Arenicola marina in infralittoral fine sand or muddy sand

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

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

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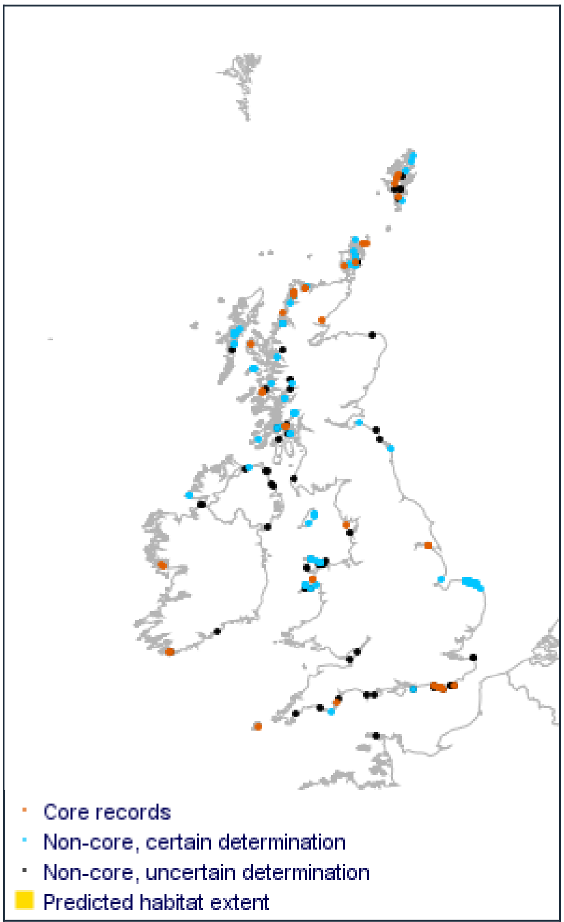

17-09-2018
Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

Researched by Dr Harvey Tyler-Walters **Refereed by** This information is not refereed.

Summary

UK and Ireland classification

EUNIS 2008	A5.243	*Arenicola marina* in infralittoral fine sand or muddy sand
JNCC 2015	SS.SSa.IMuSa.AreISa	*Arenicola marina* in infralittoral fine sand or muddy sand
JNCC 2004	SS.SSa.IMuSa.AreISa	*Arenicola marina* in infralittoral fine sand or muddy sand
1997 Biotope		

Description

In shallow fine sand or non-cohesive muddy sand in fully marine conditions (or occasionally in variable salinity) a community characterized by the polychaete *Arenicola marina* may occur. This biotope appears quite faunally sparse. Those other taxa present however, include scavenging crustacea such as *Pagurus bernhardus* and *Liocarcinus depurator*, terebellid polychaetes such as Lanice conchilega and the burrowing anemone *Cerianthus lloydii*. Occasional *Sabella pavonina* and frequent *Ensis* spp. may also be observed in some areas. At certain times of the year a diatom film may be present on the sediment surface. The majority of records for this biotope are derived from epifaunal surveys and consequently there is little information available for the associated infaunal species. It is possible that this biotope, like EcorEns (to which it is broadly similar) is an epibiotic overlay on other biotopes from the SSA complex. (Information from Connor *et al*., 2004).

Depth range

0-5 m, 5-10 m, 10-20 m

Additional information

Arenicola marina has a high fecundity and spawns synchronously within a given area, although the spawning period varies between areas. Spawning usually coincides with spring tides and fair weather (high pressure, low rainfall and wind speed) (see *Arenicola marina* review).

Wilde & Berghuis (1979b) reported 316,000 oocytes per female with an average wet weight of 4 grammes. Eggs and early larvae develop within the female burrow. Post-larvae are capable of active migration by crawling, swimming in the water column and passive transport by currents (Farke & Berghuis, 1979) e.g. Günther (1992) suggested that post-larvae of *Arenicola marina* were transported distances in the range of 1 km. Juvenile settlement is density dependant and the juveniles avoid areas of high adult abundance and settle above the adults on the shore (Farke & Berghuis, 1979; Reise *et al*., 2001). For example, on the sand flat of Sylt (North Sea), post-larvae hibernate in mussel beds and shell gravel in deep tidal channels, then migrate above the normal adult range (towards the top of the shore) and settle in conspicuous nursery beds in May to October. The juveniles migrate down the shore before or during the next winter, leaving the upper shore for the next generation. Reise *et al.* (2001) suggested that the largest and possibly oldest individuals were found seaward and in subtidal sands.

Adults reach sexual maturity by their second year (Newell, 1948; Wilde & Berghuis, 1979) but may mature by the end of their first year in favourable conditions depending on temperature, body size, and hence food availability (Wilde & Berghuis, 1979).

Beukema & de Vlas, (1979) suggested a lifespan, in the Dutch Wadden Sea, of at least 5-6 years, and cite a lifespan of at least 6 years in aquaria. They also suggested an average annual mortality or 22%, an annual recruitment of 20% and reported that the abundance of the population had been stable for the previous 10 years. However, Newell (1948) reported 40% mortality of adults after spawning in Whitstable.

McLusky *et al.* (1983) examined the effects of bait digging on blow lug populations in the Forth estuary. Dug and in-filled 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. Beukema (1995) noted that the lugworm stock recovered slowly from mechanical dredging reaching its original level in at least three years. Reise *et al.* (2001) noted that a 50% reduction in the abundance of adult lugworm on sand flats in Sylt after the severe winter of 1995/96, was replaced by an enhanced recruitment of juveniles in spring, so that the effect of the severe winter on *Arenicola marina* population was small and brief. Beukema (1995) estimated that four to five years of mechanical dredging in the Balgzand region of the Wadden Sea, increased the mortality of the *Arenicola* population by ca 17% per year to a total of ca 40% per year and resulted in a long-term decline in the lugworm stock, until the dredge moved to a richer area. However, Beukema (1995) noted that the lugworm stock recovered slowly after mechanical dredging, reaching its original level after at least three years.

Therefore, the recovery of *Arenicola marina* populations is generally regarded as rapid, and occurs by recolonization by adults or colonization by juveniles from adjacent populations or the subtidal. However, Fowler (1999) pointed out that recovery may take longer on a small pocket, isolated, beach 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.

Resilience assessment. Overall, the recovery of *Arenicola marina* is probably rapid. However, should a population be severely reduced it may take some time for recolonization to occur from other populations. Therefore, where resistance is 'Medium' or 'Low' (some or significant mortality) a resilience of **High** is recorded but where resistance is lower ('None'; severe mortality) a resilience of **Medium** (2-10 years) is recorded.

Listed By

- none -

Further information sources

Search on:

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Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

Arenicola marina is a 'funnel feeding' surface deposit feeder, ingesting sediment from the base of a funnel of sediment from within a U-shaped burrow (see *Arenicola marina* review; Wells, 1945; Zebe & Schiedek, 1996). Bioturbation by burrowing species, especially *Arenicola marina*, mobilises sediment and nutrients from the deeper sediment to the surface, making nutrients available to surface dwelling organisms. In addition, continued irrigation of their burrows by *Arenicola marina* transports oxygenated water into the sediment, resulting in oxygenated micro-environments in the vicinity of their burrows.

In high enough abundances, bioturbation by *Arenicola marina* modifies the sediment surface into mounds of casts and funnels. The resultant increase in bed roughness may result in increased susceptibility to erosion since raised features provide sites where areas of turbulent flow can be initiated. However, the effects of mucus binding in faecal pellet deposits increase the cohesiveness of the sediment, reducing its susceptibility to erosion (see Hall, 1994). Wendelboe *et al.* (2013) noted that sediment reworking by *Arenicola marina* (in mesocosms) increased the volume of sediment exposed to hydrodynamic flow and, hence, the resuspension of fine particulate and organic matter, depending on water flow, in the sediment to a depth of >20 cm. In addition, pits may capture fine detritus, resulting in increase microbial production within the pit. Therefore, bioturbation by both *Arenicola marina* can modify the sediment characteristics, its organic content, and surface profile.

Arenicola marina is the only important characterizing species within the biotope and a loss in the abundance of its population would result in loss or reclassification of the biotope. The mobile species (e.g. *Pagurus bernhardus* and *Liocarcinus depurator*) are probably found on similar sediments in the surrounding area. *Lanice conchilega* stabilises sediment in higher abundances than it is found in this biotope (see SCS.SLan) but is probably common in similar sediments. The burrowing anemone *Cerianthus lloydii* is found in a wide variety of sediments, from the lower intertidal to the subtidal. *Sabella pavonina* and frequent *Ensis* spp. are only observed in some recorded of the biotope. Therefore, the sensitivity of the biotope is dependent on the sensitivity of the population of *Arenicola marina*.

Resilience and recovery rates of habitat

Arenicola marina has a high fecundity and spawns synchronously within a given area, although the spawning period varies between areas. Spawning usually coincides with spring tides and fair weather (high pressure, low rainfall and wind speed) (see *Arenicola marina* review).

Wilde & Berghuis (1979b) reported 316,000 oocytes per female with an average wet weight of 4 grammes. Eggs and early larvae develop within the female burrow. Post-larvae are capable of active migration by crawling, swimming in the water column and passive transport by currents (Farke & Berghuis, 1979) e.g. Günther (1992) suggested that post-larvae of *Arenicola marina* were transported distances in the range of 1 km. Juvenile settlement is density dependant and the juveniles avoid areas of high adult abundance and settle above the adults on the shore (Farke & Berghuis, 1979; Reise *et al.*, 2001). For example, on the sand flat of Sylt (North Sea), post-larvae hibernate in mussel beds and shell gravel in deep tidal channels, then migrate above the normal adult range (towards the top of the shore) and settle in conspicuous nursery beds in May to October. The juveniles migrate down the shore before or during the next winter, leaving the upper shore for the next generation. Reise *et al.* (2001) suggested that the largest and possibly oldest individuals were found seaward and in subtidal sands.

Adults reach sexual maturity by their second year (Newell, 1948; Wilde & Berghuis, 1979) but may mature by the end of their first year in favourable conditions depending on temperature, body size, and hence food availability (Wilde & Berghuis, 1979). Beukema & de Vlas (1979) suggested a lifespan, in the Dutch Wadden Sea, of at least 5-6 years, and cite a lifespan of at least 6 years in aquaria. They also suggested an average annual mortality or 22%, an annual recruitment of 20% and reported that the abundance of the population had been stable for the previous 10 years. However, Newell (1948) reported 40% mortality of adults after spawning in Whitstable.

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Resilience assessment. Overall, the recovery of *Arenicola marina* is probably rapid. However, should a population be severely reduced it may take some time for recolonization to occur from other populations. Therefore, where resistance is ‘Medium’ or ‘Low’ (some or significant mortality) a resilience of **High** is recorded but where resistance is lower (‘None’; severe mortality) a resilience of **Medium** (2-10 years) is recorded.

Hydrological Pressures

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

Arenicola marina is recorded from shores of western Europe, Norway, Spitzbergen, north Siberia, and Iceland. In the western Atlantic, it has been recorded from Greenland, along the northern coast from the Bay of Fundy to Long Island. Its southern limit is about 40°N (see *Arenicola marina* review), although OBIS (2016) includes a few records from the Atlantic coast of Africa and the

Mediterranean.

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. 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 tolerance of *Arenicola marina*, with an optimum moving towards higher temperatures with decreasing latitudes, suggesting the species may adapt to long-term shifts such as 2°C but over time. 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* was most active in spring and summer months, with a mean rate of cast production fastest in spring and particularly slow in autumn and winter, suggesting feeding rate is greatest at higher temperatures (Retraubun *et al.*, 1996). Retraubun *et al.* (1996) also showed 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.

Temperature change may affect maturation, spawning time and synchronisation of spawning and reproduction in the long-term (Bentley & Pacey, 1992; Watson *et al.*, 2000). Spawning can be inhibited in gravid adults maintained above 15°C (Watson *et al.*, 2000). However, spawning success would remain dependent upon spring and autumn temperatures remaining below 15°C. Additionally, an impact from temperature change at the substratum surface may be mitigated as *Arenicola marina* is protected from direct effects by their position in the sediment.

Sensitivity assessment. *Arenicola marina* is probably not resistant of a short-term acute change in temperature of 5°C, although it is unlikely to be directly affected due to its infaunal habit and can migrate down the shore to deeper waters to avoid the changes in temperature (Reise *et al.*, 2001). Hence, a resistance of **Medium** is suggested to represent a loss of some of the *Arenicola* population and especially juveniles. Resilience is probably **High** and sensitivity is assessed as **Low**.

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

Arenicola marina is recorded from shores of western Europe, Norway, Spitzbergen, north Siberia, and Iceland. In the western Atlantic, it has been recorded from Greenland, along the northern coast from the Bay of Fundy to Long Island. Its southern limit is about 40°N (see *Arenicola marina* review), although OBIS (2016) includes a few records from the Atlantic coast of Africa and the Mediterranean.

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. Reise *et al.* (2001) stated that *Arenicola marina* was known to be a winter hardy species and that its abundance and biomass were stable even after severe winters. 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).

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

Evidence from the Sylt in the North Sea suggests that the effects of severe winters on *Arenicola marina* populations are small and brief (Reise, et al., 2001) The severe winter of 1995/1996 disrupted the usual juvenile settlement cycle in the sand flats of the Sylt, North Sea (Reise et al., 2001). In the severe winter, the adult population of *Arenicola marina* migrated down the shore, to deeper, waters to avoid low temperatures and 66 days of ice on the intertidal sand flats. Although, the adult population was halved, and no dead lugworms were observed on the surface or in the sediment. The post-larvae hibernate in the deep water channels (subtidal) in shell gravel and mussel beds. In summer the juveniles were not restricted to the upper shore but settled over a wider area of the flats, in the space left by the adult population. Reise *et al.* (2001) concluded that the enhanced recruitment demonstrated that the post-larvae did not suffer increased mortality during the winter, probably as their subtidal hibernation sites did not experience ice cover. Similarly, *Arenicola marina* was listed as 'apparently unaffected' by the severe 1962/63 winter in the UK (Crisp, 1964).

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

Salinity increase (local)	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

The biotope occurs in 'full' (35 ppt) salinity so that in an increase in salinity would result in hypersaline conditions (>40 ppt). Hypersaline conditions are only likely because of hypersaline effluents (brines). *Arenicola marina* loses weight when exposed to hyperosmotic shock (47 psu for 24 hrs) but are able to regulate and gain weight within 7-10 days (Zebe & Schiedek, 1996).

Sensitivity assessment. *Arenicola marina* was able to survive and adapt to short-term exposure to 47 psu (Zebe & Schiedek, 1996) but no evidence of the effect of long-term increases in salinity of hypersaline effluents was found. Therefore, no assessment was made.

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

This biotope is recorded from full or variable salinity (Connor *et al.*, 2004). *Arenicola marina* was recorded in biotopes from 'full' to reduced salinity (Connor *et al.*, 2004).

Once the salinity of the overlying water drops below about 55% seawater (about 18psu) *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 interstitial 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). Hayward (1994) suggested that *Arenicola marina* is unable to tolerate salinities below 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* . However, Barnes (1994) reported that *Arenicola marina* occurred at salinities down to 18 psu in Britain, but survived 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. However, *Arenicola marina* was also found in the western Baltic where salinities were as low as 10 ppt, and Baltic specimens survived at 6 ppt (Zebe & Schiedek, 1996). Therefore, regional populations can adapt to brackish conditions.

Sensitivity assessment. The evidence suggests that a reduction in salinity from ‘full’ to ‘reduced’ for a year is unlikely to adversely affect the resident *Arenicola* population. The characteristic mobile species and infauna typically occur in the intertidal and are also probably unaffected. Therefore, a resistance of **High** is suggested. Hence, resilience is **High** and the biotope is assessed as **Not sensitive** at the benchmark level.

Water flow (tidal current) changes (local)	High Q: Medium A: Medium C: Medium	High Q: High A: High C: High	Not sensitive Q: Medium A: Medium C: Medium

The biotope is found in moderately strong (<0.5-1.5 m/s) to very weak (negligible) flow in shallow fine sand or non-cohesive muddy sand (Connor *et al.*, 2004).

In 36-65 day mesocosm studies of the effects of *Arenicola marina* bioturbation, Wendelboe *et al.* (2013) found that the surface of the sediment (sand and mud mixture) was dominated faecal mounds and feeding pits at a flow rate of 0.11 m/s but was more eroded and the surface was more even at 0.25 m/s. At the low flow (0.11 m/s) there was no change in the sediment. But at 0.25 m/s, there was a substantial reduction in the silt and clay fractions of the sediment (a 36% reduction) and in the organic content of the sediment (a 42% reduction). At 0.25 m/s the material ejected into faecal casts was eroded (once the mucilaginous coating had eroded) and the water surface became turbid, resulting in loss of both silt/clay fractions and organic matter. Wendelboe *et al.* (2013) concluded that at ‘high’ flow (0.25 m/s) bioturbation by *Arenicola* (or other fauna) could lead to a gradual change in the sediment in the bioturbated sediment layer (i.e. the upper few centimetres). However, their experiment was a closed system, whereas the biotope is likely to receive regular input of organic matter.

Arenicola marina is generally absent from sediments with a mean particle size of <80μm and abundance declines in sediments >200μm (fine sand) because they cannot ingest large particles. Its absence from more fluid muddy sediments is probably because they do not produce large amounts of mucus with which to stabilise their burrows. Populations are greatest in sands of mean particle size of 100 µm. Between 100 and 200 µm the biomass of *Arenicola marina* increases with increasing organic content (Longbottom, 1970; Hayward, 1994). However, it is recorded from a variety of sediments from fine muds to muddy sands and sandy muds, clean sand and mixed sediments (Connor *et al.*, 1997b).

Sensitivity assessment. The biotope occurs in weak to very weak flow so that any further reduction is not relevant. An increase in water flow could modify the sediment. A significant increase may result in a change in the sediment from fine sands and muddy sands to gravelly sediments as the sand and fine particulates are removed. The experimental evidence suggests that a change in flow of 0.11 m/s to 0.25 m/s was enough to alter the sediment and the appearance of the biotope within 65 days. Therefore, a change in flow of 0.1-0.2 m/s may result in a reduction in the silt and organic content of the sediment, as well as the appearance of the biotope. The *Arenicola* population would persist although the sediment may become sandier over time. However, the biotope is recorded from fine sands as well as muddy sands. Therefore, a resistance of **High** is suggested. Resilience is, therefore, **High** and the biotope is assessed a**s Not sensitive** at the benchmark level.

Emergence regime changes	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

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

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

The biotope is recorded from moderately wave exposed to extremely wave sheltered conditions and moderately strong to very weak flow. The low energy habitat is probably crucial for the accumulation of the fine sands and muddy sands that typify the biotope, and those examples of the biotope that occur in moderate wave action probably occur at a greater depth than those in wave sheltered conditions.

A further decrease in wave action is not relevant. However, an increase in wave action (e.g. due to an increase in average storminess) would probably result in modification of the sediment and a change to coarse sand or gravel conditions, depending on the magnitude of the increase. *Arenicola* abundance declines in sediments >200µm (fine sand) so that the biotope would be reclassified and lost. Nevertheless, a 3-5% increase in significant wave height (the benchmark) is unlikely to be significant and the biotope is assessed as **Not sensitive** (resistance and resilience are **High**) at the benchmark level.

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

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

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

However, Bryan (1984) suggested that polychaetes are fairly resistant to heavy metals, based on the species studied. Short-term toxicity in polychaetes was highest to Hg, Cu and Ag, declined with Al, Cr, Zn and Pb whereas Cd, Ni, Co and Se the least toxic.
Therefore, although the polychaete members of the biotope may be relatively resistant to heavy metal contamination.

Nevertheless, this pressure is **Not assessed** but evidence is presented where available.

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

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

Suchanek (1993) reviewed the effects of oil spills on marine invertebrates and concluded that, in general, on soft sediment habitats, infaunal polychaetes, bivalves and amphipods were particularly affected. Crude oil and oil: dispersant mixtures were shown to cause mortalities in *Arenicola marina* (see review). Prouse & Gordon (1976) found that blow lug was driven out of the sediment by waterborne fuel oil concentrations of >1 mg/l or sediment concentration of >100 µg/g.

Nevertheless, this pressure is **Not assessed**.

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

The xenobiotic ivermectin was used to control parasitic infestations in livestock including sea lice in fish farms, degrades slowly in marine sediments (half-life >100 days). Ivermectin was found to produce a 10 day LC50 of 18µg ivermectin /kg of wet sediment in *Arenicola marina*. Sub-lethal effects were apparent between 5 - 105 µg/kg. Cole *et al.* (1999) suggested that this indicated a high intolerance. *Arenicola marina* has shown negative responses to chemical contaminants, including damaged gills following exposure to detergents (Conti, 1987), and inhibited the action of esterases following suspected exposure to point source pesticide pollution in sediments from the Ribble estuary, UK (Hannam *et al.*, 2008). Overall, therefore, members of this biotope may be sensitive synthetic chemicals to varying degrees and adverse effects on larvae may reduce recruitment in the long-term resulting in the loss of a proportion of the population.

Nevertheless, this pressure is **Not assessed** but evidence is presented where available.

Radionuclide contamination	No evidence (NEv) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

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. However, no information on the effects of radionuclide contamination was found.

Introduction of other substances	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

This pressure is **Not assessed**.

De-oxygenation	High Q: High A: High C: High	High Q: High A: High C: High	Not sensitive Q: High A: High C: High

Arenicola marina is subject to reduced oxygen concentrations regularly at low tide and is capable of anaerobic respiration. The transition from aerobic to anaerobic metabolism takes several hours and is complete within 6-8 hrs, although this is likely to be the longest period of exposure at low tide. Fully aerobic metabolism is restored within 60 min once oxygen returns (Zeber & Schiedek, 1996). This species was able to survive anoxia for 90 hrs in the presence of 10 mmol/l sulphide in laboratory tests (Zeber & Schiedek, 1996). Hydrogen sulphide (H_2S) 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 H_2S, *Arenicola marina* is able to detoxify H_2S in the presence of oxygen and maintain a low internal concentration of H_2S. At high concentrations of H_2S 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). Diaz & Rosenberg (1995) listed *Arenicola marina* as a species resistant of severe hypoxia.

Sensitivity assessment. The muddy sediments found in this biotope are organic rich and the benthic macrofauna is probably adapted to a degree of hypoxia. Burrowing species such as *Arenicola marina* burrows into anoxic sediment and may be tolerant of hypoxia. *Arenicola marina* would probably survive exposure to 2 mg O_2/l for one week (the benchmark) although they may incur a metabolic cost or reduced feeding during exposure. Therefore, resistance is assessed as **High**, resilience as **High** (by default) and the biotope is probably **Not sensitive** at the benchmark level.

Nutrient enrichment	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not sensitive Q: NR A: NR C: NR

The abundance and biomass of *Arenicola marina* increase with increased organic content in their favoured sediment (Longbottom, 1970; Hayward, 1994). Therefore, moderate nutrient enrichment may be beneficial.

Indirect effects may include algal blooms and the growth of algal mats (e.g. of *Ulva* sp.) on the surface of the intertidal flats. Algal mats smother the sediment, and create anoxic conditions in the sediment underneath, changes in the microphytobenthos, and with increasing enrichment, a reduction in species richness, the sediment becoming dominated by pollution tolerant polychaetes, e.g. *Manayunkia aestuarina*. In extreme cases, the sediment may become anoxic and defaunated (Elliot *et al.*, 1998). Algal blooms have been implicated in mass mortalities of lugworms, e.g. in South Wales where up to 99% mortality was reported (Boalch, 1979; Olive & Cadman, 1990; Holt *et al.* 1995). Feeding lugworms were present and exploitable by bait diggers within 1 month, suggesting rapid recovery, probably by migration from surrounding areas or juvenile nurseries.

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

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

The abundance and biomass of *Arenicola marina* increase with increased organic content in their favoured sediment (Longbottom, 1970; Hayward, 1994). Moderate enrichment increases food supplies, enhancing productivity and abundance. Gray *et al*. (2002) concluded that organic deposits between 50 to 300 gC m^{-2} yr^{-1}, are efficiently processed by benthic species. Substantial increases > 500 g C m^{-2} yr^{-1} would likely to have negative effects, limiting the distribution of organisms and degrade the habitat, leading to eutrophication, algal blooms, and changes in community structure to a community dominated by opportunist species (e.g. capitellids) with increased abundance but reduced species richness, and eventually to abiotic anoxic sediments (Pearson & Rosenberg, 1978; Gray, 1981; Snelgrove *et al.*,1995; Cromey *et al.*, 1998).

Borja *et al.* (2000) and Gittenberger & loon (2011) placed *Arenicola marina* into the AMBI pollution group III, defined as 'Species tolerant to excess organic matter enrichment. These species may occur under normal conditions, but their populations are stimulated by organic enrichment (slight unbalance situations)'.

Sensitivity assessment. The biotope is probably rich in organic matter as it occurs in sheltered, isolated areas. Therefore, a resistance of **High** is suggested at the benchmark level. Hence, resilience is **High** and the biotope is assessed as **Not sensitive** at the benchmark level.

Physical Pressures

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

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

	Resistance	Resilience	Sensitivity
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 and the burrowing organisms (i.e. *Arenicola marina*) would not be able to survive if the substratum type was changed to either a soft rock or hard artificial type, and the biotope would be lost.

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.

	Resistance	Resilience	Sensitivity
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

This biotope (IMuSa.AreISa) is only found in low energy conditions and is defined by the presence of muddy sands or fine sand. A change in sediment type by one Folk class (using the Long 2006 simplification) would change the sediment to either coarser sediments (e.g coarse sand and gravel) or fine sediment i.e. mud. Although the *Arenicola* population would persist in muds but the biotope would be lost and reclassified, probably as IFiMu.Are. Alternatively, a change t o coarse sediment t would probably result in loss of the *Arenicola* population, and the biotope would be reclassified and lost. Therefore, a resistance of **None** is recorded, resilience is **Very low** (the pressure is a permanent change) and sensitivity is assessed as **High**.

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

Extraction of sediment to a depth of 30 cm would remove the community within the affected area. Therefore, a resistance of **None** is suggested. Resilience is probably **Medium**, due to the isolated nature of the sea lochs and lagoons in which this biotope is found, and sensitivity is assessed as **Medium**.

	Resistance	Resilience	Sensitivity
Abrasion/disturbance of the surface of the substratum or seabed	High Q: Medium A: Medium C: Low	High Q: High A: High C: High	Not sensitive Q: Medium A: Medium C: Low

Arenicola marina lives in sediment to a depth of 20-40 cm and, therefore, is protected from most sources of abrasion and physical disturbance caused by surface action. However, it is likely to be damaged by any activity (e.g. anchors, dredging) that penetrates the sediment (see below).

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

Rees (1978 cited in Hiscock *et al*., 2002) assessed pipe laying activity in Lafan Sands, Conwy Bay, Wales. The pipe was laid in a trench dug by excavators. The spoil from the trenching was then used to bury the pipe. The trenching severely disturbed a narrow zone, but a zone some 50 m wide on each side of the pipeline was also disturbed by the passage of vehicles. The tracked vehicles damaged and exposed shallow-burrowing species such as the bivalves *Cerastoderma edule* and *Limecola balthica*, which were then preyed upon by birds. Deeper-dwelling species were apparently less affected; casts of the lugworm *Arenicola marina* and feeding marks made by the bivalve *Scrobicularia plana* were both observed in the vehicle tracks. During the construction period, the disturbed zone was continually re-populated by mobile organisms, such as the gastropod *Hydrobia ulvae*. Post-disturbance recolonization was rapid. Several species, including the polychaetes *Arenicola marina*, *Eteone longa* and *Scoloplos armiger* recruited preferentially to the disturbed area. However, the numbers of the relatively long-lived *Scrobicularia plana* were markedly depressed, without signs of obvious recruitment several years after the pipeline operations had been completed.

Sensitivity assessment. Although this biotope is found in the subtidal, it is theoretically possible for vehicles or pedestrians to traverse shallow examples of the biotope (0-5 m). Nevertheless, the evidence suggests that *Arenicola* is little affected by abrasion in the form of trampling or vehicle compaction. Therefore, a resistance of **High** is suggested so that resilience is also **High** (by default) and the biotope is probably **Not sensitive** to abrasion due to trampling or vehicular access.

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

Mendonça *et al.* (2008) studied populations of the polychaete *Arenicola marina* at Culbin Sands lagoon, Moray Firth, in NE Scotland. An unprecedented and unexpected cockle harvesting event took place, 1.5 years after the start of the sampling programme, which dramatically disturbed the sediment as it was conducted using tractors with mechanical rakes in some areas, and by boats using a suction dredge in other areas. Therefore, there was an opportunity to compare annual biomass fluctuations "before" and "after" the disturbance. *Arenicola marina* was observed to return to normal activities just a few hours after the disturbance of the sediment during the harvesting event.

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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. The basins accumulated fine sediment and organic matter and showed increased population levels for about 2-3 months after digging.

Fowler (1999) reviewed the effects of bait digging on intertidal fauna, including *Arenicola marina*. Diggers were 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 were used in the Dutch Wadden Sea where they removed 17-20 million lugworms/year. However, when combined with hand digging the harvest represented only 0.75% of the estimated population in the area. 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 and reached its original level in at least three years.

Sensitivity assessment. Penetrative gear would probably damage or remove a proportion of the population of *Arenicola* but given its potential density, the effects may be minor (e.g. Mendonça *et al.*, 2008). Similarly, recreational bait digging may have a limited effect, especially in the subtidal. However, if commercial bait digging occurred in the shallow sublittoral, then a significant proportion of the population may be removed. Hence, a resistance of **Low** is suggested. Resilience is probably **High** and sensitivity is assessed as **Low**.

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

This biotope occurs in fine sands and muddy sands that accumulate in low energy environments. Deposit feeders are unlikely to be perturbed by increased concentrations of suspended sediment since they live in sediment and are probably adapted to re-suspension of sediment by wave action, during storms or runoff.

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

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

Smothering and siltation rate changes (light)	High Q: Medium A: Medium C: Medium	High Q: High A: High C: High	Not sensitive Q: Medium A: Medium C: Medium

Arenicola marina is a sub-surface deposit feeder that derives the sediment it ingests from the surface. It rapidly reworks and mixes sediment. It grows to 12-20 cm in length and lives in burrows to a depth of 20-40 cm. It is unlikely to be perturbed by smothering by 5 cm of sediment. Juveniles may be more susceptible but both adults and juveniles are capable of leaving the sediment and swimming (on the tide) up or down the shore (see Reise *et al*., 2001). In addition, Gittenberger & Loon (2011) placed *Arenicola marina* into their AMBI Sedimentation Group III, defined as 'species insensitive to higher amounts of sedimentation, but don't easily recover from strong fluctuations in sedimentation'.

Sensitivity assessment. This biotope occurs in a depositional environment, where sedimentation is likely, to be high due to the low energy of the habitat. Therefore, resistance to a deposit of 5 cm of fine sediment is assessed as **High**. Hence, resilience is **High** (by default) and the biotope is probably **Not sensitive** at the benchmark level.

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

Arenicola marina is a sub-surface deposit feeder that derives the sediment it ingests from the surface. It rapidly reworks and mixes sediment. It grows to 12-20 cm in length and lives in burrows to a depth of 20-40 cm. Adults may be able to resist smothering by 30 cm of sediment but juveniles may be more susceptible. Both adults and juveniles are capable of leaving the sediment and swimming (on the tide) up or down the shore (see Reise *et al*., 2001). In addition, Gittenberger & Loon (2011) placed *Arenicola marina* into their AMBI sedimentation Group III, defined as 'species insensitive to higher amounts of sedimentation, but don't easily recover from strong fluctuations in sedimentation'.

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

Litter	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

Plastic debris breaks up to form microplastics. Microplastics have been shown to occur in marine sediments and to be ingested by deposit feeders such as *Arenicola marina* and holothurians, as well as by suspension feeders, e.g. *Mytilus edulis* (Wright *et al*., 2013b; Browne *et al*., 2015).

Wright *et al.* (2013) showed that the presence of microplastics (5% UPVC) in a lab study 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 33m^3 of microplastics a year.

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

Sensitivity assessment. Impacts from the pressure 'litter' would depend on upon the exact form of litter or man-made object being introduced. Browne *et al.* (2015) suggested that if effects in the laboratory occurred in nature, they could lead to significant changes in sedimentary communities as *Arenicola marina* is an important bioturbators and ecosystem engineer in sedimentary habitats. Nevertheless, while significant impacts have been shown in laboratory studies, impacts at biotope scales are still unknown and this pressure is **Not assessed.**

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

No evidence was found

Underwater noise changes	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

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

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

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

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

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

Barrier to species movement	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not 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.

Death or injury by collision	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

Not relevant to seabed habitats.

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

Not relevant.

Biological Pressures

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

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

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

Coastal and estuarine areas are among the most biologically invaded systems in the world, especially by molluscs such as the slipper limpet *Crepidula fornicata* and the Pacific oyster *Magallana gigas* (OSPAR, 2009b). The two species have not only attained considerable biomasses from Scandinavian to Mediterranean countries but have also generated ecological consequences such as alterations of benthic habitats and communities, or food chain changes. In the Wadden Sea, the main issue of concern is the pacific oyster (*Magallana gigas*), which has also spread in the

Thames estuary and along French intertidal flats. Padilla (2010) predicted that *Magallana gigas* could either displace or overgrown mussels on rocky and sedimentary habitats of low or high energy. However, Padilla (2010) also noted that there were no examples of *Magallana gigas* invading sedimentary habitats where there are no native ecosystem engineers (bivalves or *Sabellaria*).

In the Wadden Sea and the North Sea, *Magallana gigas* overgrows mussel beds in the intertidal zone (Diederich 2005, 2006; Kochmann *et al.* 2008), although they did show a preference for settling on conspecifics before the mussels and struggled to settle on mussels with a fucoid covering. However, recruitment of *Magallana gigas* was significantly higher in the intertidal than the shallow subtidal, although the survival of adult oysters or mussels in the subtidal is limited by predation.

Crepidula fornicata is known to colonize and smother a wide range of sediments in the subtidal, from mixed sediments to mud, especially in prior shellfish beds (e.g. of oysters and mussels) (Blanchard, 1997; Minchin *et al.*, 1995). *Crepidula fornicata* larvae may out-compete oyster (*Magallana gigas*) larvae during summer months where the two species co-occur. Trophic competition between adult *Crepidula fornicata* and *Magallana gigas* was reported in France during winter and spring. In Mont Saint-Michel Bay, France, slipper limpet populations have affected flatfish populations. Changes in habitat structure and reduced abundance of suspension feeding organisms upon which the flatfish feed were linked to slipper limpet extent (Decottignies *et al.*, 2007; Blanchard *et al.* 2008; and Kostecki *et al.*, 2011 cited in Sewell & Sweet, 2011).

Sensitivity assessment. *Magallana gigas* is predicted to invade sedimentary habitats, although no direct examples exist to date and *Magallana gigas* recruitment is lower in the subtidal (Diederich 2005, 2006; Padilla, 2010). *Crepdiula fornicata* is a major invader and colonizer of subtidal sediments. However, both species require hard substrata in the form of stones, debris or, preferably, the shells conspecifics to colonize the habitat. This biotope is dominated by fine mud and a shell fraction is not recorded in the description (Connor *et al.*, 2004) but if artificial hard debris (e.g. litter) was introduced to the habitat then it may provide an initial point for the colonization of *Crepidula* in particular. Although it would probably take many years, colonization by *Crepidula* would result in the complete modification of the habitat, reclassification and loss of the biotope, although a population of *Arenicola marina* may survive in the sediment itself. Therefore, a precautionary resistance of **Low** has been suggested with 'Low' confidence due to the lack of direct evidence. Resilience is likely to be **Very low** as a bed of *Crepidula* or *Magallana gigas* would need to be removed before recovery could begin. Therefore, sensitivity is assessed as **High**.

Introduction of microbial pathogens	No evidence (NEv) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

Ashworth (1904) recorded the presence of distomid cercariae and Coccidia in *Arenicola marina* from the Lancashire coast. However, no information concerning infestation or disease related mortalities was found.

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

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. The basins accumulated fine sediment and organic matter and showed increased population levels for about 2-3 months after digging.

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Sensitivity assessment. Recreational bait digging may remove a proportion of the population of *Arenicola* but given its potential density, the effects may be minor. However, if commercial bait digging occurred in the shallow sublittoral, then a significant proportion of the population may be removed. The physical effects of removal are addressed under penetration above. However, *Arenicola marina* is a bioturbator and ecosystem engineer and its removal would probably have a significant effect on the nature of the sediment and the other species that could inhabit the sediment. Hence, a resistance of **Low** is suggested. Resilience is probably **Medium**, due to the isolated nature of the sea lochs and lagoons in which this biotope if found, and sensitivity is assessed as **Medium**.

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

Arenicola marina is a bioturbator and ecosystem engineer and its incidental removal would probably have a significant effect on the nature of the sediment and the other species that could inhabit the sediment. Hence, a resistance of **Low** is suggested. Resilience is probably **Medium**, due to the isolated nature of the sea lochs and lagoons in which this biotope if found, and sensitivity is assessed as **Medium.**

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