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Hediste diversicolor and *Corophium volutator* in littoral gravelly sandy mud

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

Dr Heidi Tillin & Dr Matt Ashley

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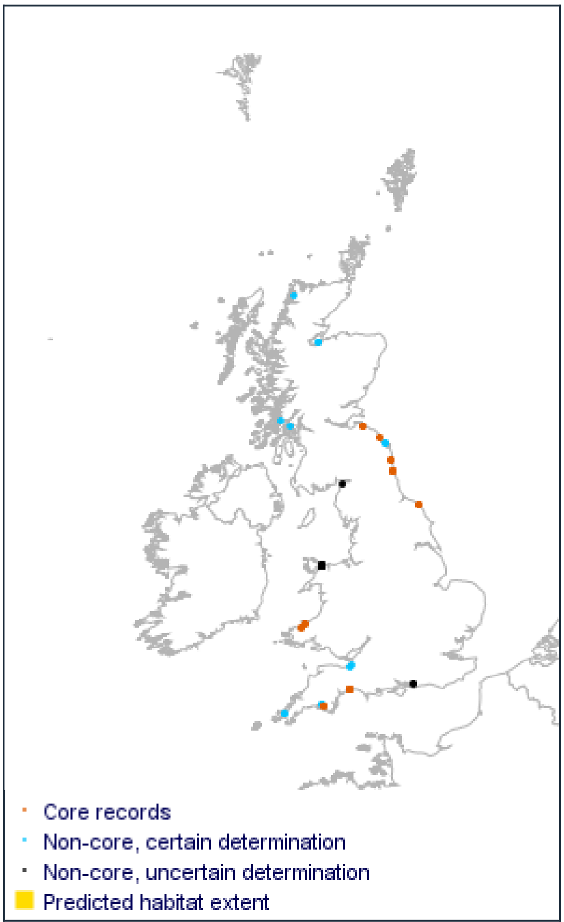

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Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

Researched by Dr Heidi Tillin & Dr Matt Ashley **Refereed by** Admin

Summary

UK and Ireland classification

EUNIS 2008	A2.4115	*Hediste diversicolor* and *Corophium volutator* in littoral gravelly sandy mud
JNCC 2015	LS.LMx.GvMu.HedMx.Cvol	*Hediste diversicolor* and *Corophium volutator* in littoral gravelly sandy mud
JNCC 2004	LS.LMx.GvMu.HedMx.Cvol	*Hediste diversicolor* and *Corophium volutator* in littoral gravelly sandy mud
1997 Biotope		

Description

Extremely sheltered gravelly sandy mud, subject to variable or reduced salinity. The infaunal community consists of the ragworm *Hediste diversicolor*, *Streblospio shrubsolii*, *Capitella capitata* and *Manayunkia aestuarina*. Oligochaetes and *Corophium volutator* are abundant. Given the low sample numbers for this biotope, more records are needed to confirm the characterizing species list. (Information from Connor *et al.*, 2004; JNCC, 2015).

Depth range

Upper shore, Mid shore, Lower shore

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 is characterized by the ragworm *Hediste diversicolor and Corophium volutator* (JNCC, 2015) and the sensitivity assessments, therefore, focus on these species and the key factors that structure this biotope and the characterizing assemblages (mixed sediments and variable or reduced salinity). The assessments also consider the sensitivity of the characterizing polychaetes *Streblospio shrubsolii*, and oligochaetes, including *Baltidrilus costata* (formerly *Heterochaeta costata*) and *Tubificoides* spp.

Resilience and recovery rates of habitat

When impacted this biotope may recover through repair of damaged individuals, adult migration by mobile species and recolonization by pelagic larvae. Resilience of the biological assemblage that characterises this biotope is assessed as 'High' (within 2 years) for most small-scale disturbances that do not require habitat recovery. The resilience assessment is based on species biological traits and examples from experiments and observations of imapcts and recovery from human activities.

The ability of postlarvae, larger juveniles, and adults of the key characterizing species *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. Such passive dispersal alone suggested that recolonization of disturbed sediments was likely to occur rapidly, depending upon larvae transport pathways.

Generally *Hediste diversicolor* is reported to reach maturity between one and three years of age, like other Nereidae, *Hediste diversicolor* are monotelic, that is, they reproduce only once in their lifetime and then die (Olive & Garwood, 1981). Mature males crawl around outside in search of a mature female and discharge sperm through the nephridia, directly outside her burrow. Direct contact between the sexes is not a necessity. Sperm is drawn into the burrow by females and fertilized eggs remain inside the burrow protected by the female. Both sexes die shortly after spawning. The trait to lay and protect eggs within a burrow is likely to increase the time populations recover from pressures that affect the sediment, such as sediment removal, as both adults and eggs will be affected. The pelagic larval dispersal phase is short (Scaps, 2002).

Populations appear to show local characteristics in terms of spawning periods. Spawning may be limited to a short period in spring or extend over the summer. In the Thames Estuary, Dales (1950) reported specimens growing to maturity within one year, spawning in February, with some individuals surviving up to 18 months. Mettam *et al.* (1982), reported that *Hediste diversicolor* from the Severn Estuary matured rapidly in the spring and spawned at two years old. Olive & Garwood (1981), found that females in the Blyth Estuary, Northumberland, were in their second year before eggs began to appear, so most probably spawned in their third year.

Some examples of recovery of populations in similar habitats to the assessed biotope have been found.

1. The effects of a pipeline construction on benthic invertebrates were investigated using a Before/After impact protocol at Clonakilty Bay, West Cork, Ireland. Benthic invertebrates

were sampled once before the excavation and at one, two, three and six months after the completion of the work. An impact was obvious in the construction site in that no live invertebrates were found at one month after disturbance, but there followed a gradual recolonization by *Hediste diversicolor*. At six months after the disturbance, there was no significant difference in the mean number of total individuals (of all species) per core sample amongst all study sites, but the apparent recovery in the impacted area was due to recovery of *Hediste diversicolor* and *Tubifex* spp. (Lewis *et al*., 2002b).

2. Bolam *et al*. (2004) experimentally simulated (in the field) the effect of dredged material emplacement (beach recharge) by manipulating defaunated sediments. Macrofaunal sampling was carried out after 1 week and after 1, 3, 6 and 12 months. Recolonization patterns were found to be species specific: abundances of the polychaete *Hediste diversicolor* and the gastropod *Hydrobia ulvae* recovered to ambient levels within one week.

In general, recovery of Hedis*te diversicolor* populations from impacts appears to be relatively rapid. Recovery will be enhanced where adult migration (active or passive) can transport adults from adjacent, unimpacted habitats. Where a large area is severely impacted, however, recovery may require longer time-scales.

Corophium volutator is a mud shrimp with a long slender body up to 11 mm in length. The amphipod occupies semi-permanent U-shaped burrows up to 5 cm deep (Meadows & Reid, 1966) in the fine sediments of mud flats, saltmarsh pools and brackish ditches. It 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 warmer regions where *Corophium volutator* is found, juveniles can mature in 2 months (Fish & Mills, 1979) and add their own broods to the population. The juveniles born in May undergo rapid growth and maturation to reproduce from July to September and generate the next overwintering population (Fish & Mills, 1979).

Corophium volutator is one of the most abundant organisms in estuarine mudflats reaching densities of 100,000 m^{-2} in the Stour Estuary, Suffolk (Hughes, 1988). Densities vary with geographical region and season, having been reported to rise considerably during the summer months in Gullmarsfjorden, Wadden Sea, and in the Crouch Estuary in southeast England (Flach & De Bruin, 1993; Gerdol & Hughes, 1993).

The polychaete Streblospio shrubsolii and the oligochaete *Tubificoides benedii* are considered opportunistic species and exhibit short lifespans and fast growth rates. *Streblospio shrubsolii* displays a flexible life history and is viewed as an indicator species: the presence of high abundances indicate a stressed environment (Borja *et al*., 2000).*Tubificoides benedii* is likely to rapidly increase in abundance in disturbed sediments and polluted conditions (Gray *et al*., 1990; Borja *et al*., 2000; Gogina *et al*., 2010). 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 *Tubificoides benedii* and *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). 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 colonizing 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 been observed in the tubificid oligochaete *Baltidrilus costata (Tubifex costatus)* which appeared in upper sediment layers in experimentally defaunated patches ($4m^2$) after 3 weeks (Gamenick *et al*., 1996).

Resilience assessment. Biotope resilience is assessed as 'High' (within 2 years), where resistance is 'High', 'Medium' or 'Low'. Resilience is assessed as 'Medium' (2-10 years) where resistance is 'None' and habitat recovery may also be required.

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)	High Q: High A: High C: High	High Q: High A: High C: High	Medium Q: High A: High C: High

Hediste diversicolor and other important characterizing species are adapted to living within the intertidal zone where temperatures fluctuate. Some resistance to temperature fluctuations is achieved by burying within the sediment, which buffers against acute temperature changes over the tidal cycle. the sensitivity assessment for this pressure is largely based on geographic range as a proxy for thermal tolerances, laboratory experiements and field observations.

The geographic range of *Hediste diversicolor* (throughout north-west Europe on the Baltic Sea, North Sea and along Atlantic coasts to the Mediterranean) suggests that it is tolerant 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 in Black Sea lagoons (>25°C) (Smith, 1977). *Hediste diversicolor* were not strongly affected by heat waves in an estuary in north western Portugal, where temperatures reached 40°C in intertidal pools (higher temperatures than experienced around UK and Irish coasts) (Dolbeth *et al.*, 2011). Grilo *et al.*, 2011) found that at a Portuguese site, surface deposit feeders gradually decreased in periods of higher temperatures. However, sub-surface deposit feeders became dominant for up to three years after heat wave conditions had passed.

Temperature change may adversely affect reproduction of *Hediste diversicolor*. 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 mature specimens die shortly after gamete release.

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).

Tubificoides benedii increased in abundance in mudflat habitats in Jade Bay, North Sea between 1930 and 2009 (Schueckel & Kroencke, 2013). Climate warming as well as decreasing nutrient loads and species introductions have occurred in the region since the 1970s, suggesting the species may adapt to temperature increases at benchmark pressures.Bamber & Spencer (1984) observed that *Tubificoide*s 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. Increased temperature was found to trigger the onset of reproduction in *Baltidrilus costata* (studied as *Tubifex costatus*) in the Thames (Birtwell & Arthur, 1980). This effect was non-lethal and may be beneficial to populations.

Streblospio shrubsolii have been shown to reproduce in a temperature range of 7.5°C – 30°C with highest reproduction levels occurring between 16°C – 21°C (Levin & Creed, 1986, Dafonsecagenevois & Cazaux, 1987, Chu & Levin, 1989, Lardicci *et al.*, 1997). The evidence was based on Mediterranean sites, limiting confidence for UK and Irish seas. The timing of reproduction and growth, although occurring throughout the year, increased in late spring and early summer but were strongly reduced during periods of higher temperatures in summer and disappeared or were strongly reduced at lower temperatures in winter (Lardicci *et al.*, 1997). The timing of growth and reproduction in *Streblospio shrubsolii* depended on the synergistic effects of temperature and photoperiod, so that cues may differ at locations at different latitudes (Chu & Levin, 1989). Both a 5°C increase in temp for one month period, or 2°C for one year are within the temperature range reproduction occurs within (7.5°C – 30°C) and within the temperature range where highest reproduction levels occur (16°C – 21°C), suggesting limited impact from the pressure at benchmark pressures is likely.

Sensitivity assessment. Typical surface water temperatures around the UK coast vary, seasonally from 4-19°C (Huthnance, 2010). It is likely that the important characteristic species are able to resist a long-term increase in temperature of 2°C and may resist a short-term increase of 5°C. *Limecola balthica* may retreat north as a result of long-term warming and climate change. However, the important characterizing species *Hediste diversicolor* are likely to survive a 5°C increase in temp for one month period, or 2°C for one year, although reproductive activities may be impacted. For instance, without colder winters spawning may not be synchronised and so recruitment would be reduced. A resistance of **'High'**, a resilience of **'High'** (as longer lived later maturing species are present) and a sensitivity of **'Not sensitive'** have been assigned.

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

A decrease in temperature has been shown to be indirectly beneficial to *Hediste diversicolor*, as case studies report a reduction in numbers of the species' predators. For instance, a severe winter in the Wadden Sea in 1995/1996 saw an increased abundance of *Hediste diversicolor* coincident with a reduction in the numbers of *Carcinus maenus* and *Crangon crangon* (Armonies *et al.*, 2001). A similar increase in abundance was noted in the same area between 1978 and 1987 after a series of cold winters (mean *Hediste diversicolor* density increased from 24/m^2 to 151/m^2 respectively) (Beukema, 1990). Decreased temperatures throughout the year may, however, limit reproduction. Bartels-Hardege & Zeeck (1990) induced spawning in the laboratory, in specimens of *Hediste diversicolor* from tidal flats of the Jadebusen (North Sea), outside the normal spawning period of early spring. Temperatures were not lowered to simulate winter conditions but maintained at 16°C. Mature specimens appeared after four weeks and released gametes after a further four weeks according to a semilunar cycle. Reproduction was sustained for a period of four months. Such an extended spawning was witnessed on the Jadebusen following an unusually warm winter. Spawning occurred from February until May and was less synchronized. In contrast, the same population spawned within two months (February - March) following lower winter temperatures in another year. They concluded that not only a threshold temperature was important for synchronized spawning but the timing of the rise in temperature following winter was also a significant factor (Bartels-Hardege & Zeeck, 1990). A reduced rise in temperature is likely to limit this factor.

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).

Streblospio shrubsolii has been shown to reproduce in a temperature range of 7.5°C – 30°C with highest reproduction levels occurring between 16°C – 21°C (Levin & Creed, 1986, Da Fonseca-Genevois & Cazaux, 1987, Chu & Levin, 1989, Lardicci *et al.*, 1997). Reproductive activity disappeared or strongly reduced at lower temperatures in winter in a Mediterranean case study (Lardicci *et al.*, 1997), this case study suggests reproduction would be delayed in UK and Irish populations that experienced both a 5°C decrease in temp for one month period, or 2°C for one year.

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).

Sensitivity assessment. The important characterizing species show limited impacts and, potentially, benefits to abundance and recruitment from decreases in temperature. Therefore, a 5°C decrease in temp for one month period, or 2°C for one year is likely to have limited negative impact on all characterizing species in the biotope, within British and Irish seas. Hence, resistance is assessed as **'High'**, resilience is assessed as **'High'**, and sensitivity as **'Not Sensitive'**.

Salinity increase (local)	High Q: High A: High C: High	High Q: High A: High C: High	Not sensitive Q: High A: High C: High

The biotope occurs in variable (18-35 ppt) salinity, the change in salinity assessed as the benchmark is to full salinity (30-35 ppt). The available evidence (summarised below) suggests that the characterizing species are tolerant of an increase to full salinity. The restriction of this biotope to variable or reduced salinity is most likely due to the requirement for shelter from wave action rather than salinity regime.

As higher salinity examples of sheltered muddy gravels tend to be more species rich than lower salinity, upper estuarine habitats (Maddock, 2008), it is likely that an increase in salinity at the pressure benchmark will lead to an increase in species richness. An increase at the pressure benchmark may, therefore, lead to the development of the variant sub-biotope LS.LMx.GvMu.HedMx.Scr that occurs in full salinity, or the biotope mayclassification may not change but be more species rich (where wave action and flows do not increase).

Hediste diversicolor, the key characterizing species, occurs across all variant sub-biotopes and as such is resistant to the salinity range, from reduced to full, that the various sub-biotopes occur within. *Hediste diversicolor* is a euryhaline species, able to tolerate a range of salinities from fully marine seawater down to 5 psu or less (Barnes, 1994).

Streblospio shrubsolii occurred in subtidal areas of the Thames estuary as well as intertidal flats, suggesting the species is resistant to higher salinities than the 'variable' levels occurring higher in estuaries (Attrill, 1998). Likewise *Tubificoides benedii* has been recorded in high abundance in offshore areas of the North Sea (Gray *et al.*, 1990). Although evidence was limited on response of these species to rapid increases in salinity it is likely they would be resistant to an increase to the fully marine category (30-40 ‰).

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. *Hediste diversicolor* and other characterizing species are likely to tolerate increased salinity levels above the reduced and variable levels encountered in the biotope and variant sub-biotopes. Biotope resistance is, therefore, assessed as **'High'** and resilience as **'High'** (by default) and the biotope is considered to be **'Not sensitive'**. In locations with extremely sheltered conditions and gravelly mud is present where the biotope LS.LMx.GvMu.HedMx.Scr characterized by *Hediste diversicolor* and *Scrobicularia plana* occurs it is possible a transition to this variant sub-biotope will occur. However, sediment is more likely to be a stronger factor influencing community structure.

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

The biotope occurs in variable (18-35 ppt) salinity, (JNCC, 2015), the decrease in salinity assessed at the benchmark is to low salinity (<18 ppt). The available evidence (summarised below) suggests that the characterizing species are tolerant of a short-term decrease to low salinity.

The key characterizing species *Hediste diversicolor* is known to tolerate low salinities below 18-24 psu and it has been shown to replace *Arenicola marina* in areas influenced by freshwater runoff or input (e.g. the head end of estuaries) (Barnes; 1994; Hayward, 1994). Lower salinities (<8 psu) can, however, have an adverse effect on *Hediste diversicolor* reproduction (Ozoh & Jones, 1990; Smith 1964). Fertilization in *Hediste diversicolor* is adapted to high salinity but not to low salinity below 7.63‰ (Ozoh & Jones, 1990). A decrease in salinity at the benchmark pressure (reduction to <18‰) may negatively impact recruitment and abundance if the dilution is close to that threshold.

Conde *et al.* (2013) found that *Streblospio shrubsolii* were a dominant species in low salinity, estuarine conditions (5-9‰) in the Tagus estuary, Portugal. In Ria de Averio, western Portugal *Streblospio shrubsolii and Tubificoides benedii* were characterizing species of communities in estuarine sample sites further upstream with lower salinity, suggesting a high resistance to a decrease in salinity (Rodrigues *et al*., 2011). Numerous studies suggest that the oligochaete *Baltidrilus costata* tolerates a wide range of salinities from 1‰ to 28‰ (Giere & Pfannkuche, 1982 and references therein), suggesting that this species is likely to still be present in the biotope.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) reduced (SS.SMu.SMuVS.CapTubi; LS.LMu.UEst.Tben) and low (SS.SMu.SMuVS.LhofTtub) habitats (JNCC,2015). In very low salinities from <15 to 0 ‰ species such as *Limnodrilus* spp. and *Tubifex tubifex* are found (Giere & Pfannkuche, 1982). A decrease in salinity at the pressure benchmark would probably result in replacement by oligochaete species more tolerant of lower salinities such as *Limnodrilus hoffmeisteri* and *Tubifex tubifex* that characterize the low salinity biotope SS.SMu.SMuVS.LhofTtub.

Corophium volutator is an exceptionally euryhaline species able to tolerate 2-50 psu (McLusky, 1968) but growth is fastest at 15-20 psu (McLusky, 1970 cited in Meadows & Ruagh, 1981). *Corophium volutator* is a hyperosmotic regulator and the tolerance of its tissues is 13-50 psu but it needs a salinity of above 5 psu in order to moult, since osmoregulation is lost during moulting (McLusky, 1967). A salinity of at least 7.5 psu is required for reproduction (McLusky, 1968).

Changes in salinity may alter population distribution and dynamics as the species is likely to move to more favourable conditions but are very unlikely to cause mortality.

Sensitivity assessment. It is considered likely that a decrease in salinity at the pressure benchmark will lead to some species replacement by polychaetes and oligochaetes more tolerant of low salinity. *Hediste diversicolor*, *Corophium volutator* and oligochaetes are likely to remain. A similar biotope could remain where salinities were close to 18 ppt but a severe reduction in salinity would probably lead to loss of the biotope. Resistance is therefore assessed as **'Low'**. Resilience (following restoration of typical conditions) is '**High'** and sensitivity is assessed as **'Low'**. It should be noted that resistance would be lower, and sensitivity greater, where salinity was reduced to a level close to freshwater.

Water flow (tidal current) changes (local)	Medium Q: Low A: NR C: NR	High Q: High A: Low C: Medium	Low Q: Low A: Low C: Low

Hediste diversicolor characteristically inhabits littoral mudflats predominantly of clay (particles < 4 µm), silt (4-63 µm) and to a lesser extent, very fine sand (63-125 µm) (Jones *et al*., 2000). Highest abundances occur in very weak (negligible) to weak < 1 knot (<0.5 m/sec.) currents. These conditions are provided by this biotope, which occurs in extremely sheltered gravelly mud to gravelly sandy mud on the mid and lower shore.

The type direction and speed of the currents control sediment deposition within an area. Finer sediment will fall to the substratum in weaker currents. An increase in water flow rate would entrain and maintain particles in suspension and erode the mud. As a result the scouring and consequent redistribution of components of the substratum would alter the extent of suitable habitat available to populations of *Hediste diversicolor* and other species in the biotope that prefer finer sediment. Recovery of *Hediste diversicolor* would be influenced by the length of time it would take for the potential habitat to return to a suitable state for recolonization by adult and juvenile specimens from adjacent habitats, and the establishment of a breeding population. Recolonization may take between one and three years, as populations differ in reaching maturity (Dales, 1950; Mettam *et al*., 1982; Olive & Garwood, 1981), from the time that the habitat again becomes suited to the species.

Small *Corophium volutator* cannot resettle after swimming at current speeds approx. 0.1 m/s (Ford & Paterson, 2001), which probably explains why they mainly swim at high tide (Hughes, 1988). An increase in water flow rate could cause swimming *Corophium volutator* to be swept away from suitable habitat and cause high mortality. Decreases in flow rate are not considered to negatively impact *Corophium volutator*.

Experimental increases in near-bed current velocity were achieved over intertidal sandflats by placing flumes on the sediment to accelerate water flows (Zuhlke & Reise, 1994). The increased flow led to the erosion of up to 4cm depth of surface sediments. No significant effect was observed on the abundance of *Capitella capitata* and numbers of *Tubificoides benedii* and *Tubificoides pseudogaster* were unaffected, as they probably avoided suspension by burrowing deeper into sediments. This was demonstrated by the decreased abundance of oligochaetes in the 0-1cm depth layer and increased abundance of oligochaetes deeper in sediments (Zuhlke & Reise, 1994). A single storm event had a similar result with decreased abundance of oligochaetes in surficial layers, coupled with an increase in deeper sediments (Zuhlke & Reise, 1994). Although *Tubificoides* spp. can resist short-term disturbances their absence from sediments exposed to higher levels of disturbance indicate that they would be sensitive to longer-term changes in sediment mobility (Zuhlke & Reise, 1994). Birtwell and Arthur (1980) reported seasonal changes in abundance in *Baltidrilus costata* (as *Tubifex costatus*) which they attributed to erosion of the upper sediment layers caused by high river flows and wave action.

Sensitivity assessment. *Corophium volutator* abundance may be reduced if juveniles are washed from the substratum and adults are not able to resettle. Loss of mud content in some areas is possible and could lead to replacement by another species but this is unlikely at the pressure benchmark levels**.** An increase in flow velocity may alter sediments, resistance has been assessed as '**Medium**', recoverability is assessed as '**High**' and sensitivity is, therefore '**Low**'.

Emergence regime changes	High Q: High A: Medium C: High	High Q: High A: High C: High	Not sensitive Q: High A: Medium C: High

The biotope LS.LMx.GvMu.HedMx.Cvol, occurs from the upper to the lower shore (JNCC, 2015) and changes in emergence are unlikely to affect the biotope where it remains within an intertidal habitat (JNCC, 2015).

Hediste diversicolor inhabits a burrow within the sediment which may be up to 0.3 m deep. The species retreats within the burrow during periods of exposure, protecting it from desiccation although increased emergence may cause a decline in the abundance of *Hediste diversicolor* at the upper limits of the intertidal zone, as they may become stressed by desiccation if the substrata begin to dry and are prone to more extremes of temperature. *Hediste diversicolor* is sufficiently mobile to gradually retreat back to damper substrata. Gogina *et al.* (2010) analysed patterns of benthic community distribution related to selected environmental parameters, including depth, in the western Baltic Sea with depths ranging from 0 m to 31 m. *Hediste diversicolor* displayed a preference for low-saline regions shallower than 18 m. Increased depth had the largest negative effect of all factors influencing distribution and abundance decreased with greater dept) Gogina *et al.* (2010).

Tubificoides benedii is capable of penetrating the substratum to depths of 10 cm, shows a resistance to hypoxia and is often typified as an 'opportunist' that is adapted to the rapid environmental fluctuations and harsh conditions in estuaries (Gogina *et al.*, 2010). Highest abundances were predicted by Gogina *et al.* (2010) to be related to depth with an optimum of 10 m to 20 m. The evidence suggests that abundance may be limited by a decrease in high water level or a change in time (increase) where substratum is not covered by the sea. An increase in the time the biotope is covered by the sea is likely to result in increased abundance of *Tubificoides benedii.*

Opportunistic, deposit feeding polychaetes, such as the characterizing *Streblospio shrubsolii*, tolerate stressful conditions, and often out-compete more sensitive species in inter-tidal environments due to greater tolerances.

Sensitivity assessment. The biotope and characterizing species are found at a range of shore heights and are considered relatively resistant to changes in emergence which do not alter the extent of the intertidal. An increase in emergence is likely to decrease the upper shore extent of *Hediste diversicolor* dominated biotopes at the land-ward extent of the intertidal as desiccation increases. A decrease in emergence under the benchmark pressure is likely to extend the upper extent of the biotope as the species recolonize or migrate to favourable conditions. Biotope resistance is, therefore, assessed as '**High',** recoverability is assessed as '**High'** (by default) and the biotope is considered to be **'Not sensitive'.**

Wave exposure changes (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 in extremely wave sheltered areas (JNCC, 2015). The key characterizing species *Hediste diversicolor* is infaunal, inhabiting a burrow in which it seeks refuge from predators and may partially emerge to seek and capture food. An alteration of factors within the environment that increases wave exposure could cause erosion of the substrata and consequently, loss of habitat.

Sensitivity assessment. Resistance to a change in nearshore significant wave height >3% but <5% of the two main characterizing species *Hediste diversicolor* and *Corophium volutator* is 'High', given that the biotope occurs in very sheltered locations and an increase in nearshore significant wave height of >3% but <5% would continue to result in sheltered conditions which are within the species tolerance limits. At the highest benchmark pressure (5% increase) the species exhibit **'High'** resistance through their traits to live relatively deep in the sediment. Resilience (recoverability) is also '**High**' giving a Sensitivity of **'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. The following review discusses impacts at higher concentrations than the pressure benchmark.

In *Hediste diversicolor* the acute toxicity is dependent on the rate of uptake of the metal, since this determines the speed with which the lethal dose is built up. The rate of intake is important because this determines whether the organism's detoxification mechanisms can regulate internal concentrations. The resistance of *Hediste diversicolor* is thought to be dependent on a complexing system which detoxifies the metal and stores it in the epidermis and nephridia (Bryan & Hummerstone, 1971; McLusky *et al.* 1986).

Hediste diversicolor has been found successfully living in estuarine sediments contaminated with copper ranging from 20 µm Cu/g in low copper areas to >4000 µm Cu/g where mining pollution is encountered e.g. Restronguet Creek, Fal Estuary, Cornwall (Bryan & Hummerstone, 1971). Attempts to change the tolerance of different populations of *Hediste diversicolor* to different sediment concentrations of copper have shown that it is not readily achieved suggesting that increased tolerance to copper has a genetic basis (Bryan & Hummerstone, 1971; Bryan & Gibbs, 1983).

Crompton (1997) reviewed the toxic effect concentrations of metals to marine invertebrates Annelid species, such as *Hediste diversicolor* were found to be at risk if metals exceeded the following concentrations during 4-14 days of exposure: >0.1 mg Hg l^{-1}, > 0.01 mg Cu l^{-1}, > 1 mg Cd l^{-1}, >1 mg Zn l^{-1},>0.1 mg Pb l^{-1}, >1 mg Cr L^{-1}, >1 mg As l^{-1} and >10 mg Ni l^{-1}. In general, for estuarine animals heavy metal toxicity increases as salinity decreases and temperature increases (McLusky *et al.*, 1986). For example, Fernandez & Jones (1990) calculated 96 hour LC_{50} Zinc values for *Hediste diversicolor* at four salinities 5, 10, 17.5 and 30 psu at 12°C. The 96 hour LC_{50} at 17.5 psu and 12°C was 38 mg Zn l^{-1}, while at 5 and 10 psu it was 7 and 19 mg Zn l^{-1} respectively. Toxicity decreased with increasing salinity. When salinity remained constant at 17.5 psu, but temperature varied, the following 96 hour LC_{50} values for Zinc were recorded: 40 mg Zn l^{-1} at 6°C, 32 mg Zn l^{-1} at 12°C and 9.1mg Zn l^{-1} at 20°C. Toxicity increased with increasing temperature. Accumulation of zinc was also greater at the lowest salinities and when the temperature was highest at 20°C. In a parallel experiment, the presence of sediment was found to reduce toxicity and body accumulation of zinc in *Hediste diversicolor*. Recovery of this species would be influenced by the length of time it would take for the potential habitat to return to a suitable state (e.g. factors such as the decline of bioavailable metals within the marine environment), recolonization by adult and juvenile specimens from adjacent habitats, and the establishment of a breeding population. Since juveniles remain in the infauna throughout their development selection for metal tolerance can be expected to be operative from an early stage (Bryan & Gibbs, 1983).

Corophium volutator is highly intolerant of metal pollution at levels often found in estuaries from industrial outfalls and contaminated sewage. A concentration of 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*., 1985). 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; 1985).

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□1copper was supplied at 2-weekly 30% water changes, at the end of which the sediment concentrations of copper in contaminated microcosms reached 411 □g g□1. 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.

Rygg (1985) classified *Tubificoides* spp as highly tolerant species, common at the most copper polluted stations (>200 mg Kg-1) in Norwegian fjords.

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 following review discusses impacts at higher concentrations than the pressure benchmark.

The 1969 West Falmouth (America) spill of Grade 2 diesel fuel documents the effects of hydrocarbons in a sheltered habitat (Suchanek, 1993). The entire benthic fauna including *Hediste diversicolor* was eradicated immediately following the spill and remobilization of oil that continued for a period > 1 year after the spill, contributed to much greater impact upon the habitat than that caused by the initial spill. Effects are likely to be prolonged as hydrocarbons incorporated within the sediment by bioturbation will remain for a long time owing to slow degradation under anoxic conditions. Oil covering the surface and within the sediment will prevent oxygen transport to the infauna and promote anoxia as the infauna utilize oxygen during respiration. Although *Hediste diversicolor* is tolerant of hypoxia and periods of anoxia, a prolonged absence of oxygen will result in the death of it and other infauna. McLusky (1982) found that petrochemical effluents released from a point source to an estuarine intertidal mudflat, caused severe pollution in the immediate vicinity. Beyond 500 m distance the effluent contributed to an enrichment of the fauna in terms of abundance and biomass similar to that reported by Pearson & Rosenberg (1978) for organic pollution, and *Hediste diversicolor* was found amongst an impoverished fauna at 250 m from the discharge.

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.

In Finland, in oligohaline inland waters near an oil refinery, *Baltidrilus costata* (as *Tubifex costatus*) appeared to be sensitive to oil pollution and had completely disappeared from sediments exposed to pollution and did not recolonize during a four year post pollution period (Leppäkoski & Lindström, 1978). *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).

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 following review discusses impacts at higher concentrations than the pressure benchmark.

Reports of the effects of synthetic chemicals on *Hediste diversicolor* illustrate that the intolerance of the species is highly dependent upon the molecular structure of the chemical, which determines the chemicals properties and use. For example:

1. Collier & Pinn (1998) observed significant differences in both the abundance and biomass of a benthic community from the Ythan Estuary, Scotland, experiencing contamination by Ivermectin. Ivermectin is the 22,23-dihydro derivative of avermectin ß which has been shown to be highly efficient in the treatment of sea lice. *Hediste diversicolor* was the most intolerant species to Ivermectin in the benthic community studied. A rapid decline in both abundance and total biomass of *Hediste diversicolor* occurred within 7 days and with increasing concentration. An Ivermectin concentration of 8.0 mg m□ caused 100% mortality within 14 days. Davies *et al*., (1998) modelled factors influencing the

concentration of Ivermectin reaching the seabed which ranged from 2.2 to 6.6 mg m. The upper limit of this range was only slightly less than the concentrations found to be toxic by Collier & Pinn (1998) and Black *et al.* (1997). Davies *et al.*(1998) concluded that there was a significant risk to benthic organisms within a radius of 50 m of salmon farms utilizing Ivermectin and that Ivermectin could accumulate (half life of Ivermectin in marine sediments > 100 days) within the sediment beyond a single treatment and reach toxic levels.

2. In contrast, Craig & Caunter (1990) examined the effects of the organosilicon compound, Polydimethylsiloxane (PDMS) in sediment on *Hediste diversicolor*. PDMS fluids are less dense than water and insoluble and form a discrete layer on the surface of the water. In an intertidal environment PDMS fluids are deposited upon the sediment surface at low tide and into contact with *Hediste diversicolor*. In laboratory tests, exposure to 10,000 mg PDMS per kg of sediment caused no deaths over 96 hours, and exposure to 1,000 mg PDMS per kg of sediment caused no deaths of *Hediste diversicolor* after 28 days.

Recovery of this species would be influenced by the length of time it would take for the potential habitat to return to a suitable state (e.g. factors such as the rate of decay of the synthetic chemical within the marine environment), recolonization by adult and juvenile specimens from adjacent habitats, and the establishment of a breeding population. This may take between one and three years, as populations differ in reaching maturity (Dales, 1950; Mettam *et al*., 1982; Olive & Garwood, 1981), from the time that the habitat again becomes suited to the species.

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 re-phasing 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	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

Beasley & Fowler (1976) and Germain *et al*., (1984) examined the accumulation and transfers of radionuclides in *Hediste diversicolor* from sediments contaminated with americium and plutonium derived from nuclear weapons testing and the release of liquid effluent from a nuclear processing plant. Both concluded that the uptake of radionuclides by *Hediste diversicolor* was small. Beasley & Fowler (1976) found *that Hediste diversicolor* accumulated only 0.05% of the concentration of radionuclides found in the sediment. Both also considered that the predominant contamination pathway for *Hediste diversicolor* was from the interstitial water. However, there is insufficient information available on the biological effects of radionuclides to comment further upon the intolerance of this species to radionuclide contamination.

Corophium volutator readily absorbs radionuclides such as americium and plutonium from water and contaminated sediments (Miramand *et al*., 1982). However, the effect of contamination of the individuals was not known but accumulation through the food chain was assumed (Miramand *et al*., 1982).

Sensitivity assessment. No evidence. Insufficient evidence was available to complete and assessment.

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

The habitats which *Hediste diversicolor* inhabits tend to have lower oxygen levels than other sediments. *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 per litre). *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 mmo1 1-') 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).

The characterizing oligochaetes and polychaetes within the biotope that display tolerance to hypoxia include *Tubificoides benedii* and *Capitella capitata*, (Gogina *et al*., 2010). Exposure to dissolved oxygen concentration of less than or equal to 2 mg/l for 1 week is likely to have limited impact on *Tubificoides benedii* and *Capitella capitata* populations.

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 conditions often occur in estuaries where drifting macroalgae (such as *Fucus* sp.) settle on the mudflats in small patches.

Oligochaete species vary in their tolerance of hypoxia and associated high sulphide levels. Most enchytraeids and naidids are sensitive to hydrogen sulphide and hypoxia while tubificids are often more resistant (Giere, 2006).

Tubificoides benedii has a high capacity to tolerate anoxic conditions, its extreme oxygen tolerance is based on an unusually low respiration rate (Giere *et al.*, 1999). Respiration rates of *Tubificoides benedii* measured at various oxygen concentrations showed that aerobic respiration is maintained even at very low oxygen concentrations (Giere *et al.*, 1999). Birtwell & Arthur (1980) showed that *Tubificoides benedii* could tolerate anoxia in the Thames Estuary (LT_{50} = 58.8 hours at 20^{o}C, 26.6 hours at 25^{o}C and 17.8 hours at 30^{o}C in experiments with worms acclimated to 20^{o}C.)

Tolerance experiments by Gamenick *et al.* (1996) found that *Baltidrilus costata* (as *Heterochaeta costata*) was not affected by hypoxic conditions for at least 3 days but the addition of sulphide 91.96 mmol/litre) caused mortality after 1 day (Gamenick *et al.*, 1996)

Sensitivity assessment. Resistance to exposure to dissolved oxygen concentration of less than or equal to 2 mg/l for 1 week is assessed as 'High' for the characterizing species *Hediste diversicolor*. It is important to consider that other species that are common or abundant in the biotope may be impacted by decreased dissolved oxygen, such as *Corophium volutator* and decreases in abundance of these species are likely. As this biotope is found in intertidal habitats oxygen levels will be recharged during the tidal cycle lowering exposure to this pressure for *Corophium volutator*. Based on the reported tolerances for anoxia and intertidal habitat, biotope resistance is assessed as **'Low'** resilience is assessed as '**High'** and sensitivity is considered to be low at the benchmark level

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

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). Primary production in the biotope will be limited to microalagae at the sediment surface, rather than macroalgae. Changes in primary production as a result of changes in nutrient enrichment are, therefore, not considered likely to directly alter the biotope.

Aberson *et al.* (2016) found nutrient enrichment promotes surface deposit feeding in *Hediste diversicolor*, over suspension feeding and predation. At sewage-polluted sites in three estuaries in SE England *Hediste diversicolor* mainly consumed microphytobenthos, sediment organic matter and filamentous macroalgae *Ulva* spp. At cleaner sites *Hediste diversicolor* relied more on suspension feeding and consumption of *Spartina anglica* (Aberson *et al.*, 2016). Whilst suggesting adaptability to nutrient enrichment this behaviour will increase predation risk.

Nutrient enrichment favours the growth of opportunistic green macro-algae blooms which can cause declines in some species and increases in others (Raffaelli, 2000). Evidence (Beukema, 1989; Reise *et al.*, 1989; Jensen, 1992) suggested a doubling in the abundance of *Hediste diversicolor* in the Dutch Wadden Sea, accompanied by a more frequent occurrence of algal blooms that were attributed to marine eutrophication. Algae may be utilized by *Hediste diversicolor* in its omnivorous diet, so some effects of nutrient enrichment may be beneficial to this species. However, evidence for the effects of algal blooms stimulated by nutrient enrichment on *Hediste diversicolor* is not consistent. Raffaelli (1999) examined a 30 year data base to examine the effect of nutrient enrichment on an estuarine food web in Aberdeenshire, Scotland. This study displayed impacts to species characterizing the biotope from development of algal mats, the density and distribution of which was related to nutrient. In areas where algal biomass was greatest reduced invertebrate densities were recorded. The mud shrimp *Corophium volutator* showed the greatest decrease in density. Densities of *Corophium volutator* and *Hediste diversicolor* were lower in 1990 compared to 1964 at sites where macro-algal mats increased over the same period. Conversely, densities were on average higher in the upper reaches where macroalgal mats were generally absent before 1990 (Raffaelli, 1999). *Capitella capitata* and *Pygospio elegans* abundance were greater in areas that received greatest nutrient enrichment (Raffaelli, 1999). Long-term nutrient enrichment may, therefore, alter the biotope if high biomass of algal mats persists.

In the Ythan Estuary, Scotland, nutrient enrichment causes the mudflats to become covered with algal mats consisting mainly of the gutweed *Ulva intestinalis*. These mats physically perturb *Corophium volutator* by preventing burrowing and normal feeding. In areas where the mats did not occur, the density of *Corophium volutator* was 11 times higher than under the algae. When the algae died back in the winter, the areas were rapidly recolonized by *Corophium volutator* from adjacent patches where the gutweed could not grow and population growth was high from feeding on the rotting algae. In the spring, the gutweed returned and the *Corophium volutator* were excluded once again (Raffaelli *et al.*, 1991).

Sensitivity assessment. The benchmark is relatively protective and is not set at a level that would allow blooms of green algae on the sediment, based on this consideration and based on the lack of primary producers structuring the biotope, resistance is assessed as **'High**' and resilience as **'High'** (by default), so that the biotope is assessed as **'Not sensitive'.**

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

All species apart from two that are abundant in the biotope are classed in a Marine Biotic Index as being indifferent to, tolerating or proliferating under organic enrichment conditions (Borja *et al.*, 2000). Only *Manayunkia aestuarina* are recorded as being sensitive to organic enrichment. Borja *et al*. (2000) and Gittenberger & Van Loon (2011) both assigned *Corophium volutator* to 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).

In Ria de Averio, western Portugal *Streblospio shrubsolii and Tubificoides benedii* were characterizing species of communities further upstream in estuarine sample sites, at sites with increased organic matter (Rodrigues *et al.*, 2011). *Streblospio shrubsolii* are also considered characteristic species communities in polluted environments, suggesting the species is likely to be resistant to increased organic enrichment (Cooksey & Hyland, 2007).

Tubificoides benedii and *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. *Tubificoides benedii* are abundant in mussel beds (mussel relaying may be the source of smothering) which has been attributed to their tolerance of organically rich deoxygenated sediment (Commito & Boncavage, 1989). *Tubificoides benedii* has also been found in elevated abundances in areas of organic enrichment around fish farms (Haskoning, 2006).

Sensitivity assessment. At the benchmark levels, a resistance of '**High**' as the main characterizing species *Hediste diversicolor* is tolerant of organic enrichment and an input at the pressure benchmark is considered unlikely to lead to gross pollution effects . A resilience of '**High**' is assigned (by default) and the biotope is assessed as '**Not sensitive'**.

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

This biotope and sub-biotopes is only found in sediment, in particular, gravelly sandy mud or gravelly mud (JNCC, 2015). The burrowing organisms characterizing this biotope, including *Hediste diversicolor* would not be able to survive if the substratum type was changed to either a soft rock or hard artificial type. Consequently, the biotope would be lost altogether if such a change occurred.

Sensitivity assessment. Biotope resistance is assessed as '**None',** resilience is '**Very low'** (as the change at the pressure benchmark is permanent) and biotope sensitivity is '**High'**.

Physical change (to another sediment type)	Low Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High

The benchmark for this pressure refers to a change in one Folk class. The pressure benchmark originally developed by Tillin *et al.* (2010) used the modified Folk triangle developed by Long (2006) which simplified sediment types into four categories: mud and sandy mud, sand and muddy sand, mixed sediments and coarse sediments. The change referred to is, therefore, a change in sediment classification rather than a change in the finer-scale original Folk categories (Folk, 1954). At the pressure benchmark a change in sediment to sandy mud and muddy sand and muds and increased coarse sediment content (to gravels or sands) is considered. The biotope occurs in gravelly sandy mud and the variant sub biotopes show some variation in species communities and sediment type (JNCC, 2015) so changes in proportion of finer or coarser sediments may lead to some biotope reversions between the sub-biotopes.

1. Decrease of gravel content is likely to lead to change to comparable mud dominated

biotopes. Where LS.LMx.GvMu.HedMx occurs it is commonly found with patches of mud and there are broad transition areas between this biotope and the corresponding muddy sediment biotopes (LS.LMu.UEst.Hed.Col. A change to finer sediemnts is therefore likely to lead to biotope reclassification but some of the key characterizing species, including H*ediste diversicolor* may remain.

2. An increase in gravel and a change to clean sands or coarse sediments is likely to have a more significant effect as sediment cohesion and ability to retain organic matter and water is reduced altering habitat suitability for burrowing polychaetes and amphipods and deposit feeders.

Hediste diversicolor is infaunal and is reliant upon a muddy/sandy sediment in which to burrow. *Hediste diversicolor* has been identified in other intertidal sediments including gravels, clays and even turf (Clay, 1967; Scaps, 2002), although abundance may be reduced in these habitats. *Limecola balthica* is likely to tolerate increased gravel content as sediment was not shown to affect burrowing (Tallqvist, 2001), however, growth, shell size and body mass were greatest in higher sand content sediment and lower in higher gravel content sediments (Azouzi *et al.* 2002), suggesting long-term health and abundance may be affected by a permanent increase in gravel content. Conde *et al.* (2011) compared recruitment of *Scrobicularia plana* to excavated and un-excavated control plots (expected to enhance the deposition of bivalve spat if the settlement of bivalves was the result of a passive process) at different shore levels in Portugal. Juveniles were found to avoid excavated plots, showing significantly higher abundance in control plots. The data strongly suggested that recruited bivalves actively avoid unsuitable substrata, including an increased gravel fraction.

Silva *et al.* (2006) found *Streblospio shrubsolii* in an estuarine site in western Portugal, were more closely associated with increasing mud content and decreasing gravel content.

Oligochaete dominated biotopes occur in a range of sedimentary habitats, where variable or reduced salinity prevent a more species-rich assemblage developing. Although the lack of identification to species level has hampered understanding of species preferences (and the species that typically occur in this biotope) it is clear that at least some species exhibit strong preferences for sediment type. *Tubificoides heterochaetu*s for example, sampled in South Carolina salt marsh and tidal inlets was found in significantly greater abundances in coarser sediments where silt and clay fractions were lower (Gillett et al., 2007).

Sensitivity assessment. An increase in mud content is likely to lead to a change to comparable mud dominated biotopes. Case studies display decreasing abundance with increased gravel content of *Hediste diversicolor*. Abundance of polychaetes is likely to depend on each species tolerance of increasing gravel content, with species, such as *Pygospio elegans*, that can exploit the conditions increasing in abundance but other species decreasing in abundance. Resistance to a change in one Folk class is assessed as **'Low'** as changes in sediment will alter the biotope character although some characterizing species may remain. Resilience is assessed as **'Very Low**' as a change at the benchmark is permanent. The sensitivity of the biotope overall is, therefore, considered to be '**High**'.

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

The substratum of this biotope consists of gravelly sandy mud or gravelly mud (Conner *et al.*, 2004). The characterizing infaunal species, including burrow into the sediment, to depths not exceeding 30 cm. The process of extraction is considered to remove all biological components of the biotope group in the impact footprint and the sediment habitat.

Sensitivity assessment. Resistance to extraction of substratum to 30 cm across the entire biotope is assessed as **'None'** based on expert judgment but supported by the literature relating to the position of these species on or within the seabed and literature on impacts of dredging and bait digging activities (see penetration and disturbance pressure). At the pressure benchmark the exposed sediments are considered to be suitable for recolonization almost immediately following extraction. Recovery will be mediated by the scale of the disturbance and the suitability of the sedimentary habitat, biotope resilience is assessed as **'High'** (based on recolonization by adults and pelagic larvae) and biotope sensitivity is assessed as '**Medium'.**

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

Muddy sand sediments, in general, tend to be cohesive although high levels of water content will reduce this and destabilise sediments. Sediment cohesion provides some sediment stabilisation to resist erosion following surface disturbance. The characterizing species associated with this biotope are infaunal and hence have some protection against surface disturbance, although siphons of bivalves and tubes of the sedentary polychaete *Pygospio elegans*, may project above the sediment surface. Damage to tubes and siphons would require repair. The snail *Hydroia ulvae* is present on the surface and abrasion may result in burial or damage to this species.

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).

The burrowing life habits of *Corophium volutator* are likely to provide some protection from abrasion at the surface only. However, any abrasion or physical disturbance is likely to reduce the density of *Corophium volutator* through emigration and increased mortality. For example, the sediment turnover caused by cockles and lugworms disturbed the burrows of *Corophium volutator* and caused 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).

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. 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 m^2 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).

Sensitivity assessment. Resistance is assessed as '**Medium',** as abrasion is unlikely to affect high numbers of infaunal burrowing species such as the key characterizing species *Hediste diversicolor* and the oligochaetes but the key characterizing species *Corophium volutator* is likely to be affected. Resilience is assessed as '**High'** and biotope sensitivity is assessed as **'Low'.**

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

As the characterizing species are burrowing species, the impact from damage to the sub-surface sea bed would be greater than damage to the sea bed surface only (see abrasion pressure). A number of studies have assessed the impacts of activities resulting in penetration and disturbance of sediments on the characterizing species in similar habitats. The characterizing species have some protective traits such as infaunal life habit, with deeper burrowing species less exposed.

The effects of pipeline construction on benthic invertebrates were also investigated using a Before/After impact protocol at Clonakilty Bay, West Cork, Ireland. Benthic invertebrates were sampled once before the excavation and at one, two, three and six months after the completion of the work. Invertebrate samples were dominated *by Hediste diversicolor*, *Scrobicularia plana* and *Tubifex* spp. An impact was obvious in the construction site in that no live invertebrates were found at one month after disturbance, but there followed a gradual recolonisation by *Hediste diversicolor*. At six months after the disturbance there was no significant difference in the mean number of total individuals (of all species) per core sample amongst all study sites, but the apparent recovery in the impacted area was due to two taxa only, *Hediste diversicolor* and *Tubifex* spp. (Lewis *et al*., 2002).

Corophium volutator burrows to 5 cm deep and is also likely to be removed. However, 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.

Tubificoides benedii can be relatively deeply buried and could avoid direct exposure to penetration and disturbance of upper sediment layers although sediment disturbance and compaction could damage these soft-bodied species and oligochaetes in general are not found in high abundances in sediments with high levels of disturbance from wave action. 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 m^2 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). These results are supported by observations that two experimental passes of an oyster dredge that removed the sediment to a depth of between 15-20 cm did not significantly affect *Tubifcoides benedii* (EMU, 1992).

Sensitivity assessment. Resistance of the biotope is assessed as **'Low'**, although the significance of the impact for the bed will depend on the spatial scale of the pressure footprint. Resilience is assessed as '**High**', and sensitivity is assessed as '**Low'**.

Changes in suspended solids (water clarity)	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low

Changes in light penetration or attenuation associated with this pressure are not relevant to *Hediste diversicolor* biotopes. As the species live in the sediment or in turbid estuarine environments, they are also likely to be adapted to increased suspended sediment (and turbidity). However, alterations in the availability of food or the energetic costs in obtaining food or changes in scour could either increase or decrease habitat suitability for the characterizing species.

Hediste diversicolor characteristically inhabits estuaries where turbidity is typically higher than other coastal waters. Changes in the turbidity may influence the abundance of phytoplankton available as a food source that may be attained through filter feeding. *Hediste diversicolor* utilizes various other feeding mechanisms and, at the benchmark level, the likely effects of a change in one rank on the WFD scale are limited.

Corophium volutator lives in areas with very high sediment loads, suggesting an increase in suspended solids would not affect them.

Sensitivity assessment. The following sensitivity assessment relies on expert judgement, utilising evidence of species traits and distribution and therefore confidence has been assessed as low. Resistance is '**High**' as no significant negative effects are identified and potential benefits from increased food resources may occur. Resilience is also '**High**' as no recovery is required under the likely impacts. Sensitivity of the biotope is, therefore, assessed as '**Not Sensitive**'.

Smothering and siltation rate changes (light)	Medium Q: High A: High C: Medium	High Q: High A: High C: High	Low Q: High A: High 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 in the same experiment (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).

The amphipod *Corophium volutator* may be sensitive to deposits at the pressure benchmark. *Corophium volutator* was categorized in AMBI sedimentation Group III – 'species insensitive to higher amounts of sedimentation, but don't easily recover from strong fluctuations in sedimentation' (Gittenberger & Van Loon, 2011). Experimental fences placed on mudflats 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 cited in Neal & Avant, 2006). Where a coarse/impermeable layer was added to the seabed the suitability of the habitat for *Corophium volutator* would be reduced if these could not reach the surface or maintain burrows. Furthermore, a deposition of fine sediment is likely to take several tidal cycles to clear in the low energetic conditions where this biotope occurs.

In intertidal mudflats with similar characterizing species, experiments testing the effects of deposition of sediments typical of beach recharge, have found that recovery of biological assemblages is complete within two years (Bolam & Whomersley, 2003).

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 *Streblospio shrubsolii*, and *Corophium volutator* may decline but the biotope is likely to be recognizable within a week 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)	Low Q: High A: High C: Medium	High Q: High A: Low C: Medium	Low Q: High A: Low C: Medium

Studies have found that beach 'replenishment' or 'nourishment' that involves the addition of sediments on beaches can have a number of impacts on the infauna (Peterson *et al*., 2000; Peterson *et al*., 2006). Impacts are more severe when the sediment added differs significantly in grain size or organic content from the natural habitat (Peterson *et al*., 2000).

Hediste diversicolor inhabits depositional environments. It is capable of burrowing to depths of up to 0.3 m and reworking sub-surface modifications of its burrow through fine clays and sand. Smith (1955) found no appreciable difference in the population of a *Hediste diversicolor* colony which had been covered by several inches of sand through which the worms tunnelled. 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.

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Sensitivity assessment. Deposition of up to 30 cm of fine material is likely to provide different impacts for the different species characterizing the biotope. Overall, although the characterizing species may have some resistance to this to this pressure, populations of *Corophium volutator* are likely to be reduced. Resistance to initial smothering is '**Low'** Resilience is '**High'** and biotope sensitivity is assessed as '**Low'**.

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

Examples of the impact of specific marine litter, including cigarette butts and micro-plastics are also considered..

Litter, in the form of cigarette butts has been shown to have an impact on ragworms. *Hediste diversicolor* showed increased burrowing times, 30% weight loss and a >2 fold increase in 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). This UK study suggests health of infauna populations are negatively impacted by this pressure.

Corophium volutator is widely used in ecotoxicological studies and know to uptake nanoplastics, but toxicity at the current environmental relevant concentrations has yet to be confirmed (Booth *et al.*, 2015) However, *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), which is likely to result in transition of the particles up the marine food chain. Nevertheless, there was insufficient evidence on which to assess the sensitivity of this biotope to the introduction of litter.

Studies of other characterizing species in relation to micro plastics were not available. However, studies of sediment dwelling, sub surface deposit feeding worms, 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 as a result decreased bioturbation levels which 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 33 m^3 of micro-plastics a year.

Sensitivity assessment. Marine litter in the form of cigarette butts or micro plastics may impact the health of populations of characterizing species. Significant impacts have been shown in laboratory studies but impacts at biotope scales are still unknown. Evidence and confidence in the assessment is limited and this pressure is **'Not assessed'**.

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

There is **no evidence** on effects of electric and magnetic fields on the characterizing species.

Electric and magnetic fields generated by sources such as marine renewable energy device/array cables may alter behaviour of predators and affect infauna populations. Evidence is limited and occurs for electric and magnetic fields below the benchmark levels, confidence in evidence of these effects is very low.

A number of studies have investigated the effects of electromagnetic fields on terrestrial oligochaetes, notable earthworms. Some negative effects have been observed e.g. Tkalec *et al*., 2013. However no evidence was found to support an assessment at the pressure benchmark for the marine oligochaetes that characterize this biotope.

Field measurements of electric fields at North Hoyle wind farm, North Wales recorded 110μ V/m (Gill *et al*., 2009). Modelled results of magnetic fields from typical subsea electrical cables, such as those used in the renewable energy industry produced magnetic fields of between 7.85 and 20 μT (Gill *et al.* 2009; Normandeau *et al.* 2012). Electric and magnetic fields smaller than those recorded by in field measurements or modelled results were shown to create increased movement in potential predators of *Hediste diversicolor*, thornback ray *Raja clavata* and attraction to the source in catshark *Scyliorhinus canicular* (Gill *et al.* 2009).

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 in to the sediment for protection. However, at the benchmark level the community is unlikely to be sensitive to noise and this therefore is '**Not relevant'.**

Introduction of light or shading	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

There is little direct evidence of effects of changes in incident light on the characterizing species of this biotope. Studentowicz (1936) found that the enchytraeid oligochaete *Enchytraeus albidus*, retracted from light, although the worms accumulated at the surface even when illuminated to avoid low oxygen and hydrogen sulpfide. Giere and Pfannkuche (1982) considered that other enchytraeids and tubificids are likely to react in the same way. As the biological assemblage occurs within the sediment and can be deeply buried (to 10cm or more) this pressure is considered 'Not relevant'. More general changes to the productivity of the biotope may, however, occur. Beneath shading structures there may be changes in microphytobenthos abundance. Littoral mud and sand 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 higher trophic levels. The impact of these indirect effects is difficult to quantify.

Sensitivity assessment. Based on the direct impact, 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	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low

Barriers that reduce the degree of tidal excursion may alter larval supply to suitable habitats from source populations. Conversely, the presence of barriers at brackish waters may enhance local population supply by preventing the loss of larvae from enclosed habitats to environments, which are unfavourable, reducing settlement outside of the population.Barriers may also act as stepping stones for larval supply over greater distances (Adams *et al.*, 2014).

If a barrier (such as a tidal barrier) incorporated renewable energy devices such as tidal energy turbines, these devices may affect hydrodynamics and so migration pathways for larvae into and out of the biotope (Adams *et al.*, 2014). Evidence on this pressure is limited.

The trait of *Hediste diversicolor* to lay and protect eggs within a burrow is likely to limit the impact of barriers to movement on populations. The ability of postlarvae, 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. A barrier to movement is likely to limit colonization outside the enclosed area, but increase populations within the enclosed area

Capitella capitata and the associated species *Pygospio elegans* are capable of both benthic and pelagic dispersal. In the sheltered waters where this biotope occurs, with reduced water exchange, in-situ reproduction may maintain populations rather than long-range pelagic dispersal. As the tubificid oligochaetes that characterize this biotope have benthic dispersal strategies (via egg cocoons laid on the surface (Giere & Pfannkuche, 1982), water transport is not a key method of dispersal over wide distances.

Sensitivity assessment. 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 interaction with bottom towed fishing gears and moorings are addressed under

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

Characterizing species have limited, visual perception, this pressure is therefore considered **'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 cultivated or translocated. This pressure is therefore considered **'Not relevant'** to this biotope group.

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

Intertidal mixed sediments may be colonized by a number of invasive non-indigenous species. Invasive species that alter the character of the biotope or that predate on characterizing species are most likely to result in significant impacts. Intertidal flats may be colonized by the invasive non-indigenous species *Crepidula fornicata* and the pacific oyster *Magallana gigas*. The two species have not only attained considerable biomasses from Scandinavian to Mediterranean countries but have also generated ecological consequences such as alterations of benthic habitats and communities and food chain changes (OSPAR, 2009b).

In the Wadden Sea, the Pacific oyster *Magallana gigas* has colonized intertidal flats (Smaal *et al*., 2005). This species consumes pelagic larvae reducing recruitment (Smaal *et al*., 2005). The most severe effects are likely to occur from impacts on sediment, where *Magallana gigas* create reefs on sedimentary flats that will prevent recruitment of juveniles and will restrict access of infauna to the sediment-water interface impacting respiration and feeding of bivalves such as *Limecola balthica* and *Scrobicularia plana* and polychaetes such as *Pygospio elegans* and *Streblospio shrubsolii* disturbing the amphipod *Corophium volutator*. Burrowing infauna such as *Hediste diversicolor* and oligochaetes may persist within sediments but the overall character of the mixed sediment biotope would be altered.In the Wadden Sea,

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

Introduction of microbial pathogens	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low

No evidence was returned by literature searches on the effect on the key characterizing species, *Hediste diversicolor* of introduction of relevant microbial pathogens or metazoan disease vectors to an area where they are currently not present.

Corophium volutator is parasitized by several species of trematodes in Europe and North American (McCurdy et al., 2000a; McCurdy et al., 2000b; Mouritsen & Jensen, 1997, cited in Shim *et al*., 2013). Mass mortalities of *Corophium volutator* have been associated to infestation by trematodes in the Wadden Sea (Jensen & Mouritsen, 1992). Studies conducted in the Baltic Sea suggested that increased parasitism by trematode species has a detrimental effect on local amphipods (Meissner & Bick, 1999; Mouritsen & Jensen, 1997 cited in Shim *et al*., 2013).

Sensitivity assessment. Although there are no records of the biotope being affected by the introduction of microbial pathogens in the British Isles, there are reports of mass mortality of characterizing species *Corophium volutator* (Jensen & Mouritsen, 1992). As the assessed biotope could revert to another sub-biotope, based on a loss of *Corophium volutator* , resistance is assessed as '**Low**', resilience is assessed as '**High**' and the biotope is classed as having '**Low**' sensitivity to the introduction of microbial pathogens.

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

The sedimentary biotope and characterizing and associated species may be disturbed and damaged by static or mobile gears that are targeting other species. These direct, physical impacts are assessed through the abrasion and penetration of the seabed pressures. The sensitivity assessment for this pressure considers any biological/ecological effects resulting from the removal of target species on this biotope. Ragworms *Hediste diversicolor* are targeted by recreational and commercial bait diggers. The extent of the impact will depend on the fishing / removal method and spatial extent.

Populations of *Hediste diversicolor* are dominated by females; males may constitute up to 40% of the population but several reports suggest that the proportion of males is frequently lower (< 20%) (see Clay, 1967c). The sexes are externally indistinguishable except when approaching maturation and during spawning (see reproduction and adult general biology).

Consequently extraction e.g. by bait digging, of 50% of the specimens from within an area is likely to remove more females than males. A reduction in the female proportion of the population prior to spawning could reduce recruitment to the population. The mechanical action of the digging, even if the worms were not actually taken, may also cause some damage to the bodies. Recovery is dependent on the reproductive success and survival of the remaining population and colonization by adults from unaffected areas.

Sensitivity assessment. The key, characterizing species *Hediste diversicolor* may be targeted and their removal will alter the character of the biotope. Due to potential impacts on *Hediste diversicolor* populations, in particular females, biotope resistance is assessed as '**Low**'. Biotope resilience is assessed as '**High**' and biotope sensitivity is assessed as '**Low**'.

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

Direct, physical impacts are assessed through the abrasion and penetration of the seabed pressures, while this pressure considers the ecological or biological effects of by-catch. Species in these biotopes, including the characterizing species, may be damaged or directly removed by static or mobile gears that are targeting other species (see abrasion and penetration pressures). Loss of these species would alter the character of the biotope resulting in re-classification, and would alter the physical structure of the habitat resulting in the loss of the ecosystem functions such as secondary production performed by these species.

Digging for *Hediste diversicolor* for bait is likely to cause significant mortality of the mud shrimp, *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). This would reduce available biomass for higher trophic levels. 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 species *Tubificoides benedii* 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, also impact other trophic levels.

Sensitivity assessment: Loss of the characterizing species of this biotope is likely to occur as by-catch. Thus, the biotope is considered to have a resistance of **'Low'** to this pressure and to have '**High'** resilience, resulting in the sensitivity being judged as '**Low'**.

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