson, 2000).

Melinna palmata lives in a mucous-lined tube covered in sediment that projects obliquely above the sediment (Fauchald & Jumars, 1979). In general, mucus tube feeders and labial palp deposit feeders were most intolerant to burial (Maurer et al., 1986). Smothering may result in this tube being broken which may result in the displacement or mortality of some individuals. It is not known whether other important characterizing fauna including the oligochaetes *Tubificoides benedii*, *Tubificoides pseudogaster* and the polychaete *Pygospio elegans* would be adversely affected by smothering but their mobility may enable them to dig back up through the sediment to the surface.

Sensitivity assessment. Biotope resistance based on the characterizing *Cerastoderma edule* is assessed as having 'Medium' resistance to siltation, (as many would be able to survive and re-emerge from a 5cm depth of sediment). Resilience is assessed as 'High' based on adult migration and repopulation by larvae. Many of the associated species are also likely to reposition although *Pygospio elegans* may be more sensitive.

Smothering and siltation rate changes (heavy)

Low

Q: High A: High C: High

Medium

Q: High A: Low C: Medium

Medium

Q: High A: Low C: Medium

Cerastoderma edule has short siphons and needs to keep in contact with the surface of the sediment. Bait digging (for large polychaete worms) disturbs the sediment down to a depth of 30cm (Jackson & James, 1979) and leads to repositioning within sediment or burial from piled sediments. Intensification of bait digging on intertidal flats on the north Norfolk coast for lugworm (*Arenicola marina*) and ragworm (*Hediste diversicolor*) was associated with declines in the *Cerastoderma edule* populations (Jackson & James, 1979). Experimental simulation of bait digging (sediment dug over to a depth of 30cm with a garden fork) led to high mortalities of cockles in dug areas rather than undug areas (48% mortality in 9 days to a maximum of 85% after 11 days) probably due to smothering (Jackson & James, 1979). The observation was tested experimentally in the laboratory by burying 3 size-classes of cockles at 0, 5 or 10cm depth in a mix of oxidated and deeper anoxic sands (mixed as a ratio of 3:1) was used as the sediment. Movements were recorded after 24, 48 and 72 hours. When buried to 5 cm depth most cockles returned to the surface but few were able to reposition to the surface if buried at 10cm depth. None had died after 72 hours. Additional burial experiments under 10 cm of sediment assessed movement and survival after 3, 6 and 9 days in two sediment types (a mix of surface mud and sand in two ratios 9:1 and 1:9). The movement towards the surface was slower in the predominantly muddy sediment and all cockles

died between 3 and 6 days. Substantial mortality resulted in the predominantly sandy mixture although some cockles were able to move towards the surface and survive for 9 days.

Field experiments where 10 cm of sediment were placed on intertidal sediments to investigate the effects of the beneficial use of dredged materials found that the abundance of *Hydrobia ulvae* had returned to ambient levels within 1 week (Bolam *et al.*, 2004). It is not clear whether this species could reposition after 30cm of sediment were placed on sediments.

Sensitivity assessment. The addition of 30cm of sediment would prevent *Cerastoderma edule* and *Abra nitida* from extending siphons to the surface. It is unlikely that these species could emerge from this depth of sediment although some individuals may survive and sediment may be rapidly removed by tide and wave action. It is likely however that there would be considerable mortality of the characterizing *Cerastoderma edule* and biotope sensitivity is based on this species. Resistance is assessed as 'Low' and resilience as 'Medium' (based on episodic recruitment). Sensitivity is therefore assessed as 'Medium'. The sensitivity of the associated species is unclear. Although some polychaetes may be able to reposition following sedimentation at the pressure benchmark this will depend on the characteristics of the overburden and sedentary species such as *Pygospio elegans* are likely to suffer high levels of mortality.

Litter

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

Not assessed. No evidence was found for ingestion of microplastics by *Cerastoderma edule*. Polychaete worm fecal casts analyzed by Mathalon & Hill (2014) had microplastic fiber concentrations resembling those found in low tide sediments. This is an indication that polychaete deposit feeders are indiscriminately feeding on microplastics, and appear to be excreting most if not all the microplastics they consume. However, polychaetes may still be affected by contaminants that are absorbed in microplastics upon ingestion. Wright *et al.*, (2013) found that deposit-feeding marine worms maintained in sediments spiked with microscopic unplastified polyvinylchloride (UPVC) at concentrations overlapping those in the environment had significantly depleted energy reserves by up to 50%. The effect was suggested to result from a combination of reduced feeding activity, longer gut residence times of ingested material and inflammation (Wright *et al.*, 2013)

Electromagnetic changes

No evidence (NEv)

Q: NR A: NR C: NR

No evidence (NEv)

Q: NR A: NR C: NR

No evidence (NEv)

Q: NR A: NR C: NR

No evidence,

Underwater noise changes

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

Cerastoderma edule can probably detect the vibration caused by predators and will withdraw its siphons. However, little information was found concerning the effect of noise or vibration on cockle populations. The polychaetes and other worms are unlikely to have the ability to detect noise and other associated fauna are also unlikely to be adversely affected. This pressure is therefore considered 'Not relevant'.

Introduction of light or shading**High**

Q: High A: High C: Medium

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: Medium

Cerastoderma edule carries about 60 eyes on the sensory siphonal tentacles (Barber & Wright 1968). The basic response to light in bivalves is defensive with responses including digging, closing of valves and siphonal withdrawal (Morton, 2008). Changes in light levels may also simulate other behavioural responses and emergence of cockles in response to darkness has been observed (Richardson *et al.*, 1993). Light levels may act as cues for reproduction (although temperature also regulates reproduction for many species) supporting synchronised spawning for species with external fertilisation. No evidence was found to suggest that light levels are an important reproductive cue for characterizing and associated species.

Aphelochaeta marioni is only active at night and Farke (1979) noted their intolerance to visual disturbance in a microsystem in the laboratory. In order to observe feeding and breeding in the microsystem, the animals had to be gradually acclimated to lamp light. Even then, additional disturbance, such as an electronic flash, caused the retraction of palps and cirri and cessation of all activity for some minutes. Visual disturbance, in the form of direct illumination during the species' active period at night, may therefore result in loss of feeding opportunities, which may compromise growth and reproduction.

Sensitivity assessment. Light penetration into sediments is limited to the surface layers and permanently buried infauna are unlikely to be affected by changes in light levels. The characterizing *Cerastoderma edule* and other species present can perceive light but the effects of changes in light level and shading or the duration of light and darkness are not clear. As it is considered unlikely that changes in light levels would have significant effects on the key and associated species (where cirratulids acclimate to the changed light level), biotope resistance is assessed as 'High' and resilience as 'High' (by default) and the biotope is considered to be 'Not sensitive'.

Barrier to species movement**High**

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

No direct evidence was found to assess this pressure. As the larvae of *Cerastoderma edule* are planktonic and are transported by water movements, barriers that reduce the degree of tidal excursion may alter larval supply to suitable habitats from source populations. However the presence of barriers may enhance local population supply by preventing the loss of larvae from enclosed habitats. Species that do not have a pelagic larval stage such as *cirratulids* or those that alternate between pelagic and benthic dispersal stages such as *Pygospio elegans* and *Capitella capitata*, are less likely to be impacted by this pressure. As both these key characterizing species are widely distributed and have larvae capable of long distance transport and long residence times in the water column, resistance to this pressure is assessed as 'High' and resilience as 'High' by default. This biotope is therefore considered to be 'Not sensitive'.

Death or injury by collision**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.

Visual disturbance

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.

 **Biological Pressures**

Resistance

Resilience

Sensitivity

Genetic modification & translocation of indigenous species

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

The key characterizing and associated species within this biotope are not cultivated or translocated. This pressure is therefore considered 'Not relevant' to this biotope group.

Due to long distance transport of pelagic larvae populations of the key characterizing species, *Cerastoderma edule*, may be interconnected and populations are not genetically isolated, with populations such as those at Pembroke showing mixing between British and Irish populations (Coscia *et al.*, 2013). It should be noted that where local hydrodynamics prevent larval transport some genetically isolated populations may occur, as in the Burry Inlet, south Wales (Coscia *et al.*, 2013).

Introduction or spread of invasive non-indigenous species

Low

Q: High A: High C: Low

Very Low

Q: Low A: NR C: NR

High

Q: Low A: Low C: Low

The OSPAR (2009) background document identifies the threat to mudflats (considered to be applicable to muddy sand sediments) from NIS as follows: 'Coastal and estuarine areas are among the most biologically invaded systems in the world, especially by molluscs such as the slipper limpet *Crepidula fornicata* and the Pacific oyster *Magallana gigas*. The two species have not only attained considerable biomasses from Scandinavian to Mediterranean countries but have also generated ecological consequences such as alterations of benthic habitats and communities, or food chain changes (OSPAR, 2009).

In the Wadden Sea, the Pacific oyster, *Magallana gigas*, has colonized intertidal flats (Smaal *et al.*, 2005). This species may consume larvae including the pelagic larvae of *Cerastoderma edule* and *Limecola balthica* and other species reducing recruitment (Smaal *et al.*, 2005). Troost *et al.* (2009) investigated whether *Magallana gigas* had a competitive feeding advantage over *Cerastoderma edule* and concluded that differences in feeding current characteristics were small and not considered to lead to significant differences in feeding efficiency. The most severe effects are likely to occur from impacts on sediment, where *Magallana gigas* create reefs on sedimentary flats that will prevent recruitment of juveniles and will restrict access of infauna to the sediment-water interface impacting respiration and feeding.

The Manila clam (*Tapes philippinarum*), which was introduced to Poole Harbour for aquaculture in 1998, has become a naturalised population on the intertidal mudflats (occurring at densities of 60 clams/m² in some locations within the harbour (Jensen *et al.* 2007, cited in Caldow *et al.* 2007). Densities of *Cerastoderma edule* and *Abra tenuis* had increased since the introduction of the Manila

clam although the abundance of *Scrobicularia plana* and *Limecola balthica* declined (Caldow *et al.* 2005).

The burrowing lifestyle of the characterizing cirratulids and other infaunal polychaetes may confer some protection from changes to the sediment surface and may provide some new habitat (as this species has been found among oyster banks).

The predatory veinedwhelk (*Rapana venosa*) and *Hemigrapsus takinei* are not established in the UK (although *Hemigrapsus takinei* has been recorded at two locations) could become significant predators of *Cerastoderma edule* and other species associated with the biotope in the future.

Sensitivity assessment. Intertidal muddy sands may be exposed to invasive species which can alter the character of the habitat (primarily *Crepidula fornicata* at the sublittoral fringe and *Magallana gigas*) leading to re-classification of this biotope, the biotope is considered to have 'Low' resistance and 'Very Low' recovery (unless invasive species are removed). Biotope sensitivity is, therefore assessed as 'High'.

Introduction of microbial pathogens

Low

Q: High A: High C: High

Medium

Q: High A: Low C: Medium

Medium

Q: High A: Low C: High

A recent review of parasites, pathogens and commensals identified a range of agents impacting European cockles, including 50 conditions affecting *Cerastoderma edule* (Longshaw & Malham, 2013). Cockles are hosts to viruses, bacteria, fungi, Apicomplexa, Amoeba, Ciliophora, Perkinsozoa, Haplosporidia, Cercozoa, Turbellaria, Digenea, Nematoda, Crustacea and Nemertea. Mortalities are associated particularly with digeneans and some protistan infections; parasites may limit growth, reduce fecundity and alter burrowing behaviour (Longshaw & Malham, 2013). A number of examples of conditions associated with mass mortalities of *Cerastoderma edule* are presented below. Parasites and disease are more likely to cause mortalities in populations that are subject to suboptimal conditions or other stressors such as hot summers or cold winters (Longshaw & Malham, 2013). Experimental infection of *Cerastoderma edule* with a trematode parasite showed that effects differed depending on habitat conditions (Wegeberg & Jensen, 2003). Infected *Cerastoderma edule* reared in sub-optimal conditions lost more body weight than infected cockles in more optimal habitats and did not regain condition when placed in higher shore habitats where immersion and food supply was limited. Infected cockles placed on lower shore sites with longer emersion times regained condition despite the infection and were equivalent to controls. The impact of trematodes is therefore mediated by habitat conditions and in some instances may have no effect (Wegeberg & Jensen, 2003).

Infestation by a trematode parasite *Cercaria cerastodermæ* impairs the burrowing ability of *Cerastoderma edule* and was identified as the likely cause of a mass mortality of cockles in Scandinavian waters in 1991 (Jonsson & André, 1992). Another trematode parasite *Gymnophallis choledochus* may castrate *Cerastoderma edule*, reducing reproduction and recruitment and indirectly leading to population declines (Thieltges, 2006). Boyden (1972) reported castration of 13% of the cockle population in the River Couch estuary due to infestation with larval digenetic trematodes.

An unidentified amoeba, measuring 18–20 µm in diameter, was described from the sub-epithelial gill tissues of *Cerastoderma edule* from Portugal (Azevedo, 1997). The amoeba was associated with haemocytic infiltration and necrosis of host cells. Affected cockles were found gaping at the surface and the infection was considered to be responsible for mass mortalities.

Cockles also suffer from disseminated neoplasia—a leukaemia like disease associated with mass mortalities. *Cerastoderma edule* from Ireland have been reported to be especially susceptible (Barber *et al.*, 2004). High mortalities of cockles observed in northwest Spain in 1997 were associated with a higher prevalence (up to 84%) of disseminated neoplasia compared to control areas (4% prevalence) not experiencing mortality (Villalba *et al.* 2001).

Other species characterizing the biotope may be infected by microbial pathogens and parasites. Nearly all *Aphelochaeta marioni* (as *Tharyx marioni* individuals from Stonehouse Pool in Plymouth were infected with a sporozoan parasite of the *Gonospora* genus but no evidence was found that the animal was adversely affected by its presence (Gibbs, 1971).

Sensitivity assessment. The available evidence suggests that the key characterizing species *Cerastoderma edule* is susceptible to a range of pathogens and parasites. The effects of these may be exacerbated by stressors such as thermal stress (amongst others). As evidence exists for mass mortalities, resistance is assessed as 'Low' and resilience is assessed as 'Medium'. Sensitivity is therefore categorised as 'Medium'.

Removal of target species

Medium

Q: High A: Medium C: Medium

Medium

Q: High A: Low C: Medium

Medium

Q: High A: Low C: Medium

The sedimentary biotope and characterizing and associated species may be disturbed and damaged by static or mobile gears that are targeting *Cerastoderma edule* or other species. These direct, physical impacts are assessed through the abrasion and penetration of the seabed pressures. The sensitivity assessment for this pressure considers any biological/ecological effects resulting from the removal of target species on this biotope. Dense populations of *Cerastoderma edule* on intertidal flats support commercial fisheries in several areas of the UK and the species is also harvested throughout Europe. Harvesting may use mechanical methods (e.g. tractor dredges or hydraulic suction dredging) or hand collection using rakes or other methods. The fishery is managed through local byelaws and local target size classes are set (usually cockles below 20 mm are not collected). The commercial importance of the fishery has stimulated research on impacts on cockles and the sedimentary habitat and associated species. In some habitats removal of *Arenicola marina* and *Hediste diversicolor* for fishing bait may occur but these species are not considered to characterize this biotope and the removal of these as target species is not considered in this review; the relevant biotopes (LS.LSa.MuSa.LimAre; SS.SMu.IFiMu.Are; LS.LMu.MEst.HedMac), characterized by these species contain more information.

The physical effects of harvesting on this species are addressed in the physical disturbance sections. Removal of *Cerastoderma edule* (cockles) by targeted harvesting may result in an altered community and may alter the character and reduce the spatial extent of the *Cerastoderma edule* and polychaetes in littoral muddy sand biotope.

The method of harvesting cockles will influence the proportions that are removed and damaged. Pickett (1973) found that intense dredging for a short period on a bed of cockle spat had little effect on survival and growth although Cook (1991) found that impacts on small cockles from dredging were variable, with little reduction one year but a reduction in density observed the following year. Cotter *et al.* (1997) assessed the catch rates and damage and mortality of *Cerastoderma edule* resulting from experimental tractor dredging at the Burry Inlet (Wales). Stocks of adult cockles were reduced by 31 and 49% in low and high density areas respectively. Similarly mechanical cockle harvesting in muddy sand reduced the abundance of *Cerastoderma edule* by ca 34%. Populations had not recovered their original abundance after 174 days (Ferns *et al.* 2000).

Following size sorting (either mechanically or by hand), undersized cockles are deposited on the sediment surface. Damage rates and survival rates of harvested and discarded cockles and rates of reburrowing and displacement have been examined in a number of studies. Cook (1991) reported overall damage rates of 11-14% of rejects from rotary riddles on three hydraulic section dredgers operating. Undersized and rejected cockles may be stunned where these suffer prolonged vibrations from passage through mechanical gear and sorters, this can delay reburrowing, leading to increased predation and/or distribution by tidal waves and currents (Coffen-Smout & Rees, 1998).

The sediment on which discards are deposited affects burrowing. Experimental displacement to simulate harvesting impacts, found that cockles deposited in pools are more able to rebury while none of those deposited on drained (and hence hard) sands were able to reburrow (Coffen-Smout & Rees, 1999). Greater proportions of smaller cockles than medium or large reburrow, so that larger cockles are more likely to be displaced by tides (Coffen-Smout & Rees, 1999). Cockles that were transported up to 200m on the flood tide could reburrow if habitats in the new position were suitable (Coffen-Smout & Rees, 1999).

Hand raking for cockles on intertidal silty sandflats, using rakes that penetrated the surface by 5-10cm, resulted in a three-fold increase in the damage rate of cockles compared to control plots and, in the short-term, led to a relative decrease in the overall abundance of fauna (Kaiser *et al.*, 2001). After 56 days the small (9 m²) plots had recovered but the larger (36 m²) plots remained in an altered state. Results collected over a year after the disturbance suggested that while effects of hand-raking may be significant within a year, they are unlikely to persist beyond this time-scale unless there are larger long-lived species present within the community (Kaiser *et al.*, 2001).

The presence of dense cockle beds inhibit the establishment of other benthic species through space and resource competition, disturbance (Flach, 1996) and consumption of larvae (Andre *et al.*, 2003) and changes in sediment characteristics (). Removal of adult cockles by harvesting or other factors allows other species to establish. Following experimental removal of large adult *Cerastoderma edule* by Frid & Casear (2012) sediments showed increased biodiversity and assemblages dominated by traits common to opportunist taxa at a species-poor shore at Warton Sands, Morecambe Bay, and a more diverse shore at Thurstaston, Dee estuary. The movements of cockles disturb and exclude the amphipod *Corophium volutator* and other species (Flach, 1996; Flach & de Bruin, 1994) the removal of cockles may therefore allow this species to colonize intertidal flats. During periods of low cockle density, Desprez *et al.*, (1992) observed that *Pygospio elegans* established dense populations; when cockles returned these were lost within one year.

It should be noted that removal of *Cerastoderma edule* by targeted harvesting may lead to wider ecological effects through starvation of shore birds in winter. This has been observed in the Dutch Wadden Sea (Smit *et al.*, 1998). This effect is not directly of significance to this biotope and is not considered within the assessment.

Sensitivity assessment. Removal of the key characterizing species *Cerastoderma edule* by targeted harvesting would alter the character of the biotope and result in reclassification. The abundance of other soft-sediment infauna (particularly opportunist species such as *Pygospio elegans* and *Capitella capitata*) may increase in disturbed patches in the short-term as a result of removal of cockles resulting in reduced competition for space and predation (on larvae). Where sediments remain suitable cockles are likely to recolonize via adult migration, survival of small, discarded cockles or via larval recruitment. In general fishing practices will be efficient at removing this species, resistance is therefore assessed as 'Low' (removal is not considered to be total as smaller

individuals are not retained and harvesting is unlikely to be 100% efficient at removing larger cockles). Resilience is assessed as 'Medium', so that sensitivity is assessed as 'Medium'. Recovery will be influenced by a range of factors as outlined in the resilience section. Small patches are likely to be in-filled by adult cockle movement, large patches will recover through larval recruitment, which again is subject to many factors, and may be improved by the removal of adult cockles. However, as *Cerastoderma edule* recruitment is episodic, a recovery of 'Medium' to represent recovery of age-classes from broad-scale removal was considered appropriate. Biotope sensitivity is therefore assessed as 'Medium'. Although some experiments have shown rapid recovery, the plots used in experiments are small and subject to low levels of harvesting compared to intertidal flats that are harvested at larger scales and where patches may be re-worked over a season.

Removal of non-target species

Low

Q: Low A: NR C: NR

Medium

Q: High A: Low C: Medium

Medium

Q: Low A: Low C: Low

The sedimentary biotope and characterizing and associated species may be disturbed and damaged by static or mobile gears that are targeting other species. These direct, physical impacts are assessed through the abrasion and penetration of the seabed pressures. A number of studies have assessed the impact of *Cerastoderma edule* removal on non-target infauna (Hall & Harding, 1998; Hiddink, 2003). However, these studies are relevant to physical damage and are discussed in those sections. The sensitivity assessment for this pressure considers any biological/ecological effects resulting from the removal of non-target species on this biotope. Dense beds of *Cerastoderma edule* occur in situations where the faunal assemblage is species-diverse and productive, but also where very few taxa are present (Cesar, 2012). These observations suggest that *Cerastoderma edule* populations are not dependent on other invertebrate species and are therefore unlikely to be impacted by ecological/biological effects from removal of other species. The removal of predators such as shrimp and crab may enhance recruitment and survival of larvae (Beukema & Dekker, 2005; Sanchez-Salazar *et al.*, 1987). The physical effects of removal of other species such as polychaete worms targeted by bait diggers may, however, impact *Cerastoderma edule* and other species associated with this biotope, through direct damage, smothering (Jackson & James, 1979) and removal and displacement. These direct effects of sediment disturbance are assessed in the physical damage sections.

The removal of *Cerastoderma edule* (as by-catch from another fishery) and other associated species would alter the biotope from the description and change community structure (diversity, biomass and abundance), potentially altering ecosystem function and the delivery of ecosystem goods and services (including the supply of food to fish and birds).

Sensitivity assessment. The assessment considers whether the removal of characterizing and associated species as by-catch would impact the biotope. Lethal damage to and removal of *Cerastoderma edule* and other species as by-catch would alter the character of the biotope through changes in the structure of the biological assemblage (changes to species richness, abundance and biomass). As *Cerastoderma edule* and other species are either sedentary or incapable of rapid evasive movements, biotope resistance is assessed as 'Low'. Resilience is assessed as 'Medium' based on *Cerastoderma edule* and sensitivity is therefore categorized as 'Medium'. Physical damage to the sediment and other physical damage factors are considered in the abrasion and extraction pressures

Bibliography

- Ansell, A.D., Barnett, P.R.O., Boday, A. & Masse, H., 1981. Upper temperature tolerances of some European Mollusca III. *Cardium glaucum*, *C. tuberculata* and *C. edule*. *Marine Biology*, **65**, 177-183.
- Bagheri, E.A. & McLusky, D.S., 1984. The oxygen consumption of *Tubificoides benedeni* (Udekem) in relation to temperature and its application to production biology. *Journal of Experimental Marine Biology and Ecology*, **78**, 187-197.
- Barnett, B.E., 1983. Oligochaetes as indicators of pollution in the Humber estuary, with special reference to *Tubificoides benedii*. *Environmental Pollution (Series A)*, **30**, 277-291.
- Bestwick, B.W., Robbins, I.J. & Warren, L.M., 1989. Metabolic adaptations of the intertidal polychaete *Cirriformia tentaculata* to life in an oxygen-sink environment. *Journal of Experimental Marine Biology and Ecology*, **125**, 193-202
- Beukema, J.J., 1990. Expected effects of changes in winter temperatures on benthic animals living in soft sediments in coastal North Sea areas. In *Expected effects of climatic change on marine coastal ecosystems* (ed. J.J. Beukema, W.J. Wolff & J.J.W.M. Brouns), pp. 83-92. Dordrecht: Kluwer Academic Publ.
- Boström, C. & Bonsdorff, E., 2000. Zoobenthic community establishment and habitat complexity - the importance of seagrass shoot density, morphology and physical disturbance for faunal recruitment. *Marine Ecology Progress Series*, **205**, 123-138.
- Boyden, C.R. & Russel, P.J.C., 1972. The distribution and habitat range of the brackish water cockle (*Cardium (Cerastoderma) edule*) in the British Isles. *Journal of Animal Ecology*, **41**, 719-734.
- Boyden, C.R., 1972. Behaviour, survival and respiration of the cockles *Cerastoderma edule* and *C. glaucum* in air. *Journal of the Marine Biological Association of the United Kingdom*, **52**, 661-680.
- Brock, V., 1979. Habitat selection of two congeneric bivalves, *Cardium edule* and *C. glaucum* in sympatric and allopatric populations. *Marine Biology*, **54**, 149-156.
- Broom, M.J., Davies, J., Hutchings, B. & Halcrow, W., 1991. Environmental assessment of the effects of polluting discharges: stage 1: developing a post-facto baseline. *Estuarine, Coastal and Shelf Science*, **33**, 71-87.
- Charles, G.H., 1966. Sense organs (less Cephalopods). In *Physiology of Mollusca*, vol. 2 (ed. K.M. Wilbur & C.M. Yonge), pp. 455-521. New York: Academic Press.
- Coffen-Smout, S.S. & Rees, E.I.S., 1999. Burrowing behaviour and dispersion of cockles *Cerastoderma edule* following simulated fishing disturbance. *Fisheries Research*, **40**, 65-72.
- 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.*
- Dales, R.P. & Warren, L.M., 1980. Survival of hypoxic conditions by the polychaete *Cirriformia tentaculata*. *Journal of the Marine Biological Association of the United Kingdom*, **60**, 509-516.
- Dales, R.P., 1951. Notes on the reproduction and early development of the cirratulid *Tharyx marioni* (St Joseph). *Journal of the Marine Biological Association of the United Kingdom*, **30**, 113-117.
- Dauvin, J.C., 1982. Impact of Amoco Cadiz oil spill on the muddy fine sand *Abra alba - Melinna palmata* community from the Bay of Morlaix. *Estuarine and Coastal Shelf Science*, **14**, 517-531.
- Dauvin, J.C., 2000. The muddy fine sand *Abra alba - Melinna palmata* community of the Bay of Morlaix twenty years after the Amoco Cadiz oil spill. *Marine Pollution Bulletin*, **40**, 528-536.
- Desprez, M.H., Rybarczyk, H., Wilson, J.G., Ducrotoy, J.P., Sueur, F., Olivesi, R. & Elkaim, B., 1992. Biological impact of eutrophication in the Bay of Somme and the induction and impact of anoxia. *Netherlands Journal of Sea Research*, **30**, 149-159.
- Diaz, R.J., 1980. Ecology of tidal freshwater and estuarine Tubificidae (Oligochaeta). In *Aquatic oligochaete biology, Proceedings of the first international symposium on aquatic oligochaete biology, Sydney, British Columbia, Canada, May 1-4, 1979*, (ed. R.O. Brinkhurst & D.G. Cook), pp. 319-330. New York: Plenum Press.
- Ducrotoy, C.R., Rybarczyk, H., Souprayen, J., Bachelet, G., Beukema, J.J., Desprez, M., Dörjes, J., Essink, K., Guillou, J., Michaelis, H., Sylvand, B., Wilson, J.G., Elkaïm, B. & Ibanez, F., 1991. A comparison of the population dynamics of the cockle (*Cerastoderma edule*) in North-Western Europe. In *Proceedings of the Estuarine and Coastal Sciences Association Symposium, ECSA 19, 4-8 September 1989, University of Caen, France. Estuaries and Coasts: Spatial and Temporal Intercomparisons*, pp. 173-184. Denmark: Olsen & Olsen.
- Eltringham, S.K., 1971. *Life in mud and sand*. London: The English Universities Press Ltd.
- Farke, H., 1979. Population dynamics, reproduction and early development of *Tharyx marioni* (Polychaeta, Cirratulidae) on tidal flats of the German Bight. *Veröffentlichungen des Instituts für Meeresforschung in Bremerhaven*, **18**, 69-99.
- Fauchald, J. & Jumars, P.A., 1979. The diet of worms: a study of polychaete feeding guilds. *Oceanography and Marine Biology: an Annual Review*, **17**, 193-284.
- Ferns, P.N., Rostron, D.M. & Siman, H.Y., 2000. Effects of mechanical cockle harvesting on intertidal communities. *Journal of Applied Ecology*, **37**, 464-474.
- Flach, E.C., 1996. The influence of the cockle, *Cerastoderma edule*, on the macrozoobenthic community of tidal flats of the Wadden Sea. *Marine Biology*, **17**, 87-98.
- Fowler, S.L., 1999. Guidelines for managing the collection of bait and other shoreline animals within UK European marine sites.

- Natura 2000 report prepared by the Nature Conservation Bureau Ltd. for the UK Marine SACs Project, 132 pp., Peterborough: English Nature (UK Marine SACs Project)., <http://www.english-nature.org.uk/uk-marine/reports/reports.htm>
- George, J.D., 1963. Behavioural differences between the larval stages of *Cirriformia tentaculata* (Montagu) from Drake's Island (Plymouth Sound) and from Southampton Water. *Nature*, **99**, 195.
- George, J.D., 1964a. The life history of the cirratulid worm, *Cirriformia tentaculata*, on the intertidal mudflat. *Journal of the Marine Biological Association of the United Kingdom*, **44**, 47-65.
- George, J.D., 1964b. On some environmental factors affecting the distribution of *Cirriformia tentaculata* (Polychaete) at Hamble. *Journal of the Marine Biological Association of the United Kingdom*, **44**, 383-388.
- George, J.D., 1968. The effect of the 1962-63 winter on the distribution of the cirratulid polychaetes, *Cirratulus cirratus* (Müller) and *Cirriformia tentaculata* (Montagu) in the British Isles. *Journal of Animal Ecology*, **37**, 321-31.
- Gibbs, P.E., 1969. A quantitative study of the polychaete fauna of certain fine deposits in Plymouth Sound. *Journal of the Marine Biological Association of the United Kingdom*, **49**, 311-326.
- Gibbs, P.E., 1971. Reproductive cycles in four polychaete species belonging to the family Cirratulidae. *Journal of the Marine Biological Association of the United Kingdom*, **51**, 745-769.
- Giere, O., Preusse, J. & Dubilier, N. 1999. *Tubificoides benedii* (Tubificidae, Oligochaeta) - a pioneer in hypoxic and sulfide environments. An overview of adaptive pathways. *Hydrobiologia*, **406**, 235-241.
- Goss-Custard, J.D., 1977a. The energetics of prey selection by redshank *Tring totanus* (L.), in relation to prey density. *Journal of Animal Ecology*, **46**, 1-19.
- Goss-Custard, J.D., 1977b. Predator responses and prey mortality in redshank *Tring totanus* (L.), and a preferred prey, *Corophium volutator* (Pallas). *Journal of Animal Ecology*, **46**, 21-35.
- Hall, S.J. & Harding, M.J.C., 1997. Physical disturbance and marine benthic communities: the effects of mechanical harvesting of cockles on non-target benthic infauna. *Journal of Applied Ecology*, **34**, 497-517.
- Hancock, D.A. & Franklin, A., 1972. Seasonal changes in the condition of the edible cockle *Cardium edule* (L.). *Journal of Applied Ecology*, **9**, 567-579.
- Hancock, D.A., 1967. Growth and mesh selection in the edible cockle (*Cardium edule* L.). *Journal of Applied Ecology*, **4**, 137-157.
- Hayward, P.J. 1994. *Animals of sandy shores*. Slough, England: The Richmond Publishing Co. Ltd. [Naturalists' Handbook 21.]
- 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.
- Hummel, H. & Bogaards, R.H., 1989. Changes in the reproductive cycle of the cockle *Cerastoderma edule* after disturbance by means of tidal manipulation. In *Proceedings of the 23rd European Marine Biology Symposium, School of Biological Sciences, University of Wales Swansea, 5-9 September 1988. Reproduction, Genetics and Distribution of Marine Organisms*, (ed. J.S. Ryland & P.A. Tyler), p.133-136. Denmark: Olsen & Olsen.
- Jackson, M.J. & James, R., 1979. The influence of bait digging on cockle *Cerastoderma edule*, populations in north Norfolk. *Journal of Applied Ecology*, **16**, 671-679.
- Jensen, J.N., 1988. Recruitment, growth and mortality of juvenile *Corbula gibba* and *Abra alba* in the Limfjord, Denmark. The Baltic Sea environment: history, eutrophication, recruitment and toxicology. *Kieler Meeresforschungen (Sonderheft)*, **6**, 357-365.
- JNCC, 2015. The Marine Habitat Classification for Britain and Ireland Version 15.03. (20/05/2015). Available from <https://mhc.jncc.gov.uk/>
- Kristensen, I., 1958. Differences in density and growth in a cockle population in the Dutch Wadden Sea. *Archives Néerlandaises de Zoologie*, **12**, 351-453.
- Kukert, H. & Smith, C.R., 1992. Disturbance, colonization and succession in a deep-sea sediment community: artificial-mound experiments. *Deep-Sea Research*, **39**, 1349-1371.
- Maurer, D., Keck, R.T., Tinsman, J.C., Leatham, W.A., Wethe, C., Lord, C. & Church, T.M., 1986. Vertical migration and mortality of marine benthos in dredged material: a synthesis. *Internationale Revue der Gesamten Hydrobiologie*, **71**, 49-63.
- McLusky, D.S., 1967. Some effects of salinity on the survival, moulting, and growth of *Corophium volutator* (Amphipoda). *Journal of the Marine Biological Association of the United Kingdom*, **47**, 607-617.
- McLusky, D.S., 1968. Some effects of salinity on the distribution and abundance of *Corophium volutator* in the Ythan estuary. *Journal of the Marine Biological Association of the United Kingdom*, **48**, 443-454.
- Moore, J., 1991. Studies on the Impact of Hydraulic Cockle Dredging on Intertidal Sediment Flat Communities. A report to the Nature Conservancy Council from the Field Studies Council Research Centre, Pembroke, Wales, FSC/RC/4/91.
- Navarro, E., Iglesias, J.I.P. & Ortega, M.M., 1992. Natural sediment as a food source for the cockle *Cerastoderma edule* (L.), effects of variable particle concentrations on feeding, digestion and scope for growth. *Journal of Experimental Marine Biology and Ecology*, **156**, 69-87.
- Navarro, J.M. & Widdows, J., 1997. Feeding physiology of *Cerastoderma edule* in response to a wide range of seston concentrations. *Marine Ecology Progress Series*, **152**, 175-186.
- Newell, R.I.E. & Bayne, B.L. 1980. Seasonal changes in the physiology, reproductive condition and carbohydrate content of the cockle *Cardium* (= *Cerastoderma*) *edule* (Bivalvia: Cardidae). *Marine Biology*, **56**, 11-19.

- Nubilier, N., Windoffer, R., Grieshaber, M.K. & Giere, O., 1997. Ultrastructure and anaerobic metabolism of mitochondria in the marine oligochaete *Tubificoides benedii*: effects of hypoxia and sulfide. *Marine Biology*, **127**, 637-645.
- Olive, P.J.W. & Morgan, P.J., 1991. The reproductive cycles of four British intertidal *Nephtys* species in relation to their geographical distribution (Polychaeta: Nephtyidae). *Ophelia*, Supplement 5, 351-361.
- Orton, J.H., 1926. On the growth rate of *Cardium edule*, part 1. Experimental observations. *Journal of the Marine Biological Association of the United Kingdom*, **14**, 239-280.
- Petersen, M.E., 1999. Reproduction and development in Cirratulidae (Annelida: Polychaeta). *Marine Biology*, **8**, 243-259.
- Pickett, G.D., 1973. The impact of mechanised harvesting on the Thames estuary cockle fishery. *MAFF Laboratory Leaflet*, no. 29, Fisheries Laboratory, Lowestoft, pp. 9.
- Raffaelli, D.G., Raven, J.A. & Poole, L.J., 1998. Ecological impact of green macroalgal blooms. *Oceanography and Marine Biology: an Annual Review*, **36**, 97-125.
- Raman, A.V. & Ganapati, P.N., 1983. Pollution effects on ecobiology of benthic polychaetes in Visakhapatnam Harbour (Bay of Bengal). *Marine Pollution Bulletin*, **14**, 46-52.
- Rosenberg, R. & Loo, L., 1988. Marine eutrophication induced oxygen deficiency: effects on soft bottom fauna, western Sweden. *Ophelia*, **29**, 213-225.
- Rosenberg, R., Hellman, B. & Johansson, B., 1991. Hypoxic tolerance of marine benthic fauna. *Marine Ecology Progress Series*, **79**, 127-131.
- Rostron, D.M., 1998. *Sea Empress* oil spill: sediment shore impact assessment. Infauna of heavily oiled shores at Milford Haven and Carmarthen Bay. *CCW Sea Empress Contract Report*, no. 144, 49 pp.
- Seed, R. & Brown, R.A., 1977. A comparison of the reproductive cycles of *Modiolus modiolus* (L.), *Cerastoderma* (= *Cardium*) *edule* (L.), and *Mytilus edulis* L. in Strangford Lough, Northern Ireland. *Oecologia*, **30**, 173-188.
- SEEEC (Sea Empress Environmental Evaluation Committee), 1998. The environmental impact of the *Sea Empress* oil spill. *Final Report of the Sea Empress Environmental Evaluation Committee*, 135 pp., London: HMSO.
- Smaal, A.C., Vonck, A.P.M.A. & Bakker, M., 1997. Seasonal variation in physiological energetics of *Mytilus edulis* and *Cerastoderma edule* of different size classes. *Journal of the Marine Biological Association of the United Kingdom*, **77**, 817-838.
- Suchanek, T.H., 1993. Oil impacts on marine invertebrate populations and communities. *American Zoologist*, **33**, 510-523.
- Theede, H., Ponat, A., Hiroki, K. & Schlieper, C., 1969. Studies on the resistance of marine bottom invertebrates to oxygen-deficiency and hydrogen sulphide. *Marine Biology*, **2**, 325-337.
- Thiermann, F., Niemeyer, A-S. & Giere, O., 1996. Variations in the sulfide regime and the distribution of macrofauna in an intertidal flat in the North Sea. *Helgolander Meeresuntersuchungen*, **50**, 87-104.
- Thompson, C.E.L. & Amos, C.L., 2002. The impact of mobile disarticulated shells of *Cerastoderma edulis* on the abrasion of a cohesive substrate. *Estuaries*, **25**, 204-214.
- Trueman, E.R. & Ansell, A.D., 1969. The mechanisms of burrowing into soft substrata by marine animals. *Oceanography and Marine Biology: an Annual Review*, **7**, 315-366.
- Wilson, J.G., 1981. Temperature tolerance of circatidal bivalves in relation to their distribution. *Journal of Thermal Biology*, **6**, 279-286.
- Wilson, J.G., 1983. The uptake and accumulation of Ni by *Cerastoderma edule* and its effect on mortality, body condition and respiration rate. *Marine Environmental Research*, **8**, 129-148.
- Ysebaert, T. & Herman, P.M.J., 2002. Spatial and temporal variation in benthic macrofauna and relationships with environmental variables in an estuarine, intertidal soft-sediment environment. *Marine Ecology Progress Series*, **244**, 105-124.