



# MarLIN

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# *Cerastoderma edule* with *Abra nitida* in infralittoral mud

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

Dr Heidi Tillin & Dr Harvey Tyler-Walters

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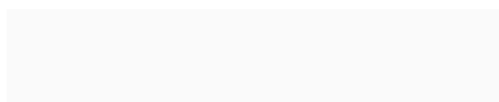
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Researched by Dr Heidi Tillin & Dr Harvey Tyler-Walters

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## Summary

### ☰ UK and Ireland classification

EUNIS 2008 A5.341 *Cerastoderma edule* with *Abra nitida* in infralittoral mud

JNCC 2015 SS.SMu.IFiMu.CerAnit *Cerastoderma edule* with *Abra nitida* in infralittoral mud

JNCC 2004 SS.SMu.IFiMu.CerAnit *Cerastoderma edule* with *Abra nitida* in infralittoral mud

1997 Biotope

### 🔍 Description

Sheltered shallow sublittoral muds and gravelly muds in marine embayments, inlets or harbours may contain populations of the edible cockle *Cerastoderma edule* with *Abra nitida*. Other taxa may include the gastropod *Hydrobia ulvae*, cirraltulid polychaetes such as *Caulleriella* spp. and other polychaetes including *Hediste diversicolor* and *Aphelochaeta marioni*. Available data for this biotope are limited to parts of Southampton Water, Chichester Harbour and also in the Wash. The species list given here may therefore be far from complete. It is not known at this stage whether this

biotope is a sublittoral extension of intertidal cockle beds (e.g. LSA.CerPo) or whether it exists independently of intertidal populations of *Cerastoderma edule* (JNCC; 2015).

### ↓ Depth range

0-5 m, 5-10 m

### 🏛️ Additional information

-

### ✓ Listed By

- none -

### 🔗 Further information sources

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## Sensitivity review

### Sensitivity characteristics of the habitat and relevant characteristic species

The biotope description and characterizing species is taken from JNCC (2015). The species described in the biotope title- *Cerastoderma edule* and *Abra nitida*- are considered to be key species defining the biotope and are considered specifically in the assessments. Other taxa that are frequently found in high abundance are the mud snail *Hydrobia ulvae* and cirratulid polychaetes such as *Caulleriella* spp. and *Aphelochaeta marioni*, and these species are also generally considered within assessments.

The sedimentary habitat (muds and gravelly muds) is a key element of the biotope, therefore, the sensitivity of this component is discussed where it is likely to be altered by the assessed pressure.

### 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 other soft-sediment species. In general, 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* and *Limecola balthica* can disperse again through 'byssal-pelagic' dispersal (drifting on byssal threads), (de Montaudouin, 1997; Bouma *et al.* 2001; Huxham & Richards, 2003; Hiddink & Wolff, 2002; 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 m<sup>2</sup>) at a mean rate of 2.2 individuals/m<sup>2</sup>/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; Schitema, 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 dense beds

could rapidly recover through adult migration. Other species associated with this biotope such as the small snail *Hydrobia ulvae*, the shrimp and amphipods and active polychaetes (including *Eteone longa* and *Scoloplos armiger*) may actively migrate into disturbed patches although more sedentary species such as the tube-dwelling *Pygospio elegans* may depend on larval recolonization rather than active migration.

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, *Hydrobia ulvae* have high powers of regeneration to the extent that head structures can be re-grown suggesting that individuals can recover from damage (Gorbushin *et al.*, 2001). Recovery from superficial damage may be rapid. 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).

Recruitment to suitable habitats and 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 spat fall of cockle is adequate or good in half of the years studied ; 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/m<sup>2</sup>, and that the larvae 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 (Ducrottoy *et al.*, 1991). The influence of the density of adult *Limecola balthica* on the growth and density of juveniles (1 to 5 weeks) was investigated in the field in southern Sweden (Olafsson, 1989). The results indicated that the growth of juveniles was reduced in the presence of adults at normal field density in a sublittoral, sheltered, muddy-sand sediment but was not reduced under similar conditions in a sublittoral, wave-exposed, sand sediment. The density of juveniles was not affected by adults in either habitat or in the laboratory. The growth reduction observed in juveniles at normal adult clam densities in the muddy sand habitat (where adults and juveniles are deposit feeders) but not in the sand habitat (where adults are suspension feeders and juveniles deposit feeders) indicated that intraspecific competition between adults and juveniles increases with increasing levels of dietary resource overlap between them. 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* and *Limecola balthica* 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*.

*Abra nitida* is considered to be an opportunistic species (Josefson, 1982) capable of exploiting

newly disturbed substratum through larval recruitment, secondary settlement of post-metamorphosis juveniles, or re-distribution of adults (Rees & Dare 1993). *Abra nitida* recruitment tends to be episodic and may be negatively affected by the presence of predators and inhibited by high densities of adults (Josefson, 1982). *Abra nitida* has a larval planktonic phase indicating a high dispersal potential. In addition to dispersal via the plankton, dispersal of post-settlement juveniles in *Abra* spp. may occur via byssus drifting (Sigurdsson *et al.*, 1976) and probably bed load transport (Emerson & Grant, 1991). Usually this species occurs in dense aggregations that undergo subsequent decline and then recover through dense settlement (Josefson, 1982).

Many cirratulids are thought to have direct development so that dispersal is likely to be low (see section on recruitment processes). George (1968) discussed possible recolonization in the two cirratulids *Cirratulus cirratus* and *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.

**Resilience assessment.** The evidence to support the assessment of *Cerastoderma edule* is based on intertidal populations, the applicability to subtidal populations is not clear but it is likely that

similar life-history and dispersal characteristics determine recovery both intertidally and subtidally. Unlike beds of other reef-forming bivalves such as the blue mussel, *Mytilus edulis* and the horse mussel *Modiolus modiolus*, which are more stable and long-lived, patches of intertidal cockles are naturally more variable over space and time (Smaal *et al.*, 2005) and beds are subject to either gradual declines as the population aged but inhibits recruitment or occasional mass mortalities that have been attributed to a number of causes (Burdon *et al.*, 2014). Small disturbed patches may be rapidly infilled by movement of adult cockles by tidal currents and wave action or active migration of adults. The characterizing species *Abra nitida* is likely to recover rapidly although recruitment may be episodic. Active burrowing polychaetes and mud snails, *Hydrobia ulvae* may move in and out of areas of habitat. Recovery of cirratulids may require longer due to low dispersal and mobility but as these are not key characteristic species, the biotope can be considered to have recovered without the recovery of populations of these species.

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 (where the habitat remains suitable). As recruitment in *Cerastoderma edule* and *Abra nitida* is episodic, 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). It should be noted that small patches of disturbance within dense beds of cockles may recover rapidly through migration and displacement of cockles.

**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: Medium C: Medium	High Q: High A: High C: High	Not sensitive Q: High A: Medium 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). 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 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).

Other species associated with the biotope may be more tolerant of increased temperatures than *Cerastoderma edule*. 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 *Cirriiformia 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 *Cirriiformia tentaculata* from the Hamble were reported to be of 32 °C and 29 °C for 5-6 day old and adult *Cirriiformia tentaculata* respectively (George, 1964b). *Cirriiformia 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 *Cirriiformia tentaculata* was found to be twice as fast at 20 °C than at 8 °C.

**Sensitivity assessment.** Typical surface water temperatures around the UK coast vary, seasonally from 4-19°C (Huthnance, 2010). The 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: Low C: Medium

**Medium**

Q: High A: Low C: High

**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  $-2^{\circ}\text{C}$  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 *Cerastoderma edule* and other bivalves 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).

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). In fact, *Aphelochaeta marioni* displays a remarkable tolerance for salinity 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.** Typical surface water temperatures around the UK coast vary, seasonally from  $4-19^{\circ}\text{C}$  (Huthnance, 2010). The biotope is considered to tolerate a chronic change at the pressure benchmark ( $2^{\circ}\text{C}$  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*) 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.

<b>Salinity increase (local)</b>	<b>Low</b>	<b>Medium</b>	<b>Medium</b>
	Q: High A: Medium C: Medium	Q: High A: Low C: Medium	Q: High A: Medium C: Medium

This biotope is reported to occur in full (30-35 ppt) salinity (JNCC, 2015). A change at the pressure benchmark is considered to represent an increase to  $>40$  ppt. Little evidence was found for tolerances of elevated salinity although populations are likely to be acclimated to short-term increased salinities in surface sediment layers as evaporation on hot days, or wind driven desiccation leads to increased salinities.

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 dependent (after 3 days, 100% survival at 33 psu and  $35-38^{\circ}\text{C}$ , but 50% mortality occurred at 20 psu and  $37^{\circ}\text{C}$  and 100% mortality at 13 psu and  $37^{\circ}\text{C}$ ). 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 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)

**Medium**

Q: High A: Medium C: High

**High**

Q: High A: Low C: Medium

**Low**

Q: High A: Low C: Medium

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). In fact, *Aphelochaeta marioni* displays a remarkable tolerance for salinity 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 suggests that adult *Cerastoderma edule* may survive a reduction in salinity to reduced or variable and populations may become locally acclimated to reduced salinities. As a reduction may lead to some mortalities and a reduction in growth and reproductive success of the key characterizing *Cerastoderma edule*, biotope resistance is assessed as 'Medium', recovery (following a return to usual habitat conditions) is assessed as 'High' and sensitivity is therefore assessed as 'Low'.

#### Water flow (tidal current) changes (local)

**Medium**

Q: High A: Low C: Low

**High**

Q: High A: Low C: Medium

**Low**

Q: High A: Low C: Low

Cockles are dependent on water flow to deliver suspended food particles. The hydrodynamic regime strongly influences the sediment structure and removal of biodeposits and faeces, oxygenation, food supply and recruitment. *Cerastoderma edule* prefers muddy-sand to sandy-mud or fine sand substrates. Increases in water flow above the critical erosion rate would re-suspend fine sediments and would alter the habitat. Increased sediment coarseness would reduce habitat suitability (as assessed below). 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.

Newly settled spat and juveniles (<4.8 mm) are capable of bysso-pelagic dispersal. Water flow rates probably affect the distribution and dispersal of juveniles. Increasing water flow may remove adult cockles from the sediment surface and carry them to unfavourable substratum or deep water, where they may be lost from the population. Coffen-Smout and Rees (1999) reported that exposed cockles on the sediment surface could be distributed up to 0.45 m on neap tides or between 94 m and 164 m on spring tides. Theoretical estimates suggest that the critical force for displacing exposed cockles is 0.3 m/s (Coffen-Smout & Rees, 1999).

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). At 0.45 m/s, sand grains (1-3 mm) began to roll along the bed and this may have reduced clearance rate. At 0.7 m/s, feeding appeared to cease due to the movement

of sediment as well as cockles (Widdows & Navarro, 2007).

**Sensitivity assessment.** The characterizing *Cerastoderma edule* and *Abra nitida* were considered to have some resistance to this pressure as they are found in habitats experiencing a range of flow speeds. However decreased flow rates (at the pressure benchmark) in sheltered habitats may reduce food supply and enhance sediment deposition favouring deposit feeders. The associated cirratulids and *Abra nitida* are therefore considered to be 'Not Sensitive' to this pressure, as burrowing life habits coupled with deposit feeding types were considered to be protective. At the pressure benchmark *Cerastoderma edule* may be affected by a decrease in water flow at the pressure benchmark through reduced suspended food, biotope resistance is, therefore, assessed as 'Medium' and resilience as 'High' so that sensitivity is assessed as 'Low'.

### Emergence regime changes

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not sensitive

Q: NR A: NR C: NR

Not relevant to subtidal biotopes.

### Wave exposure changes (local)

High

Q: High A: Low C: NR

High

Q: High A: High C: High

Not sensitive

Q: High A: Low C: Low

This biotope is recorded from locations that are very sheltered (JNCC, 2015). Changes in wave exposure greater than the pressure benchmark are likely to have marked effects on the sediment dynamics of the shore. Increased exposure could 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 exceed 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 Restronguet Creek area of the Fal (Bryan & Gibbs, 1983). Adult *Cerastoderma edule* were found to be more tolerant to metal toxicity than the juvenile or larval stages which appear unable to withstand the high concentrations of copper and zinc. However, transplantation of *Cerastoderma edule* into Restronguet Creek (highly polluted by heavy metals) resulted in 10-15% mortality within 63 days but 100% within about four months. The toxic body-burden of copper to *Cerastoderma edule* was found to be ca. 250 µg / g with zinc being less toxic. Bryan & Gibbs (1983) stated that *Cerastoderma edule* takes up heavy metals mainly from solution rather than from sediment and that it was excluded from Restronguet Creek by the high levels of Cu and Zn.

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<sup>-1</sup> 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<sup>-1</sup>. 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.

In a review of chemical use on salmon aquaculture, Burrige *et al.* (2008) described how despite the binding of copper in sediments, it can be toxic (copper is used as an antifoulant and may also be a constituent of the food fed to farmed salmon). Sediments under salmon cages in the Bay of Fundy and at various distances away from the cages were evaluated for toxicity and in addition to elevated levels of copper (above the threshold effects level), the sediments also had elevated zinc, other metals, ammonia nitrogen, sulphide, total organic carbon, and other organic compounds. Sediments enriched in copper, zinc and silver caused decreased reproduction in the clam *Limecola balthica*, due to failed gamete production. Reproductive recovery occurred when contamination decreased (Hornberger *et al.*, 2000). It was noted that studies from field sites have numerous metals rather than just copper alone, and it is difficult to attribute toxicity to any particular metal.

*Abra* spp. can live in polluted sediments (Dauvin, pers. comm.), for example, near Calais where high densities of *Abra alba* were found in sediment containing 8 mg/g iron and 4 mg/g titanium (Dewarumez *et al.* 1976). The capacity of bivalves to accumulate heavy metals in their tissues, far in excess of environmental levels, is well known. Reactions to sub-lethal levels of heavy metals include siphon retraction, valve closure, inhibition of byssal thread production, disruption of burrowing behaviour, inhibition of respiration, inhibition of filtration rate, inhibition of protein synthesis and suppressed growth (see review by Aberkali & Trueman, 1985). Bryan (1984) states that Hg is the most toxic metal to bivalve molluscs while Cu, Cd and Zn seem to be most problematic in the field. In bivalve molluscs, Hg was reported to have the highest toxicity, mortalities occurring above 0.1-1 g/l after 4-14 days exposure (Crompton, 1997), toxicity decreasing from Hg > Cu and Cd > Zn > Pb and As > Cr ( in bivalve larvae, Hg and Cu > Zn > Cd, Pb, As, and Ni > to Cr).

Rygg (1985) classified *Abra nitida* as non-tolerant of Cu (absent from stations in Norwegian fjords where sediment Cu concentrations were >200 ppm (mg kg<sup>-1</sup>)). However, this species dominated harbour sediments in Ceuta, North Africa where 'very high' levels of organic matter (5-13% of

sediment) and heavy metals were found (Guerra-García & García-Gómez, 2004). The high levels of organic matter may have reduced the bioavailability of Zn and Cu. However, Zn concentrations at stations where this species was found, ranged from 67- 207 ppm and Cu ranged from 40-209 ppm.

Bryan & Gibbs (1983) found that *Aphelochaeta marioni* (studied as *Tharyx marioni*) contained exceptionally high concentrations of arsenic (> 2000 µg / gram dry body weight) without obvious adverse effects and therefore appear to have adapted to the very high concentrations in Restronguet Creek in the highly contaminated Fal estuary.

#### 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. Laboratory studies have demonstrated that *Cerastoderma edule* is sensitive to oil and polycyclic aromatic hydrocarbons (Wootton *et al.*, 2003).

Following the Sea Empress oil spill in Milford Haven, Wales, high mortalities of the cockles *Cerastoderma edule* were reported and large numbers of moribund and dead marine animals, including *Cerastoderma edule*, were washed ashore after the Sea Empress oil spill, however, no commercial stocks were affected (Rostron, 1998; SEEC 1998). 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.

Cirratulids appeared to Suchanek (1993) to be mostly immune to oil spills because their feeding tentacles are protected by a heavy secretion of mucus. This immunity is supported by observations of *Aphelochaeta marioni* following the Amoco Cadiz oil spill in March, 1978 (Dauvin, 1982, 2000). Prior to the spill, *Aphelochaeta marioni* (studied as *Tharyx marioni*) was present in very low numbers in the Bay of Morlaix, western English Channel. Following the spill, the level of hydrocarbons in the sediment increased from 10 mg/kg dry sediment to 1443 mg/kg dry sediment 6 months afterwards. In the same period, *Aphelochaeta marioni* increased in abundance to a mean of 76 individuals per m<sup>2</sup>, which placed it among the top five dominant species in the faunal assemblage. It was suggested that the population explosion occurred due to the increased food availability because of accumulation of organic matter resulting from high mortality of browsers. Six years later, abundance of *Aphelochaeta marioni* began to fall away again, accompanied by gradual decontamination of the sediments.

#### 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.

The effects of medetomidine, a novel antifouling candidate, on *Abra nitida* were studied by Bellas *et al.*, (2006). Medetomidine caused a significant decrease in the burrowing response and in the sediment reworking activity. The median effective concentrations (EC50) were 430 nM (86 µg/l) and 4.4 nM (0.9 µg/l), respectively. No effects on the faeces production were detected. Although significant effects of medetomidine on *Abra nitida* were registered, a reversibility of the effects was observed when 24 h exposed animals were incubated in clean seawater and sediment for 24 h.

#### Radionuclide contamination

No evidence (NEv)

Q: NR A: NR C: NR

Not relevant (NR)

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: Medium

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 cm<sup>3</sup>/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 edule* 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 significantly 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).

**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 immersion 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: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

This pressure relates to increased levels of nitrogen, phosphorus and silicon in the marine environment compared to background concentrations. The benchmark is set at compliance with WFD criteria for good status, based on nitrogen concentration (UKTAG, 2014).

Changes in the nutrient concentrations (e.g. nitrogen and phosphates) are likely to have indirect

rather than direct effects on *Cerastoderma edule*. Increased levels of nutrients at low level may increase phytoplankton productivity and increase food availability for *Cerastoderma edule*. However, higher nutrient inputs are associated with eutrophication, resulting in increased oxygen consumption and decreased oxygen concentration. Rosenberg and Loo (1988) suggested that the mass mortalities of *Cerastoderma edule* observed in Laholm Bay, western Sweden during the 1980s was correlated with increased nutrient levels, and associated decrease in oxygen levels during this period (see oxygenation below). However, no direct causal link was established.

Desprez *et al.* (1992) implicated a eutrophication-induced plankton bloom as the cause of the decline of *Cerastoderma edule* populations in the Bay of Somme, France. Prior to the event in 1982, densities were several 1000 / m<sup>2</sup> but by 1982, this had fallen to just a few hundred individuals / m<sup>2</sup>. By 1987, the cockle population had returned.

**Sensitivity assessment.** As *Cerastoderma edule* and other characterizing species in the biotope are not primary producers and are therefore 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 but supply is not considered to be affected at the pressure benchmark levels. This species 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

Q: High A: Medium C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: Medium 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. In the sheltered areas where this biotope occurs, organic matter is less likely to be removed by currents and is likely to be deposited on and incorporated into sediments.

*Cerastoderma edule* and *Abra nitida* have 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). *Abra nitida* occurs in organically enriched areas such as sediments beneath fish farms (Bannister *et al.*, 2014, Kutti *et al.*, 2008).

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 (Pearson & Rosenberg 1978, Samuelson 2001, Bouchet & Saurier 2008). The associated cirratulids within the biotope are therefore likely to benefit from organic enrichment.

**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 *Abra alba* and other associated species are not considered sensitive to organic enrichment. The deposit feeding *Abra nitida* and 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
<b>Physical loss (to land or freshwater habitat)</b>	<b>None</b> Q: High A: High C: High	<b>Very Low</b> Q: High A: High C: High	<b>High</b> 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.

<b>Physical change (to another seabed type)</b>	<b>None</b> Q: High A: High C: High	<b>Very Low</b> Q: High A: High C: High	<b>High</b> Q: High A: High C: High
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This biotope is characterized by mud and gravelly mud (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'.

<b>Physical change (to another sediment type)</b>	<b>None</b> Q: High A: High C: High	<b>Very Low</b> Q: High A: High C: High	<b>High</b> Q: High A: High C: High
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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 occurs within muds and gravelly muds (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 *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. Presumably these observed effects would also be likely to occur in subtidal sediments.

**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 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 *Abra alba*. 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: High

**Medium**

Q: High A: Low C: Medium

**Medium**

Q: High A: Low C: Medium

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: Medium

**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 populations of shallow buried *Cerastoderma edule* and soft-bodied species that live on or very close to the surface. 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

In contrast to rocky shores, few soft sediment fauna are found on the sediment surface at low tide. As a consequence, harvesting of soft sediment fauna requires the physical disturbance of the substratum. Moreover, these habitats tend to extend over large areas which, coupled with their low topography and the structure of the substratum, makes them amenable to extensive mechanical harvesting (Kaiser *et al.*, 2001). Towed demersal gears, such as beam trawls, otter trawls, scallop dredges, could be deployed in intertidal sandy and muddy habitats depending on the tidal regime and the morphology of the coastline (Hall *et al.*, 2008). Due to commercial interest and the accessibility of intertidal areas, a number of academic studies have assessed the effects of these fisheries, including the impact of sediment disturbance on the species found within this biotope. This assessment is divided into three sections; considering impacts on the key characterizing *Cerastoderma edule*; associated species and the sedimentary habitat. Changes to sediment are also relevant to the physical change assessments and the evidence for impacts of substratum changes and the impact on the biotope is considered more fully in that section.

*Impacts on Cerastoderma edule.*

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.

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).

### *Impacts on associated species*

Experiments found that suction dredging to remove cockles led to a decline in associated species richness and species abundance (Hall & Harding, 1998). In contrast, tractor dredging did not lead to significant, observable effects on non-target species. Recovery was tracked following the disturbance, after 56 days there was little difference between dredge and control sites. This rapid recovery coincided with annual recruitment supporting recovery (Hall & Harding, 1998). Several studies have assessed the impact of cockle dredging on non-target species including *Limecola balthica*. Piersma *et al.* (2001) showed that after suction dredging for cockles (*Cerastoderma edule*) in the Dutch Wadden Sea, the abundance of *Limecola balthica* declined for 8 years. Declines of bivalve stocks were caused by low rates of settlement in the fished areas. Hiddink (2003) also reported a significant negative effect of cockle dredging on the density of 0-group *Limecola balthica*, which persisted for one year after dredging, likely due to the habitat being less suitable following dredging. Kraan *et al.* (2007) also showed that the deep disturbance from cockle dredging led to decreased densities of *Limecola balthica* on intertidal mudflats flats (sand and muddy sand sediment) in the Dutch Wadden Sea.

Bergman and Hup (1992) found that worm species (including *Scoloplos armiger*) showed no change in total density after trawling a subtidal habitat. Conversely, a later study by Bergman and Santbrink (2000) found that the direct mortality of *Scoloplos armiger* from a single passage of a beam trawl in silty grounds was 18% of the population. Rostron (1995) undertook experimental dredging of sandflats with a mechanical cockle dredger, including a site comprised of stable, poorly

sorted fine sands with small pools and *Arenicola marina* casts with some algal growths. At this site, post-dredging *Scoloplos armiger* had disappeared from some dredged plots. Ferns *et al.* (2000) used a tractor-towed cockle harvester, to extract cockles from intertidal plots of muddy sand and clean sand, to investigate the effects on non-target organisms; 31% of the population of *Scoloplos armiger* (initial density of 120 per m<sup>2</sup>) were removed. Populations of *Scoloplos armiger* remained significantly depleted in the area of muddy sand for more than 50 days after harvesting. Ball *et al.* (2000) found that species including *Scoloplos armiger* showed a significant decrease in abundance of between 56-27% after 16 months of otter trawling at a previously unfished Scottish sea loch. Chandrasekara and Frid (1996, cited in Tyler-Walters & Arnold, 2008) found that along a pathway heavily used for five summer months (ca. 50 individuals day<sup>-1</sup>), *Scoloplos armiger* reduced in abundance. Recovery took place within 5-6 months. These studies suggest that *Scoloplos armiger* is likely to be impacted by sediment disturbance and that recovery to previous densities may require more than two years.

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/ m<sup>2</sup>). 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.

Rees, 1978, (cited in Hiscock *et al.*, 2002), assessed pipe-laying activities. The pipe was laid in a trench dug by excavators and the spoil from the trenching was then used to bury the pipe. The trenching severely disturbed a narrow zone, but a zone some 50 m wide on each side of the pipeline was also disturbed by the passage of vehicles. The tracked vehicles damaged and exposed shallow-burrowing species such as *Cerastoderma edule* and *Limecola balthica*, which were then preyed upon by birds. During the construction period, the disturbed zone was continually re-populated by mobile organisms, such as the mud snail *Hydrobia ulvae*. Post-disturbance recolonisation was rapid. Several species, including the polychaetes, *Eteone longa*, and *Scoloplos armiger* were recruited preferentially to the disturbed area.

### *Impacts on sediment*

Tractor dredging leaves visible tracks in the sediment, which can act as lines for erosion and accelerate erosion of the sediment (Moore, 1991; Gubbay & Knapman, 1999). In most cases, the subsequent settlement was good especially in areas of previously high population density; however, Franklin and Pickett (1978) noted that subsequent spat survival was markedly reduced. Hall & Harding, (1998), assessed the effects of tractor towed cockle dredgers on sediment erodibility. Effects were short-term, with dredged sediments having greater erodibility (lower shear stress) following dredging which increased over 48 hours back to the levels observed in the undredged plots. Cotter *et al.*, (1997) also noted that dredge tracks not clearly visible after 1 day, demonstrating rapid infilling.

**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

Increasing total particulate concentrations have been shown to decrease clearance rates and increase pseudofaeces production (Navarro *et al.*, 1992; Navarro & Widdows, 1997). Filtration rates increased with particulate concentration until 300 mg/l at which concentration filtration rates abruptly declined. Pseudofaeces production was triggered by concentrations of total particulate matter of 1.5 mg/l (Navarro *et al.*, 1992) or 4.8 mg/l (Navarro & Widdows, 1997). However, the absorption efficiency remained independent of particulate concentration over a large range but reduced at concentrations above 250 mg/l (Navarro & Widdows, 1997). Navarro and Widdows (1997) concluded that *Cerastoderma edule* was well adapted to living in turbid environments such as intertidal mudflats. Increased siltation and suspended sediment concentration result in increased pseudofaeces production and concomitant loss of energy and carbon as mucus. Increasing turbidity may reduce phytoplankton productivity and hence decrease food availability, however, *Cerastoderma edule* is capable of ingesting organic seston and is adapted to life in sedimentary and estuarine conditions where turbidity is high (Navarro & Widdows, 1997). *Abra nitida* is likely to switch between suspension and deposit feeding depending on the conditions.

**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 cirratulids and other deposit feeders. 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: Low C: Medium

**Low**

Q: High A: Low C: Medium

*Cerastoderma edule* has short siphons and needs to keep in contact with the surface of the sediment. Richardson *et al.* (1993) reported that they burrow quickly to the surface if covered by 2 cm of sediment (under laboratory or field conditions) when emerged (45% of cockles emerged onto the surface in light and 60% in darkness). In light the cockles quickly re-burrow, however, in darkness they move across the substratum, partly to increase the distance between neighbours.

Richardson et al. (1993) suggested that surface movement in darkness might be a response to coverage from siltation.

Bait digging (for large polychaete worms) disturbs the sediment down to a depth of 30cm (Jackson & James, 1979) and results in repositioning of species when the extracted sediment is placed back in holes or smothering where sediment is piled on the surface. 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.

Gam et al. (2010) compared population dynamics and secondary production of *Cerastoderma edule* between Merja Zerga on the Moroccan Atlantic coast (close to the species southerly limit) and Arcachon Bay on the French Atlantic coast. During their study of recruitment in January 2007, mass mortalities were observed in both adult and juvenile cockles and this was attributed to high sand bank displacements in the previous year, which partly covered and smothered the cockle population.

*Limecola balthica* is able to burrow both vertically and horizontally through the substratum. It is likely that *Limecola balthica* is not sensitive to smothering by a layer of sediment 5 cm thick as it is a mobile species able to burrow upwards and surface from a depth of 5 - 6 cm (Brafield & Newell, 1961; Brafield, 1963; Stekoll et al., 1980). Turk & Risk (1981) investigated the effect of experimentally induced sedimentation (through fences and boxes that induced sediment deposition on intertidal mudflats in the Bay of Fundy), of 1-3.5cm at a rate of 1.9-10.2 cm/month. The results showed that *Limecola balthica* was generally unaffected.

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 and 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. The breeding season is often quite protracted. The dispersive ability of the abundant pelagic larval form is considerable. Adults can also immigrate into the area by floating on a mucous raft (Jackson, 2000).

**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: Medium

**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.

Maurer *et al.* (1986) studied the effects of dredged material on the vertical migration and mortality of four species of benthic invertebrates (including two polychaetes) and reported that the intolerance of species to smothering was influenced by the nature of the sediment. They predicted that some individuals of both the polychaete species studied (*Nereis succinea* and *Scoloplos fragilis*) would be capable of vertical migration through 0.9 m of sediment if that sediment was indigenous to their usual habitat (Marshall, 2008).

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 one 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 30 cm of sediment would prevent *Cerastoderma edule* and *Limecola balthica* 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 indicates 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 unplasticised 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

Not relevant.

## Introduction of light or shading

High

Q: High A: Medium C: Medium

High

Q: High A: High C: High

Not sensitive

Q: High A: Low C: Medium

The key characterizing and associated species do not photosynthesize and are unlikely to be directly affected by shading or increased light levels. The abundance and production of microphytobenthos in sediments may be impacted by shading and this may have indirect effects on secondary production by animals that feed on these. The key characterizing species *Cerastoderma edule* feeds on suspended seston and is unlikely to be directly affected by localised changes in

microphytobenthos production.

*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* and *Abra nitida* 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. As both these key characterizing species are widely distributed and have larvae capable of long distance transport, 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' to seabed habitats. NB. Collision by grounding vessels is addressed under surface abrasion.

#### 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

No evidence found. As the species characterizing this biotope are not primary producers, have limited visual acuity and inhabit turbid, coastal waters and estuaries where light penetration may be limited the pressure is assessed as 'Not relevant' to this biotope.

## Biological Pressures

	Resistance	Resilience	Sensitivity
<b>Genetic modification &amp; translocation of indigenous species</b>	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).

	Low	Very Low	High
<b>Introduction or spread of invasive non-indigenous species</b>	Q: High A: High C: Low	Q: Low A: NR C: NR	Q: Low A: Low C: Low

Subtidal sheltered muddy sediments may be colonized by the invasive non-indigenous species *Crepidula fornicata*. This species has not only attained considerable biomasses from Scandinavian to Mediterranean countries but has also generated ecological consequences such as alterations of benthic habitats and communities, or food chain changes (OSPAR, 2009).

**Sensitivity assessment.** Subtidal muddy gravels may be exposed to invasive species which can alter the character of the habitat (primarily *Crepidula fornicata*) 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'.

	Low	Medium	Medium
<b>Introduction of microbial pathogens</b>	Q: High A: High C: High	Q: High A: Low C: High	Q: High A: Low C: Medium

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).

An unidentified amoeba, measuring 18–20 mm 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 north west 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).

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 *Cerastoderma edule* and other associated species are susceptible to a range of pathogens and parasites. The effects of these may be exacerbated by stressors such as short immersion times and thermal stress (amongst others). As evidence exists for mass mortalities, biotope resistance is assessed as 'Low' (based on *Cerastoderma edule*) and resilience is assessed as 'Medium'. Sensitivity is therefore categorised as 'Medium'.

#### Removal of target species

**Low**

Q: High A: High C: High

**Medium**

Q: High A: High C: Medium

**Medium**

Q: High A: High C: Medium

The sensitivity assessment for this pressure considers any biological/ecological effects resulting from the removal of target species on this biotope. 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 biotope.

Suction dredgers and hydraulic lift dredgers can be deployed in the shallow subtidal, although most studies on impacts have focussed on intertidal populations. Fisheries are managed through local bylaws and local target size classes are set (usually cockles below 20 mm are not collected).

Coffen-Smout (1998) studied simulated fisheries impacts on *Cerastoderma edule* and reported that

the cockle shell withstood between 12.9 and 171.4 newtons (N) of force depending on shell size and position of load (a 1 kg weight exerts about 10 N). Cockles are often damaged during mechanical harvesting, e.g. 5-15% were damaged by tractor dredging (Cotter *et al.*, 1997) and ca 20% were too damaged to be processed after hydraulic dredging (Pickett, 1973). 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).

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. 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). In this subtidal biotope, reburial rates should be high. 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).

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).

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.

**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 *Capitella capitata*) may increase in disturbed patches in the short-term as a result of the 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 the 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 intertidal 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: High A: High C: Medium

**Medium**

Q: High A: High C: Medium

**Medium**

Q: High A: High C: Medium

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 species and are therefore unlikely to be impacted by ecological/biological effects from the removal of others species. The removal of predators such as shrimp and crab may enhance recruitment of larvae (Beukema & Dekker, 2005). The physical effects of removal of other species may, however, impact *Cerastoderma edule* and other species associated with this biotope, through direct damage and removal and displacement. These direct effects of sediment disturbance are assessed in the physical damage sections.

The removal of *Cerastoderma edule* 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. As *Cerastoderma edule* and *Abra alba* and other species are shallowly buried and either sedentary or incapable of rapid evasive movements, resistance is assessed as 'Low'. Resilience is assessed as 'Medium' based on episodic recruitment of *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.

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