Limnodrilus hoffmeisteri, *Tubifex tubifex* and *Gammarus* spp. in low salinity infralittoral muddy sediment

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

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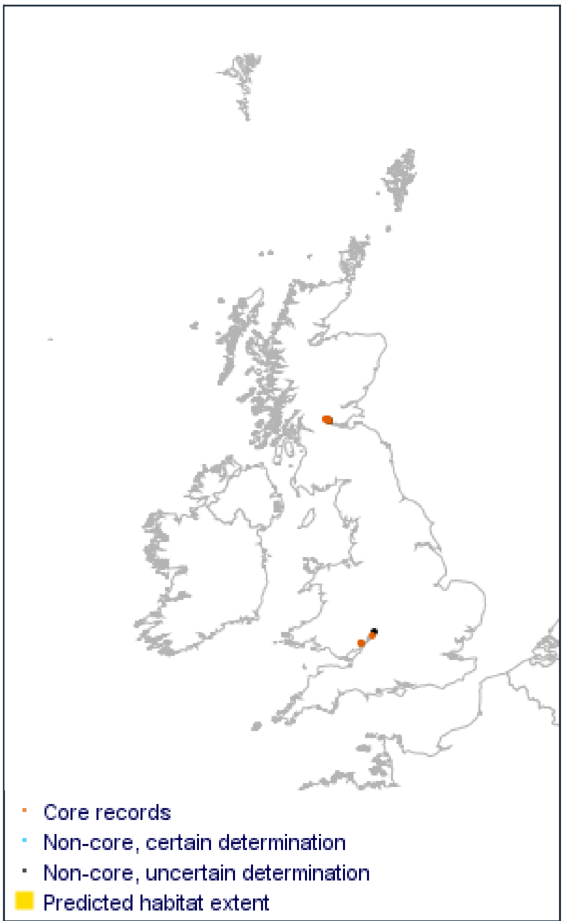

17-09-2018
Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

Researched by Dr Heidi Tillin & Georgina Budd **Refereed by** Admin

Summary

UK and Ireland classification

EUNIS 2008	A5.327	*Limnodrilus hoffmeisteri*, *Tubifex tubifex* and *Gammarus* spp. in low salinity infralittoral muddy sediment
JNCC 2015	SS.SMu.SMuVS.LhofTtub	*Limnodrilus hoffmeisteri*, *Tubifex tubifex* and *Gammarus* spp. in low salinity infralittoral muddy sediment
JNCC 2004	SS.SMu.SMuVS.LhofTtub	*Limnodrilus hoffmeisteri*, *Tubifex tubifex* and *Gammarus spp.* in low salinity infralittoral muddy sediment
1997 Biotope	SS.IMU.EstMu.LimTtub	*Limnodrilus hoffmeisteri*, *Tubifex tubifex* and *Gammarus spp.* in low salinity infralittoral muddy sediment

Description

Upper estuary muddy sediments with very low fluctuating salinity, characterized by the oligochaetes *Limnodrilus hoffmeisteri* and *Tubifex tubifex*. Other taxa may include *Marenzelleria* *wireni*, *Gammarus zaddachi*, *Paranais litoralis* and *Heterochaeta costata*. The biotope contains elements of both freshwater and brackish communities (JNCC, 2015).

Depth range

0-5 m

Additional information

No text entered.

Listed By

- none -

Further information sources

Search on:

G G G JNCC

Habitat review

Ecology

Ecological and functional relationships

- Interstitial salinity is an important factor determining the occurrence of the IMU.LimTtub community. Although tidal, the uppermost part of an estuary may predominantly experience freshwater conditions and this is the case over the first 16 km of the Forth estuary from Stirling, Scotland. Over the first 10 km interstitial salinity is low, is always less than 1psu; at 10 km it is between 1 -1.9 psu, and at 16 km it is between 1.6-4.1psu (McLusky *et al*., 1981). The infauna consists exclusively of the **freshwater oligochaetes**, *Limnodrilus hoffmeisteri* and *Tubifex tubifex*. Stczynska-Jurewicz (1972) reported that the maximum salinity at which *Tubifex tubifex* could survive was 9 psu and the maximum at which natural egg laying and development occurred was 4 psu. Kennedy (1965) stated that salinity controlled the distribution of *Limnodrilus hoffmeisteri*, but gave no precise limits. McLusky *et al.* (1981) found *Tubifex tubifex* in localities with a maximum salinity of 4.1 psu, and *Limnodrilus hoffmeisteri* occurred at salinities of up to 7.7 psu.
- To a certain extent, the distribution of *Gammarus* species is also correlated with salinity. Distinct zonation patterns may be observed, *Gammarus salinus* prefers intermediate salinities, whilst *Gammarus zaddachi* and *Gammarus duebeni* predominantly live in more dilute brackish waters, locally penetrating into freshwater transition zones (Bulnheim, 1984).
- Tubificids ingest sediment and derive the bulk of their nutrition from bacteria (Brinkhurst & Chuan, 1969; Wavre & Brinkhurst, 1971) and perhaps from algae (Moore, 1978b). Consequently, when large densities of oligochaetes occur (e.g. 127,400 m^{-2} at the most densely populated site, in the Forth estuary (McLusky *et al*., 1980) they have a significant effect upon sedimentary structure through their subsurface ingestion of sediments and surface egestion. Davis (1974) found that feeding and subsequent movement of sediment to the surface occurred mainly at 3-4 cm depth, but small amounts of sediment from as deep as 8-9 cm could also be transported to the surface.
- The work of Alsterberg (1925) (incomplete citation in Birtwell & Arthur, 1980) indicated that in any 24 hour period *Tubifex tubifex* and *Limnodrilus hoffmeisteri* displace a quantity of mud four times greater than their body weight. Appleby & Brinkhurst (1970) found the amount to be greater at higher temperatures, about eight times the body weight. Birtwell & Arthur (1980) considered that such activity could influence the oxygen concentration of the environment as, by bringing sediments of a 'reduced' nature to the surface and into contact with oxygenated water rapid biological and chemical oxidation of organic matter would proceed. Whilst this would increase the oxygen demand of the environment, the anoxic layer may remain at depth (Birtwell & Arthur, 1980).
- Owing to their feeding method oligochaetes may mediate the passage of heavy metals from contaminated sediment to fish (Patrick & Loutit, 1976; 1978). Several other predators feed upon aquatic oligochaetes other than fish, including leeches, ducks and a variety of invertebrates such as chironomids (Brinkhurst, 1982).
- *Limnodrilus hoffmeisteri* competes with *Tubifex tubifex* in very polluted environments, its abundance being related to the organic content of the sediments and it may dominate the population (Poddubnaya, 1980).
- The activity of tubificids also affects the stability of surface layers of sediment as they loosen the sediment and render the surface layers susceptible to scour. When sediment

scour occurs, fine sediment particles and organic matter are carried into suspension and the resulting oxygen demand is high (HMSO, 1964; Edwards & Rolley, 1965).

Seasonal and longer term change

- Differences, sometimes distinctly seasonal, may be observed in the breeding period of characterizing oligochaete species according to variation in local conditions, especially temperature, organic enrichment of the sediment and population density (see recruitment processes).
- The amphipod *Gammarus zaddachi* conducts extensive migrations along estuaries, it may be found near the limit of tidal influence in winter but moves to more downstream reaches (where reproduction occurs) in spring. A return migration then takes place, primarily by juveniles, until the seaward areas are depopulated in winter (Hough & Naylor, 1992).

Habitat structure and complexity

The substratum consists of cohesive muds which have little inherent structural complexity. Some structural complexity is provided by the burrows of infauna although these are generally simple. Species living within the sediment are likely to be limited to the area above the anoxic layer, the depth of which will vary depending on sediment particle size, organic content and influence of the biotic community (see ecological relationships).

Productivity

Productivity in the biotope is expected to be high. Production in IMU.LimTtub is mostly secondary, derived from detritus and organic material. Food becomes available to deposit feeders by sedimentation on the substratum surface. The sediment in the biotope may be nutrient enriched due to proximity to anthropogenic nutrient sources such as sewage outfalls or eutrophicated rivers. In such instances, the species may be particularly abundant. For example, in their study of domestic and industrial pollution, McLusky *et al.* (1980) found the heavily industrialised, upper Forth estuary, Scotland, in its most polluted sections to be inhabited solely by *Tubifex tubifex* and *Limnodrilus hoffmeisteri*. The mean number of these species at the most densely populated site reached 127,400 m^{-2} for *Tubifex tubifex* and 105,800 m^{-2} for *Limnodrilus hoffmeisteri* respectively, with mean biomass of 57.663 and 22.154 g dry wt m^{-2} respectively. McLusky *et al.* (1980) used the P:B ratio of 3:1 for oligochaetes calculated by Haka *et al.* (1974) and Giere (1975) to give an estimation of the production of oligochaetes on the upper Forth estuary to be 83.91 g/dry wt/m^{2}/yr. These oligochaete species represent a major pathway for the transfer of energy from the sediment to secondary consumers.

Recruitment processes

Oligochaetes are hermaphroditic and posses distinct and complex reproductive systems, including permanent gonads. Free spawning and indirect larval development do not occur in the Oligochaeta and would not be especially successful within the typical environment in which oligochaetes occur (cohesive muds). The success of oligochaete species is reliant upon contact mating, exchange of sperm and direct development. The higher survival rate of zygotes produced by such reproduction merits the high parental investment. Furthermore, hermaphroditism is one way for relatively immobile species, who might encounter sexual partners infrequently, to increase their reproductive output, and self fertilization is also a possibility (Brusca & Brusca, 1990). During copulation the mating worms align themselves side-by-side, but face opposite directions so that the male gonopores of one are aligned with the spermathecal openings of the other. Sperm is mutually exchanged and following separation, each functions as an inseminated female. Fertilization occurs in a cocoon (a sheet of mucus produced around the clitellum and all anterior segments) which once formed moves towards the anterior end of the oligochaete by a backward muscular motion of the body. The cocoon is sealed as it passes off the end of the body and it is deposited in benthic debris. Development of the zygote is direct (no larval stage) and time may vary from a week to several months depending on the species and environmental conditions. In climates were relatively severe conditions development time is sufficient to ensure that juveniles hatch in the spring, while in more stable conditions, development time may be shorter and less seasonal (Brusca & Brusca, 1990). More detailed accounts of the recruitment processes of characterizing species follows below, and information is largely based on research by Poddubnaya (1980), who studied the life cycles of several species of tubificid.

Tubifex tubifex:

The embryonic period in *Tubifex tubifex* at various temperatures (2-30°C) lasts from 12 to 60 days, with high mortality observed at temperatures below 10°C and above 20°C. in the earliest stages of development embryos are especially sensitive to changes in dissolved oxygen concentrations between 2-7°C, whilst normal development proceeds between 6-19°C at a dissolved oxygen concentration of 2.5-7 mg/O_2/L. After 12-15 days the juvenile worms hatch (3 mm in length, 0.08 mg on average) and their course of maturation is influenced by environmental conditions and population density (which is itself influenced by the productivity of the habitat, e.g. enriched by organic pollution). At 20°C and a population density of < 20000>Tubifex tubifex attains maturity within two months, however, lower water temperature (2°C) and higher population density (> 70000 m) delay maturation by up to 10 months (Poddubnaya, 1980). Duration of the reproductive period varies and is influenced by water temperature, dissolved oxygen concentration and population density. The intensity of reproduction also varies within the year. Mass laying of cocoons in spring and winter alternates with a sudden abatement or halt of sexual activity in summer and autumn and individuals are capable of sexual activity for 3-4 months without interruption. Cocoons laid in winter (January-February) hatch in April, and go on to reproduce once within the first year, during the second year each individual reproduces twice. A fourth period of reproduction is possible in the third year of life, but the life cycle of the species typically lasts between 2-2.5 years (Poddubnaya, 1976).

Limnodrilus hoffmeisteri:

Observations on the life cycle of *Limnodrilus hoffmeisteri* in Estonian and English water bodies and in Upper Volga reservoirs indicate a great plasticity and dependence of the life cycle upon local conditions (organic enrichment, temperature, population density) (Timm, 1962; Kennedy, 1966; 1966b; Poddubnaya, 1980). Breeding activity is possible throughout the year, although peaks are apparent but they occur in different months in different localities, e.g. in the River Thames greatest activity occurs between December and July (Kennedy, 1966). The embryonic period lasts between 15-75 days, with normal development occurring within a temperature range of 10-25°C and at dissolved oxygen concentration of 2.5-10 mg/O_2/L. High mortality of embryos occurs in cocoons at low (2-5°C) and high (30°C) temperatures. Like those of *Tubifex tubifex*, the embryos are especially sensitive to variations in dissolved oxygen concentration and to low temperatures. The worms mature as early as two months and reproduce within their first year, although maturation may be delayed by low or high temperatures (1-4°C and > 30°C) and high population density (> 35000 m). In the organically enriched River Thames and Shropshire Union canal , *Limnodrilus hoffmeisteri* bred throughout the year, but with increased activity in winter and spring, but in less productive habitats the species commenced breeding only after it was a year old and the breeding period was shorter and more seasonal (Kennedy, 1966). Potter & Learner (1974) suggested that *Limnodrilus hoffmeisteri* could produce four or five generations a year in a small Welsh reservoir with a temperature 17-18.6 °C over four months, whereas Ladle (1971) reported the species to produce

only a single generation. The whole life cycle of *Limnodrilus hoffmeisteri* is completed within 2-3 years.
***Gammarus* species:**
Sexes are generally separate and species show precopula behaviour, during which the male holds the female using its gnathopods, and carries her for some days before mating. Fertilization is external with sperm being deposited in a brood chamber formed of brood plates that arise from the base of thoracic appendages (Fish & Fish, 1996). *Gammarus salinus* produces two generations per year. Mature females are present in the population between late November through to July, but the main period of reproduction occurs over the winter (Leineweber, 1985).

Time for community to reach maturity

Following successful hatching of juveniles, important characterizing oligochaete species (*Limnodrilus hoffmeisteri* and *Tubifex tubifex*) are able to reproduce within a year, and proceed to produce more than one generation in the second year of life. Thus within a period of five years, several generations will have reproduced and a population established. However, in terms of the species present the biotope may be recognizable in as little as 1-2 years.

Additional information

No text entered.

Preferences & Distribution

Habitat preferences

Depth Range	0-5 m
Water clarity preferences	Field Unresearched
Limiting Nutrients	Field unresearched
Salinity preferences	Low (<18 psu)
Physiographic preferences	Isolated saline water (Lagoon)
Biological zone preferences	Infralittoral
Substratum/habitat preferences	Mud
Tidal strength preferences	Very Weak (negligible), Weak < 1 knot (<0.5 m/sec.)
Wave exposure preferences	Extremely sheltered, Very sheltered
Other preferences	Very low, fluctuating salinity; possibly with a high biochemical

Additional Information

No text entered.

Species composition

Species found especially in this biotope

- *Limnodrilus hoffmeisteri*

- *Tubifex tubifex*

Rare or scarce species associated with this biotope

-

Additional information

No text entered.

Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

The biotope description and characterizing species are taken from JNCC (2015). The biotope occurs in upper estuary muddy sediments with very low, fluctuating salinity; both the sediments and salinity are considered to structure the biotope and are considered in assessments where the pressure may lead to a change in these factors. The biotope is characterized by the tubificid oligochaetes *Limnodrilus hoffmeisteri*,*Tubifex tubifex Paranais litoralis* and *Heterochaeta costata*. The sensitivity assessments focus on these species, but use general information on Tubificid oligochaetes where evidence is limited.

Resilience and recovery rates of habitat

Usually for oligochaetes fertilization is internal and relatively few large eggs are shed directly into a cocoon that is secreted by the worm (Giere & Pfannkuche, 1982). Asexual reproduction is possible in some species by spontaneous fission (Giere & Pfannkuche, 1982).
The naid oligochaete *Panais litoralis* can produce asexually producing clones, the rapid rate of increase (18 times population abundance in 3 months, Gillett *et al*., 2007) allows this species (which is sensitive to high temperatures, hypoxia and is exposed to predation due to shallow burial) to repopulate rapidly when conditions are favourable. However, few Tubificidae and Enchytraeidae produce asexually (Giere & Pfannkuche, 1982).

Tubificid populations tend to be large and to be constant throughout the year, although some studies have noticed seasonal variations (Giere & Pfannkuche, 1982). Many species, including *Tubificoides benedii* and *Baltidrilus costata* have a two-year reproductive cycle and only part of the population reproduces each season (Giere & Pfannkuche, 1982). Tubificids exhibit many of the traits of opportunistic species. They often reach huge population densities in coastal areas that are enriched in organic matter and are often described as 'opportunist' species adapted to rapid environmental fluctuations and stress (Giere, 2006; Bagheri & McLusky, 1982). However, unlike other opportunist species they have a long-life span (a few years, Giere, 2006), a prolonged reproductive period from reaching maturity to maximum cocoon deposition and exhibit internal fertilisation, with brooding rather than pelagic dispersal. These factors mean that recolonization is slower than for some opportunistic species such as *Capitella capitata* and nematodes which may be present in similar habitats.

Bolam and Whomersley (2003) observed faunal recolonization of fine sediments placed on saltmarsh as a beneficial use and disposal of fine grained dredged sediments. They found that tubificid oligochaetes began colonising sediments from the first week following a beneficial use scheme involving the placement of fine-grained dredged material on a salt marsh in southeast England. The abundance of *Tubificoides benedii* recovered slowly in the recharge stations and required 18 months to match reference sites and those in the recharge stations prior to placement of sediments. The results indicate that some post-juvenile immigration is possible and that an in-situ recovery of abundance is likely to require more than 1 year.

The embryonic period in *Tubifex tubifex* at various temperatures (2-30°C) lasts from 12 to 60 days, with high mortality observed at temperatures below 10°C and above 20°C. in the earliest stages of development embryos are especially sensitive to changes in dissolved oxygen concentrations between 2-7°C, whilst normal development proceeds between 6-19°C at a dissolved oxygen concentration of 2.5-7 mg/O2/L. After 12-15 days the juvenile worms hatch (3 mm in length, 0.08

mg on average) and their course of maturation is influenced by environmental conditions and population density (which is itself influenced by the productivity of the habitat, e.g. enriched by organic pollution). At 20°C and a population density of < 20000 m^{-2}, *Tubifex tubifex* attains maturity within two months, however, lower water temperature (2°C) and higher population density (> 70000 m^{-2}) delay maturation by up to 10 months (Poddubnaya, 1980). Duration of the reproductive period varies and is influenced by water temperature, dissolved oxygen concentration and population density. The intensity of reproduction also varies within the year. Mass laying of cocoons in spring and winter alternates with a sudden abatement or halt of sexual activity in summer and autumn and individuals are capable of sexual activity for 3-4 months without interruption. Cocoons laid in winter (January-February) hatch in April, and go on to reproduce once within the first year, during the second year each individual reproduces twice. A fourth period of reproduction is possible in the third year of life, but the life cycle of the species typically lasts between 2-2.5 years (Poddubnaya, 1976).

Observations on the life cycle of *Limnodrilus hoffmeisteri* in Estonian and English water bodies and in Upper Volga reservoirs indicate a great plasticity and dependence of the life cycle upon local conditions (organic enrichment, temperature, population density) (Timm, 1962; Kennedy, 1966; 1966b; Poddubnaya, 1980). Breeding activity is possible throughout the year, although peaks are apparent but they occur in different months in different localities, e.g. in the River Thames greatest activity occurs between December and July (Kennedy, 1966). The embryonic period lasts between 15-75 days, with normal development occurring within a temperature range of 10-25°C and at dissolved oxygen concentration of 2.5-10 mg/O2/L. High mortality of embryos occurs in cocoons at low (2-5°C) and high (30°C) temperatures. Like those of *Tubifex tubifex*, the embryos are especially sensitive to variations in dissolved oxygen concentration and to low temperatures. The worms mature as early as two months and reproduce within their first year, although maturation may be delayed by low or high temperatures (1-4°C and > 30°C) and high population density (> 35000 m^{-2}). In the organically enriched River Thames and Shropshire Union canal , *Limnodrilus hoffmeisteri* bred throughout the year, but with increased activity in winter and spring, but in less productive habitats the species commenced breeding only after it was a year old and the breeding period was shorter and more seasonal (Kennedy, 1966). Potter & Learner (1974) suggested that *Limnodrilus hoffmeisteri* could produce four or five generations a year in a small Welsh reservoir with a temperature 17-18.6 °C over four months, whereas Ladle (1971) reported the species to produce only a single generation. The whole life cycle of *Limnodrilus hoffmeisteri* is completed within 2-3 years.

Rapid recolonization has also been observed in the tubificid oligochaete *Baltidrilus costata (Tubifex costatus)* which appeared in upper sediment layers in experimentally defaunated patches (4m2) after 3 weeks (Gamenick *et al*., 1996).

Resilience assessment. In general there was little information found for *the characterizing* oligochaetes, but, taking into consideration the life history information, this review considers that the recoverability of oligochaetes is generally ‘High’, so that recovery from defaunation is suggested to occur within two years and that therefore, recovery from any impact (resistance is ‘None’, ‘Low’ or ‘Medium’) is assessed as ‘High’. Abundance and biomass may be depleted for longer than two years, following complete removal, but the biotope would probably be recognizable. As there is no pelagic larval stage dispersal may be limited; where populations are entirely removed over wide areas, recovery may be delayed. Oligochaetes may, however, be passively transported via the water column.

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

Hydrological Pressures

	Resistance	Resilience	Sensitivity
Temperature increase (local)	High Q: High A: High C: High	High Q: High A: High C: High	Not sensitive Q: High A: High C: High

Palmer (1968) (cited in Birtwell & Arthur, 1980) recorded large populations of *Limnodrilus hoffmeisteri* and *Tubifex tubifex* (up to 5.7 x 106m) close to the heated effluent discharge of an electrical generating plant upstream of London Bridge on the River Thames. Birtwell & Arthur (1980) examined the tolerance of *Tubifex tubifex* from the Thames estuary to elevated temperature and found the 96 h LC50 value to be 33.9 °C, a temperature that would not be encountered within the main body of the estuary, but possibly close to discharges of heated cooling water from electrical generating plants. In the same study, the tolerance of *Limnodrilus hoffmeisteri* was found to be even greater, its 96 h LC50 was 37.5°C. Although, evidently tolerant of elevated temperature, sub-lethal effects have been reported. Chapman *et al*. (1982) observed that at 10°C both *Limnodrilus hoffmeisteri* and *Tubifex tubifex* were capable of regulating their respiration, whilst at 20°C respiration rate was greatly elevated and only partially regulated. High temperatures have been reported to cause mortality of cocoons and will delay, but not prevent maturation of juveniles.

Specimens of *Gammarus salinus* were tolerant of temperature fluctuations between 8 °C and 20 °C over a period of up to four weeks, acute temperature changes caused additional stress but did not result in mortality (Furch, 1972), as gammarid shrimps are very mobile they are able to avoid adverse conditions. Community composition is unlikely to significantly change and recoverability has been assessed to be very high.

Increased temperature was found to trigger the onset of reproduction in *Baltidrilus costata* (studied as *Tubifex costatus*) in the Thames (Birtwell & Arthur, 1980). This effect was non-lethal and may be beneficial to populations.

Sensitivity assessment. The dominance of the characterizing tubificid oligochaetes. in sediments exposed to heated effluent suggests that this genus would be highly resistant to an increase in temperature at the pressure benchmark. Biotope resistance based on the characterizing and associated species. is therefore assessed as ‘High’ and resilience as ‘High’ (by default), so that the biotope is considered to be ‘Not sensitive’.

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

Most littoral oligochaetes, including tubificids and enchytraeids, can survive freezing temperatures and can survive in frozen sediments (Giere & Pfannkuche, 1982). *Tubificoides benedii* (studied as *Peloscolex benedeni*) recovered after being frozen for several tides in a mudflat (Linke, 1939). Early stages may be more susceptible as low water temperatures (< 10°C) were reported by Poddubnaya (1980) to cause significant levels of mortality in embryonic stages (within cocoon) of both *Tubifex tubifex* and *Limnodrilus hoffmeisteri*, and also delayed attainment of maturity, but did not prevent it.

Sensitivity assessment. Typical surface water temperatures around the UK coast vary, seasonally from 4-19 °C (Huthnance, 2010). The biotope, based on the characterizing is considered to tolerate a 2 °C decrease in temperature for a year. An acute decrease may disrupt reproduction and the production of juveniles. Adults may be unaffected and populations may recover within a year. Biotope resistance based on the characterizing and associated tubificid oligochaetes is therefore assessed as 'High' and resilience as 'High' (by default), so that the biotope is considered to be 'Not sensitive'.

Salinity increase (local)	None Q: High A: High C: High	High Q: High A: Low C: Medium	Medium Q: High A: Low C: Medium

This biotope is present in low salinity habitats (<18 ppt) (JNCC, 2015). Interstitial salinity is an important factor determining the occurrence of the SS.SMu.SMuVS.LhofTtub community. The key functional species, *Limnodrilus hoffmeisteri* and *Tubifex tubifex*, are essentially freshwater species, able to tolerate very low interstitial salinities and therefore able to penetrate from freshwater ecosystems into upper estuaries, which although tidal, are dominated by freshwater conditions, e.g. the upper Forth estuary, Scotland (see McLusky *et al*., 1980). As salinity increases seawards, the infaunal species composition and indeed the dominant class of annelid eventually changes, so that larger estuarine polychaetes become important bioturbators (Diaz, 1980).

Stczynska-Jurewicz (1972) reported that the maximum salinity at which *Tubifex tubifex* could survive was 9 psu and the maximum at which natural egg laying and development occurred was 4 psu. Kennedy (1965) stated that salinity also controlled the distribution of *Limnodrilus hoffmeisteri*, but gave no precise limits. In the Forth estuary, McLusky *et al.* (1980) found *Tubifex tubifex* in localities with a maximum salinity of 4.1 psu, and *Limnodrilus hoffmeisteri* occurred at salinities of up to 7.7 psu, these species dominated the initial 16 km of the estuary from Stirling. Between 16 and 28 km the interstitial salinity increased progressively from a mean of 3.2 psu to 26.4 psu, and over that stretch of the estuary the dominant oligochaete was *Tubifex costatus* (now *Baltidrilus costata*). *Tubificoides benedeni* (as *Peloscolex benedeni*) became the dominant oligochaete in the lower part of the estuary. This estuarine succession of *Tubifex tubifex* and *Limnodrilus hoffmeisteri*, then *Tubifex costatus* (*Baltidrilus costata*), then *Tubificoides benedeni*, was also found by Hunter and Arthur (1978) in the Thames estuary. This evidence suggests that the SS.SMu.SMuVS.LhofTtub biotope would be highly intolerant of increased salinity and that community composition of the infaunal oligochaete community would change.

Sensitivity assessment. As this biotope is restricted to low salinities an increase in salinity at the pressure benchmark would lead to loss of the characterizing species *Limnodrilus hoffmeisteri*, *Tubifex tubifex*. The biological assemblage associated with the biotope is considered to have 'No' resistance and 'High' resilience (resilience will be lower where populations are removed over wide areas). Biotope sensitivity is, therefore, 'Medium'.

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

This biotope is present in low salinity habitats (<18 ppt) (JNCC, 2015). The key functional oligochaete species, *Limnodrilus hoffmeisteri* and *Tubifex tubifex*, are freshwater aquatic oligochaetes, able to penetrate from freshwater ecosystems into upper estuaries, which although tidal, are dominated by freshwater conditions, e.g. the upper Forth estuary, Scotland (see McLusky *et al*., 1980). The benchmark decrease in salinity would mean that the community would be exposed to freshwater. *Limnodrilus hoffmeisteri* and *Tubifex tubifex* are not likely to be adversely affected. To a certain extent the distribution of *Gammarus* species is also correlated with salinity. Distinct zonation patterns may be observed, *Gammarus salinus* prefers intermediate salinities, whilst *Gammarus zaddachi* and *Gammarus duebeni* predominantly live in more dilute brackish waters, locally penetrating into freshwater transition zones (Bulnheim, 1984).

Stczynska-Jurewicz (1972) reported that the maximum salinity at which *Tubifex tubifex* could survive was 9 psu and the maximum at which natural egg laying and development occurred was 4 psu . Kennedy (1965) stated that salinity also controlled the distribution of *Limnodrilus hoffmeisteri*, but gave no precise limits. In the Forth estuary, McLusky *et al.* (1980) found *Tubifex tubifex* in localities with a maximum salinity of 4.1 psu , and *Limnodrilus hoffmeisteri* occurred at salinities of up to 7.7 psu , these species dominated the initial 16 km of the estuary from Stirling. Between 16 and 28 km the interstitial salinity increased progressively from a mean of 3.2 psu to 26.4 psu , and over that stretch of the estuary the dominant oligochaete was *Tubifex costatus* (now *Baltidrilus costata*).

Sensitivity assessment. At the benchmark level, a decrease in salinity is unlikely to cause significant changes in community composition, and an assessment of 'Not sensitive' has been made, based on 'High' resistance and resilience.

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

This biotope is found in areas where tidal streams are estimated to range from moderately strong (0.5-1.5 m/s) to weak (<0.5 m/s), (JNCC, 2015). Increases and decreases in water velocity may lead to increased erosion or deposition. The associated pressures alteration to sediment type and siltation are assessed separately.

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

Birtwell and Arthur (1980) reported seasonal changes in abundance in *Baltidrilus costata* (as *Tubifex* *costatus*) which they attributed to erosion of the upper sediment layers caused by high river flows and wave action.

Decreases in water flow with increased siltation of fine particles are considered unlikely to alter the physical character of this habitat type as it is already found in sheltered areas where siltation occurs and where particles are predominantly fine. Reductions in waterflow occurring through the presence of trestles (for off-bottom oyster cultivation) arranged in parallel rows in the intertidal area (Goulletquer & Héral, 1997) reducing the strength of tidal currents (Nugues *et al.*, 1996) has been observed to limit the dispersal of pseudofaeces and faeces in the water column and thus increase the natural sedimentation process by several orders of magnitude (Ottman & Sornin, 1985, summarised in Bouchet & Sauriau, 2008). As the characterizing oligochaetes can live relatively deeply buried and in depositional environments with low water flows (based on habitat preferences) and low oxygenation they are considered to be not sensitive to decreases in water flow.

Sensitivity assessment. As muds tend to be cohesive and the surface tends to be smooth reducing turbulent flow, an increase at the pressure benchmark may not lead to increased erosion. Biotope resistance is assessed as 'High' based on the tidal stream range (JNCC, 2015). Resilience is assessed as 'High' (following restoration of usual conditions) and sensitivity is assessed as 'Low'. The biotope is not considered to be sensitive to decreased flows due to its presence in sheltered habitats and the tolerance of oligochaetes, in general, for low oxygen and sediment deposition.

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

Not relevant to sublittoral biotopes.

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

As this biotope occurs across two wave exposure categories; extremely sheltered and very sheltered, JNCC (2015), this is considered to indicate that mid-range biotopes would tolerate both an increase or decrease in wave exposure at the pressure benchmark. Resistance is therefore assessed as 'High' and resilience as 'High' by default and the biotope is considered to be 'Not sensitive'. An increase in wave exposure at the pressure benchmark would be likely to re-suspend sediments and increase erosion altering sediment type. Some oligochaete dominated biotopes occur in areas with mobile sediments and it is possible the biotope would revert to one of these.

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.

Heavy metal studies with oligochaetes have concentrated almost exclusively on tubificids, in particular *Limnodrilus hoffmeisteri* and *Tubifex tubifex* . Chapman *et al.*, (1980) reviewed the literature available on the subject and concluded both species to be particularly tolerant of heavy metal contamination. Early work concentrated on determining LD_{50} concentrations and ranking toxicity, e.g. Brkovic-Popovic & Popovic (1977) suggested that tubificid oligochaetes were most intolerant of Cu, Cd and Hg in solution than to Zn, Cr, Ni and Pb. However, as tubificids are infaunal species that are not directly exposed to conditions in the water column, their tolerances to heavy metals should be considered on the basis of metal levels in sediments and interstitial water. Wensel *et al.* (1977) measured metal levels in Palestine Lake, Indiana by nitric-perchloric digestion and found that *Limnodrilus* spp. survived Cd, Zn and Cr levels (in µg/g dry weight) of 970, 14000 and 2100 respectively. These levels had eliminated most of the rest of the benthos.

The emphasis of more recent research has moved to the detection of sub-lethal effects as a more sensitive indicator of toxicity. Reported sub-lethal effects of certain metals on *Limnodrilus hoffmeisteri* and *Tubifex tubifex* include reduced and elevated respiration rates, decreased concentration of haemoglobin, autotomy, excessive mucus production and reduced number of cocoons arising from reproduction (Whitley & Sikora, 1970; Brkovic-Popovic & Popovic, 1977b; Vecchi *et al.*, 1999; Martinez-Tabche *et al.*, 1999; Bouche *et al.*, 2000). Research has also focused on the mechanisms of oligochaete resistance to metal toxicity. Klerks & Levinton (1989) reported that *Limnodrilus hoffmeisteri* from a metal polluted cove had evolved resistance to a combination of Cd, Ni and Co and Klerks & Bartholomew (1991) examined the physiological mechanisms by which such resistance is achieved. A later paper by Martinez & Levinton (1996) suggest that one gene controls resistance to metal in the metal tolerant aquatic oligochaete *Limnodrilus hoffmeisteri*.

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.

Little information is available specifically concerning the effects of hydrocarbon contamination on oligochaete populations. The IMU.LimTtub biotope occurs in low energy environments protected from wave and tidal flow in upper estuaries. Sediments are rich in organic matter, and in the event of an oil spill, the high organic content promotes sorption of oil into the sediments. Furthermore, in such environments the bacterial degradation of oil is hindered by conditions of low oxygenation. The best documented oil spill in a protected habitat with soft mud/sandy substrata is the 1969 West Falmouth spill of #2 diesel fuel (Sanders, 1978). As a consequence of conditions outlined above, remobilisation of oil (especially within subtidal regions) continued for more than a year after the original spill and caused greater contamination than the initial impact. Virtually the entire fauna was eradicated following the spill, but populations of opportunistic species soon flourished.

Following the *Exxon Valdez* spill in Prince William Sound, Alaska, the abundance of oligochaetes in the intertidal region was noted to have increased, and more than 10 years after the spill their continued presence may be indicative of a subtle but significant alteration in the infauna of Prince William Sound (Highsmith *et al.*, 1996; McRoy, 2000). Although, the infauna may be eradicated in the worst affected areas, e.g. through direct effects of toxicity, smothering and deoxygenation (sensitivity assessed elsewhere), fringe populations of oligochaetes in less affected areas may benefit primarily from the additional food resources (bacteria & micro-organisms) that arise, and are likely to transfer ingested contaminants from the sediment directly to other food web predators, e.g. birds, fish and predatory invertebrates.

In Finland in oligohaline inland waters near an oil refinery, *Baltidrilus costata* (as *Tubifex costatus*) appeared to be sensitive to oil pollution and had completely disappeared from sediments exposed to pollution and did not recolonize during a 4y ear post pollution period (Leppäkoski & Lindström, 1978). *Tubificoides benedii* appears to be more tolerant and was found in UK waters near oil refineries as the sole surviving member of the macrofauna. Populations were however apparently reduced and the worms were absent from areas of oil discharge and other studies indicate sensitivity to oiling (Giere & Pfannkuche, 1982, references therein).

Synthetic compound contamination	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

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

Oligochaetes may be especially susceptible to synthetic chemicals that bind to sediments. Evidence suggests that some synthetic chemicals would adversely affect the important functional species of oligochaetes in this biotope, through both lethal and sub lethal effects. For example, Lotufo & Fleeger (1996) investigated acute and sub-lethal toxicity of sediment spiked with pyrene and phenanthrene to *Limnodrilus hoffmeisteri*. Phenanthrene was acutely toxic at high sediment concentrations (297. 5 µg/g 10-day median lethal concentration), whilst pyrene was not acutely toxic, even at concentrations as high as 841 µg/g. Both chemicals adversely affected the feeding activity of *Limnodrilus hoffmeisteri* and some burrowing avoidance was detected in sediment spiked with high phenanthrene concentrations (143-612 µg/ g), but was not detected with pyrene. Offspring production was also significantly reduced in contaminated sediments.

Keilty *et al*., (1988) observed that endrin contaminated sediments inhibited the burial of *Limnodrilus hoffmeisteri*. Dad *et al*., (1982) reported on the acute toxicity and presumable harmless concentration of two commercial insecticides, Furadan 3G and Matalaf 50 E, for *Limnodrilus hoffmeisteri* and *Tubifex tubifex*. *Limnodrilus hoffmeisteri* was found more susceptible to both insecticides, with Furadan being the most toxic. Sub-lethal effects including reduced reproductive potential have been reported for gammarid species exposed to a surfactant TWEEN 80 and pentachlorophenol (PCP) and benzo[a]pyrene (B[a]P) (Lyes, 1979; Lawrence & Poulter, 2001).

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

No evidence.

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

This pressure is **Not assessed**.

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

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

Research by Birtwell & Arthur (1980) on the ecology of tubificids in the Thames estuary included investigation of their tolerance of anaerobic conditions and low dissolved oxygen concentrations in the field. In laboratory studies, *Limnodrilus hoffmeisteri* was found to have a greater anaerobic tolerance than *Tubifex tubifex* at all water temperatures tested (20, 25 & 30°C). At 20°C, *Limnodrilus hoffmeisteri* had a LC_{50} time of 52 h, whilst *Tubifex tubifex* had a LC_{50} time of 28 h. At 30°C the LC_{50} for *Limnodrilus hoffmeisteri* decreased to 18 h, *Tubifex tubifex* also had a decreased tolerance at 30°C with a LC_{50} of 12 h. In the field, populations of the two species seemed able to tolerate conditions of low dissolved oxygen and periodic episodes of < 5% air saturation (< 2 mg O_2/l). For example, large populations of *Limnodrilus hoffmeisteri* occurred on the Thames between Greenwich and Woolwich, where average weekly dissolved oxygen concentration was just 2 mgO_2/l between December 1968 and September 1971. Birtwell & Arthur (1980), suggested that the low metabolic rate of *Limnodrilus hoffmeisteri*, coupled with its relatively better ability to survive periodic anaerobic conditions without incurring an oxygen debt, suited its survival in such locations. Although, *Tubifex tubifex* demonstrated a relatively lower tolerance to anaerobic conditions than *Limnodrilus hoffmeisteri*, it occurred in locations with a low average oxygen concentrations and survived periodic anoxia, although such situations were considered by Birtwell & Arthur (1980) to be less conducive to the establishment of populations of *Tubifex tubifex*. Embryos of both species are intolerant of low oxygen concentrations in combination with low temperature (see recruitment processes). Fisher & Beeton (1975) noted from vertical burrowing experiments in conditions of anoxia, that a more even distribution of *Limnodrilus hoffmeisteri* occurred in the upper 6 cm of sediment than in controls, and in vertical burrowing experiments avoidance of anoxic sediment was significant.

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

Sensitivity assessments. Based on the reported tolerances for the characterizing oligochaete species (Birtwell & Arthur, 1980), biotope resistance is assessed as 'Medium' as populations are likely to survive but there may be some loss of *Baltidrilus costasta* and impacts on juveniles, resilience is assessed as 'High' (by default) and biotope sensitivity is assessed as 'Low'.

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

In nutrient enriched tidal sediments oligochaetes can dominate assemblages (Gray, 1971; Leppäkoski, 1975; Birtwell & Arthur, 1980).

Sensitivity assessment. As the benchmark is relatively protective, biotope resistance is assessed as 'High', resilience is assessed as 'High' and the biotope is considered to be 'Not sensitive'.

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

Limnodrilus hoffmeisteri competes with *Tubifex tubifex* in very polluted environments, its abundance being related to the organic content of the sediments and it may dominate the population (Poddubnaya, 1980). The oligochaete *Baltidrilus costatus* is also very tolerant of high levels of organic enrichment and often dominate sediments where sewage has been discharged, or other forms of organic enrichment have occurred (Pearson & Rosenberg, 1978; Gray, 1971; McLusky *et* *al*., 1980).

Sensitivity assessment. The above evidence indicates that increased organic matter levels can favour the characterizing oligochaetes. Biotope resistance, is therefore considered to be 'High', resilience 'High' (by default) and the species is 'Not Sensitive'.

Physical Pressures

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

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

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

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

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

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

Giere & Pfannkuche (1982) suggest that factors that correlate to substratum types such as organic matter availability, size and shape of the intertstitial space between grains, the level of sediment disturbance and water content, are all factors influencing the distribution of oligochaetes. A change in sediment type to sand and mixed sediments is likely to reduce habitat suitability and result in loss of the biotopes.

Sensitivity assessment. Biotope resistance is assessed as 'None' and resilience as Very low (the pressure is a permanent change) and sensitivity is assessed as High.

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

Removal of 30 cm of surface sediment will remove the oligochaete community and other species present in the biotope. Recovery of the biological assemblage may take place before the original topography is restored, if the exposed, underlying sediments are similar to those that were removed.

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

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

No evidence was found for the characterizing species and the assessment is based on other tubificid oligochaetes. Experimental studies on crab-tiling impacts have found that densities of *Tubificoides benedii* and *Tubificoides pseudogaster* were higher in non-trampled plots (Sheehan *et al*., 2010), indicating that these oligochaetes have some sensitivity to trampling.

Sensitivity assessment. Disturbance of the surficial layers may have little effect on oligochaetes. Abrasion with associated compaction (as in trampling) may have a greater impact. Resistance is therefore assessed as 'Medium' and resilience as 'High' (by default) so that sensitivity is assessed as 'Low'.

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

No evidence was found for the characterizing species and the assessment is based on other tubificid oligochaetes. Whomersley *et al.* (2010) conducted experimental raking on intertidal mudflats at two sites (Creeksea- Crouch estuary England and Blackness- lower Forth estuary, Scotland), where *Tubificoides benedii* were dominant species. For each treatment 1 m^2 plots were raked twice to a depth of 4cm (using a garden rake). Plots were subject to either low intensity treatments (raking every four weeks) or high (raking every two weeks). The experiment was carried out for 10 months at Creeksea and a year at Blackness. The high and low raking treatments appeared to have little effect on *Tubificoides benedii* (Whomersley *et al*., 2010). These results are supported by observations that two experimental passes of an oyster dredge that removed the sediment to a depth of between 15-20 cm did not significantly affect *Tubifcoides benedii* (EMU, 1992).

Sensitivity assessment. The experiments by Whomersley *et al*., (2010) and EMU (1992), suggest that penetration and disturbance of the upper surface has little effect on tubificid oligochaetes. Many individuals are likely to be buried more deeply and can migrate to the surface following disturbance so that little impact is observed through sampling. Resistance is therefore assessed as 'Medium' and resilience as 'High' so that sensitivity is assessed as 'Low'.

Changes in suspended solids (water clarity)	Medium	High	Low
	Q: Low A: NR C: NR	Q: High A: Low C: Medium	Q: Low A: Low C: Low

Estuaries where this biotope is found form can be naturally turbid systems due to sediment resuspension by wave and tide action and inputs of high levels of suspended solids, transported by rivers. The level of suspended solids depends on a variety of factors including; substrate type, river flow, tidal height, water velocity, wind reach/speed and depth of water mixing (Parr *et al*. 1998). Transported sediment including silt and organic detritus can become trapped in the system where the river water meets seawater. Dissolved material in the river water flocculates when it comes into contact with the salt wedge pushing its way upriver. These processes result in elevated levels of suspended particulate material with peak levels confined to a discrete region (the turbidity maximum), usually in the upper-middle reaches, which moves up and down the estuary with the tidal ebb and flow. Intertidal mudflats depend on the supply of particulate matter to maintain mudflats and the associated biological community is exposed naturally to relatively high levels of turbidity/particulate matter.

Sensitivity assessment. The biological assemblage characterizing this biotope is infaunal and consists of sub-surface deposit feeders. Increased suspended solids are unlikely to have an impact and resistance is assessed as 'High' and resilience as 'High', so that the biotope is considered to be 'Not sensitive'. A reduction in suspended solids may reduce deposition and supply of organic matter, resistance to a decrease is therefore assessed as 'Medium' as a shift between deposition and erosion could result in the net loss of surficial sediments. A reduction in organic matter as suspended solids could also reduce production within this biotope. Resistance is assessed as 'Medium' as over a year the impact may be relatively small and resistance is assessed as 'High', following restoration of usual conditions. Biotope sensitivity is therefore assessed as 'Low'.

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

Subtidal muds occur in sheltered environments and, in general, are accreting environments meaning that deposition rather than erosion is the dominant process, this means that the assemblages present (primarily deposit feeders) are adapted to natural levels of siltation through life history traits and can withstand burial (by repositioning in sediment or similarly extending tubes or feeding and respiration structures above the sediment surface). At low levels of siltation the high bioturbatory nature of mudflat organisms decreases sensitivity to effects (Elliott *et al*. 1998) as sediment turnover rates are relatively rapid.

Gammarus species live in a variety of locations within the estuarine environment: amongst algae and other vegetation, as well as generally over the sediment surface and beneath stones. They are mobile species capable of a rapid escape response (back flip) if disturbed, however in the event of suddenly being smothered by 5 cm of sediment individuals resting on the surface may be killed

Sensitivity assessment. The characterizing oligochaete species are considered to be able to survive under a deposit of fine grained sediment up to 5cm thick and to burrow and reposition within this.The biotope (based on the biological assemblage) is therefore considered to have 'High' resistance, resilience is assessed as 'High' (by default) and the biotope is considered to be 'Not sensitive'.

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

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

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

Not assessed.

Electromagnetic changes	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

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

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

Infaunal oligochaetes may be able to detect vibration caused by localized noise and withdraw into the sediment, but are unlikely to be adversely affected by noise at the benchmark level. This pressure is considered to be 'Not relevant'.

Introduction of light or shading	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

No evidence was found to assess this pressure. Studentowicz (1936) found that the enchytraeid oligochaete *Enchytraeus albidus*, retracted from light, although the worms accumulated at the surface even when illuminated to avoid low oxygen and hydrogen sulpfide. Giere and Pfannkuche (1982) considered that other enchytraeids and tubificids are likely to react in the same way. As the oligochaete assemblage occurs within the sediment and can be deeply buried (to 10cm or more) this pressure is considered 'Not relevant'.

Barrier to species movement	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low

As the tubificid oligochaetes that characterize this biotope have benthic dispersal strategies (via egg cocoons laid on the surface, Giere & Pfannkuche, 1982), water transport is not a key method of dispersal over wide distances, as it is for some marine invertebrates that produce pelagic larvae. The biotope (based on the biological assemblage) is therefore considered to have 'High' resistance to the presence of barriers that lead to a reduction in tidal excursion, resilience is assessed as 'High' (by default) and the biotope is considered to be 'Not sensitive'

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

Not relevant' to seabed habitats. NB. Collision by grounding vessels is addressed under 'surface abrasion.

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

Not relevant. Characterizing species are unlikely to possess the visual acuity to detect the visual presence of objects outlined in the benchmark.

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. This pressure is therefore considered 'Not relevant' to this biotope group.

Introduction or spread of invasive non-indigenous species	None Q: High A: High C: Low	Very Low Q: Low A: NR C: NR	High Q: Low A: Low C: Low

Tang & Kristensen (2010) found that abundance of macrofauna, including *Tubificoides* was lower in marsh invaded by the hybrid cordgrass *Spartina anglica* than in mudflats. Colonization of upper mudflats by this species would alter the character of the biotope resulting in loss and reclassification.

Infaunal non-natives may impact the biotope through sediment disturbance, predation or competition for resources. No examples were found. The polychaete *Marenzellaria viridis* has become established in estuaries in Europe but a recent paper on its impacts where *Tubificoides* were abundant did not report on oligochaete impacts (Delefosse *et al*., 2012).

Sensitivity assessment. The biotope may be sensitive to invasion by *Spartina anglica* which would alter the character of the mudflat and the biological assemblage. Resistance is assessed as 'None' and resilience as 'Very low' as the biotope will not recover unless the INIS is removed. Sensitivity is therefore assessed as 'High'.

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

Marine oligochaetes host numerous protozoan parasites without apparent pathogenic effects even at high infestation levels (Giere & Pfannkuche, 1982 and references therein). *Limnodrilus hoffmeisteri* is parasitized by the caryophyllidean cestode *Archigetes iowensis* (Williams, 1979). *Tubifex tubifex* is an intermediate host to a myosporean parasite, *Myxobolus macrocapsularis* (Myxosporea: Myxobolidae) of the common bream, *Abramis brama* (Szekely *et al*., 2002). *Tubifex tubifex* is also an intermediate host to the parasite *Myxobolus cerebralis* which causes Salmonid Whirling Disease (Zendt & Bergersen, 2000).

Sensitivity assessment. Based on the lack of evidence for mass mortalities in oligochaetes from microbial pathogens, resistance is assessed as 'High' and resilience as 'High', by default, so that the biotope is assessed as 'Not sensitive'.

Removal of target 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

No characterizing species within the biotope are targeted by commercial or recreational fishers or harvesters. This pressure is therefore considered 'Not relevant'.

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

Incidental removal of the characterizing species would alter the character of the biotope and the delivery of ecosystem services such as secondary production and bioturbation. Populations of oligochaetes provide food for macroinvertebrates fish and birds. For example Müller (1968) found that in western Baltic shallow flats *Paranais littoralis* was the preferred food for young flounders and plaice. Polychaetes and crustaceans are also predators of oligochaetes and may significantly reduce numbers (Giere & Pfannkuche, 1982 and references therein). The loss of the oligochaete population could, therefore, impact other trophic levels.

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

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