Limecola balthica and *Arenicola marina* in littoral muddy sand

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Limecola balthica **and** ***Arenicola marina*** **in littoral muddy sand**
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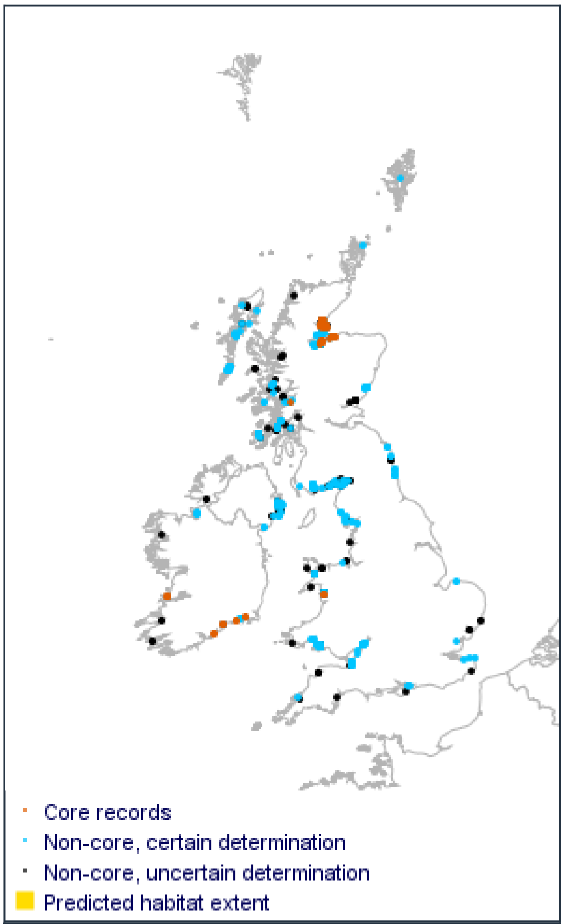

17-09-2018
Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

Researched by Matthew Ashley **Refereed by** Admin

Summary

UK and Ireland classification

EUNIS 2008	A2.241	*Macoma balthica* and *Arenicola marina* in muddy sand shores
JNCC 2015	LS.LSa.MuSa.LimAre	*Limecola balthica* and *Arenicola marina* in littoral muddy sand
JNCC 2004	LS.LSa.MuSa.MacAre	*Macoma balthica* and *Arenicola marina* in littoral muddy sand
1997 Biotope	LS.LMS.MS.MacAre	*Macoma balthica* and *Arenicola marina* in muddy sand shores

Description

Muddy sand or fine sand, often occurring as extensive intertidal flats both on open coasts and in marine inlets. The sediment is often compacted, with a rippled surface, areas of standing water, and generally remains water-saturated during low water. Scattered stones, cobbles and boulders with attached fucoids may be present. An anoxic layer is usually present within 5 cm of the sediment surface and is often visible in worm casts. The habitat may be subject to variable salinity conditions in marine inlets. The species assemblage is characterized by the lugworm *Arenicola* *marina* and the Baltic tellin *Limecola balthica*. The polychaetes *Scoloplos armiger* and *Pygospio elegans* are typically superabundant and common, respectively. Oligochaetes, probably mainly *Tubificoides benedii* and *Tubificoides pseudogaster*, may be common, and the cockle *Cerastoderma edule* may be abundant. (Information from Connor *et al.*, 2004; JNCC, 2015).

Depth range

Upper shore, Mid shore, Lower shore

Additional information

-

Listed By

- none -

Further information sources

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G G G JNCC

Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

This biotope occurs in association with muddy sand or fine sand, often as extensive intertidal flats both on open coasts and in marine inlets. The sediment is often compacted, with a rippled surface, areas of standing water, and generally remains water-saturated during low water. Scattered stones, cobbles and boulders with attached fucoids may be present. An anoxic layer is usually present within 5 cm of the sediment surface and is often visible in worm casts. The habitat may be subject to variable salinity conditions in marine inlets.

The species assemblage is characterized by the lugworm *Arenicola marina* and the Baltic tellin *Limecola balthica*. Focus is given to the sensitivity of these two important characterizing species as their abundance is important for the recognition of the biotope under the habitat classification. The polychaetes *Scoloplos armiger* and *Pygospio elegans* are typically superabundant and common. Sensitivity of these species is considered generally within the biotope as these species contribute to the assemblage characterizing the biotope. Oligochaetes, mainly *Tubificoides benedii* and *Tubificoides pseudogaster*, may be common, and the cockle *Cerastoderma edule* may be abundant. The sensitivity of these species are considered where particular sensitivity to certain pressures is known.

The sediment habitat (muddy sand or fine sand) is a key element of the biotope, therefore, the sensitivity of this component is discussed where it is likely to be altered by the assessed pressure.

Resilience and recovery rates of habitat

Case studies are available on recovery of lugworm *Arenicola marina* populations and further species characterizing the biotope, particularly in relation to bait digging and fisheries impacts (McLusky *et al.*, 1983; Beukema, 1995; Hall & Harding 1997; Fowler, 1999; Hiddink, 2003). McLusky *et al.* (1983) examined the effects of bait digging on blow lug populations in the Forth Estuary. Dug and infilled areas and unfilled basins left after digging re-populated within 1 month, whereas mounds of dug sediment took longer and showed a reduced population. Basins accumulated fine sediment and organic matter and showed increased population levels for about 2-3 months after digging. Overall recovery is generally regarded as rapid. Hiddink (2003) reported that the density of *Limecola balthica* (as *Macoma balthica)* was reduced in areas of the Wadden sea (Netherlands) that had experienced suction dredging for cockles, which removes the surface sediment. The disturbance to the sediment also appeared to leave the habitat less suitable for settlement of young *Limecola balthica* (Hiddink, 2003). McLusky *et al.* (1983) found that *Limecola balthica* (as *Macoma balthica*) populations were unaffected by bait digging and re-colonized dug mounds. *Pygospio elegans* were significantly depleted for >100 days after harvesting (surpassing the study monitoring timeline) and *Scoloplos armiger* demonstrated recovery >50 days after harvesting in muddy sands (Ferns *et al.*, 2000). In summary, these studies suggest recovery from fisheries pressures occurs in 4 months to >3 years depending upon the harvesting method (such as hand digging or mechanical dredging) and the size of the area impacted (McLusky *et al.*, 1983; Beukema, 1995; Fowler, 1999; Ferns *et al.*, 2000; Dernie *et al.*, 2003; Hiddink, 2003).

Arenicola marina and *Scoloplos armiger* are considered to be species that characterize the end of the transitional phase and the final equilibrium communities following impact or disturbance, rather than initial opportunistic species (Newell *et al.*, 1998). As a tube building polychaete *Pygospio elegans* aids stabilisation of sediments following disturbance. Re-colonization and hence recovery may be aided by bed load transport of juvenile polychaetes and bivalves. Re-colonization of *Pygospio elegans*, and *Scoloplos armiger* was observed in 2 weeks by Dittmann *et al.* (1999) following a 1 month long defaunation of the sediment. Recovery of some elements such as *Arenicola marina*, *Limecola balthica* and *Cerastoderma edule* depends on sporadic recruitment events.

Resilience assessment. In general, recovery of muddy sand biotopes is dependent on the return of suitable sediment and recruitment of individuals. When muddy sand assemblages are disturbed, recruitment comes from a combination of adult migration and larval immigration with larval importance increasing with the size of the spatial footprint. Overall recovery will vary according to site-specific factors including hydrographic regime and sediment supply. Once suitable substratum returns, initial recolonization is likely to be rapid, especially for rapidly reproducing species such as polychaetes, oligochaetes and some amphipods and bivalves. The important characterizing species, *Limecola balthica* and *Arenicola marina* have lifespans of 5-10 years, exhibit generation times of 1-2 years and reach maturity at 1-2 years. Hence recovery is probably rapid and complete in approximately 2 years ('**High**' resilience) where resistance is High, Medium or Low but full population recovery, following large scale removal of a population (resistance is None) may take >2 years (resilience is '**Medium**').

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

Hydrological Pressures

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

The important characterizing species *Arenicola marina* and *Limecola balthica* are adapted to living within the intertidal zone. Some resistance to temperature fluctuations is achieved by burying within the sediment, which buffers against acute temperature changes over the tidal cycle.

Sommer *et al.* (1997) examined sub-lethal effects of temperature in *Arenicola marina* and suggested a critical upper and lower temperature of 20°C and 5°C respectively in North Sea specimens. Above or below these critical temperatures specimens resort to anaerobic respiration. Sommer *et al.* (1997) noted that specimens could not acclimate to a 4°C increase above the critical temperature. Therefore, *Arenicola marina* is probably intolerant of a short-term acute change in temperature of 5°C although it is unlikely to be directly affected due to its infaunal habit. However, temperature change may adversely affect reproduction, for example, spawning can be inhibited in gravid adults maintained above 15°C and temperature change may affect maturation, spawning time, synchronization of spawning and reproduction in the long-term (Bentley & Pacey, 1992; Watson *et al.*, 2000). Therefore, temperature change may affect lugworm recruitment in the long-term.

Arenicola marina's optimum temperature range appears region specific, with the optimum temperature range increasing as latitude decreases (Schroeer *et al*., 2009). Therefore, *Arenicola marina* in UK and Irish populations will occupy an optimum temperature range in relation to UK and Irish latitudes. An upper limit above 20°C may occur in more southerly populations.

In studies in Whitley Bay, Tyne and Wear, UK, *Arenicola marina* were most active in spring and summer months, with mean rate of cast production fastest in spring and particularly slow in autumn and winter, suggesting feeding rate is greatest in higher temperatures (Retraubun *et al*., 1996). Retraubun *et al.* (1996) also show that cast production by specimens in lab experiments increased with temperature, peaking at 20°C before declining. Rates of cast production at 30°C were still higher than at 10°C, suggesting UK populations may have greater tolerance to higher temperatures than populations studied in more northerly latitudes. Tolerance to temperature changes within specific regions, such as a 5°C increase for one month or a 2°C for one year would be relative to the existing temperature in that region and intolerance of an acute temperature change of 5°C is still probable.

Temperature change may affect maturation, spawning time and synchronisation of spawning and reproduction in the long-term (Watson *et al*., 2000). However, spawning success would remain dependent upon spring and autumn temperatures the seasons when spawning occurs in relation to spring and neap tides, remaining below 13-15°C. Additionally, impact from temperature change at the substratum surface may be mitigated as, being a burrowing species, *Arenicola marina* are protected from direct effects. Increased temperatures may affect infauna indirectly, by stimulating increased bacterial activity, increased oxygen consumption and therefore depletion of oxygen from the interstitial waters resulting in reduced oxygen levels (hypoxia) or absence of oxygen (anoxia) in the sediment (Hayward, 1994). De Wilde & Berghuis (1979) reported 20% mortality of juveniles reared at 5°C, negligible mortality at 10 and 15°C but 50% mortality at 20°C and 90% at 25°C. Schroeer *et al.* (2009) identified a shift in the thermal window of *Arenicola marina*, with an optimum towards higher temperatures with decreasing latitudes, suggesting the species may adapt to long-term shifts such as a 2°C but over a time period beyond the one year benchmark pressure.

In Europe, *Limecola balthica* occurs as far south as the Iberian Peninsula and hence, would be expected to tolerate higher temperatures than experienced in Britain and Ireland. Oertzen (1969) recorded that *Limecola balthica* (as *Macoma balthica*) could tolerate temperatures up to 49°C before thermal numbing of gill cilia occurred presumably resulting in death. Ratcliffe *et al.* (1981) reported that *Limecola balthica* from the Humber Estuary, UK, tolerated six hours of exposure to temperatures up to 37.5°C with no mortality. However, Barda *et al.* (2014) found that increased temperature reduced growth rates in populations in the Baltic Sea. Beukema *et al.* (2014) also warn that increasing water temperatures as a result of global warming are likely to shorten the growing season (typically late winter to early spring) if warmer spring and summer water temperatures are experienced. Jansen *et al*. (2007) suggest that temperature increases in the Spanish coast along the Bay of Biscay over the past 40 years have caused loss of *Limecola balthica* populations, due to short-term but frequent exposure to >30°C in the Spanish estuaries, which induced elevated maintenance rates in *Limecola balthica*, and ultimately starvation. Jansen *et al*. (2007) predict the southern limit of the species will progressively shift north if temperatures continue to rise.

It seems likely, therefore, that the *Limecola balthica* could tolerate a chronic change in UK waters with limited mortality but length of growing season will likely be reduced if a short-term 5°C temperature increase in temperature for one month period occurred during winter or spring months, or a long-term increase of 2°C for one year.

Both of the polychaete species that are typically superabundant and common in the biotope, *Scoloplos armiger* and *Pygospio elegans*, show a relationship between timing of reproduction and temperature. Studies on the polychaete *Scoloplos armiger* in the Wadden Sea (North Sea) displayed that intertidal 'Type I' *Scoloplos armiger* reproduce in spring, through holobenthic development, triggered by a rise in seawater temperature above 5°C (Kruse *et al.*, 2004). Gibson & Harvey (2000), in a study on asexual reproduction of *Pygospio elegans* in Nova Scotia, Canada, found temperature did not influence reproduction strategy (planktotrophy, lecithotrophy or asexual reproduction) but that environmental conditions, including temperature, influence timing of reproduction. Anger (1984) found a population in the Kiel Bight, Baltic Sea to also reproduce exclusively through asexual reproduction while two additional populations were predominantly sexual (Anger, 1984).

Both *Scoloplos armiger* and *Pygospio elegans* tolerate a wide temperature range although optimal temperature ranges, based on feeding and reproductive success are more restricted, suggesting a 5°C increase in temperature over a month may increase temperatures above the preferred range, but not cause widespread mortality. *Pygospio elegans* has been recorded in seas with a temperature range of 1.6°C to 12.5°C (OBIS, 2016). *Scoloplos armiger* occurs in seas with a temperature range of between 8.8°C and 13°C (OBIS, 2016). These temperature ranges are not derived from peer reviewed studies and therefore caution should be used with the interpretation.

Sensitivity assessment. Therefore, of the species characterizing the biotope, *Arenicola marina* would be least tolerant of a 5°C increase in temp for one month period, or 2°C for one year. Other species characterizing the biotope may tolerate this pressure at the benchmark levels but timing of reproduction may be impacted. Impacts on timing of reproduction may affect recruitment in the long-term.

A resistance of '**Medium**' has been assigned. In general, impacts to reproduction of species characterizing the biotope would rate as high resistance, however, for the biotope resistance was raised to medium as *Arenicola marina* specimens were shown not to acclimatise to a 4°C rise above 20°C (Sommer *et al.*, 1997; Sommer & Portner, 1999). A 5°C increase in temperature for a one month period may also extend periods during the year when temperatures exceed the preferred range of the polychaete species *Scoloplos armiger* and *Pygospio elegans*, dependent on the season the change occurred in (e.g. occurring in winter, spring and autumn).

Based on lifespan and age at sexual maturity, *Arenicola marina* (5-6 years lifespan, maturity reached at 1-2 years) recovery of populations may take over 2 years suggesting resilience is '**Medium**' (2-10 years) for this characterizing species. Additional pressures such as presence of suitable sediments will also affect recovery times (Marine Ecological Surveys Limited (MES), 2008).

Resistance to an acute and chronic change in temperature at the pressure benchmark is assessed as '**Medium**' and recovery as '**High**' and the biotope sensitivity is considered **'Low**' at the benchmark level. The timing, strength (°C change) and duration will also affect recovery times. For instance timing of acute changes may lead to greater impacts, temperature increases in the warmest months may exceed thermal tolerances whilst changes in colder periods may stress individuals acclimated to the lower temperatures. Local populations may be acclimated to the prevailing temperature regime and may, therefore, exhibit different tolerances to populations from other latitudes. Therefore, caution should be used when inferring tolerances from populations in different regions.

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

Arenicola marina displays a greater tolerance to decreases in temperature than to increases, although optimum temperatures are reported to be between 5°C and 20°C. Sommer *et al*. (1997) report populations in the White Sea (sub polar) acclimatised to -2°C in winter. Populations in the North Sea (boreal) were less tolerant of temperatures below 5°C, although in laboratory experiments on individual lugworms from North Sea populations worms survived a temperature drop from 6 or 12°C to -1.7°C for more than a week (Sommer & Portner, 1999).

Spawning success is dependent upon spring and autumn temperatures, the seasons when spawning occurs in relation to spring and neap tides, remaining below 13-15°C. Temperature change may affect maturation, spawning time and synchronization of spawning and reproduction in the long-term (Watson *et al*., 2000). De Wilde & Berghuis (1979) reported 20% mortality of juveniles reared at 5°C, negligible mortality at 10°C and 15°C but 50% at 20°C and 90% mortality at 25°C (Tyler-Walters, 2008).

Temperature change at the pressure benchmark levels may impact timing of reproduction. The preferred spring and autumn temperature for spawning to occur and juvenile mortality to be negligible (13-15°C) may be extended into late spring and early autumn months. There is, however, increased risk in winter and early spring months of juvenile mortality at low temperatures (at or below 5°C), in particular if the pressure benchmark of a 5°C decrease in temperature for one month occurs during these periods.

The geographical distribution of *Limecola balthica* suggests that it is very tolerant of low temperature. The species occurs in the Gulfs of Finland and Bothnia where the sea freezes for several months of the year (Green, 1968). It must therefore tolerate much lower temperatures than it experiences in Britain and Ireland. Furthermore, *Limecola balthica* was apparently unaffected by the severe winter of 1962/3 which decimated populations of many other bivalve species (Crisp, 1964), and De Wilde (1975) noted that *Limecola balthica* kept at 0°C maintained a high level of feeding activity. It is unlikely, therefore, that in seas around the UK and Ireland *Limecola balthica* would be intolerant of decreases in temperature at the benchmark level.

Both of the polychaete species that are typically superabundant and common in the biotope, *Scoloplos armiger* and *Pygospio elegans*, show a relationship between timing of reproduction and temperature. Studies on the polychaete *Scoloplos armiger* in the Wadden Sea (North Sea) displayed that intertidal 'Type I' *Scoloplos armiger* reproduce in spring, through holobenthic development triggered by a rise in seawater temperature above 5°C (Kruse *et al*., 2004). Timing of reproduction of *Pygospio elegans* in a study from the Baltic Sea was linked to environmental conditions including temperature (Anger, 1984). A 5°C decrease in temperature for a one month period, or a 2°C decrease for one year would remain within the preferred temperature range *Pygospio elegans* occurs within (1.6 °C to 12.5 °C) (OBIS, 2016). However, these benchmark temperature decreases would potentially result in winter temperatures below the optimum range for *Scoloplos armiger* (of between 8.8°C and 13°C) but remain within the range the species occurs within (-2.1°C and 29.5°C) (OBIS, 2016).

Sensitivity assessment. Species characterizing the biotope may resist this pressure at the benchmark levels but timing of reproduction may be impacted. Impacts on timing of reproduction may affect recruitment in the long-term. Due to the natural range and resistance of low temperatures of *Arenicola marina*, *Limecola balthica* and both the typically superabundant and common polychaete species in the biotope, *Scoloplos armiger* and *Pygospio elegans* it is unlikely that a change in the pressure at the benchmark will have a significant impact on condition of this biotope. Therefore, this biotope is assessed to have '**High**' resistance to decreased temperatures at the benchmark (acute and chronic). Therefore, resilience is '**High**' and this biotope is assessed as '**Not Sensitive**' at the benchmark level.

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

This biotope is recorded from variable to fully marine (Connor *et al.*, 2004). An increase of one MNCR salinity category would be to fully marine 30-40 ‰ or beyond this level to >40 ‰. *Arenicola marina* would be expected to exhibit reduced tolerance to an increase in salinity as the species reached highest densities in estuarine systems in Welsh study sites (Cadman, 1997). However, *Arenicola marina* exposed to hyper-osmotic shock (47 psu), lose weight, but are able to regulate and gain weight within 7-10 days (Zebe & Schiedek, 1996).

Environmental fluctuations in salinity are only likely to affect the surface of the sediment, and not deeper buried organisms, since the interstitial or burrow water is less affected. However, under longer term or permanent increase in salinity, sediment waters would be expected to also adjust. Behavioural responses are shown by *Arenicola marina* to cope with rapid salinity changes in the intertidal. The animals withdraw in their burrows when the salinity is unfavourable, and remain inactive except for infrequent "samplings" of the overlying water (Spaargaren & Weber, 1979).

Limecola balthica is found in brackish and fully saline waters but is more common in brackish waters (Clay, 1967b) so may tolerate a state of flux. Seitz (2011) found *Limecola balthica* (as *Macoma balthica*) distribution across a salinity gradient between a minimum and maximum of 8.8 psu to 19 psu in Cheaspeake Bay was not influenced by salinity. Instead, resource availability was the principal influence on *Limecola balthica* at a broad scale, suggesting changes in one MNCR salinity category would have limited impact. McLusky & Allan (1976) reported that *Limecola balthica* (as *Macoma balthica*) failed to grow at 41 psu. It is likely that *Limecola balthica* would be tolerant of an increase in salinity category to fully marine but further increases to >40 ‰ are likely to affect growth and condition.

In the western Baltic Sea *Scoloplos armiger* abundance was greatest between 12 psu and 17 psu and reduced abundance with increasing salinity was observed (Gogina *et al.*, 2010). As *Scoloplos armiger* is a species complex and is not a cosmopolitan species there may be inconsistencies between general environmental setting found in literature and observed and predicted distribution limits within study sites (Bleidorn *et al.*, 2006 cited in Gogina *et al.*, 2010). *Pygospio elegans* is common in both marine and brackish waters in the Schelde estuary (Netherlands) suggesting in European habitats the species tolerates a broad salinity range (Ysebaert *et al.*, 1993). Studies of *Pygospio elegans* population structure in the Baltic Sea and North Sea also found larvae were not hampered by changes in salinity (Kesaniemi *et al.*, 2012). Although case studies are lacking for British and Irish coasts, the existing evidence suggests *Pygospio elegans* would tolerate salinity changes at the pressure benchmark level.

Although increases in salinity are tolerated by these polychaete species an increase in one MNCR salinity category above the usual range of the biotope may reduce abundance as both species are most abundant in variable and fully marine salinity categories (and *Scoloplos armiger* has displayed negative responses to increasing salinity).

Sensitivity assessment. A short-term increase in one MNCR salinity category above the usual range of the biotope/habitat is likely to negatively impact body condition and growth of characterizing species of the biotope. Hypersaline conditions are likely to cause mortality to characterizing species. For extended periods this will impact the biotope but if salinity conditions return to those characterizing the biotope recovery is likely in 1-2 years and full recovery of populations in 2-10 years. Resistance to changes at pressure benchmark level is **'Medium'**. *Arenicola marina* and *Limecola balthica* both have lifespans of 5-10 years and generation times of 1-2 years, resilience (recovery) would be expected in 1-2 years, following restoration of salinity regime, therefore giving a **'High'** resilience and a sensitivity of '**Low**'.

Salinity decrease (local)	High Q: High A: Medium C: Medium	High Q: High A: High C: High	Not sensitive Q: High A: Medium C: Medium

Arenicola marina is unable to tolerate salinities below 18-24 psu and is excluded from areas influenced by freshwater runoff or input (e.g. the head end of estuaries) where it is replaced by *Hediste diversicolor* (Barnes, 1994; Hayward, 1994). Once the salinity of the overlying water drops below about 55% seawater (about 18 psu) *Arenicola marina* stops irrigation, and compresses itself at the bottom of its burrow. It raises its tails to the head of the burrow to 'test' the water at intervals, about once an hour. Once normal salinities return they resume usual activity (Shumway & Davenport, 1977; Rankin & Davenport, 1981; Zebe & Schiedek, 1996). This behaviour, together with their burrow habitat, enabled the lugworm to maintain its coelomic fluid and tissue constituents at a constant level, whereas individuals exposed to fluctuating salinities outside their burrow did not (Shumway & Davenport, 1977). Environmental fluctuations in salinity are only likely to affect the surface of the sediment, and not deeper organisms, since the interstital or burrow water is little affected. However, lugworms may be affected by low salinities at low tide after heavy rains. *Arenicola marina* was able to osmoregulate intracellular and extracellular volume within 72-114 hrs by increased urine production and increased amino acid concentration in response to hypo-osmotic shock (low salinity) (see Zebe & Schiedek, 1996).

Arenicola marina in the Baltic are more tolerant of reduced salinity. For example, Barnes (1994) reports that *Arenicola marina* occurs at salinities down to 18 psu in Britain, but survives as low as 8 psu in the Baltic, whereas Shumway & Davenport (1977) reported that this species cannot survive less than 10 psu in the Baltic. The reported salinity tolerance in the Baltic is probably a local adaptation.

McLusky & Allan (1976) conducted salinity survival experiments with *Limecola balthica* (as *Macoma balthica*) over a period of 150 days. Survival times declined with decreased salinity. At 12 psu specimens survived 78 days, whilst specimens at 8.5 psu survived 40 days. Some specimens of *Limecola balthica* survived 2.5 days at 0.8 psu, which was apparently due to the animals ability to clamp its valves shut in adverse conditions. McLusky & Allan (1976) also reported that *Limecola balthica* failed to grow (increase shell length) at 15 psu. *Limecola balthica* is found in brackish and fully saline waters (Clay, 1967b) so may tolerate a state of flux. Its distribution in combination with the experimental evidence of McLusky & Allan (1976) suggests that *Limecola balthica* is likely to be very tolerant to a decreased salinity over a short period. A decline in salinity in the long-term may have implications for the species viability in terms of growth, and the distribution of the species may alter as specimens at the extremes retreat to more favourable conditions. Metabolic function should, however, return quickly to normal when salinity returns to original levels. Decreased salinity may also affect the ability of *Limecola balthica* to tolerate contaminants such as heavy metals (see Bryant *et al*., 1985, 1985a). Usually, contaminants become more toxic at low salinity (Langston, W.J. pers comm.).

Scoloplos armiger shows a lower salinity limit of 10.5 psu (Gogina *et al*., 2010), suggesting the species is tolerant of a decrease from the variable salinity category to the reduced salinity category and even the low salinity category in the MNCR scale. *Pygospio elegans* was common in both marine and brackish waters in the Schelde estuary (Netherlands) suggesting in European habitats the species tolerates a broad salinity range (Ysebaert *et al*., 1993). Studies of *Pygospio elegans* population structure in the Baltic Sea and North Sea also found larvae were not hampered by changes in salinity (Kesaniemi *et al*., 2012). Although case studies are lacking for British and Irish coasts the existing evidence suggests *Pygospio elegans* would tolerate salinity changes at the pressure benchmark level.

Sensitivity assessment. The characterizing species within the biotope occupy between 'variable' and 'fully marine' category salinities and can tolerate greater osmotic stress for short periods, caused by decreases in salinity below 18 □⁄□□ (the lower limit for 'low' category salinity). Resistance to the assessed decrease in salinity from variable (18-35 □⁄□□) to reduced (18-30 □⁄□□) is probably **'High'**, so that resilience is also **'High'** and the biotope is assessed as '**Not Sensitive**' at the benchmark level.

Freshwater run-off may cause a further decrease, beyond just one salinity category, to the 'low' salinity category. Abundance of key characterizing species may be limited or growth rates reduced from the long-term exposure to reduced salinity. The biotope would be replaced by those dominated by species occurring in lower salinities such as *Hediste diversicolor*. Resistance following long-term exposure to the 'L**o**w' category (below 18 □⁄□□) would be 'medium' and recovery 'M**edium**'. Sensitivity under this further decrease in salinity would, therefore, be '**Medium**' (if a decrease continued beyond one salinity category).

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

A local change in water flow is likely to have a greater impact on sediment transport than direct impacts on populations of *Arenicola marina*. At low current velocities *Arenicola marina* casts and burrows enable the deposition and adherence of macroalgae (Puls *et al*., 2012). At high current velocities *Arenicola marina* faecal casts are quickly eroded and sediment particles are suspended in the water column. As suspended particles (in particular fine particles) may be transported away by water currents, this process, over time, can facilitate a gradual change of sediment properties in the entire bioturbated sediment layer (to the depth of worm burrows). Therefore, an increase in water flow may cause the depletion of fine particle matter, leaving coarser particles and change the sediment type (Wendelboe *et al*., 2013). Coarser sediment may influence populations of other species within the biotope, such as *Limecola balthica* which prefers finer particle sizes and *Scoloplos armiger* and *Pygospio elegans* that thrive in medium particle sizes.

Limecola balthica is likely to experience greater impact from increased water flow as the species thrives in low energy environments, such as estuaries that characterize the biotope (Tebble, 1976). *Limecola balthica* also shows preference for substratum that has a high proportion of fine sediment (Budd & Rayment, 2001). Increased water flow rate is likely to change the sediment characteristics in this biotope, primarily by re-suspending and preventing deposition of finer particles (Hiscock, 1983). This would result in erosion of the preferred habitat, which may cause mortality of some portion of the population of *Limecola balthica*. Higher current velocity (0.18 m/s) recorded in flume experiments conducted in the Isle of Sylt (North Sea) led to juvenile *Limecola balthica* being washed out of the sediment (Zuhlke & Reise, 1994). Green (1968) recorded that towards the mouth of an estuary where sediments became coarser and cleaner, *Limecola balthica* was replaced by another tellin species, *Tellina tenuis*.

Sensitivity assessment. A decrease in water flow may result in accretion of fine sand, and, thereby, a change to muddy sand and mud. As the biotope occurs in association with muddy sand or fine sand a decrease in water flow is unlikely to impact the biotope (although under an excessive deposition of mud or silt, mud communities, e.g. HedLim, may replace the biotope, but this is unlikely at the benchmark levels).

Finer sediment has a predicted threshold velocity (flow velocity at which fine grain size sediment would be picked up from the sea bed) of ~0.05 m/s (Gray & Elliott, 2009), therefore an increase of 0.1-0.2 m/s may cause a significant change in grain size of sediments. Although resistance is '**None**' if cases occurred where *Limecola balthica* was replaced by another tellin species and the biotope would be altered, resilience is '**High**'. The resulting sensitivity score is '**Medium**' given the potential scenario that an increase in peak mean spring bed flow velocity of between 0.1 m/s to 0.2 m/s for more than 1 year may result in a characterizing species, *Limecola balthica* being replaced by another species.

Emergence regime changes	Low Q: High A: Medium C: Medium	Medium Q: High A: Medium C: Medium	Medium Q: High A: Medium C: Medium

When the burrow of the lugworm *Arenicola marina* is emersed, ventilation becomes impossible and the animal is exposed to increasing hypoxia (see de-oxygenation section below). Partial pressure of dissolved oxygen (pO_2) in the remaining water of the lugworm burrow has been shown to decrease from 33 to 13 torr during 2 hours of tidal emersion (Jones, 1955 cited in Volkel *et al*., 1995). During periods when burrows are not covered (by seawater), blood oxygen drops close to 0 within 1 hour of emersion (Toulmond, 1973), *Arenicola marina* reduces its ventilation movements and O_2 consumption and switches from aerobic to anaerobic metabolism (Schottler *et al*., 1984; Toulmond & Tchernigovtzeff, 1984; Toulmond, 1987). When the tide comes back in, *Arenicola marina* returns to aerobic metabolism and tissue metabolites return to pre-emersion levels within 1 to 2 hours (Portner *et al*., 1979).

An increase in time not covered by the sea for a period of ≥1 year or a decrease in high water level for ≥1 year will increase the time *Arenicola marina* spends metabolising anerobically. This is likely to reduce abundance, as survivability of *Arenicola marina* during spawning times has been shown to be reduced dramatically during anaerobic conditions (Schottler, 1989). Coosen *et al*. (1994) found that in an intertidal estuary in the south-west Netherlands settlement of juvenile *Arenicola marina* was interrupted during periods of reduced tidal amplitude. Therefore, adult and juvenile populations are likely to be negatively impacted under this pressure at the benchmark level. Increased emergence, however, will increase the risk of hypoxia and anoxia (see de-oxygenation). Increased emersion is likely to result in a depressed upper limit of the species on the shore, especially in juveniles.

An increase in relative sea level has been related to an increase in *Arenicola marina* abundance in the upper tidal zone in eastern North Sea mudflats since the 1930s (Reise *et al*., 2008). *Arenicola marina* typically occupy the higher intertidal shore, exposed even on neap low tides, and the black lug *Arenicola defodiens* is dominant in communities further down the shore, in regions only exposed at spring low water. A change in relative sea level or time covered by seawater is likely to result in changes in spatial distribution of the species. Decreased emergence is likely to increase the extent of the *Arenicola marina* population higher on the shore (but lower on the shore the upper extent of *Arenicola defodiens* may increase).

Limecola balthica occurs in the upper regions of the intertidal (Tebble, 1976) and is therefore likely to be tolerant of prolonged emergence. It is a bivalve and can close tightly by contraction of the adductor muscle, storing moisture inside the shell. The silty sediments in which the species lives have a high water content and are therefore resistant to desiccation. Furthermore, *Limecola balthica* is mobile and able to relocate in the intertidal by burrowing (Bonsdorff, 1984) or floating (Sörlin, 1988). It would be expected to react to an increase in emergence by migrating down the shore to its preferred position. There may be an energetic cost to this migration but it is not expected that mortality would result. *Limecola balthica* should quickly recover from the energetic cost of relocation.

Limecola balthica occurs in the intertidal and sublittorally down to depths of 190 m (Olafsson, 1986), although is more abundant in the intertidal, so would be expected to be tolerant of a decrease in emergence regime. However, a case study predicting changes in biomass of *Limecola balthica* in the Humber Estuary, UK (western North Sea) under expected sea level rise conditions displayed negative impacts. As the coastal squeeze resulting from sea level rise would produce steeper and more homogenous beach face profiles, biomass of *Limecola balthica* was predicted to decrease (Fujii & Raffaelli, 2008). The sensitivity assessment given in relation to the benchmark pressure should, therefore, be interpreted in relation to intertidal habitat availability following the relative sea level changes.

Scoloplos armiger occurs from <1 to 113 meters depth (OBIS, 2016). Two sympatric sibling species have been suggested for *Scoloplos armiger*, 'Type I' living in the intertidal zone and 'Type S' living subtidally (Kruse *et al*., 2004). Schueckel *et al*. (2013) show depth was a significant variable influencing *Scoloplos armiger* abundance in intertidal zones within Jade Bay (Wadden Sea). *Scoloplos armiger* occurred in greatest abundance in the two intertidal communities associated with longest submergence times (14 hours and 24 hours saturated) (Schueckel *et al*., 2013). A change in relative sea level and change in time covered may influence abundance. A decrease in time covered, would likely reduce the upper limit of the biotope on the shore (as the *Scoloplos armiger* population would be redistributed to lower down the shore). An increase in time covered or an increase in relative sea level may result in *Scoloplos armiger* becoming constantly subtidal. Under a decrease in emergence 'Type I' *Scoloplos armiger* populations are likely to be replaced by 'Type S' *Scoloplos armiger* populations. This change is based upon findings of Kruse & Reise (2003) that, for North Sea *Scoloplos armiger* populations, genetically distinct 'Type I' and 'Type S' populations occur. Instead of settling across intertidal and subtidal habitats, juveniles hatched from cocoons (Type I) in the intertidal suffer high mortality when translocated from the intertidal. Meanwhile, pelagic larvae of subtidal origin (Type II) either find their way back to subtidal habitat or suffer high post-settlement mortality in the intertidal (Kruse & Reise, 2003).

Sensitivity assessment. Emergence regime changes are likely to alter the upper and lower extent of the biotope. Although species characterizing the biotope may tolerate increased emersion, a decrease in high water level, increasing the time the biotope is not covered by the sea ≥ 1 year, is likely to reduce survivability and abundance.

All species characterizing the biotope may be resistant to decreased emergence and this is likely to increase the extent of the characterizing species *Arenicola marina* higher on the shore, however, lower portions of the biotope may be colonized by *Arenicola defodiens*. Populations of the superabundant polychaete *Scoloplos armiger* ('Type I') would increase in the upper shore but in the lower shore 'Type S' *Scoloplos armiger* (that occupy subtidal habitats) would dominate. The upper and lower extent of the biotope are likely to move further up the shore.

As a combined assessment, taking account of both benchmarks, Resistance in **'Low'** due to the impact of increased emergence on survivability of *Arenicola marina*, especially during spawning times. Resilience is '**Medium**' and sensitivity is **'Medium'**.

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

Evidence is limited for the effect of wave exposure changes on characterizing species and therefore the confidence in this assessment is low. Increased wave action results in increased water flow in the shallow subtidal. This is likely to have similar impacts to those under the pressure; 'water flow changes'. A significant increase in water flow may result in a move to medium to coarse sand, a change that is likely to alter the biotope. However, this biotope occurs in moderate exposure to extreme shelter and at the benchmark level there is unlikely to be a significant change in sediment. Wave mediated water flow tends to be oscillatory, i.e. moves back and forth (Hiscock, 1983), and may result in dislodgement or removal of individuals while covered at high water. As characterizing species live relatively deeply in the sediment this behaviour is likely to provide some tolerance to increases in wave exposure (Coosen *et al*., 1994).

Arenicola marina occupies moderately exposed through to very sheltered exposure and is therefore considered llikely to tolerate a change in nearshore significant wave height >3% but <5%.

To avoid the danger of being washed out of the substratum, wave action stimulates *Limecola balthica* to start burrowing and individuals have been shown to continue burrowing for a longer period of time than in still water (Breum, 1970). Limited zoobenthic biomass was recorded in areas exposed to strong currents and wave action (Beukema, 2002), however, impacts from this pressure at the benchmark level may be low for this biotope, as the biotope is limited to sheltered locations. Increases in wave action may therefore remain within the limits of the species tolerance but factors such as sediment redistribution may alter the physical biotope.

Sensitivity assessment. Resistance to a change in nearshore significant wave height >3% but <5% of the two main characterizing species *Arenicola marina* and *Limecola balthica* 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 resistance through their traits to live relatively deep in the sediment. Resilience (recoverability) is also '**High**' giving a sensitivity of '**Not Sensitive**'. Due to limited evidence, confidence in this assessment is '**Low'**.

Chemical Pressures

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

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

Contamination at levels greater than the pressure benchmark may adversely affect the biotope. Bryan (1984) reported that short-term toxicity in polychaetes was highest to Hg, Cu and Ag, declined with Al, Cr, Zn and Pb with Cd, Ni, Co and Se being the least toxic. It was recorded that polychaetes have a range of tolerances to heavy metals levels of Cu, Zn, As and Sn being in the order of 1500-3500 µg/g.

These tolerances need to be assessed in relation to other pressures. For instance, toxicity of copper has been shown to increase under predicted ocean acidification levels recreated in a laboratory, reducing survival of *Arenicola marina* larvae by 24%, if exposed to copper under recreated ocean acidification conditions, compared to separate exposures (either copper or ocean acidification conditions separately) (Campbell *et al*., 2014).

Arenicola marina is presently used routinely as a standard bioassay organism for assessing the toxicity of marine sediments (Bat & Raffaelli, 1998). At high concentrations of Cu, Cd or Zn the blow lug left the sediment (Bat & Raffaelli, 1998). Exposure to 10 ppm Cd in seawater halted feeding in *Arenicola marina* although they continued at 1 ppm (Rasmussen *et al*., 1998). Rasmussen *et al*. (1998) pointed out that bioturbation by the blow lug increases the rate of uptake of Cd from the water to the sediment, however, where sediments were already contaminated, bioturbation ensured that some fraction of the contaminant would be mobilised to the surface sediment and the environment.

Arenicola marina was found to accumulate As, Cd, Sb, Cu, and Cr when exposed to pulverised fuel ash (PFA) in sediments (Jenner & Bowmer, 1990). Jenner & Bowmer (1990) also noted 95% mortality when exposed to 100% PFA for 90 days and 75% exposed to 50% PFA for the same period, however, the above mortality may have been due to the unsuitability of PFA as a substrate rather than the heavy metal contamination. The following toxicities have been reported in *Arenicola marina*:

- no mortality after 10 days at 7 µg Cu /g sediment, 23µg Zn/g and 9µg Cd /g;

- median lethal concentrations (LC50) of 20 µg Cu/g, 50 µg Zn/g, and 25 µg Cd/g (Bat & Raffaelli, 1998).

Bryan (1984) stated that Hg is the most toxic metal to bivalves. Studies of *Cerastoderma edule* transplanted populations from polluted and un-contaminated sites resulted in 10-15% mortality within 63 days but 100% within 4 months at the Restronguet Creek (Bryan & Gibbs, 1983). Additionally, Cu and Zn are believed to inhibit the settlement of juvenile *Cerastoderma edule,* leading to patchy distributions (Langston *et al*., 2003). Exposure to pulverised fuel ash resulted in high mortality of *Cerastoderma edule* but no mortality occurred for *Limecola balthica* (Jenner & Bowmer, 1990).

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.

Contamination at levels greater than the pressure benchmark may adversely influence the biotope. Suchanek (1993) concluded that, in general, on soft sediment habitats, infaunal polychaetes, bivalves and amphipods were particularly affected by oil spills. Hailey (1995) cited substantial kills of *Nereis*, *Cerastoderma*, *Macoma*, *Arenicola* and *Hydrobia* as a result of the *Sivand* oil spill in the Humber estuary in 1983. Levell (1976) examined the effects of experimental spills of crude oil and oil dispersant (BP1100X) mixtures on *Arenicola marina*. Single spills caused 25-50 % reduction in abundance and additional reduction in feeding activity. Up to 4 repeated spillages (over a 10 month period) resulted in complete eradication of the affected population either due to death or migration out of the sediment. Levell (1976) noted that recolonization was inhibited but not prevented. Prouse & Gordon (1976) examined the effects of surface fuel oil contamination and fuel oil sediment mixtures on the blow lug in the laboratory. They found that blow lug was driven out of the sediment by waterborne concentration of >1 mg/l or sediment concentration of >100 µg/g. Worms forced out of sediment may be able to migrate out of affected area but will be exposed to severe predation risk, especially in daylight. Seawater oil concentrations of 0.7 mg oil/l reduced feeding after 5 hrs and all worms exposed for 22 hrs to 5 mg/l oil left the sediment and died after 3 days. However, the sample size in this experiment was very small (6 worms). Sediment concentration >10 µg/g could reduce feeding activity. *Arenicola marina* can recolonize sediment relatively quickly (within 1 month), however, contaminated sediments would probably take longer to recover, extending recovery times.

Scoloplos armiger show a similar intolerance to hydrocarbon contaminates. Gray *et al.* (1990) found that *Scoloplos armiger* were a dominant species in uncontaminated soft sediments at a case study site adjacent to the Ekofisk oil field but were not present at contaminated sites.

Savari *et al*. (1991a) observed the density and growth of *Cerastoderma edule* decreased with increasing hydrocarbon concentration. McLusky (1982) examined the intertidal mudflat fauna at Kinneil in the Forth Estuary that received petroleum, chemical and domestic effluents. Evidence suggests that soft sediment communities are highly susceptible of hydrocarbon contamination. In the littoral zone especially, oil spills resulting from tanker accidents are likely to be deposited directly on the sediment of the biotope, preventing oxygen transport to the substratum and oil pushed in to the substratum by tidal-pulsing will destabilize the sediment (Elliott *et al*., 1998).

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.

Limited evidence concerning specific effects of synthetic chemical contaminants on *Arenicola marina* or *Limecola balthica* was found. *Arenicola marina* has, however, shown negative responses to chemical contaminants, including damaged gills following exposure to detergents (Conti, 1987), and inhibited action of esterases following suspected exposure to point source pesticide pollution in sediments from the Ribble estuary, UK (Hannam *et al*., 2008).

Specific deleterious effects of synthetic chemicals (Ivermecten, tri-butyl-tin (TBT)) have been reported for various polychaetes, including characterizing species e.g. *Arenicola marina* and *Scoloplos armiger* (Collier & Pinn, 1998; Beaumont *et al*., 1989; Bryan & Gibbs, 1991). Beaumont *et al*. (1989) concluded that bivalves are particularly sensitive to TBT. For example, when exposed to 1-3 µg TBT/l, *Cerastoderma edule* (sometimes abundant in the biotope) suffered 100% mortality after two weeks. Bryan & Gibbs (1991) presented evidence that TBT caused recruitment failure in bivalves, due to either reproductive failure or larval mortality. Waldock *et al.* (1999) examined recovery of benthic infauna of the Crouch Estuary after a ban on the use of TBT on small boats. They observed marked increases in species diversity, especially of *Ampeliscid amphipods* and polychaetes (*Tubificoides* spp. and *Aphelochaeta marioni*) which mirrored the decline in sediment TBT concentration. Whilst a causal link could not be shown, the study by Waldock *et al.* (1999) suggested that crustacean and polychaete diversity may be inhibited by TBT contamination.

Polychaetes vary greatly in their tolerance of chemical contamination. The persistence of these chemical residues is highly dependent on the matrix and ambient environmental conditions. Generally, residues in water are less likely to be a long-term concern because of photo-degendation and dilution to below biological significant concentrations. However, TBT has a high binding affinity to sediments and residues incorporated into the sediment tend to persist for longer periods (Austen & McEvoy, 1997; Huntington *et al.*, 2006).

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

Reports on littoral sediment benthic communities at Sandside Bay, adjacent to Dounray nuclear facility, Scotland, (where radioactive particles have been detected and removed) reported *Arenicola marina* were abundant (SEPA, 2008). Kennedy *et al.* (1988) reported levels of ^{137}Cs in *Arenicola* spp. of 220-440 Bq/kg from the Solway Firth.

Hutchins *et al.* (1998) described the effect of temperature on bioaccumulation by *Limecola balthica* (as *Macoma balthica*) of radioactive americium, caesium and cobalt, but made no comment on the intolerance of the species. Insufficient evidence was available on the effects of radionuclide contamination to assess this pressure.

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**. However, some limited evidence was returned by searches on activated carbon (AC). AC is utilised in some instances to effectively remove organic substances from aquatic and sediment matrices. Lillicrap *et al.* (2015) demonstrate that AC may have physical effects on benthic dwelling organisms at environmentally relevant concentrations at remediated sites.

De-oxygenation	Medium Q: High A: Medium C: High	High Q: High A: Low C: Medium	Low Q: High A: Low C: Medium

Occurrence of dissolved oxygen concentration of less than or equal to 2 mg/l for 1 week, will reduce the oxygen availability when *Arenicola marina* switches back to aerobic metabolism.

Arenicola marina was able to survive anoxia for 90 hrs in the presence of 10 mmol/l sulphide in laboratory tests (Zeber & Schiedek, 1996). Hydrogen sulphide (H2S) produced by chemoautotrophs within the surrounding anoxic sediment and may, therefore, be present in *Arenicola marina* burrows. Although the population density of *Arenicola marina* decreases with increasing H2S, *Arenicola marina* is able to detoxify H2S in the presence of oxygen and maintain low internal concentration of H2S. At high concentrations of H2S in the lab (0.5, 0.76 and 1.26 mmol/l) the lugworm resorts to anaerobic metabolism (Zeber & Schiedek, 1996). At 16°C *Arenicola marina* survived 72 hrs of anoxia but only 36 hrs at 20°C. Tolerance of anoxia was also seasonal, and in winter anoxia tolerance was reduced at temperatures above 7°C. Juveniles have a lower tolerance of anoxia but are capable of anaerobic metabolism (Zebe & Schiedek, 1996). However, *Arenicola marina* has been found to be unaffected by short periods of anoxia and to survive for 9 days without oxygen (Borden, 1931 and Hecht, 1932 cited in Dales, 1958; Hayward, 1994).

Limecola balthica appears to be relatively tolerant of deoxygenation. Brafield & Newell (1961) frequently observed that in conditions of oxygen deficiency (e.g. less than 1 mg O2/l) *Limecola balthica* (as *Macoma balthica*) survived low oxygen concentrations and shell growth continued (Jansson *et al*., 2015). In hypoxic conditions individual *Limecola balthica* moved upwards to fully expose itself on the surface of the sand or buried at shallower depths, leaving them at greater risk of predation (Long *et al*., 2014). Specimens lay on their side with the foot and siphons retracted but with valves gaping slightly allowing the mantle edge to be brought into full contact with the more oxygenated surface water lying between sand ripples. In addition, Limecola balthica was observed, under laboratory conditions, to extend its siphons upwards out of the sand in to the overlying water when water was slowly deoxygenated with a stream of nitrogen. The lower the oxygen concentration became the further the siphons extended.

This behaviour, an initial increase in activity stimulated by oxygen deficiency, is of interest because the activity of lamellibranchs is generally inhibited by oxygen deficient conditions (Brafield & Newell, 1961). Dries & Theede (1974) reported the following LT50 values for *Limecola balthica* (as *Macoma balthica*) maintained in anoxic conditions: 50 -70 days at 5°C, 30 days at 10°C, 25 days at 15°C and 11 days at 20°C. Theede (1984) reported that the ability of *Limecola balthica* to resist extreme oxygen deficiency was mainly due to cellular mechanisms. Of considerable importance are sufficient accumulations of reserve compounds e.g. glycogen and the ability to reduce energy requirements for maintenance of life by reducing overall activity (Theede, 1984). *Limecola balthica* is therefore very tolerant of hypoxia, although it may react by reducing metabolic activity and predation risk may increase. Metabolic function should quickly return to normal when oxygen levels are resumed and so recovery is expected.

Rosenberg *et al.* (1991) observed that *Cerastoderma edule* migrated to the sediment surface in response to reduced oxygen concentrations in the upper sediment layers and reported 100% mortality of *Cerastoderma edule* exposed to 0.5-1.0 ml/l oxygen for 43 days. Theede *et al.* (1969) reported 50% mortality after 4.25 days at 1.5 ml/l oxygen. Theede *et al.* (1969) added that *Cerastoderma edule* only survived 4 days' exposure of <6.1 cm□/l of hydrogen sulphide, which is associated with anoxic conditions. Fatalities of the abundant species in the biotope, *Cerastoderma edule* are likely to occur at the benchmark.

During low tide the superabundant polychaete *Scoloplos armiger* survives de-oxygenation by ascending into the oxidative layer where it is able to maintain aerobic metabolism. In laboratory conditions *Scoloplos armiger* survived low oxygen conditions for 40 hours (Schöttler & Grieshaber, 1988). Limited evidence was returned by searches on extended exposure to low levels of dissolved oxygen.

Sensitivity assessment. The characterizing species of the biotope display tolerance of low dissolved oxygen over tidal cycles although some mortality may be expected at the extent of the pressure benchmark for certain species. *Arenicola marina* have shown tolerance for up to 9 days. *Limecola balthica* is likely to experience increased predation pressure as a result of extending its syphon under low oxygen conditions. *Cerastoderma edule* only survived 4 days' exposure of <6.1 cm□/l of hydrogen sulphide, which is associated with anoxic conditions and is most likely to experience large scale mortality. *Scoloplos armiger* displays tolerance to these conditions for up to 40 hours but evidence returned by searches was limited beyond that.

Resistance is assessed as '**Medium'**, resilience is assessed as '**High'** and therefore, sensitivity is assessed as '**Low'**.

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

This pressure relates to increased levels of nitrogen, phosphorus and silicon in the marine environment compared to background concentrations.

An influx of high quality organic matter (Graf, 1989; Levin *et al.*, 1997), may influence the distribution of species and the surrounding sediments, to support microbial communities that differ from those in the surface sediments (Kristensen & Kostka, 2005; Papaspyrou *et al.*, 2005; Laverock *et al.*, 2010; Braeckman *et al.*, 2014). Additionally, bioturbators (such as *Arenicola marina*) may stimulate biogeochemical processes along the burrow walls resulting in an increase of nutrient fluxes to the water column (Stief, 2013). At the same time, higher coupled nitrification-denitrification rates along burrow walls give rise to an important release of nitrogen gas from the sedimentary nitrogen cycle (Stief, 2013), thereby counteracting nitrogen eutrophication (Seitzinger, 1988).

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

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

Benthic responses to organic enrichment have been described by Pearson & Rosenberg (1978) and Gray (1981). Moderate enrichment increases food supplies, enhancing productivity and abundance. Gray *et al.* (2002) concluded that organic deposits between 50 to 300 g C/m^2/year, is efficiently processed by the benthic species. Whilst substantial increases >500 g C/m^2/year would likely to have negative effects, limiting the distribution of organisms, and degrade the habitat, by leading to eutrophication, algal blooms and changes in community structure (see nutrient enrichment and de-oxygenation) (Snelgrove & Butman, 1995; Cromey *et al.*, 1998).

Mudflats can be sensitive to organic enrichment which can result in blooms of opportunistic ephemeral seaweeds such as *Enteromorph*a spp. These can form dense mats, shading the mud surface and lead to anoxic conditions altering community structure and reducing diversity and abundance and interference with bird feeding (Simpson, 1997). *Limecola balthica* have been shown experimentally to resist periods of up to 9 weeks under algal clover; their long siphon allowing them to reach oxygenated water although other bivalves decreased in abundance (Thiel *et al.*, 1998).

Organic enrichment from waste-water discharge (Dutch Wadden Sea) resulted in positive effects on *Limecola balthica* abundance, biomass, shell growth and production. These effects were concluded to be due to increased food supply (Madsen & Jensen, 1987). Organic enrichment, related to increased food supply has also been related to significantly increased settlement of juvenile *Arenicola marina* (Hardege *et al.*, 1998).

Borja *et al.* (2000) assessed relative sensitivity of *Scoloplos armiger* as an ABMI Ecological Group II species (indifferent/tolerant to enrichment). Gittenberger & Van Loon (2011) assessed *Pygospio* *elegans* as an AMBI Group III species 'not sensitive to organic enrichment'.

Sensitivity assessment. There is little empirical evidence to quantify the effect of organic enrichment deposits of 100 g C/m□/year on *Arenicola marina* and *Limecola balthica* but the existing studies suggest these species would not suffer negative impacts under the benchmark pressure, although deposits of greater than the benchmark (e.g. 500 g C/m□/year would negatively impact the biotope).

Therefore, a resistance of '**High**' is recorded so that resilience is also '**High**' and the biotope is probably biotope is '**Not Sensitive'** at the benchmark level.

Physical Pressures

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

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

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

This biotope is only found in sediment, in particular muddy sand or fine sand the burrowing organisms, *Arenicola marina*, and *Limecola balthica* 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. The resistance to this change is **'None'**, and the resilience is assessed as '**Very Low**' as the change at the pressure benchmark is permanent. The biotope is assessed to have a **'High**' sensitivity to this pressure at the benchmark.

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

The change in one Folk class is considered to relate to a change in classification to adjacent categories in the modified Folk triangle (Long, 2006). For this biotope three adjacent categories are relevant, these include a change from muddy sand to i) sandy mud or ii) gravelly muddy sand or a change from sand to; iii) gravelly sand (Folk, 1954 cited in Long 2006).

A change to sandy mud is likely to have limited impact on the characterizing species as these conditions would remain close to preferred habitat conditions. For example, *Arenicola marina* displays a broad sediment habitat preference including sandy mud (Tyler-Walters, 2008). *Limecola balthica* prefers very fine sediments with high mud content and *Scoloplos armiger* sediments 200-350 µm that are enriched with mud (Degraer *et al*., 2006).

An increase in gravel content to either ii) gravelly muddy sand or iii) gravelly sand is likely to influence the benthic species community within the biotope. *Arenicola marina* displays some tolerance to increased gravel content in UK case studies, but generally abundance decreases (Chapman & Newell, 1949; King, 1980). *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 long-term increased gravel content.

Coarser sediments provide inhospitable conditions for colonizing infauna. *Scoloplos armiger* and *Pygospio elegans* are opportunistic species that are capable of exploiting these inhospitable conditions (Gray, 1981). Therefore, these species are likely to be less affected and even increase in abundance under a change in Folk class from muddy sand to gravelly muddy sand or a change from sand to gravelly sand.

Sensitivity assessment. Although a change to sandy mud is likely to have limited impact a change to ii) gravelly muddy sand or iii) gravelly sand are likely to impact the characterizing species *Arenicola marina* and *Limecola balthica*. Case studies from UK sites display decreasing abundance with increased gravel content (*Arenicola marina*) and reduced growth rates (*Limecola balthica*). This suggests that the resistance is '**None**' as abundance of these key characterizing species would possibly decrease and the biotope would alter if an increase in gravel content persisted. Resilience as **Very low** (the pressure is a permanent change), and sensitivity as **High.**

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

The substratum of this biotope consists of fine sand or muddy sand with scattered pebbles, boulders and cobbles (Conner *et al*., 2004). The characterizing species *Arenicola marina* and *Limecola balthica* 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. If extraction occurred across the entire biotope, loss of the biotope would occur. Recovery would require substratum to return to fine sand and muddy sand sediments with scattered pebbles, boulders and cobbles. Recovery of benthic infauna communities from an impact such as extraction of substratum (from activities such as use of bottom towed fishing gears, aggregate dredging or storm impacts) is predicted to follow succession from initial colonization community of opportunistic species that reproduce rapidly, have small body sizes, short lifespans and early reproductive ages, through to a transitional community and finally an equilibrium community of slower growing, longer lived, larger species (Newell *et al*., 1998).

Arenicola marina and *Limecola balthica* are more likely to occur in the late transitional and the equilibrium communities that rely on more stable sediments that have recovered from disturbance (Newell *et al*., 1998). Therefore, even if hydrological conditions allow for re-establishment of fine sand and muddy sand, recovery times to an equilibrium community, from an impact such as dredging are predicted to be between 2-3 years minimum and often 5-10 years (Newell *et al*., 1998).

Hiddink (2003) showed that the density of *Limecola balthica* (as *Macoma balthica*) was reduced in areas in the Wadden Sea (Netherlands) that had experienced suction dredging for cockles, which removes the surface sediment. The disturbance to the sediment also appeared to leave the habitat less suitable for settlement of young *Limecola balthica* (Hiddink, 2003).

Smaller scale extraction of patches of substratum through activities such as bait digging may have impacts over finer spatial scales within the biotope. If the impact is not spread over a larger area the effects are likely to occur within the dug area. McLusky *et al.* (1983) found that *Arenicola marina* rapidly recolonise basins created by bait digging but populations were reduced in the dug mounds. *Limecola balthica* populations were unaffected suggesting the biotope would recover from this impact if it occurred over a limited spatial scale.

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. At the pressure benchmark, the exposed sediments are considered to be suitable for recolonisation almost immediately following extraction. Recovery will be mediated by the scale of the disturbance and the suitability of the sedimentary habitat. Recovery is most likely to occur via larval recolonization, following a succession from colonization communities to equilibrium communities only after 2-10 years (not including time for sediment to recover). Resilience is considered to be '**Medium**'. Sensitivity based on resistance and resilience is therefore categorized as **'Medium'**.

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

Damage to seabed surface features may occur due to human activities such as bottom towed fishing gear (trawling and dredging), construction of renewable energy devices offshore and natural disturbance from storms are considered in this assessment.The burrowing traits of *Arenicola marina* and *Limecola balthica* may provide some resistance to this pressure. However, Boldina & Beninger (2014) reported decreases in naturally occurring aggregations of *Arenicola marina* in trawled areas, which suggests consequences reproduction, recruitment, growth and feeding.

Ferns *et al.* (2000) reported a decline of 31% in populations of *Scoloplos armiger* (initial density 120/m▯) in muddy sands and an 83% decline in *Pygospio elegans* (initial density 1850/m▯) when a mechanical tractor towed harvester was used (in a cockle fishery). *Pygospio elegans* were significantly depleted for >100 days after harvesting (surpassing the study monitoring timeline).

Scoloplos armiger demonstrated recovery >50 days after harvesting in muddy sands. *Cerastoderma edule* recovered more quickly than those in muddy sand with a more structured community, which included *Pygospio elegans* in clean sands (Ferns *et al.*, 2000).

Collie *et al.* (2000) identified that well established sand and muddy sand intertidal communities (such as this biotope) suffered the greatest impact from bottom towed fishing activities. Mean response in muddy sand communities was much more negative than other habitats and most negative responses were for the polychaetes *Arenicola marina* and *Scoloplos armiger*. *Limecola balthica* and *Cerastoderma edule* were also more negatively impacted, although this may be due to direct targeting of *Cerastoderma edule* by cockle fisheries. The review concluded that there were ecologically important impacts from removal of >50% of fauna from bottom towed fishing activity (dredge and trawls) (Collie *et al.*, 2000).

Construction of offshore wind farms or deployment of wave energy device bases are likely to remove the biotope at the site of the wind farm tower or concrete wave energy base. Drilling and piling during construction will also re-suspend sediment into the water column, with coarser material settling close to the base and finer material being deposited at a greater distance in the direction of water flow at the site (Coates *et al*., 2014). Pre-existing characterizing communities will be impacted and a risk of recovery to a different equilibrium community may occur (Newell *et al*., 1998; Coates *et al*., 2014; Coates *et al*., 2015).

Changes in sediment, close to device bases, will prevent the establishment of this biotope and finer sediment is likely to be deposited close to a device base in the wake of the main current (Coates *et al*., 2014). In a case study in the Belgium North Sea, this process resulted in shifts in species dominance to tube building polychaetes (which may stabilise fine sediments), this impact was highest within 15 m of device bases (Coates *et al*., 2014). Where scour protection is not present, coarser material may be exposed adjacent to device bases and finer material that has been removed by scour, deposited along the wake of the main current (Hiscock, 2002). Shifts in species communities and dominant species occur in both examples but are limited to 15 m to 20 m from the device bases.

Boat moorings were demonstrated to also impact species communities close to the mooring buoy in a case study in the Fal and Helford estuaries (south west UK). Coarser sediment was exposed close to mooring buoys, caused by suspension of fine sediments by movement of the chain (Latham *et al*., 2012). However, fine sand and muddy sediments displayed the least influence from disturbance from moorings, suggesting a smaller impact to this biotope than other intertidal biotopes.

Sensitivity assessment. Resistance is '**Low**' as significant mortality of characterizing species was recorded in the above evidence. Resilience is '**Medium**' if the impact is less than 3 times a year, as recovery is expected in 2-10 years based on the life cycle traits of the characterizing species. Sensitivity for occasional (less than 3 times a year) damage to the seabed surface features is therefore '**Medium**' at the benchmark level.

Penetration or disturbance of the substratum subsurface	None Q: High A: High C: High	Low Q: High A: High C: High	High Q: High A: High C: High

Penetration and or disturbance of the substratum would result in similar, if not identical results as 'abrasion' or 'removal' of this biotope. 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.

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 **'Low'**, and sensitivity is assessed as '**High'.**

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 *Arenicola marina* and *Limecola balthica* biotopes. As the species live in the sediment 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 *Arenicola marina*, *Limecola balthica* as characterizing species and for other abundant species such as *Scoloplos armiger*, *Pygospio elegans* and *Cerastoderma edule.*

Increases in turbidity may reduce benthic diatom productivity and productivity of phytoplankton in the water column. Increased clarity, however, may increase primary production. In cases of increased turbidity impacts may be small for *Arenicola marina* as the species feeds on meiofauna, bacteria and organic particles in the sediment and reductions in food availability in phytoplankton may be mitigated.

An increase in suspended solids (inorganic or organic) may also increase food availability if sediment containing meiofauna, bacteria or organic particles is transported in the water column. However, higher energetic expenditure to unclog the feeding apparatus may occur, which may alter habitat suitability.

An increase in food availability through either increased phytoplankton abundance (under increased water clarity) or increased food resources suspended in the water column (under increased turbidity) may enhance growth and reproduction of both suspension and deposit feeding species.

Sensitivity assessment. Resistance is '**High**' as no significant negative effects are identified and potential benefits from increased food resources may occur, based on expert judgement, utilising evidence of species traits and distribution. 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)	High Q: Low A: NR C: NR	High Q: High A: Low C: Medium	Not sensitive Q: Low A: Low C: Low

The biotope occurs in extensive intertidal flats both on open coasts and in marine inlets (Conner *et al*., 2004). These locations would be likely to experience some redistribution of fine material during tidal cycles. Although the biotope occurs in sheltered locations some mixing from wave action may also be expected. The characterizing species *Arenicola marina* and *Limecola balthica* live in the sediment, to depths of 40 cm and 5-6 cm respectively (Stekoll *et al*., 1980; Volkenborn & Reise, 2006) and would be expected to be well adapted to these conditions.

Longer term deposition of fine material (e.g. continuous deposition) would be expected to lead to higher densities of macrobenthic organisms. For example, in the North Sea (Belgium) deposition of fine particle sediment, disturbed by scour around the base of a wind farm tower led to higher macrobenthic densities and created a shift in macrobenthic communities around the wind farm tower (influenced by the direction fine material had settled) (Coates *et al*., 2014).

Sensitivity assessment. As the exposure to the pressure is for a single discrete event, resistance is assessed as '**High**', resilience is also '**High**' and sensitivity is assessed as '**Not Sensitive**'. Confidence in this assessment is lower as the assessment is based on traits of the species characterizing the biotope and the relevant direct case studies present examples where impacts are not from single discrete events.

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

Limited evidence was found on responses of characterizing species to a deposition of up to 30 cm of fine material. Evidence is therefore assessed for evidence of deposits of fine material from sources such as dredge waste spoil and bait digging mounds (which may not be 30 cm).

Smaller scale extraction of patches of substratum through activities such as bait digging may have impacts over finer spatial scales within the biotope. If the impact is not spread over a larger area the effects are likely to occur within the dug area. McLusky *et al.* (1983) found that *Arenicola marina* rapidly recolonise basins created by bait digging but populations were reduced in the dug mounds, suggesting the species would be negatively impacted by heavy deposition of sediment. *Limecola balthica* populations were unaffected by bait digging suggesting the species can re-colonise areas where heavy deposition of sediment has occurred.

Witt *et al.* (2004) identified an increased in *Limecola balthica* populations in areas of disposal of dredge waste spoil, possibly due to nutrient input at the disposal site. This suggests *Limecola balthica* responds opportunistically and is robust to this pressure.

Cerastoderma edule on the north Norfolk coastline was shown to be severely depleted from the effects of bait digging, as a result of 10 cm of sediment being placed on the sediment surface (Jackson & James, 1979; McLusky *et al.*, 1983; Cryer *et al.*, 1987). Small, surface-dwelling, polychaete species have been shown to be compromised by changes to sediment structure as a result of heavy muddy sediment spoil from bait digging (Brown *et al.*, 1997). This has the potential to disturb the species composition and the abundance of opportunistic species may increase, negatively impacting the biotope.

Pygospio elegans was classified as 'Group III' by Borja *et al.* (2000) as tolerant of disturbance and excess organic content. As a tube building worm, *Pygospio elegans* also stabilises sediments, a trait which aids recolonization of disturbed sediments or deposited material (Bolam & Fernandes, 2002).

Longer term or heavy deposition of fine material (e.g. continuous deposition) would be expected to lead to higher densities of macrobenthic organisms. For example, in the North Sea (Belgium) deposition of fine particle sediment, disturbed by scour around the base of a wind farm tower led to higher macrobenthic densities and created a shift in macrobenthic communities around the wind farm tower (in the direction fine material had settled) (Coates *et al.*, 2014).

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, though the pressure is likely to negatively impact the biotope as the characterizing species *Arenicola marina* may experience reduced abundance. *Limecola balthica* and the polychaete *Pygospio elegans* are likely to be able to exploit the increased nutrient input and rapidly colonize the deposited sediment.

Other opportunistic species are likely to colonize the biotope if heavy deposition of fine material occurs. The deposited sediment is likely to release large quantities of organic materials enhancing population density but with the risk that pre-impacted communities will shift to a different state (Coates *et al.*, 2014; Coates *et al.*, 2015). Recovery to pre-impact communities, given the pressure occurs as a single discrete event is likely to require succession through transitional communities before an equilibrium community is reached, taking up to 10 years (Newell *et al.*, 1998).

Resistance is assessed as '**Low**', due to loss of abundance of at least one characterizing species. Resilience is assessed as '**Medium**' as recovery may take 2-10 years. The final sensitivity is therefore '**Medium**'.

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 are considered of the impact of specific marine litter, including cigarette butts and microplastics.

Litter, in the form of cigarette butts has been shown to have an impact on worms living in the sediment, although effects have not been studied directly on species characterizing this biotope. Ragworms *Hediste diversicolor*, which also inhabit intertidal sediments 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). Studies are limited on impacts of litter on infauna and this UK study suggests health of infauna populations are negatively impacted by this pressure.

Arenicola marina ingests microplastics that are present within the sediment it feeds within. Wright *et al.* (2013) carried out a lab study that displayed presence of microplastics (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 colonization of sediment by other species, reducing diversity in the biotopes the species occurs within. Wright *et al.* (2013) suggested, that in the intertidal regions of the Wadden Sea, where *Arenicola marina* is an important ecosystem engineer, *Arenicola marina* could ingest 33 m▯ of microplastics a year.

Sensitivity assessment. Impacts from the pressure 'litter' would depend upon the exact form of litter or man-made object being introduced. In the case of marine litter in the form of cigarette butts or microplastics health of populations of characterizing species would be impacted. Significant impacts have been shown in laboratory studies but impacts at biotope scales are still unknown and this pressure is ▯**Not assessed.**

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

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 level, confidence in evidence of these effects is low.

Field measurements of electric fields at North Hoyle wind farm, North Wales recorded 110 µV/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 thornback ray *Raja clavata* and attraction to the source in catshark *Scyliorhinus canicular* (Gill *et al.*, 2009).

Flatfish, which are predators of many polychaete species, including dab *Limanda limanda* and sole *Solea solea* have been shown to decrease in abundance in a wind farm array or remain at distance from wind farm towers (Vandendriessche *et al*., 2015; Winter *et al*., 2010). However, larger plaice increased in abundance (Vandendriessche *et al*., 2015). There have been no direct causal links identified to explain these results.

However, there is not enough evidence to assess the sensitivity of the characterizing species and sediments to litter.

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 respond to noise and therefore is '**Not relevant'.**

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

There is no direct evidence of effects of changes in incident light on the characterizing species of this biotope. All characterizing species live in the sediment and do not rely on light levels directly to feed or find prey so limited direct impact is expected. As this biotope is not characterized by the presence of primary producers it is not considered that shading would alter the character of the habitat directly.

More general changes to the productivity of the biotope may, however, occur. Beneath shading structures there may be changes in microphytobenthos abundance. Littoral muddy sands support microphytobenthos on the sediment surface and within the sediment. The microphytobenthos consists of unicellular eukaryotic algae and cyanobacteria that grow within the upper several millimetres of illuminated sediments, typically appearing only as a subtle brownish or greenish shading. 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	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'. This pressure is considered applicable to mobile species, e.g. fish and marine mammals rather than seabed habitats. Physical and hydrographic barriers may limit the dispersal of seed. But seed dispersal is not considered under the pressure definition and benchmark.

Barriers that reduce the degree of tidal excursion may alter larval supply to suitable habitats from source populations. Barriers may also act as stepping stones for larval supply over greater distances (Adams *et al*., 2014). Conversely, the presence of barriers in 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. If a barrier (such as a tidal barrier) incorporated renewable energy devices such as tidal energy turbines, these devices may affect hydrodynamics and, therefore, migration pathways for larvae into and out of the biotope (Adams *et al*., 2014). However, evidence is limited.

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 ‘surface abrasion’.

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

Arenicola marina larvae and the other associated polychaete species may have some limited visual perception. As they live in the sediment the species will most probably not be impacted at the pressure benchmark.

Sensitivity assessment. As the characterizing species live within the sediment and are likely to have limited visual perception this pressure is assessed as ‘**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

Key characterizing species within this biotope are not cultivated or translocated. Therefore, this pressure is considered ‘**Not relevant’** to this biotope group.

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

No direct evidence relating to detrimental impacts of the introduction of non-indigenous species was found for *Arenicola marina* or *Limecola balthica*.

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

'No evidence' on the effect on *Arenicola marina* of introduction of relevant microbial pathogens or metazoan disease vectors was found.

Limecola balthica in Delaware Bay, north-east USA, was found to host *Perkinsus* genus pathogens (Lindsay *et al*., 2007). *Cerastoderma edule* has been reported to host approximately 50 viruses, bacteria and fungi, including turbellaria, digeneans and cestodes (Longshaw & Malham, 2012).

Bacterial diseases are more significant in the larval stages and protozoans are the most common cause of epizootic outbreaks leading to mass mortalities of bivalves. Parasitic worms, trematodes, cestodes and nematodes can reduce growth and fecundity in bivalves and may in some instances cause death (Dame, 1996). *Cerastoderma edule* may be infected by numerous larval digenean trematodes and the parasitic copepod *Paranthessius rostatus* but no evidence of mass mortalities of cockles in the British Isles attributable to parasites was found. Boyden (1972) reported castration in cockles by parasites from the River Couch estuary, Essex, potentially reducing subsequent population sizes.

Mortality rates in the commercial *Cerastoderma edule* fishery in Galicia (NW Spain) increased sharply in April 2012, reaching 100% by May. Marteiliosis, which was first detected in February 2012 and reached 100% prevalence in April 2012, was identified as the most probable cause. Extensive surveillance of the Galician coast in May to July 2012 detected marteiliosis in most cockle beds of the Ría de Arousa, whereas it was not found in other rías 2 months later, the cockle catch in the Ría de Arousa became negligible as a result of a *Martelia cochillia* protozoan infection (Villalba *et al*., 2014). There is insufficient information to assess the recoverability of *Cerastoderma edule* and parasitic infection by *Martelia cochillia* and other related protozoan species such as *Martelia refringens*, which affects European bivalves (Carrasco *et al*., 2012).

Sensitivity assessment. Based on the evidence for the *Cerastoderma edule*, it is likely that parasitic infection may indirectly alter the species composition of the biotope. Although less evidence was retuned for the characterizing mollusc species *Limecola balthica*. Although evidence and so confidence is limited, resistance is assessed as '**Medium**', resilience is assessed as **'High**' and sensitivity is therefore assessed as **'Low'**.

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

Fowler (1999) reviewed the effects of bait digging on intertidal fauna, including *Arenicola marina*. Diggers have been reported to remove 50 or 70% of the blow lug population. Heavy commercial exploitation in Budle Bay in winter 1984 removed 4 million worms in 6 weeks, reducing the population from 40 to <1 per m▯. Recovery occurred within a few months by recolonization from surrounding sediment (Fowler, 1999). However, Cryer *et al*. (1987) reported no recovery for 6 months over summer after mortalities due to bait digging. Mechanical lugworm dredgers have been used in the Dutch Wadden Sea where they removed 17-20 million lugworm/year. A near doubling of the lugworm mortality in dredged areas was reported, resulting in a gradual substantial decline in the local population over a 4 year period. The effects of mechanical lugworm dredging is more severe and can result in the complete removal of *Arenicola marina* (Beukema, 1995; Fowler, 1999). Beukema (1995) noted that the lugworm stock recovered slowly reaching its original level in at least three years. McLusky *et al*. (1983) examined the effects of bait digging on blow lug populations in the Forth Estuary. Dug and infilled areas and unfilled basins left after digging re-populated within 1 month, whereas mounds of dug sediment took showed a reduced population. Basins accumulated fine sediment and organic matter and showed increased population levels for about 2-3 months after digging. Overall, recovery is generally regarded as rapid. However, Fowler

(1999) pointed out that recovery may take longer on small pocket beaches with limited possibility of recolonization from surrounding areas. Therefore, if adjacent populations are available, recovery will be rapid. However, where the affected population is isolated or severely reduced (e.g. by long-term mechanical dredging), then recovery may be extended.

Smaller scale extraction of patches of substratum through activities such as bait digging may have impacts over finer spatial scales within the biotope. If the impact is not spread over a larger area the effects are likely to occur within the dug area. McLusky *et al.* (1983) found that *Arenicola marina* rapidly re-colonize basins created by bait digging but populations were reduced in the dug mounds. *Limecola balthica* populations were unaffected in dug areas, suggesting the biotope would recover from this impact if it occurred over a limited spatial scale.

Hiddink (2003) showed that the density of *Limecola balthica* was reduced in areas in the Wadden Sea (Netherlands) that had experienced suction dredging for cockles, which removed the surface sediment. The disturbance to the sediment also appeared to leave the habitat less suitable for settlement of young *Limecola balthica* (Hiddink, 2003). This study provides evidence of loss of a characterizing species from the biotope and that recovery is unlikely to occur until the sediment characteristics have returned to pre-impact conditions. Removal of target species such as cockles *Cerastoderma edule* or bait digging for *Arenicola marina* is likely to impact the biotope. The extent of the impact will depend on the fishing / removal method and spatial extent.

Sensitivity assessment. *Arenicola marina* re-colonize basins created by bait digging but increased recovery times for larger scale mechanical dredging have been reported to occur (up to 3 years). *Limecola balthica* populations were unaffected by manual bait digging but were reduced in areas in the Wadden Sea (Netherlands) that had experienced suction dredging for cockles, which removes the surface sediment. The following sensitivity assessment therefore considers the greater impact, from commercial scale mechanical dredging (lugworm) or suction dredging (cockles). Resistance is assessed as '**Low**' and resilience is assessed as '**Medium**' (for cases where removal is large scale, e.g. mechanical dredging where recovery can take up to 3 years). Therefore, sensitivity to large scale mechanical or suction dredging is therefore assessed as '**Medium**'.

Removal of non-target species	Low Q: Low A: NR C: NR	Medium Q: High A: Medium C: Medium	Medium 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, *Arenicola marina* and *Limecola balthica* as well as the abundant species: *Scoloplos armiger* and *Pygospio elegans*, *Tubificoides benedii* and *Tubificoides pseudogaster*, and the cockle *Cerastoderma edule*, may be damaged or directly removed by static or mobile gears that are targeting other species (see abrasion and penetration pressures).

Commercial fisheries may discard damaged or dead non-target species, which could result in increased available food supply to deposit feeding characterizing species that may have survived in the area targeted by fisheries, but may also attract mobile predators and scavengers including fish and crustaceans which may alter predation rates in the biotopes.

Sensitivity assessment. The intertidal fine and muddy sand sediments present in this biotope are targeted by dredge fisheries for cockles and commercial bait digging and mechanical dredging for lugworms. Otter trawling and beam trawling is also possible in deeper areas at high water. Species recovery rates range from up to 3 years for *Arenicola marina* impacted by large scale mechanical dredging and >50-100 days for superabundant polychaete species removed incidentally.

Resistance is assessed as **‘Low’** (for cases where significant mortality/extraction of key characterizing species occurs), Resilience is assessed as ‘**Medium**’ (for cases where removal is large scale, e.g. mechanical dredging where recovery can take up to 3 years) and sensitivity to incidental non-targeted catch is therefore assessed as ‘**Medium**’.

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