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

Sublittoral mixed sediment in low or reduced salinity (lagoons)

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

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Sublittoral mixed sediment in low or reduced salinity (lagoons)
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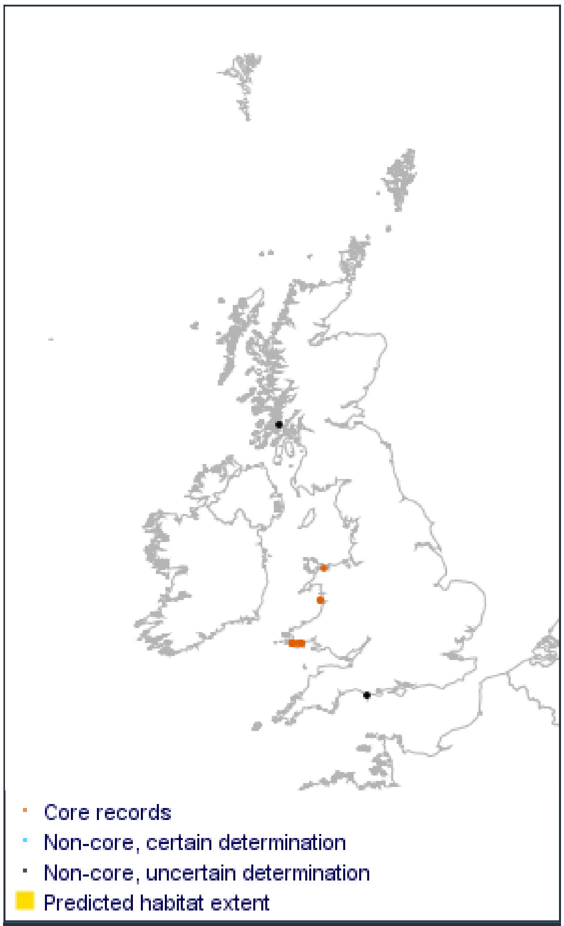

17-09-2018
Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

Researched by Dr Heidi Tillin & Dr Harvey Tyler-Walters **Refereed by** Admin

Summary

UK and Ireland classification

EUNIS 2008	A5.41	Sublittoral mixed sediment in low or reduced salinity
JNCC 2015	SS.SMx.SMxLS	Sublittoral mixed sediment in low or reduced salinity (lagoons)
JNCC 2004	SS.SMx.SMxLS	Sublittoral mixed sediment in low or reduced salinity (lagoons)
1997 Biotope		

Description

Shallow, muddy mixed sediments in areas of low or reduced, although stable, salinity (may vary annually) with largely ephemeral faunal communities. Characterized infaunally by oligochaetes, including *Heterochaeta costata* and members of the Enchytraeidae, polychaetes such as *Hediste diversicolor*, *Polydora ciliata* and *Pygospio elegans*,and bivalves such as *Mya arenaria* and the lagoon cockle *Cerastoderma glaucum*. These bivalve species may also form conspicuious members of the epifauna together with more ubiquitous species like the common goby *Pomatoschistus microps*

(JNCC, 2015).

Depth range

0-5 m

Additional information

-

Listed By

- none -

Further information sources

Search on:

G g G JNCC

Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

The biotope description and characterizing species is taken from (JNCC, 2015). This biotope is characterized infaunally by oligochaetes, including *Heterochaeta costata* and members of the Enchytraeidae, polychaetes including *Hediste diversicolor* and *Pygospio elegans* and bivalves including *Mya arenaria* and the lagoon cockle *Cerastoderma glaucum*. The sensitivity assessments are based on these species.

The lagoon habitat and salinity conditions are key factors structuring this habitat and these factors are considered in the sensitivity assessments where the pressure may alter these.

Resilience and recovery rates of habitat

Saline lagoons are defined as areas of typically (but not exclusively) shallow, coastal saline water, wholly or partially separated from the sea by sandbanks, shingle or, less frequently, rocks or other hard substrata. They retain a proportion of their water at low tide and may develop as brackish, fully saline or hyper-saline water bodies (Brown *et al*., 1997). There are a number of factors which are thought to contribute to the rarity of these habitats in the UK. Many sedimentary lagoons do not appear in many of the areas suitable for them because of the macro-tidal regimes found within the north east Atlantic (Barnes, 1991). The high energy coastlines common around the UK mean that shingle lagoons can be both created from off-shore glacial deposits and removed, therefore they are often short lived on geological time scales, and are now less common than they were at the end of the last ice age (Bamber *et al*., 2001).

Recovery of impacted lagoon assemblages may occur through repair of damaged individuals, active migration or passive water transport od adults and juveniles and recolonization by pelagic larvae. A number of characterizing species, including *Cerastoderma glaucum*, and *Hediste diversicolor* produce pelagic larvae. Dispersal in *Corophium volutator* and oligochates may be more limited as these species brood young and produce egg cocoons rather than releasing pelagic larvae. *Pygospio elegans* and *Hydrobia ulvae* may produce either benthic or planktonic larvae/juveniles. Restricted water movements within lagoon system may prevent loss of larvae but could also reduce water transport of larvae into the biotope to replenish lost populations. Local hydrodynamics will strongly influence larval transport. Key life history factors and examples of recovery are outlined below for the key species. *Mya arenaria*, *Cerastoderma glaucum* and *Hediste diversicolor* are larger, longer-lived species and may structure the biotope through sediment disturbance and predation. Their populations may take longer to recover to typical age and biomass structures than those of the short-lived, more opportunistic *Hydrobia ulvae*, *Corophium volutator* and *Pygospio elegans*. The oligochaetes are intermediate between the two groups as they are longer-lived but their populations may be abundant and they are likely to recover rapidly (see below).

The cockle, *Cerastoderma glaucum* is a filter feeding bivalve which burrows shallowly in soft sediments and produces pelagic larvae. The species exists in two forms, a typical thin-shelled variety found in brackish lagoon habitats and a thicker shelled variety occurring in estuaries. It is widely distributed in north-west Europe. Limited evidence was found for recruitment in *Cerastoderma glaucum*. The congener *Cerastoderma edule* has been more extensively studied and general patterns are probably similar between the two species. A number of factors have been identified that affect larval supply and recruitment to adult populations of *Cerastoderma edule*. Survival during the first few months of life appears to be the decisive factor for recruitment success (Beukema & Dekker, 2005). High levels of juvenile recruitment have been observed where previous severe winters with heavy storm surges have reduced the population density of adults and reduced numbers of infaunal predators (Ducrotoy *et al*., 1991).

The ability of postlarvae and larger juveniles and adults of *Hediste diversicolor* to swim, burrow and be carried by bedload transport can aid the rapid recolonization of disturbed sediments. (Shull, 1997). Davey & George (1986), found evidence that larvae of *Hediste diversicolor* were tidally dispersed within the Tamar estuary over a distance of 3 km, suggesting recolonization of disturbed sediments, or populations removed from bait digging is likely to occur rapidly, depending upon larvae transport pathways. *Hediste diversicolor* are more likely to occur in the late transitional and the equilibrium communities that rely on more stable sediments that have recovered from disturbance (Newell *et al*., 1998).

The amphipod *Corophium volutator* lives for a maximum of one year (Hughes, 1988) and females can have 2-4 broods in a lifetime (Conradi & Depledge, 1999). Populations in southerly areas such as the Dovey Estuary, Wales or Starrs Point, Nova Scotia have two reproductive episodes per year. Those populations in colder, more northerly areas such as the Ythan Estuary, Scotland or in the Baltic Sea only have one (Wilson & Parker, 1996). On the west coast of Wales, breeding takes places from April to October and mating takes place in the burrow. Adult males crawl over the surface of the moist sediment as the tide recedes in search of burrows occupied by mature females. *Corophium volutator* forms an important food source for several species of birds and mobile predators such as fish and crabs (Hughes, 1988; Jensen & Kristensen, 1990; Raffaelli *et al*., 1991; Flach & de Bruin, 1994; Brown *et al*., 1999), so this behaviour makes them vulnerable to predation (Fish & Mills, 1979; Hughes, 1988; Forbes *et al*., 1996). The females can produce 20-52 embryos in each reproductive episode (Fish & Mills 1979; Jensen & Kristensen, 1990). Juveniles are released from the brood chamber after about 14 days, and development is synchronized with spring tides, possibly to aid dispersal. Recruitment occurs within a few centimetres of the parent, although they may disperse later by swimming (Hughes, 1988). In the Columbia river, no significant difference was found in *Corophium volutator* densities before and after dredging a channel and no difference between the dredged site and a control site (McCabe *et al*., 1998). Presumably, the dredging did cause mortality of *Corophium volutator* but recolonization was so rapid that no difference was found.

Hydrobia ulvae may live from just over 1 year up to 2.5 years. Minimum egg hatching time has been recorded as five days. Individuals hatching from eggs laid in spring can breed in autumn, whereas those hatching in autumn overwinter before breeding in spring. Between 7 and 50 eggs are laid and both planktotrophic and lecithotrophic larvae have been recorded (Fretter & Graham, 1994; Barnes, 1988; Clay, 1960; Barnes, 1990; Fish & Fish, 1974; Anderson, 1971; Sola, 1996; Pilkington, 1971). *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.

The polychaete *Pygospio elegans* exhibit a number of reproductive strategies (a trait known as poecilogony). Larvae may develop directly allowing rapid population increase in suitable patches or they may have a planktonic stage (allowing colonization of new habitats). Experimental defaunation studies have shown an increase in *Pygospio elegans*, higher than background abundances within 2 months, reaching maximum abundance within 100 days (Van Colen *et al*. 2008). Following a period of anoxia in the Bay of Somme (north France) that removed cockles, *Pygospio elegans* increased rapidly but then decreased as cockle abundance recovered and sediments were disturbed by cockle movement (Desprez *et al*., 1992). Recovery will depend on the lack of stronger competitors and the supply of larvae and hence the season of disturbance will moderate recovery time. In general recovery is predicted to occur within 6 months. However, where conditions are stable these species are likely to be replaced by competitive dominants, particularly bivalves. 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).

Tubificid populations tend to be large and to be constant throughout the year, although some studies have noticed seasonal variations (Giere & Pfannkuche, 1982). Many species, including *Baltidrilus costata* have a two-year reproductive cycle and only part of the population reproduces each season (Giere & Pfannkuche, 1982). Populations of *Tubificoides benedii* in the Fourth estuary have not demonstrated clear seasonality in recruitment (Bagheri & McLusky, 1982), although mature *Tubificoides benedii* (as *Peloscolex benedeni*) in the Thames Estuary were reported to occur in December with a maximum in late February (Hunter & Arthur, 1978), breeding worms increased from April and maximum cocoon deposition was observed in July (Hunter & Arthur, 1978). Oligochaetes can be dominant species within sediments, often reaching huge population densities in coastal areas that are enriched in organic matter, and are often described as ‘opportunist’ species adapted to rapid environmental fluctuations and stress (Giere, 2006; Bagheri & McLusky, 1982). However, unlike other opportunist species oligochates such as *Tubificoides benedii* have a long lifespan (a few years, Giere, 2006), a prolonged reproductive period from reaching maturity to maximum cocoon deposition and exhibits internal fertilisation with brooding rather than pelagic dispersal. These factors mean that recolonization is slower than for some opportunistic species which may be present in similar habitats.

Bolam and Whomersley (2003) observed faunal recolonization of fine sediments placed on saltmarsh as a beneficial use and disposal of fine-grained dredged sediments. They found that tubificid oligochaetes began colonising sediments from the first week following a beneficial use scheme involving the placement of fine-grained dredged material on a salt marsh in southeast England. The abundance of *Tubificoides benedii* recovered slowly in the recharge stations and required 18 months to match reference sites and those in the recharge stations prior to placement of sediments. The results indicate that some post-juvenile immigration is possible and that an in-situ recovery of abundance is likely to require more than 1 year. Rapid recolonization has also been observed in the tubificid oligochaete *Baltidrilus costata (Tubifex costatus)* appeared in upper sediment layer s in experimentally defaunated patches ($4m^2$) after 3 weeks (Gamenick *et al*., 1996).

Resilience assessment. Overall, the recovery *potential* of the bivalves, the associated polychaetes and oligochaetes and other species is probably rapid. It must be considered that the location of this biotope within lagoon habitats will limit the ability of this biotope to be quickly recolonized. The low flushing times and high water retention rates within saline lagoons means that larva and propagule supply will also be slow. Populations of species such as oligochaetes which produce egg cocoons and *Corophium volutator* which brood young may be self-recruiting and recovery from some mortality may be rapid. However, should a population be severely reduced it may take some time for recolonization to occur from other populations. Therefore, where resistance is ‘Medium’ (some mortality) a resilience of **High** is recorded but where resistance is lower (‘Low’ to ‘None’; significant mortality) a resilience of **Medium** (2-10 years) is recorded, to represent the isolated waters in which this biotope is found.

Lagoons are rare within the UK and, on geological timescales, are short-lived coastal features. Spencer & Brooks (2012) state that over decadal timescales, the seaward barriers that enclose saline lagoons naturally migrate progressively landwards. This is part of the natural succession of the habitat. However, these seaward barriers will move even faster if local geomorphological conditions change. A change in geomorphological conditions could both speed up the movement of the lagoon landwards, and change the supply of sediment to the barrier. Ultimately this could lead to the total removal of the barrier and the loss of the lagoon. The effects of an artificial structure built behind a lagoon must also be taken into consideration. It is possible that such a structure could potentially inhibit the natural migration of the lagoon land wards, and thus reduce the lifespan of the lagoon. Where a pressure is likely to remove the lagoon habitat, recovery may be protracted or may not occur.

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 recognizable 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)	Medium Q: High A: High C: Medium	High Q: High A: High C: High	Low Q: High A: High C: Medium

Lagoon environments are typically shallow (Barnes, 1994) and will, therefore, heat and cool more rapidly than deeper habitats or those that are more connected to the sea and tidally flushed. Species that characterize this habitat are therefore likely to be able to tolerate higher and lower temperatures than open coast species from the shallow subtidal. Populations may be acclimated to the temperatures or able to recover rapidly where populations are impacted.

Corophium volutator is widely distributed in the north Atlantic, American and European coasts; from western Norway to the Mediterranean and the Black Sea and Azov Sea (Neal & Avant, 2006). The amphipod is subject to temperatures of 1°C in the winter to 17°C in the summer (Wilson & Parker, 1996) but can resist much higher temperatures (Meadows & Ruagh, 1981).

Cerastoderma glaucum occurs from Norway and the Baltic to the Mediterranean and Black Seas. *Cerastoderma glaucum* can tolerate a wide range of temperatures. Populations have been observed to survive in lagoons in conditions to more than 30°C.

The geographic range of *Hediste diversicolor* suggests that it is resistant of a range of temperatures and a temperature increase at benchmark levels is unlikely to have an adverse effect on UK populations. *Hediste diversicolor* can tolerate temperatures from below zero under Baltic ice to high summer temperatures (>20°C) in Black Sea lagoons (Smith, 1977). *Hediste diversicolor* were not strongly affected by heatwaves in an estuary in north western Portugal, where temperatures may reach 40°C in intertidal pools (higher temperatures than experienced around UK and Irish coasts) (Dolbeth *et al.* 2011). Temperature change may adversely affect reproduction. Bartels-Hardege and Zeeck (1990) demonstrated that an increase from 12°C and maintenance of water temperature at 16°C induced reproduction in *Hediste diversicolor* specimens outside the normal period of spawning, and without a drop in temperature to simulate winter conditions the spawning period was prolonged and release of gametes was not synchronized. Poor synchronization of spawning could result in reduced recruitment, as gametes are wasted and adults die shortly after gamete release.

Deeper burrowing oligochaetes are protected from fluctuations in temperature by the overlaying sediments which dampen changes if poorly drained (Giere & Pfannkuche, 1982). Bamber & Spencer (1984) observed that *Tubificoides* were dominant species in an area affected by thermal discharge in the River Medway estuary. Sediments were exposed to the passage of a temperature front of approximately 10°C between heated effluent and estuarine waters during the tidal cycles. *Pygospio elegans* were summer visitors to the areas affected by heated effluent.
Pygospio elegans also shows a relationship between timing of reproduction and temperature. Gibson and Harvey (2000) in a study on asexual reproduction of *Pygospio elegans* in Nova Scotia, Canada found temperature did not influence reproduction strategy (planktotrophy, lecithotrophy or asexual reproduction) but cite Anger (1984) that environmental conditions, including temperature influence timing of reproduction.

Sensitivity assessment. Based on species distributions and evidence for temperature tolerance, the characterizing species are likely to be tolerant of a chronic increase in temperature at the pressure benchmark. Species are unlikely to be removed entirely but may be impacted by a short-term acute change in temperature of 5°C. Hence, a resistance of **Medium** is suggested to represent a loss of some of the population. Resilience is probably **High** and sensitivity is assessed as **Low**.

Temperature decrease (local)	High Q: High A: High C: High	High Q: High A: High C: High	Not sensitive Q: High A: High C: High

Lagoon environments are typically shallow (Barnes, 1994) and will, therefore, heat and cool more rapidly than deepen habitats or those that are more connected to the sea and tidally flushed. Species that characterize this habitat are therefore likely to be able to tolerate higher and lower temperatures than open coast species from the shallow subtidal. Populations may be acclimated to the temperatures or able to recover rapidly where populations are impacted.

Temperature change may affect maturation, spawning time and synchronisation of spawning and reproduction in the long-term (Bentley & Pacey, 1992; Watson *et al.*, 2000). Spawning success is dependent upon spring and autumn temperatures, the seasons when spawning occurs in relation to spring and neap tides, remaining below 13-15°C. De Wilde & Berghuis (1979) reported 20% mortality of juveniles reared at 5 °C, negligible mortality at 10 °C and 15 °C but 50% at 20°C and 90% mortality at 25°C.

The geographic range of *Hediste diversicolor* suggests that it is resistant of a range of temperatures and a temperature increase at benchmark levels is unlikely to have an adverse effect on UK populations. *Hediste diversicolor* can tolerate temperatures from below zero under Baltic ice to high summer temperatures (>20°C) in Black Sea lagoons (Smith, 1977).

Cerastoderma glaucum occurs from Norway and the Baltic to the Mediterranean and Black Seas. *Cerastoderma glaucum* can also tolerate a wide range of temperatures. Populations have been observed to survive in lagoons in conditions from almost freezing to more than 30 °C. However, a high mortality of cockles was observed in South East England after the exceptionally cold winter of 1962/3. Boyden (1972) observed that *Cerastoderma glaucum* has a LD50 of 62.3 hours at 20 degrees C in air. *Corophium volutator* is widely distributed in the north Atlantic, American and European coasts; from western Norway to the Mediterranean and the Black Sea and Azov Sea (Neal & Avant, 2006). The amphipod is subject to temperatures of 1°C in the winter to 17°C in the summer (Wilson & Parker, 1996) but can resist much higher temperatures (Meadows & Ruagh, 1981).

Most littoral oligochaetes, including tubificids and enchytraeids, can survive freezing temperatures and can survive in frozen sediments (Giere & Pfannkuche, 1982). *Tubificoides benedii* (studied as *Peloscolex benedeni*) recovered after being frozen for several tides in a mudflat (Linke, 1939).

Crisp (1964) reported that species of amphipod and isopods seemed to be unharmed by the severe winter of 1962-1963. This may be due to burial in sediments buffering temperature or seasonal migration to deeper waters to avoid freezing. *Corophium volutator* is subject to temperatures of 1°C in the winter to 17°C in the summer (Wilson & Parker, 1996). The population may reduce activity and delay reproduction if the temperature drops below 7°C. Sudden pulses of very cold water can disrupt the circa-tidal rhythms of *Corophium volutator* by resetting the onset of swimming behaviour. For example, a 6 hour cold spell would lead to the population trying to swim at low tide and leave them vulnerable to increased predation. However, it took temperatures of 15-20°C below ambient temperature to induce this response (Holmström & Morgan, 1983b).

Sensitivity assessment. Populations present in the biotope are distributed to the north of the British Isles, exhibit regional acclimation to temperature, are known to be winter hardy, and can migrate to deeper waters or within sediments to avoid change in temperature and even ice. Therefore, the biotope is probably resistant of a short to long-term decrease in temperature at the benchmark level and a resistance of **High** is suggested. Hence, resilience is **High** and the biotope is assessed as **Not sensitive** at the benchmark level.

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

This biotope occurs in low (<18 ppt) salinity (JNCC, 2015). Biotopes that occur in low salinity are considered tolerant of an increase to reduced salinity as this is likely to fall within the habitat range of the characterizing species. Species acclimated to lagoon conditions may be able to tolerate some fluctuations in salinity as evaporation on hot days may increase salinity and tidal flushing may lead to daily changes in salinity.

Cerastoderma glaucum has a high tolerance of different salinities, being found across its geographic range in salinities that vary from 4-100 PSU (Russell & Petersen, 1973).

Pygospio elegans is common in both marine and brackish waters and in European habitats the species tolerates a broad salinity range (Ysebaert *et al*., 1993). Studies of *Pygospio elegans* population structure in the Baltic Sea and North Sea found that larvae were not hampered by changes in salinity (Kesaniemi *et al*., 2012). Although case studies are lacking for British and Irish coasts, the existing evidence suggests *Pygospio elegans* would tolerate salinity changes at the pressure benchmark levels. Hylleberg (1975) also found that under controlled conditions of salinity ranging from 10 to 30‰ and temperatures ranging from 5 to 35° C, shows that *Hydrobia ulvae* has maximal egestion at the combination of high salinity (30‰) and high temperature (30°C). The species would be likely to show high resistance to an increase in salinity from the reduced and variable conditions the biotope occurs within.

Oligochaete dominated biotopes are recorded from a range of salinity regimes from full (LS.LSa.MoSa.Ol; LS.LSa.MoSa.Ol.FS), variable (SS.SMu.SMuVS.CapTubi) to low (SS.SMu.SMuVS.LhofTtub) habitats (JNCC,2015). The species characterizing these biotopes are likely to vary. Giere & Pfannkuche (1982) identified how species change over a hypothetical salinity gradient with marine stenohaline species present at full salinities replaced by more euryhaline oligochaete species including *Tubificoides benedii* and *Tubificoides pseudogaster*, *Paranais litoralis* and *Baltidrilus costata* (formerly *Heterochaeta costata*). Studies in the Rhine delta have found that *Tubificoides benedii*, is more tolerant of a range of salinities than *Baltidrilus costata* (as *Heterochaeta costata*) which preferred shallow water brackish stations (Verdonschot *et al*. 1982). However, numerous studies suggest that *Baltidrilus costata* tolerates a wide range of salinities from 1‰ to 28‰ (Giere & Pfannkuche, 1982 and references therein), suggesting that while tolerant of some changes, an increase to full salinity may lead to reductions in abundance of this species.

Sensitivity assessment. The characterizing species are able to survive in both fully marine and brackish water and may be unaffected by an increase in salinity (although some acclimation may be required). As salinity is a key structuring factor it is likely that a long-term change in salinity would alter the biological assemblage allowing species that are intolerant of low salinity to colonize. Biotope resistance is therefore assessed as **Low** and resilience as **Medium**, so that sensitivity to this pressure is assessed as **Medium**.

Salinity decrease (local)	None Q: Low A: NR C: NR	Medium Q: Low A: NR C: NR	Medium Q: Low A: Low C: Low

This biotope occurs in low (<18 ppt) salinity (JNCC, 2015). A change at the pressure benchmark is assessed as a change to freshwater. Few of the characterizing species are likey to tolerate a long-term salinity reduction at the pressure benchmark. Biotope resistance is therefore assessed as **None** and resilience as **Medium** (following habitat recovery). Biotope sensitivity is therefore assessed as **Medium.**

Water flow (tidal current) changes (local)	None Q: Low A: NR C: NR	High Q: Low A: NR C: NR	Medium Q: Low A: Low C: Low

This biotope is found in very weak tidal conditions where water flow is negligible (JNCC, 2015). An increase in water flow at the benchmark is unlikely to have a significant negative effect on the biological composition of the biotope as many of the characterizing species are found in biotopes that are exposed to stronger tidal streams. However, it must be assumed that if there is an increase in the water flow within the biotope there will also be an increase in the water flow around the lagoon. An increase or decrease in the water flow at the pressure benchmark may result in increased erosion of sands or deposition of fine silts resulting in changes in sediment composition. An increase in water flow above the level of the benchmark this could consequently lead to the loss/collapse of a lagoon wall and completely change the physical environment of the biotope, and lead to the loss of the lagoon biotope altogether. Decreased water flow may also have implications for oxygenation and larval transport as water exchange and flushing are reduced. General predictions are limited as the change will depend on site-specific factors such as the structure of the lagoon, the degree of water exchange and sediment supply.

Sensitivity assessment. The biotope occurs in weak to very weak flow so that any further reduction is not relevant. An increase in water flow could modify the sediment. A significant increase may result in a change in the sediment from fine muds to sand muds and the fine particulates are removed. The experimental evidence suggests that a change in the flow of 0.11 m/s to 0.25 m/s was enough to alter the sediment and the appearance of the biotope within 65 days. Therefore, a reduction in flow of 0.1-0.2 m/s may alter the sediment and the appearance of the biotope resulting in a change to the mud lagoon SS.SMu.SMuLS. Therefore, a resistance of **None** is suggested. Resilience is probably **High** as, once the low energy conditions return, it may only take a couple of years for the mud to deposit in these otherwise sheltered and isolated habitats. Hence, sensitivity is assessed as **Medium**.

Emergence regime 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

Changes in emergence is only relevant to intertidal and sublittoral fringe biotopes.

Wave exposure changes (local)	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low

This biotope is found in extremely sheltered conditions. An increase or decrease in wave exposure at the benchmark is unlikely to have a significant negative effect on the biological composition of the biotope. However, it might be assumed that if there is an increase in the wave height within the biotope there will also be an increase in the water flow around the lagoon. This increase could have a detrimental effect on the structure of the lagoon through erosion. This could consequently lead to the loss collapse of a lagoon wall and completely change the physical environment of the biotope, and lead to the loss of the lagoon biotope altogether.

Sensitivity assessment. Wave exposure can have a significant structuring effect on biotopes through direct effects on species and indirectly through changes in sediment composition and transport and physical disturbance. As lagoons are sheltered from waves a change at the pressure benchmark is very small. Resistance and resilience are assessed as 'High' and the biotope is assessed as 'Not Sensitive'.

Chemical Pressures

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

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

Contamination at levels exceeding the pressure benchmark may have negative effects. A 2-year microcosm experiment was undertaken to investigate the impact of copper on the benthic fauna of the lower Tyne Estuary (UK) by Hall & Frid (1995). During a 1-year simulated contamination period, 1 mg/l copper was supplied at 2-weekly 30% water changes, at the end of which the sediment concentrations of copper in contaminated microcosms reached 411 µg/g. Toxicity effects reduced populations of the four dominant taxa including *Tubificoides* spp.). When copper dosage was ceased and clean water supplied, sediment copper 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 copper 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 taking up to a year.

Corophium volutator is highly intolerant of metal pollution at levels often found in estuaries from industrial outfalls and contaminated sewage. A concentration 38 mg Cu/l was needed to kill 50% of *Corophium volutator* in 96 hour exposures (Bat *et al.*, 1998). Other metals are far more toxic to *Corophium volutator*, e.g. zinc is toxic over 1 mg/l and toxicity to metals increases with increasing temperature and salinity (Bryant *et al.*, 1985b). Mortality of 50% is caused by 14 mg/l (Bat *et al.*, 1998). Although exposure to zinc may not be lethal, it may affect the perpetuation of a population by reducing growth and reproductive fitness. Mercury was found to be very toxic to*Corophium volutator*, e.g. concentrations as low as 0.1 mg/l caused 50% mortality in 12 days. Other metals known to be toxic include cadmium, which causes 50% mortality at 12 mg/l (Bat *et al.*, 1998); and arsenic, nickel and chromium which are all toxic over 2 mg/l (Bryant *et al.*, 1984; Bryant *et al.*, 1985a).

Sediment may act as a sink for heavy metals contamination so that deposit feeding species may be particularly vulnerable to heavy metal contamination through ingestion of particulates. At high concentrations of Cu, Cd or Zn the blow lug left the sediment (Bat & Raffaelli, 1998). The following toxicities have been reported in *Arenicola marina*:

- no mortality after 10 days at 7 μg Cu/g sediment, 23 μg Zn/g and 9 μg Cd/g;
- median lethal concentrations (LC_{50}) of 20 μg Cu/g, 50 μg Zn/g, and 25 μg Cd/g (Bat & Raffaelli, 1998).

Bryan (1984) suggested that polychaetes are fairly resistant to heavy metals, based on the species studied. Short-term toxicity in polychaetes was highest to Hg, Cu and Ag, declined with Al, Cr, Zn and Pb whereas Cd, Ni, Co and Se the least toxic.

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.

Sheltered embayments and lagoons, where this biotope is found, are particularly vulnerable to oil pollution, which may settle onto the sediment and persist for years (Cole *et al.*, 1999). Subsequent digestion or degradation of the oil by microbes may result in nutrient enrichment and eutrophication (see nutrients below). Although protected from direct smothering by oil by its depth, the biotope is relatively shallow and would be exposed to the water soluble fraction of oil, water soluble PAHs, and oil adsorbed onto particulates.

Light fractions (C10 - C19) of oils are much more toxic to *Corophium volutator* than heavier fractions (C19 - C40). In exposures of up to 14 days, light fraction concentrations of 0.1 g/kg sediment caused high mortality. It took 9 g/kg sediment to achieve similar mortalities with the heavy fraction (Brils *et al.*, 2002). In the Forth estuary, *Corophium volutator* was excluded for several hundred metres around the outfalls from hydrocarbon processing plants. Roddie *et al.* (1994) found high levels of mortality of *Corophium* at sites contaminated with crude oil.

Tubificoides benedii appears to be more tolerant and was found in UK waters near oil refineries as the sole surviving member of the macrofauna. Populations were however apparently reduced and the worms were absent from areas of oil discharge and other studies indicate sensitivity to oiling (Giere & Pfannkuche, 1982, references therein).

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.

Corophium volutator is paralysed by pyrethrum based insecticide sprayed onto the surface of the mud (Gerdol & Hughes, 1993) and pyrethrum would probably cause significant mortalities if it found its way into estuaries from agricultural runoff. Nonylphenol is an anthropogenic pollutant that regularly occurs in water bodies, it is an oestrogen mimic that is produced during the sewage treatment of non-ionic surfactants and can affect*Corophium volutator* (Brown *et al*., 1999). Nonylphenol is a hydrophobic molecule and often becomes attached to sediment in water bodies. This will make nonylphenol available for ingestion by *Corophium volutator* in estuaries where much of the riverine water-borne sediment flocculates and precipitates out of suspension to form mudflats. Nonylphenol is not lethal to *Corophium volutator* but does reduce growth and has the effect of causing the secondary antennae of males to become enlarged which can make the amphipods more vulnerable to predators (Brown *et al*., 1999). *Corophium volutator* is killed by 1% ethanol if exposed for 24 hours or more but can withstand higher concentrations in short pulses. Such short pulses, however, have the effect of rephasing the diel rhythm and will delay the timing of swimming activity for the duration of the ethanol pulse (Harris & Morgan, 1984b).

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	High Q: High A: High C: High	High Q: High A: High C: High	Not sensitive Q: High A: High C: High

Species that are likely to be sensitive to de-oxygenation at the pressure benchmark are juvenile *Cerastoderma glaucum*, *Pygospio elegans* and *Corophium volutator*. *Pygospio elegans* is highly sensitive to hypoxia (Gogina *et al*., 2010). Exposure to dissolved oxygen concentration of less than or equal to 2 mg/l for 1 week is likely to limit *Pygospio elegans* abundance. Juvenile *Cerastoderma glaucum* are also very intolerant of low oxygen concentrations. However adults can survive for 84 hours in oxygen free water (Boyden, 1972). In a series of experiments Gamenick *et al*., (1996) suggested that *Corophium volutator* is highly sensitive to hypoxia and suffers 50% mortality after just 4 hours in hypoxic conditions, or in 2 hours if there is rapid build-up of sulphide (Gamenick *et al*., 1996). These results are largely in concordance with other work by Gamble (1970) who found that survival rates were temperature dependent with individuals surviving longer at lower temperatures. The level of oxygen was not assessed by Gamenick *et al*., 1996) and the description of the experimental set-up suggests that anoxic test conditions were used rather than hypoxic. Gamble (1970) found that at 5°C most individuals were inactive after 30 minutes exposure to anaerobic seawater and that mortality occurred later, the inactivity may have allowed the species to survive longer (Gamble, 1970).

Other species within the biotope are more tolerant of hypoxia. *Hediste diversicolor* is resistant to moderate hypoxia (Diaz & Rosenberg, 1995). Vismann (1990) demonstrated a mortality of only 15% during a 22 day exposure of *Hediste diversicolor* at 10% oxygen (ca. 2.8 mg O_2 /l). *Hediste diversicolor* is active at the sediment/water interface where hydrogen sulphide concentrations increase during periods of hypoxia. Vismann (1990) also demonstrated that the high tolerance of *Hediste diversicolor* to hypoxia in the presence of sulphide is enabled by elevated sulphide oxidation activity in the blood. *Hediste diversicolor* may also exhibit a behavioural response to hypoxia by leaving the sediment (Vismann, 1990) in the presence of sulphide. After 10 days of hypoxia (10% oxygen saturation) with sulphide (172-187 µmM) only 35% of *Hediste diversicolor* had left the sediment compared to 100% of *Nereis virens*. Laboratory experiments in the absence of sediments, found that *Hediste diversicolor* could survive hypoxia for more than 5 days and that it had a higher tolerance to hypoxia than *Nereis virens, Nereis succinea* and *Nereis pelagica* (Theede, 1973; Dries & Theede, 1974; Theede *et al*., 1973). Juvenile *Hediste diversicolor* survived hypoxic conditions for 4 days in laboratory conditions and combined hypoxia and increased sulphide (1 mmol/l) for 3 days (Gamenick *et al*., 1996). Post larvae *Hediste diversicolor* were the only life stage to show les tolerance to hypoxia, surviving for only 14 hr (Gamenick *et al*., 1996).

Sensitivity assessment. Burrowing species such as *Hediste diversicolor* and the oligochaetes burrow in anoxic sediment and may be tolerant of hypoxia. Species that occur at the surface and that are frequently found in well-oxygenated sandy sediments such as *Pygospio* elegans and *Corohpium volutator* are likely to be more sensitive. At the pressure benchmark biotope resistance is assessed as **Low** based on the loss of some characterizing species, biotope resilience is assessed as **High** and sensitivity is **Low**.

Nutrient enrichment	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

Indirect effects may include algal blooms and the growth of algal mats (e.g. of *Ulva* sp.) on the surface of the intertidal flats. Algal mats smother the sediment, and create anoxic conditions in the sediment underneath, changes in the microphytobenthos, and with increasing enrichment, a reduction in species richness, the sediment becoming dominated by pollution tolerant polychaetes, e.g. *Capitella capitata* and *Manayunkia aestuarina*. In extreme cases, the sediment may become anoxic and defaunated (Elliot *et al*., 1998). Algal blooms have been implicated in mass mortalities of lugworms, e.g. in South Wales where up to 99% mortality was reported (Boalch, 1979; Olive & Cadman, 1990; Holt *et al*. 1995).

Nevertheless, this biotope is considered to be **Not sensitive** at the pressure benchmark that assumes compliance with good status as defined by the WFD.

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

This biotope is characterized by species that are exclusively deposit feeders or that can switch to deposit feeding, including *Hediste diversicolor*, *Pygospio elegans*, oligochaetes and *Corophium* *volutator*. An input of organic matter may provide a food subsidy for these species.

The oligochaete *Baltidrilus costatus* are both very tolerant of high levels of organic enrichment and often dominate sediments where sewage has been discharged or other forms of organic enrichment have occurred (Pearson & Rosenberg, 1978; Gray, 1971; McLusky *et al*., 1980). Their tolerance for organic enrichment is attributed to their adaptation to live in and feed on enriched organic deposits (Pearson & Rosenberg, 1978) and their high population densities in such areas is enhanced by the lack of predation and competition.

Sensitivity assessment. The biotope is probably rich in organic matter as it occurs in sheltered, isolated areas. An input of organic matter at the pressure benchmark is likely to provide food for deposit feeders within the biotope. Therefore, a resistance of **High** is suggested at the benchmark level. Hence, resilience is **High** and the biotope is assessed as **Not sensitive** at the benchmark level.

Physical Pressures

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

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

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

The biotope is characterized by the sedimentary lagoon habitat (JNCC, 2015), so a change to an artificial or rock substratum would alter the character of the biotope leading to reclassification and the loss of the sedimentary community including the characterizing bivalves, polychaetes and echinoderms that live buried within the sediment.

Sensitivity assessment. Based on the loss of the biotope, resistance is assessed as 'None', recovery is assessed as 'Very low' (as the change at the pressure benchmark is permanent), and sensitivity is assessed as 'High'.

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

A change in sediment type by one Folk class (using the Long 2006 simplification) would change the sediment to mud or mixed sediments. Although many of the characterizing species are likely to persist, the biotope would probably be re-classified to the sublittoral mud lagoon type SS.SMu.SMuLS or the mixed sediment SS.SMx.SMxLS. A change to coarse sediments would significantly alter species composition through loss of *Arenicola marina* and amphipods and oligochaetes and other associated species. Therefore, a resistance of **None** is recorded, resilience is **Very low** (the pressure is a permanent change) and sensitivity is assessed as **High**.

Habitat structure changes - removal of substratum (extraction)	None Q: Low A: NR C: NR	Medium Q: High A: Low C: Medium	Medium Q: Low A: Low C: Low

Sedimentary communities are likely to be highly intolerant of substratum removal, which will lead to partial or complete defaunation, exposing 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). Any remaining species, given their new position at the sediment/water interface, may be exposed to conditions to which they are not suited. Removal of 30 cm of surface sediment will remove the polychaete and oligochaete community and other species present in the biotope. Recovery of the biological assemblage may take place before the original topography is restored, if the exposed, underlying sediments are similar to those that were removed.

Sensitivity assessment. Extraction of 30 cm of sediment will remove the characterizing biological component of the biotope. Resistance is assessed as ‘None’ and biotope resilience is assessed as ’Medium’. Biotope sensitivity is therefore ‘Medium’.

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

Abrasion and compaction of the surficial layer may damage individuals, species that live close to the surface or move on the surface such as *Pygospio elegans*, *Corophium volutator* and the lagoon cockle *Cerastoderma glaucum* are likely to be more sensitive than species that burrow deeply into sediments such as *Hediste diversicolor*, oligochaetes and *Arenicola marina*.

No evidence was found to assess the sensitivity of *Cerastoderma glaucum* but the shells of *Cerastoderma glaucum* are rather thin and brittle, so it is probably quite intolerant of abrasion.

There are few studies on the effects of trampling on sedimentary habitats. Most studies suggest that the effects of trampling across sedimentary habitats depend on the relative proportion of mud to sand (sediment porosity), the dominant infauna (nematodes and polychaetes vs. bivalves) and the presence of burrows (Tyler-Walters & Arnold, 2008). Recovery from impact is relatively fast as shown by Chandrasekara & Frid (1996), where no difference was reported between samples in winter following summer trampling. Wynberg & Branch (1997) suggest that trampling effects are most severe in sediments dominated by animals with stable burrows, as these collapse and the sediment becomes compacted. Rossi *et al.* (2007) examined trampling across intertidal mudflats but were not able to show a significant difference in *Arenicola* abundance between trampled and control sites due to the natural variation in abundance between study sites. Experimental studies on crab-tiling impacts have found that densities of *Tubificoides benedii* and *Tubificoides pseudogaster* were higher in non-trampled plots (Sheehan *et al*., 2010), indicating that these oligochaetes have some sensitivity to trampling.

Sensitivity assessment. Abrasion may damage or kill a proportion of the population of the characterizing and associated species. *Arenicola marina* and *Tubificoides* spp. that are generally buried more deeply within sediments are likely to be more resistant than species such as *Pygospio elegans* that inhabit fragile tubes that extend above the sediment surface. Biotope resistance is assessed as **Medium** and resilience as **High**, so sensitivity is assessed as **Low**.

Penetration or disturbance of the substratum subsurface	Low Q: High A: High C: Medium	Medium Q: High A: High C: High	Medium Q: High A: High C: Medium

Disturbance of the sediment below the surface may affect all the characterizing infauna and a number of studies demonstrate effects on the characterizing species.

Whomersley *et al*., (2010) conducted experimental raking on intertidal mudflats at two sites (Creeksea- Crouch estuary England and Blackness- lower Forth estuary, Scotland), where *Tubificoides benedii* were dominant species. For each treatment 1 m2 plots were raked twice to a depth of 4cm (using a garden rake). Plots were subject to either low-intensity treatments (raking every four weeks) or high (raking every two weeks). The experiment was carried out for 10 months at Creeksea and a year at Blackness. The high and low raking treatments appeared to have little effect on *Tubificoides benedii* (Whomersley *et al*., 2010).

Ferns *et al.* (2000) studied effects of harvesting of cockles and reported a decline in muddy sands of 83% in *Pygospio elegans* (initial density 1850 m^{-2}) when a mechanical tractor towed harvester was used in a cockle fishery. *Pygospio elegans* and *Hydrobia ulvae* were significantly depleted for >100 days after harvesting (surpassing the study monitoring timeline).

Kaiser *et al.* (2001) carried out experimental hand raking, similar to that used in inter tidal cockle fisheries. Both small and large raked plots showed changed communities in comparison to control plots, smaller plots recovered in 56 days, whilst larger plots remained in an altered state. A three-fold damage rate for undersized cockles was recorded in hand-raked plots compared to control plots.

The extraction of cockles by sediment raking and mechanical disturbance and digging for lugworms causes significant mortality of *Corophium volutator*. Bait digging was found to reduce *Corophium volutator* densities by 39%, juveniles were most affected suffering a 55% reduction in dug areas (Shepherd & Boates, 1999).

Sensitivity assessment. Penetrative gear would probably damage or remove a proportion of the population of *Arenicola marina* and the characterizing oligochaetes but given potential density, the effects may be minor. Other characterizing species including *Pygospio elegans* and *Corophium volutator* may be damaged and suffer high levels of mortality. Hence, a resistance of **Low** is suggested. Resilience is probably **Medium**, due to the isolated nature of the sea lochs and lagoons in which this biotope if found, and sensitivity is assessed as **Medium**.

Changes in suspended solids (water clarity)	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 in low energy environments (wave sheltered and weak flow) in shallow isolated water bodies. Deposit feeders are unlikely to be perturbed by increased concentrations of suspended sediment since they live in sediment and are probably adapted to re-suspension of sediment by wave action, during storms or runoff.

In 36-65 day mesocosm studies of the effects of *Arenicola marina* bioturbation, Wendelboe *et al.* (2013) found that the surface of the sediment was dominated by faecal mounds and feeding pits at a flow rate of 0.11 m/s, but was more eroded and the surface was more even at 0.25 m/s. At the low flow (0.11 m/s) there was no change in the sediment. However, at 0.25 m/s, there was a substantial reduction in the silt and clay fractions of the sediment (a 36% reduction) and in the organic content of the sediment (a 42% reduction). At 0.25 m/s the material ejected into faecal casts was eroded (once the mucilaginous coating had eroded) and the water surface became turbid, resulting in loss of both silt/clay fractions and organic matter.

Sensitivity assessment. The evidence from Wendelboe *et al.* (2013) suggests that an increase in water movement due to storms, or runoff is likely to disturb the sediment surface regularly, especially in winter months, so that the biotope is probably not affected by changes in suspended sediment. In addition, *Arenicola marina* occurs at high abundances in mudflats and sandflats in estuaries where suspended sediment levels may reach grammes per litre. Therefore, a resistance of **High** is suggested so that resilience is **High** (by default) and the biotope is assessed as **Not sensitive** at the benchmark level.

Smothering and siltation rate changes (light)	Medium Q: High A: Medium C: Medium	High Q: High A: High C: High	Low Q: High A: Medium C: Medium

The degree to which the characterizing species are able to resist this pressure depends primarily on species mobility, ability to survive within sediment without contact with the surface and ability to escape from the over-burden. Factors that affect the ability to regain the surface include grain size (Maurer *et al.*, 1986), temperature and water content (Chandrasekara & Frid, 1998).

Mobile polychaetes have been demonstrated to burrow through thick layers of deposits. Powilleit *et al.*, (2009) studied the response of the polychaete *Nephtys hombergii* to smothering. This species successfully migrated to the surface of 32-41 cm deposited sediment layer of till or sand/till mixture and restored contact with the overlying water. While crawling upward to the new sediment surfaces burrowing velocities of up to 20 cm/day were recorded for *Nephtys hombergii*. Similarly, Bijkerk (1988, results cited from Essink 1999) indicated that the maximal overburden through which species could migrate was 60 cm through mud for *Nephtys* and 90 cm through sand. No further information was available on the rates of survivorship or the time taken to reach the surface.

Tubificoides spp. and other oligochaetes live relatively deeply buried and can tolerate periods of low oxygen that may occur following the deposition of a fine layer of sediment. *Tubificoides* spp. showed some recovery through vertical migration following the placement of a sediment overburden 6cm thick on top of sediments (Bolam, 2011). Whomersley *et al.*, (2010) experimentally buried plots on intertidal mudflats at two sites (Creeksea- Crouch Estuary, England and Blackness- lower Forth Estuary, Scotland), where *Tubificoides benedii* were dominant species. For each treatment anoxic mud was spread evenly to a depth of 4 cm on top of each treatment plot. The mud was taken from areas adjacent to the plots, and was obtained by scraping off the surface oxic layer and digging up the underlying mud from approximately 20 cm depth. Plots were subject to either low intensity treatments (burial every four weeks) or high (burial every two weeks). The experiment was carried out for 10 months at Creeksea and a year at Blackness. At Creeksea numbers of *Tubificoides benedii* increased in both burial treatments until the third month (high burial) and sixth month (low burial). At Blackness increased numbers of*Tubificoides benedii* were found in both burial treatments after one month (Whomersley *et al.*, 2010).

Laboratory experiments have shown that the snail *Hydrobia ulvae* can rapidly resurface through 5cm thick fine deposits, although this ability is reduced where deposited sediments contain little water (Chandrasekara & Frid, 1998). Field experiments where 10 cm of sediment were placed on intertidal sediments to investigate the effects of the beneficial use of dredged materials found that the abundance of *Hydrobia ulvae* had returned to ambient levels within 1 week (Bolam *et al*., 2004).

Cerastoderma glaucum has short siphons and needs to keep in contact with the surface of the sediment. Richardson *et al*. (1993) reported that the congener *Cerastoderma edule* can burrow quickly to the surface if covered by 2 cm of sediment (under laboratory or field conditions) when emersed (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. Experimental simulation of bait digging (sediment dug over to a depth of 30cm with a garden fork) led to high mortalities of the cockle *Cerastoderma edule* 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.

The associated species *Pygospio elegans* is limited by high sedimentation rates (Nugues *et al*., 1996) and the species does not appear to be well adapted to oyster culture areas where there are high rates of accumulation of faeces and pseudo faeces (Sornin *et al*., 1983; Deslous-Paoli *et al*., 1992; Mitchell, 2006 and Bouchet & Sauriau 2008). *Pygospio elegans* is known to decline in areas following re-deposition of very fine particulate matter (Rhoads & Young, 1971; Brenchley, 1981). Experimental relaying of mussels on intertidal fine sands led to the absence of *Pygospio elegans* compared to adjacent control plots. The increase in fine sediment fraction from increased sediment deposition and biodeposition alongside possible organic enrichment and decline in sediment oxygen levels was thought to account for this (Ragnarsson & Rafaelli, 1999).

The amphipod *Corophium volutator* may be sensitive to deposits at the pressure benchmark. Experimental fences placed on mudflats that caused sedimentation rates of 2-2.5 cm/month and reduced *Corophium volutator* densities from approximately 1700 m to approximately 400 m. In areas without fences,*Corophium volutator* numbers increased from approximately 1700 per m to 3500 per m (Turk & Risk, 1981).

Sensitivity assessment. As the exposure to the pressure is for a single discrete event, resistance is assessed as '**Medium**' as some species associated with the biotope such as *Corophium volutator* and *Pygospio elegans* may decline but the biotope is likely to be recognizable within weeks due to repositioning and migration of mobile species. Resilience is assessed as '**High**' and sensitivity is assessed as '**Low**.

Smothering and siltation rate changes (heavy)	Medium Q: Low A: NR C: NR	High Q: High A: High C: High	Low Q: Low A: Low C: Low

The pressure benchmark (30 cm deposit) represents a significant burial event and the deposit may remain for some time in a sheltered mudflat. Some impacts on *Tubificoides benedii* and other characterizing oligochaetes may occur and it is considered unlikely that significant numbers of the population could reposition, based on (Bolam, 2011). Placement of the deposit will, therefore, result in a defaunated habitat until the deposit is recolonized. Biotope resistance is therefore assessed as 'Low' as some removal of deposit and vertical migration through the deposit may occur. Resilience is assessed as 'High' as migration and recolonization of oligochaetes is likely to occur within two years, biotope sensitivity is therefore assessed as 'Low'.

Cerastoderma glaucum 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 30 cm (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 (H*ediste diversicolor*) was associated with declines in the congener *Cerastoderma edule* populations (Jackson & James, 1979). Experimental simulation of bait digging (sediment dug over to a depth of 30 cm 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 10 cm 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 90 cm 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 1 week (Bolam *et al*. 2004). It is not clear whether this species could reposition after 30cm of sediment were placed on sediments.

Sensitivity assessment. This biotope occurs in a depositional environment, where sedimentation is likely, to be high due to the low energy of the habitat. However, the deposit of 30 cm in a single event is probably greater than the normal range of sedimentation and, in theses sheltered habitats, likely to remain. Therefore, a proportion of the adults and a greater proportion of the juveniles may not be able to realign themselves with the surface of the sediment and resistance is assessed as **Medium**. Resilience of key characterizing species is considered to be **High** and sensitivity is assessed as **Low** at the benchmark level.

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

DNA damage when exposed to water with toxicants (present in cigarette butts) in quantities 60 fold lower than reported from urban run-off (Wright *et al.*, 2015). Studies are limited on impacts of litter on infauna and this UK study suggests health of infauna populations are negatively impacted by this pressure.

Studies of sediment dwelling, sub surface deposit feeding worms, a trait shared by species abundant in this biotope, showed negative impacts from ingestion of micro plastics. For instance, *Arenicola marina* ingests micro-plastics that are present within the sediment it feeds within. Wright *et al.* (2013) carried out a lab study that displayed presence of micro-plastics (5% UPVC) significantly reduced feeding activity when compared to concentrations of 1% UPVC and controls. As a result, *Arenicola marina* showed significantly decreased energy reserves (by 50%), took longer to digest food, and decreased bioturbation levels. These effects would be likely to impact colonisation of sediment by other species, reducing diversity in the biotopes the species occurs within. Wright *et al.* (2013) also present a case study based on their results, that in the intertidal regions of the Wadden Sea, where *Arenicola marina* is an important ecosystem engineer, *Arenicola marina* could ingest 33m□; of micro plastics a year.

In a similar experiment, Browne *et al.* (2013) exposed *Arenicola marina* to sediments with 5% PVC particles or sand presorbed with pollutants nonylophenol and phenanthrene for 10 days. PVC is dense and sinks to the sediment. The experiment used Both microplastics and sand transferred the pollutants into the tissues of the lugworm by absorption through the gut. The worms accumulated over 250% more of these pollutants from sand than from the PVC particulates. The lugworms were also exposed to PVC particulates presorbed with plastic additive, the flame retardant PBDE-47 and antimicrobial Triclosan. The worms accumulated up to 3,500% of the concentration of theses contaminants when compared when to the experimental sediment. Clean sand and PVC with contaminants reduced feeding but PVC with Triclosan reduced feeding by over 65%. In the PVC with Triclosan treatments 55% of the lugworms died. Browne *et al.*, 2013 concluded that the contaminants tested reduced feeding, immunity, response to oxidative stress, and survival (in the case of Triclosan).

Sensitivity assessment. Impacts from the pressure 'litter' would depend upon the exact form of litter and the extent. In the case of marine litter in the form of cigarette butts or micro plastics health of populations of characterizing species would be impacted. Significant impacts have been shown in laboratory studies but impacts at biotope scales are still unknown and this pressure is 'Not assessed'.

Electromagnetic changes	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 was found

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

Species within the biotope can probably detect vibrations caused by noise and in response may retreat into the sediment for protection. However, at the benchmark level, the community is unlikely to be respond to noise and therefore is **Not sensitive.**

Introduction of light or shading	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low

All characterizing species live in the sediment and do not rely on light levels directly to feed or so limited direct impact is expected. As this biotope is not characterized by the presence of primary producers it is not considered that shading would alter the character of the habitat directly.

Beneath shading structures, there may be changes in microphytobenthos abundance. This biotope may support microphytobenthos on the sediment surface and within the sediment. Mucilaginous secretions produced by these algae may stabilise fine substrata (Tait & Dipper, 1998). Shading will prevent photosynthesis leading to death or migration of sediment microalgae altering sediment cohesion and food supply to deposit feeders like *Arenicola* and synaptid holothurians, although they fed on a range of organic matter within the sediment.

Sensitivity assessment. Therefore, biotope resistance is assessed as '**High**' and resilience is assessed as '**High**' (by default) and the biotope is considered to be '**Not sensitive'**.

Barrier to species movement	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 - this pressure is considered applicable to mobile species, e.g. fish and marine mammals rather than seabed habitats. Physical and hydrographic barriers may limit the dispersal of seed. But seed dispersal is not considered under the pressure definition and benchmark.

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.

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

Not relevant.

Biological Pressures

	Resistance	Resilience	Sensitivity
Genetic modification & translocation of indigenous species	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

Important characterizing species within this biotope are not genetically modified or translocated. Therefore, this pressure is considered 'Not relevant' to this biotope group.

Introduction or spread of invasive non-indigenous species	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

No evidence.

Introduction of microbial pathogens	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

Parasitic worms, trematodes, cestodes and nematodes can reduce growth and fecundity in bivalves and may in some instances cause death (Dame, 1996). Bacterial diseases are more significant in the larval stages and protozoans are the most common cause of epizootic outbreaks leading to mass mortalities of bivalves.

In the Danish Wadden Sea, a dense field of *Corophium volutator* disappeared completely, and the density of the mud snail *Hydrobia ulvae* declined by 40 % during spring 1990 as a result of an epizootic by trematodes. High spring temperature accelerated both the development rate and the release of infective larval stages of an infectious trematode from the snail. This event coincided with a high positive NAO index, high temperatures, strong winds, and increased precipitation in northern Europe (Mouritsen & Poulin, 2002a, and references therein). The transmission rates of larval parasites from snail to amphipods and the rate of parasite-induced amphipod mortality are both strong positive functions of temperature (Jensen & Mouritsen, 1992). Using a simulation model, Mouritsen *et al.* (2005) demonstrated that a 3.8 °C increase in ambient temperature would probably result in a parasite induced collapse of the amphipod population in the Wadden Sea.

Marine oligochaetes host numerous protozoan parasites without apparent pathogenic effects even at high infestation levels (Giere & Pfannkuche, 1982 and references therein)

Sensitivity assessment. Outbreaks of pathogens and parasites may occur in this biotope and lead to changes in species abundance and composition. Biotope resistance is assessed as 'Medium' as the evidence suggests that infections are species-specific and changes in abundance are unlikely to result in biotope classification. Resilience is assessed as 'High' and biotope sensitivity is assessed as 'Low'.

Removal of target species	Low Q: High A: Medium C: Medium	Medium Q: High A: High C: High	Medium Q: High A: Medium C: Medium

Within this biotope the polychaete *Hediste diversicolor* may be targeted recreationally or commercially. The lagoon cockle *Cerastoderma glaucum* is targeted in some parts of its range and may be harvested but no evidence was found.

Smaller scale extraction of patches of substratum through activities such as bait digging for *Hediste diversicolor* may have impacts over finer spatial scales within the biotope. If the impact is not spread over a larger area the effects are likely to occur within the dug area. However, Neves de Carvalho *et al.* (2013) calculated that bait digging activities in the Douro estuary, Portugal may remove up to 9.9 tonnes of *Hediste diversicolor*.

Corophium species are affected by sediment disturbance from deposit feeders and removal of *Cerastoderma glaucum* may be beneficial for these species. The sediment turnover caused by cockles and other deposit feeders and burrower disturbs the burrows of *Corophium volutator*. This can lead to a significant negative effect on *Corophium volutator* density as a result of increased rate of swimming making the amphipod more vulnerable to predation (Flach & de Bruin, 1993, 1994). *Cerastoderma edule* can entrain large amounts of settling bivalve (40% -André & Rosenberg, 1991): removal of *Cerastoderma glaucum* may enhance recruitment of other species as it is likely to also consumes larvae.

Sensitivity assessment. Recreational bait digging may remove a proportion of the population of *Hediste diversicolor* and *Arenicola*. The physical effects of removal are addressed under penetration above. *Arenicola marina* is a bioturbator and ecosystem engineer and its removal would probably have a significant effect on the nature of the sediment and the other species that could inhabit the sediment. As both species are relatively sedentary and targeted removal is likely to remove large proportions of the population, a resistance of **Low** is suggested. Resilience is probably **Medium**, due to the isolated nature of the sea lochs and lagoons in which this biotope if found, and sensitivity is assessed as **Medium**. This biotope occurs in the sublittoral fringe and this may limit targeted removal where the biotope is never exposed during the tidal cycle.

Removal of non-target species	Low Q: Low A: NR C: NR	Medium Q: High A: High C: High	Medium Q: Low A: Low C: Low

Incidental removal of the characterizing species would alter the character of the biotope and the delivery of ecosystem services such as secondary production and bioturbation.

Many lagoons are important feeding areas for birds (Barnes, 1994) and removal of species such as *Hydrobia ulvae*, *Cerastodoerma glaucum* and Corophium spp. will alter food supply. The removal of *Cladophora* could remove refugia enhancing predation on species (Barnes, 1994). Juvenile *Cerastoderma glaucum* inhabit *Chaetomorpha linum* and other vegetation before settling on sediments (Ivell, 1979), removal of algae will therefore remove habitat for juveniles. Populations of oligochaetes provide food for macroinvertebrates fish and birds. For example up to 67% of flounder and plaice stomachs examined from the Medway estuary (UK) (Van den Broek, 1978) contained the remains of *Tubificoides benedii* (studied as *Peloscolex benedeni)* and shrimps which in turn support higher trophic levels (predatory birds and fish). For some migratory birds the characterizing oligochaetes can form an important part of the diet during winter (Bagheri & McLusky, 1984). Polychaetes and crustaceans are also predators of oligochaetes and may significantly reduce numbers (Giere & Pfannkuche, 1982 and references therein). The loss of the oligochaete population could, therefore, impact other trophic levels.

Sensitivity assessment. Removal of the characterizing species would alter the character of the biotope. Resistance is therefore assessed as ‘Low’ and resilience as ‘Medium’ so that sensitivity is categorised as ‘Low’.

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