# *Serpula vermicularis* reefs on very sheltered circalittoral muddy sand

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

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**A colony of tube worms forming a small reef, Loch Creran.**
**Photographer:** David Connor
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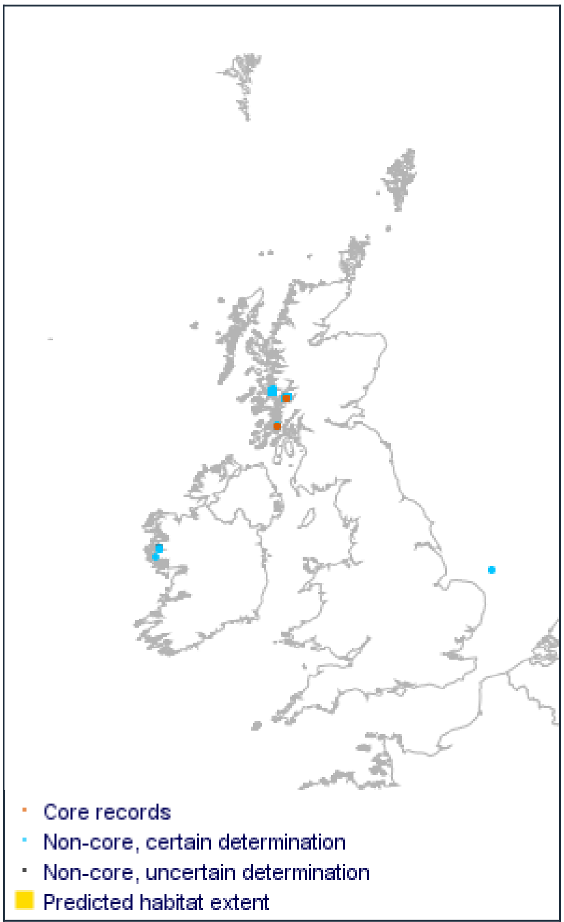


17-09-2018
Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

**Researched by** Frances Perry, Catherine Wilding, Jacqueline Hill and Dr Harvey Tyler-Walters **Refereed by** Dr Daniel B. Harries

# Summary

## UK and Ireland classification

| | | |
|---|---|---|
| **EUNIS 2008** | A5.613 | *Serpula vermicularis* reefs on very sheltered circalittoral muddy sand |
| **JNCC 2015** | SS.SBR.PoR.Ser | *Serpula vermicularis* reefs on very sheltered circalittoral muddy sand |
| **JNCC 2004** | SS.SBR.PoR.Ser | *Serpula vermicularis* reefs on very sheltered circalittoral muddy sand |
| **1997 Biotope** | SS.CMS._.Ser | Serpula vermicularis reefs on very sheltered circalittoral muddy sand |

## Description

Large clumps (mini 'reefs') of the calcareous tubes of *Serpula vermicularis*, typically attached to stones on muddy sediment in very sheltered conditions in sealochs and other marine inlets. A rich associated biota attached to the calcareous tube may include *Esperiopsis fucorum*, thin encrusting sponges, and the ascidians *Ascidiella aspersa*, *Ascidia mentula*, *Dendrodoa grossularia* and *Diplosoma listerianum*. The echinoderms *Ophiothrix fragilis* and *Psammechinus miliaris* and the queen scallop (*Aequipecten opercularis*) are also found throughout this biotope. In shallow water, dense *Phycodrys rubens* may grow on the 'reefs'. This biotope has been recorded in the UK from Loch Creran, where these reefs have been well studied (Moore, 1996), and Loch Sween, where they are reported to have deteriorated. The only other known sites for this biotope are Salt Lake, Clifden and Killary Harbour, Co. Galway. (Information from Connor *et al.*, 2004; JNCC, 2015).

## Depth range

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

## Additional information

Aggregations and larger 'reefs' of *Serpula vermicularis* have been recorded from Killary Harbour, Co. Galway, Killary Harbour, Ardbear Lough and Blacksod Bay (Minchin, 1987; Moore *et al.*, 1998; MERC, 2008) and from the west coasts of Scotland, notably in Loch Creran (Bosence, 1979b; Moore *et al.*, 1998b, 2003, 2009; Poloczanska *et al.* 2004; Chapman *et al.*, 2012), Loch Teacuis (an arm of Loch Sunart) (Dodd *et al.*, 2009) and Loch Ailort (SNH, 2018). The largest extent of serpulid reefs in the world occurred in Loch Creran where the 'reef' was reported to cover ca 108 ha (Moore *et al.*, 2009). However, the aggregations recorded in Loch Teacuis (SNH, 2015, unpublished) and Loch Creran (Tulbure, 2015; Harbour, 2017) have declined and the aggregations in Loch Sween are extinct (Hughes *et al.*, 2008, 2011).

## Listed By

- none -

## Further information sources

Search on:

G G G JNCC

# Habitat review

## Ecology

### Ecological and functional relationships

- *Serpula vermicularis* normally occurs as individuals encrusted on hard surfaces. It forms aggregations in certain conditions but true reefs have an extremely limited distribution. It has been suggested that dense aggregations of *Serpula vermicularis* tubes only occur in enclosed and sheltered locations, where dispersal of larvae may be limited and where a suitable substratum is present. The hypothesis that reef formation occurs in Loch Creran due to limited larval dispersal is not currently backed up by any evidence. Loch Creran has quite a high flushing rate (Hughes pers. comm.) and there are many far more restricted sites in the area with no reef development. It is also questionable whether the lack of suitable substratum is a factor leading to reef development. There are extensive areas of bedrock outcropping from the floor of Loch Creran but these typically support very limited and localised reef growth. Further, Chapman *et al.* (2007) suggest that the lower depth limit of reefs is not set by a shortage of available substrata. The formation of reefs, therefore, is likely to be due to a complex interaction of many factors.
- In Loch Creran individual reefs are reported to reach a height of about over 50 cm and width of 60 cm but vary considerably (Moore *et al.*, 2009). Few reefs exceed 100 cm in height because once they reach 60 cm they fragment, resulting in lateral growth that often produces concentric 'ring reefs' up to 2 m in diameter, although individual reefs may overlap (Moore *et al.*, 2009; Hughes *et al.*, 2001). Adjacent reefs may coalesce to form larger reefs up to 3 m across (Moore, 1996). Bosence (1979b) described reefs up to 2 m in height and 1 m across from Ardbear Lough but suggested that aggregated reefs could extend for several hundred metres. The reef in Ardbear Lough was reported to cover ca 25% of the Lough (ca 3 ha), although it had subsequently declined (Bosence, 1979b; Moore *et al.*, 2009). However, in Loch Creran to reefs were estimated to cover an area of ca 108 ha (Moore *et al.*, 2009).
- *Serpula vermicularis* requires a hard substratum on which to construct its tube. The most common substratum for settlement is bivalve shells. In Loch Creran it was particularly common on shells of *Pecten*, *Aequipecten* and *Modiolus*. Reefs form predominantly in areas where there is suitable substratum scattered throughout a muddy sand bottom (Moore *et al.*, 1998b, 2009; Chapman *et al.*, 2007). Chapman *et al.* (2007) reported a marked preference by settling *Serpula vermicularis* larvae for the underside of scallop shells or vertical scallop shells in settlement experiments when compared to the upper side of the shells, slate or the occupied or unoccupied *Serpula vermicularis* tubes. Chapman *et al.* (2007) found no evidence of gregarious, preferential, settlement on either the occupied or unoccupied tubes of *Serpula vermicularis.*
- The structure of *Serpula vermicularis* reefs is quite open, increasing surface and space for colonization, as well as for food and refuge, for an abundant and varied animal community. The open structure appears to be related to the regular spacing of the apertures of the tubes at 10-15 mm apart which gives enough space for the expansion of the branchial crowns during feeding (Bosence, 1979b).
- Predation of *Serpula vermicularis* by several species has been described by Bosence (1979b) although the importance of the species as a food source is unknown. The wrasse *Ctenolabrus rupestris* and *Crenilabrus melops* were frequently seen biting serpulid tubes and extracting the worms. The starfish *Asterias rubens* was frequently seen with its stomach

everted down the serpulid tubes. Bosence (1979b) also observed the urchins *Echinus esculentus* and *Psammechinus miliaris* feeding on serpulid tubes but thought it unlikely that they were feeding directly on the worms, which can withdraw into their tubes very rapidly, and were more likely to be eating the epifauna and epiflora on the tubes. Predation of *Serpula vermicularis* by *Cancer pagurus*, *Carcinus maenas*, *Asterias rubens* and *Ctenolabrus rupestris* was observed in Salt Lake, Ardbear Lough (Minchin, 1987). However, long-term video monitoring of reefs in Loch Creran revealed very few instances of attempted predation on the worms (Poloczanska *et al.*, 2004).

**Seasonal and longer term change**

The growth of *Serpula vermicularis* reefs may take many years so the major change over time is likely to be an increase in the size of the reef. However, as the growth of the reef proceeds, the old base is weakened by biological erosion by boring sponges and algae, and grazing by fish and echinoderms. Segments of the reef then break off and provide new areas for larval settlement and this is the main way in which a reef growing from an original rocky substratum can extend outwards to cover areas of soft substratum (Bosence, 1979b, Moore *et al.*, 2009). There may be seasonal changes in abundance of other species, such as hydroids and amphipods, which often have lifespans less than a year, and due to periodic recruitment of larvae.

**Habitat structure and complexity**

The reef is a structurally complex habitat as the open form of the aggregated tubes provides a large surface area and many spaces which supports a high diversity of sessile and mobile macrofauna. Initial growth is encrusting but after that, the worms grow away from the substratum in a sinuous fashion, sometimes becoming intertwined and the reefs develop as new worms are added to old tubes.

In Loch Creran, Scotland reefs were found growing in bedrock, boulders, stones, shells and man-made substrata (Moore *et al.*, 1998b). Large reefs were only rarely found growing on rock. In Loch Creran individual reefs are reported to reach a height of about over 50 cm and width of 60 cm but vary considerably (Moore *et al.*, 2009). Few reefs exceed 100 cm in height because once they reach 60 cm they fragment, resulting in lateral growth that often produces concentric 'ring reefs' up to 2 m in diameter, although individual reefs may overlap (Moore *et al.*, 2009; Hughes *et al.*, 2001). Adjacent reefs may coalesce to form larger reefs up to 3 m across (Moore, 1996). Bosence (1979b) described reefs up to 2 m in height and 1 m across from Ardbear Lough but suggested that aggregated reefs could extend for several hundred metres.

*Serpula vermicularis* aggregations and reefs provide structurally diverse habitats in otherwise sedimentary habitats and can support high levels of biodiversity. The rich associated fauna of organisms includes sessile organisms such as ascidians, hydroids, bivalves and other polychaete worms such as *Spirobranchus triqueter* and *Sabella pavonina*. There is also a mobile component of the associated macrofauna that is rich in amphipods, and also includes fish, crabs, whelks and echinoderms that use the reefs for feeding, refuge and egg-laying (Moore *et al.*, 1998b; Poloczanska *et al.*, 2004; Chapman *et al.*, 2012). Chapman *et al.* (2012) reported that the community was dominated by numerically polychaetes, molluscs and crustaceans. Chapman *et al.* (2012) recorded 278 species from ten serpulid aggregates, with a level of biodiversity similar to that recorded on horse mussel beds. Species richness increased with increasing size of the reef (Chapman *et al.*, 2012).

### Productivity

The community is predominantly faunal so productivity in the biotope is largely secondary. Red algae such as *Phycodrys rubens* and encrusting corallines are present in the biotope, although not in very high abundance and so levels of primary production are not likely to be high. Although no information was found regarding the diet of *Serpula vermicularis*, analysis of digestive enzymes suggests that quite large detrital particles may form an important part of the diet (Michel & De Villez, 1978). Several of the other species in the biotope, such as the ascidians and other polychaetes, are also suspension feeders. Phytoplankton, supplemented by non-living detritus, is likely to be the main food source for all these species (Hughes, pers. comm.). Secondary production could be substantial in large reefs.

### Recruitment processes

- In the British Isles spawning occurs in the summer months (Elmhirst, 1922; Allen, 1915). Orten (1914) studied *Serpula vermicularis* in the south-west of England and found that worms reproduced successfully at ten months old.
- In Loch Creran, Chapman *et al.* (2007) reported that larval settlement occurred between mid-June and mid-October with a peak between mid-August and mid-September. Similarly, Cotter *et al.* (2003) reported larval settlement between June and August with a peak in July in Bantry Bay, Ireland and Bosence (1979b) reported settlement on plates deployed in August in Ardbear Lough, Ireland. Elmhirst (1922) reported larval settlement between June and August in the first of Clyde, Scotland but gave no information to support the observation (Chapman *et al.*, 2007).
- *Serpula vermicularis* requires a hard substratum on which to construct its tube. The most common substratum for settlement is bivalve shells. In Loch Creran, it was particularly common on shells of *Pecten*, *Aequipecten* and *Modiolus*. Reefs form predominantly in areas where there is suitable substratum scattered throughout a muddy sand bottom (Moore *et al.*, 1998b, 2009; Chapman *et al.*, 2007).
- Chapman *et al.* (2007) reported a marked preference by settling *Serpula vermicularis* larvae for the underside of scallop shells or vertical scallop shells in settlement experiments when compared to the upper side of the shells, slate or the occupied or unoccupied *Serpula vermicularis* tubes. Chapman *et al.* (2007) found no evidence of gregarious, preferential, settlement on either the occupied (with a living worm) or unoccupied tubes of *Serpula vermicularis* but Cook (2016) suggested further study was required to explain the dense aggregations observed. Chapman *et al.* (2007) also noted that settlement on slates was greater than the settlement on the upper side of scallop shells. Negative phototaxis was suggested to explain the preference of serpulid larvae for the lower surfaces (undersides) of settlement plates, as a mechanism to avoid siltation (Bosence, 1979b; Cotter *et al.*, 2003). The larvae of *Serpula columbiana* were reported to exhibit negative phototaxis in light but negative geotaxis in the dark (Young & Chia, 1982; cited in Chapman *et al.*, 2007).
- Chapman *et al.* (2007) also noted a marked reduction in settlement density on plates between 6 m and 12 m. While *Serpula vermicularis* was distributed from the lower shore to at least 17 m in Loch Creran (or to ca 210 m around the coasts of Scotland) the area of reefs in Loch Creran had a restricted depth range from a mean upper limit of 2.7 m to 6.6 m in the upper basin or 9.9 m in the lower basin (Moore *et al.*, 2006; Chapman *et al.*, 2007). Therefore, Chapman *et al.* (2007) suggested that the lower reef boundary resulted from a depth-correlated settlement response rather than lack of suitable substratum or depth-correlated mortality and that light or another factor was more important in determining

the depth distribution of settlement than siltation. Cook (2016) also noted that artificial substrata composed of scallop shells in large bags received 9.6% serpulids (*Serpula vermicularis* and *Spirobranchus triqueter*) than 'cobbles in large bags' but the difference was not significant. However, both of these treatments had the highest serpulid settlement compared with the other treatments studied, probably due to their high substratum complexity (Cook, 2016).

- Recruitment of sessile organisms in the biotope, such as sponges, ascidians and hydroids, is almost entirely from planktonic sources. Some species have larvae that can disperse widely and these may arrive from distant locations. Others, particularly the hydroids and some ascidians have short-lived planktonic larvae so dispersal distances are short and recruitment will largely be from local populations. In Loch Creran, *Spirobranchus* spp. settlement occurred in late May to early June before *Serpula vermicularis* settlement (Chapman *et al*., 2007).
- Recruitment of the mobile predators and grazers may be through immigration of adults or via a larval dispersal phase. Mobile species such as decapod crustaceans, echinoderms and fish will settle from planktonic stages or migrate into the biotope.
- Red algae have non-flagellate, and non-motile spores that stick on contact with the substratum. Norton (1992) noted that algal spore dispersal is probably determined by currents and turbulent deposition. However, red algae produce large numbers of spores that may settle close to the adult especially where currents are reduced such as in sheltered locations.

**Time for community to reach maturity**

Growth rates of *Serpula vermicularis* vary. A maximum growth rate for *Serpula vermicularis* (measured as the linear tube extension in transplanted specimens) was reported as 81 mm after one-years deployment in Loch Creran (Hughes *et al*., 2008). The mean growth rate was 32 mm/yr or 33.7 mm/yr at the two sites in Loch Creran studied. However, there was considerable variation in growth rate between individual tubes with the most frequent rates of growth at 10-20 mm/yr or 30-40 mm/yr, and rates over 60 mm/yr were rare. Bosence (1973) reported a linear extension rate of 9 mm in the month of August 1972 in Ardbear Lough, Ireland (Bosence 1973; cited in Hughes *et al*., 2008). Hughes *et al.* (2009) suggested that growth rates were probably seasonal and probably increased in warmer weather. Hughes *et al.* (2009) also noted that individual tubes can reach 20 cm in length, which would require ca 6 years based on an average extension rate of 33 mm/yr, although the more rapid growth rates of juveniles would mean this was a maximum estimate of age for the largest tubes. If the mean growth rates of *Serpula vermicularis* in Loch Creran (ca 33 mm/yr) were applied to the mean height of *Serpula vermicularis* in Loch Teacuis, then it would take ca 8 years for the reefs to regain the same height. A typical reef height of 50 cm in Loch Creran could take ca 15 years to develop and a reef of up to 2 m height described by Bosence (1979b) could take ca 60 years to reach a similar height, based on a mean tube extension of 33 mm/yr. Nevertheless, these estimates are based on tube growth and, since new recruits tend to settle below the top of the reef, the overall increase in 'reef' height would be lower than the average of 33 mm/yr (D. Harries, pers comm.). The reef develops upwards and outwards as larvae settle on to the tubes of existing worms and so it may take many periods of recruitment for reefs to become large.

Many other species in the biotope, such as ascidians, hydroids and bryozoans exhibit annual recruitment and many are short-lived so populations are likely to reach maturity rapidly. There are some slow-growing species, such as encrusting coralline algae, which take longer to achieve significant coverage. Species diversity within the reef is likely to increase with time. However, the time to maturity of the biotope will depend on the time for reef development, which is likely to be many years

### Additional information

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## Preferences & Distribution

### Habitat preferences

| | |
|---|---|
| **Depth Range** | 0-5 m, 5-10 m, 10-20 m |
| Water clarity preferences | No information |
| **Limiting Nutrients** | No information |
| **Salinity preferences** | Full (30-40 psu), Variable (18-40 psu) |
| **Physiographic preferences** | Sea loch / Sea lough |
| **Biological zone preferences** | Circalittoral, Lower infralittoral |
| **Substratum/habitat preferences** | Bedrock, Gravel / shingle, Pebbles, Sandy mud |
| **Tidal strength preferences** | Very Weak (negligible), Weak < 1 knot (<0.5 m/sec.) |
| **Wave exposure preferences** | Extremely sheltered, Sheltered, Very sheltered |
| **Other preferences** | Calcareous tubes; pebbles; shells; gravel on sandy mud |

### Additional Information

No text entered

## Species composition

### Species found especially in this biotope

- *Serpula vermicularis*

### Rare or scarce species associated with this biotope

-

### Additional information

No text entered.

# Sensitivity review

## Sensitivity characteristics of the habitat and relevant characteristic species

*Serpula vermicularis* is found all around the British Isles (NBN Gateway, 2016), however, there are very few examples of *Serpula vermicularis* aggregations or 'reefs' (Dodd *et al.*, 2009; Moore *et al.*, 2009). Live reefs are considered rare (Dodd *et al.*, 2009). Aggregations and larger 'reefs' of *Serpula vermicularis* have been recorded from Killary Harbour, Co. Galway, Killary Harbour, Ardbear Lough and Blacksod Bay (Minchin, 1987; Moore *et al.*, 1998; MERC, 2008) and from the west coasts of Scotland, notably in Loch Creran (Bosence, 1979b; Moore *et al.*, 1998b, 2003, 2009; Poloczanska *et al.* 2004; Chapman *et al.*, 2012), Loch Teacuis (an arm of Loch Sunart) (Dodd *et al.*, 2009) and Loch Ailort (SNH, 2018). However, the aggregations recorded in Loch Teacuis (SNH, 2015, unpublished) and Loch Creran (Tulbure, 2015; Harbour, 2017) have declined and the aggregations in Loch Sween are extinct (Hughes *et al.*, 2008, 2011).

*Serpula vermicularis* aggregates and reefs are intricate, three-dimensional structures known to increase local habitat complexity and support a rich associated fauna (Bosence, 1979b; Poloczanska *et al.*, 2004; Dodd *et al.*, 2009; Chapman *et al.*, 2012). The aggregates and reefs provide hard substratum for epifauna and epiflora in otherwise sedimentary habitats, and their structure provides niches for interstitial species (e.g. amphipods, isopods and copepods) and mobile species such as grazing gastropods, echinoderms, and decapods.

Although the biotope has high species diversity (Chapman *et al.*, 2012), the individual species present may vary and the loss of these species is not likely to affect the function and existence of the biotope. *Spirobranchus triqueter* is known to stabilise the structure of tubes created by *Serpula vermicularis* (D. Harries, pers. comm.) and grazing urchins may contribute to the erosion of their tubes, the 'aggregates' and 'reefs', and the associated community, that define the biotope are dependent on the structure provided by the tubes of *Serpula vermicularis.* Therefore, *Serpula vermicularis* is the only species selected to represent the sensitivity of the biotope, although the sensitivity of associated species is discussed where relevant.

## Resilience and recovery rates of habitat

Little is known about the reproductive cycle of *Serpula vermicularis.* In the British Isles spawning occurs in the summer months (Elmhirst, 1922; Allen, 1915). Orten (1914) studied *Serpula vermicularis* in the south-west of England and found that worms reproduced successfully at ten months old. It is thought that worms can survive for several years but there is no published evidence to support this supposition (Holt *et al.*, 1998). In Loch Creran, Chapman *et al.* (2007) reported that larval settlement occurred between mid-June and mid-October with a peak between mid-August and mid-September. Similarly, Cotter *et al.* (2003) reported larval settlement between June and August with a peak in July in Bantry Bay, Ireland and Bosence (1979b) reported settlement on plates deployed in August in Ardbear Lough, Ireland. Elmhirst (1922) reported larval settlement between June and August in the first of Clyde, Scotland but gave no information to support the observation (Chapman *et al.*, 2007).

*Serpula vermicularis* reefs recorded in Ireland and Scotland are all in sheltered sea lochs with restricted entrances. It was suggested that sheltered conditions with a limited turnover of water are required for larval retention and, therefore, the development of the large number of *Serpula vermicularis* to enable the creation of reefs (Bosence, 1979b; Moore, 1996; Dodd *et al.*, 2009). Dodd *et al.* (2009) suggested that the density of individuals in a system also needs to be at a certain level before the necessary number of larvae can be produced and retained triggering reef development. Poloczanska *et al.* (2004) reported that larvae settle near conspecifics to create monospecific reefs. *Serpula vermicularis* reefs were suggested to spread partly by fragmentation (Bosence, 1979b). However, there is no evidence to support the suggestion in Loch Creran and there are numerous lochs with limited water exchange and 'plenty' of *Serpula vermicularis* but no reefs (D. Harries pers comm.). Bosence (1979b) suggested that reef become more fragile with age. *Cliona celata* the boring sponge was suggested to contribute to the increasing fragility of reefs with age (Bosence, 1979b). Moore (1996) suggested that overgrowth of the *Serpula vermicularis* reefs by encrusting organisms (e.g. other tube worms) may contribute to strengthening the colonies (cited from Holt *et al.*, 1998).

*Serpula vermicularis* requires a hard substratum on which to construct its tube. The most common substratum for settlement is bivalve shells. In Loch Creran, it was particularly common on shells of *Pecten*, *Aequipecten* and *Modiolus*. Reefs form predominantly in areas where there is suitable substratum scattered throughout a muddy sand bottom (Moore *et al.*, 1998b, 2009; Chapman *et al.*, 2007). Chapman *et al.* (2007) reported a marked preference by settling *Serpula vermicularis* larvae for the underside of scallop shells or vertical scallop shells in settlement experiments when compared to the upper side of the shells, slate or the occupied or unoccupied *Serpula vermicularis* tubes. Chapman *et al.* (2007) found no evidence of gregarious, preferential, settlement on either the occupied (with a living worm) or unoccupied tubes of *Serpula vermicularis* but Cook (2016) suggested further study was required to explain the dense aggregations observed. Chapman *et al.* (2007) also noted that settlement on slates was greater than the settlement on the upper side of scallop shells. Negative phototaxis was suggested to explain the preference of serpulid larvae for the lower surfaces (undersides) of settlement plates, as a mechanism to avoid siltation (Bosence, 1979b; Cotter *et al.*, 2003). The larvae of *Serpula columbiana* were reported to exhibit negative phototaxis in light but negative geotaxis in the dark (Young & Chia, 1982; cited in Chapman *et al.*, 2007). Chapman *et al.* (2007) also noted a marked reduction in settlement density on plates between 6 m and 12 m. While *Serpula vermicularis* was distributed from the lower shore to at least 17 m in Loch Creran (or to ca 210 m around the coasts of Scotland) the area of reefs in Loch Creran had a restricted depth range from a mean upper limit of 2.7 m to 6.6 m in the upper basin or 9.9 m in the lower basin (Moore *et al.*, 2006; Chapman *et al.*, 2007). Therefore, Chapman *et al.* (2007) suggested that the lower reef boundary resulted from a depth-correlated settlement response rather than lack of suitable substratum or depth-correlated mortality and that light or another factor was more important in determining the depth distribution of settlement than siltation. Cook (2016) also noted that artificial substrata composed of scallop shells in large bags received 9.6% serpulids (*Serpula vermicularis* and *Spirobranchus triqueter*) than 'cobbles in large bags' but the difference was not significant. However, both of these treatments had the highest serpulid settlement compared with the other treatments studied, probably due to their high substratum complexity (Cook, 2016).

In Loch Creran individual reefs are reported to reach a height of about over 50 cm and width of 60 cm but vary considerably (Moore *et al.*, 2009). Few reefs exceed 100 cm in height because once they reach ca 60 cm they fragment, resulting in lateral growth that often produces concentric 'ring reefs' up to 2 m in diameter, although individual reefs may overlap (Moore *et al.*, 2009; Hughes *et al.*, 2001). Adjacent reefs may coalesce to form larger reefs up to 3 m across (Moore, 1996). Minchin (1987) reported that the *Serpula vermicularis* reefs in Northern Ireland reached a maximum height of 1 m. The mean height of *Serpula vermicularis* reefs in Loch Teacuis was 26±9 cm (Dodd *et al.*, 2009). The tallest *Serpula vermicularis* reefs recorded were 2 m high in Ardbear Lough, Ireland (Bosence, 1979b). Bosence (1979b) described reefs up to 2 m in height and 1 m across from Ardbear Lough but suggested that aggregated reefs could extend for several hundred metres.

Growth rates of *Serpula vermicularis* vary. A maximum growth rate for *Serpula vermicularis* (measured as the linear tube extension in transplanted specimens) was reported as 81 mm after one-years deployment in Loch Creran (Hughes *et al.*, 2008). The mean growth rate was 32 mm/yr or 33.7 mm/yr at the two sites in Loch Creran studied. However, there was considerable variation in growth rate between individual tubes with the most frequent rates of growth at 10-20 mm/yr or 30-40 mm/yr, and rates over 60 mm/yr were rare. Bosence (1973) reported a linear extension rate of 9 mm in the month of August 1972 in Ardbear Lough, Ireland (Bosence 1973; cited in Hughes *et al.*, 2008). Hughes *et al.* (2009) suggested that growth rates were probably seasonal and probably increased in warmer weather. Hughes *et al.* (2009) also noted that individual tubes can reach 20 cm in length, which would require ca 6 years based on an average extension rate of 33 mm/yr, although the more rapid growth rates of juveniles would mean this was a maximum estimate of age for the largest tubes. If the mean growth rates of *Serpula vermicularis* in Loch Creran (ca 33 mm/yr) were applied to the mean height of *Serpula vermicularis* in Loch Teacuis, then it would take ca 8 years for the reefs to regain the same height. A typical reef height of 50 cm in Loch Creran could take ca 15 years to develop and a reef of up to 2 m height described by Bosence (1979b) could take ca 60 years to reach a similar height, based on a mean tube extension of 33 mm/yr. Nevertheless, these estimates are based on tube growth and, since new recruits tend to settle below the top of the reef, the overall increase in 'reef' height would be lower than the average of 33 mm/yr (D. Harries, pers comm.).

*Serpula vermicularis* reefs were first reported from Linne Mhuirich in Loch Sween, in 1979 (Bosence, 1979b). However, when this site was resurveyed in 1994 only empty tubes were found (O. Paisley & D. Hughes, pers. comm.; Dodd *et al.*, 2009; Hughes *et al.*, 2011). No recovery of the reefs had occurred by 2008 (Hughes *et al.*, 2008). Mortality of *Serpula vermicularis* reefs also occurred in Ireland (Bianchi *et al.*, 1995; Henry, 2002). In both cases, it was not known why the reef was lost, or why the reef was not able to recover (Dodd *et al.*, 2009). A survey of Loch Teacuis (SNH, 2015) found that a significant reduction in the abundance and distribution of the *Serpula vermicularis* reef in the loch had occurred since it was first described in 2006 (Kamphausen, 2015). Tulbure (2015) quantified the change in the condition of the *Serpula vermicularis* reefs in Loch Creran since 2005. It was found that there had been a significant decline in the condition of the reefs, with half of the sites showing more than 80% collapse (Tulbure, 2015).

Hughes *et al.* (2011) noted that the first record of serpulid aggregations in Loch Creran was in 1882 but there were no further records until 1989 and no evidence of continuity between those dates and that there was a lack of tube debris in Loch Creran to suggest long-term occupancy by aggregations of *Serpula vermicularis*. However, in Loch Sween reef fragments persisted for at least 15 yrs after the last survey and may have been >20 yrs old. Hughes *et al.* (2011) found that the rates of bioerosion in fragments placed in Loch Creran was low and that the growth of new recruits could outweigh bioerosion or chemical dissolution. Therefore, they suggested that the *Serpula vermicularis* reefs in Scotland were relatively transient features, forming and disappearing over decadal timescales (Hughes *et al.*, 2011). However, microscopic analysis of sedimentary cores from Loch Creran, in the vicinity of existing 'reefs', revealed reef fragments at depth in the sediment (Harbour, 2017; Pedicini, 2017). In two (of eight cores), reef fragments were found in throughout the cores to a depth of 80 cm (Harbour, 2017). Pedicini (2017) noted that most serpulid tube fragments were in the top 10-20 cm or 30-40 cm of the cores. Harbour (2017) suggested that *Serpula vermicularis* reefs were a persistent feature of Loch Creran but that further radioisotopic dating was required before the timescale could be accurately determined. Pedicini (2017) noted that no natural occurring regeneration of the reefs was evident in her study.

**Resilience assessment.** This biotope is rare and there is a lack of knowledge regarding the life cycle of *Serpula vermicularis* and the correct conditions that create suitable habitat for aggregate and reef formation. Fragmentation (or collapse) appears to be a natural part of reef development (Bosence, 1979b; Moore *et al.*, 2009). Studies of growth rates suggest that the recovery is probably slow, depending on the size and extent of the reef prior to disturbance or loss. For example, reefs typical of Loch Creran (e.g. 50 cm) may take at least 15 years to recover their original hight (based on an average tube extension of 33 mm/yr), and the tall reefs described by Bosence (1979b) in Ireland would require at least 60 years, especially as serpulids tend to recruit below the top of the reef and the growth rates in terms of height are likely to be an overestimate (D. Harries, pers comm.). In the literature, any recorded loss of reef has never recovered (Minchin, 1987; Dodd *et al.*, 2009). However, current evidence suggests that *Serpula vermicularis* aggregations and reefs may be persistent features of lochs (e.g. Loch Creran) but undergo cycles of growth and destruction over periods of 10s or 100s of years, although the timescales and causes remain unclear. Therefore, if resistance to a pressure is 'Medium' and only part of the reef dies then there is the potential for the *Serpula vermicularis* reef to regenerate and a resistance of **'Low'** is suggested. For the pressures where resistance is assessed as 'Low' or 'None' resilience is assessed as **'Very low'**. If resistance to a pressure is assessed as 'High' then naturally, the resilience is also 'High'.

## Hydrological Pressures

| | Resistance | Resilience | Sensitivity |
|---|---|---|---|
| **Temperature increase (local)** | High<br>Q: High A: Medium C: Medium | High<br>Q: High A: High C: High | Not sensitive<br>Q: High A: Medium C: Medium |

*Serpula vermicularis* is found throughout the British Isles (NBN, 2016), and its range extends through the North East Atlantic and the Mediterranean (Holt *et al.*, 1998). This range suggests it is tolerant of some temperature change. In Loch Creran in Scotland, the temperature regime within the main basin is similar to that in the adjacent sea with a low of about 6°C in February/March and a high of 13 -15°C in August/September (Gage, 1972). The peak in larval recruitment of *Serpula vermicularis* in Loch Creran coincides with this peak in temperature (Chapman *et al.*, 2007). Additionally, Hughes *et al.* (2005) found the species to be tolerant of changes in temperature "with upper lethal limits exceeding any value that they could conceivably experience in the field".

**Sensitivity assessment.** At the pressure benchmark, the characterizing species *Serpula vermicularis* is not thought to be sensitive. Some of the other species in the biotope may be less tolerant of an increase in temperature, although overall species diversity is not expected to be significantly affected. Therefore, resistance and resilience have been assessed as 'High' so that sensitivity is assessed as **'Not sensitive'** at the benchmark level.

| | Resistance | Resilience | Sensitivity |
|---|---|---|---|
| **Temperature decrease (local)** | High<br>Q: High A: Medium C: Medium | High<br>Q: High A: High C: High | Not sensitive<br>Q: High A: Medium C: Medium |

*Serpula vermicularis* is found throughout the British Isles (NBN, 2016), and its range extends through the North East Atlantic and the Mediterranean (Holt *et al.*, 1998). It would be expected that in shallow enclosed areas, the temperature will fall during periods of cold winter weather so decreases in temperature are probably tolerated by reefs. Hughes *et al.* (2005) found the species to be tolerant of a wide range of temperatures.

**Sensitivity assessment.** At the pressure benchmark, the characterizing species *Serpula vermicularis* is not thought to be sensitive. Some of the other species in the biotope may be less tolerant of an increase in temperature, although overall species diversity is not expected to be significantly affected. Therefore, resistance and resilience have been assessed as 'High' so that sensitivity is assessed as **'Not sensitive' at the benchmark level.**

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

This biotope occurs in variable and full marine salinity regimes (Connor *et al.*, 2004). *Serpula vermicularis* is not found in areas where hypersaline conditions occur, such as rock pools or lagoons, so it seems likely that the species would be intolerant of increases in salinity. An increase in salinity at the benchmark level would result in a salinity of >40 psu and, as hypersaline water is likely to sink to the seabed, the biotope may be affected by hypersaline effluents. Ruso *et al.* (2007) reported that changes in the community structure of soft sediment communities due to desalinisation plant effluent in Alicante, Spain. In particular, in close vicinity to the effluent, where the salinity reached 39 psu, the community of polychaetes, crustaceans and molluscs was lost and replaced by one dominated by nematodes. Roberts *et al.* (2010b) suggested that hypersaline effluent dispersed quickly but was more of a concern at the seabed and in areas of low energy where widespread alternations in the community of soft sediments were observed. In several studies, echinoderms and ascidians were amongst the most sensitive groups examined (Roberts *et al.*, 2010b).

**Sensitivity assessment.** A long-term increase to hypersaline conditions would probably result in loss of reefs and the loss of many of the other species that colonize the reefs. Therefore, resistance is assessed as **'None'**, as a long-term change in the salinity regime at the benchmark would most likely cause the severe mortality of the characterizing species and a large number of the other species found within the biotope. Resilience is assessed as **'Very low'** due to the very unlikely recovery of the biotope so that sensitivity is assessed as **'High'.**

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

This biotope is recorded from both full marine and variable salinity regimes (Connor *et al.*, 2004). Bosence (1979b) suggested that the layer of low salinity water in the upper layers of the water in Ardbear Loch in Galway, Eire is partly responsible for the lack of *Serpula vermicularis* individuals above a depth of 2 m. However, *Serpula vermicularis* is known to tolerate reduced salinities (Hartmann-Schröder, 1971; Mastrangelo & Passeri, 1975; cited in Moore *et al.*, 1998b; Cook, 2016) and in Loch Creran in Scotland, individual specimens of *Serpula vermicularis* were commonly observed in shallow waters where salinities could fall to around 23 psu at 4 m (Moore *et al.*, 1998b). Small enclosed lochs such as Loch Sween & Ardbear Loch are often subject to extremely variable salinity so the species seems to be tolerant of shorter-term changes. *Serpula vermicularis* reefs were also observed in intertidal areas of Loch Creran during the 19th century, where salinity is likely to vary. Therefore, it seems likely that the species can tolerate some decreases in salinity. However, when reduced salinity interacts with variation in temperature, larval mortality occurs (Gray, 1976). Cook (2016) also noted that Loch Creran experienced an extreme rainfall event in January 2014 that resulted in a reduction in salinity of at least 3.5 ppt at 6 m at all of his study sites.

**Sensitivity assessment.** A long-term (one year) reduction in salinity to reduced (18-30) regime will remove both *Serpula vermicularis* and the other species within this biotope from their optimal

habitat conditions. It is possible that some of the *Serpula vermicularis* would die because of this change in salinity, although their tubes and the structure of the reef would remain.
Hence, resistance is assessed as **'Medium'**. Therefore, resilience is assessed as **'Low'** so that sensitivity is assessed as **'Medium'**.

| | | | |
|---|---|---|---|
| **Water flow (tidal current) changes (local)** | High<br>Q: High A: Medium C: Medium | High<br>Q: High A: High C: High | Not sensitive<br>Q: High A: Medium C: Medium |

The tidal flows within this biotope are recorded as weak (<1 knot) and very weak (negligible) (Connor *et al.*, 2004). All of the *Serpula vermicularis* reefs recorded in Ireland and Scotland are found in sheltered sea lochs/loughs with restricted entrances. This has led to the suggestion that sheltered conditions with a limited turnover of water are required for the development of *Serpula vermicularis* reefs (Bosence, 1979b; Dodd *et al.*, 2009). In Loch Creran, no reefs were recorded in the outer section of the loch beyond the narrows at Sgeir Calliach, despite the presence of suitable depths and substrata. This is a well-flushed section of the loch, where the larvae of *Serpula vermicularis* will presumably be at lower concentrations than further up the loch (Moore, 1998b). Moore *et al.* (1998b) also noted that reefs were absent from parts of the upper basin exposed to strong currents even though suitable substratum was present. Therefore, the biotope is likely to be intolerant of an increase in water flow rate as larvae are likely to be taken away from the reefs, old worms will die and, without a supply of new individuals, the reef will die. With the collapse of dead *Serpula vermicularis* reefs, species diversity will decline significantly because the open structure of the reefs provides substratum and crevices for many other organisms.

**Sensitivity assessment.** Although water flows seem to be an important environmental factor for the growth of *Serpula vermicularis* reefs, this pressure is unlikely to have a negative impact on the biotope at the level of the benchmark (a change of 0.1-0.2 m/s). Therefore, resistance and resilience are assessed as 'High' and sensitivity as **'Not sensitive' at the benchmark level.**

| | | | |
|---|---|---|---|
| **Emergence regime changes** | Not relevant (NR)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR |

This biotope does not occur in the intertidal and a change in emergence is not relevant to this biotope.

| | | | |
|---|---|---|---|
| **Wave exposure changes (local)** | High<br>Q: Medium A: Medium C: Medium | High<br>Q: High A: High C: High | Not sensitive<br>Q: Medium A: Medium C: Medium |

This biotope occurs in sea lochs where wave exposure is recorded as sheltered to extremely sheltered (Connor *et al.*, 2004). The *Serpula vermicularis* reefs are open and quite fragile structures and are not likely to be resistant of wave exposure. No reefs are reported at depths of zero metres, which may be the effect of turbulence on larval recruitment (Champan *et al.*, 2007). Tulbure (2015) found that in Loch Creran the more wave exposed areas of the loch contained lower total coverage of *Serpula vermicularis.*

**Sensitivity assessment.** An increase in wave exposure may damage existing reefs, while a decrease might increase the available space for colonization. A single storm may cause significant damage to a reef (D. Harries, pers. comm.). However, an increase in the pressure at the benchmark (an increase of 3-5% in significant wave height) is unlikely to affect the biotope. Therefore, resistance and resilience are assessed as **'High'** and sensitivity assessed as **'Not sensitive' at the benchmark level.**

## Chemical Pressures

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

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

| | Resistance | Resilience | Sensitivity |
|---|---|---|---|
| **Hydrocarbon & PAH contamination** | Not Assessed (NA)<br>Q: NR A: NR C: NR | Not assessed (NA)<br>Q: NR A: NR C: NR | Not assessed (NA)<br>Q: NR A: NR C: NR |

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

| | Resistance | Resilience | Sensitivity |
|---|---|---|---|
| **Synthetic compound contamination** | Not Assessed (NA)<br>Q: NR A: NR C: NR | Not assessed (NA)<br>Q: NR A: NR C: NR | Not assessed (NA)<br>Q: NR A: NR C: NR |

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

| | Resistance | Resilience | Sensitivity |
|---|---|---|---|
| **Radionuclide contamination** | No evidence (NEv)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | No evidence (NEv)<br>Q: NR A: NR C: NR |

No evidence.

| | Resistance | Resilience | Sensitivity |
|---|---|---|---|
| **Introduction of other substances** | Not Assessed (NA)<br>Q: NR A: NR C: NR | Not assessed (NA)<br>Q: NR A: NR C: NR | Not assessed (NA)<br>Q: NR A: NR C: NR |

This pressure is **Not assessed**.

| | Resistance | Resilience | Sensitivity |
|---|---|---|---|
| **De-oxygenation** | Low<br>Q: Low A: NR C: NR | Very Low<br>Q: High A: Medium C: Medium | High<br>Q: Low A: Low C: Low |

There is no information regarding the tolerance of *Serpula vermicularis* to deoxygenation. Cole *et al.* (1999) suggest possible adverse effects on marine species below 4 mg/l and probable adverse effects below 2 mg/l. Bosence (1979b) observed that the lower limit of larval settlement in Ardbear Lough, Eire coincided with mud-rich and possibly oxygen poor water. Gage (1972) found the dissolved oxygen concentration in the lower basin of Loch Creran in Scotland, where *Serpula vermicularis* reefs form, did not fall below 87% saturation. Therefore, the species, and the larvae, in particular, may be intolerant of deoxygenated water. Other species in the biotope may also be intolerant of changes in oxygen availability resulting in a possible loss of species diversity.

**Sensitivity assessment.** The resistance of this biotope to de-oxygenation at the level of the benchmark is assessed as **'Low'** but with 'Low' confidence. Therefore, resilience is assessed as **'Very low'** and the overall sensitivity of the biotope to this pressure is assessed as **'High'.**

**Nutrient enrichment**

| | | |
|---|---|---|
| Not relevant (NR) | Not relevant (NR) | Not sensitive |
| Q: NR A: NR C: NR | Q: NR A: NR C: NR | Q: NR A: NR C: NR |

This pressure relates to increased levels of nitrogen, phosphorus and silicon in the marine environment compared to background concentrations. The consequent changes in ecosystem functions can lead to the progression of eutrophic symptoms (Bricker *et al.*, 2008), changes in species diversity and evenness (Johnston & Roberts, 2009) decreases in dissolved oxygen and uncharacteristic microalgal blooms (Bricker *et al.*, 1999, 2008). Johnston & Roberts (2009) undertook a review and meta-analysis of the effect of contaminants on species richness and evenness in the marine environment. Of the 47 papers reviewed relating to nutrients as contaminants, over 75% found that it had a negative impact on species diversity, <5% found increased diversity, and the remaining papers finding no detectable effect. Due to the 'remarkably consistent' effect of marine pollutants on species diversity, this finding is probably relevant to this biotope (Johnston & Roberts, 2009). It was found that any single pollutant reduced species richness by 30-50% within any of the marine habitats considered (Johnston & Roberts, 2009). Throughout their investigation, there were only a few examples where species richness was increased due to the anthropogenic introduction of a contaminant. These examples were almost entirely from the introduction of nutrients, either from aquaculture or sewage outfalls (Johnston & Roberts, 2009).

**Sensitivity assessment.** Moderate nutrient enrichment, especially in the form of organic particulates and dissolved organic material, is likely to increase food availability for all the suspension feeders within the biotope. However, long-term or high levels of organic enrichment may result in eutrophication and have indirect adverse effects, such as increased turbidity, increased suspended sediment, increased risk of deoxygenation and the risk of algal blooms. D. Harries (pers comm.) noted that increased algal growth on reefs was suggested as a possible cause of the deterioration in Loch Teacuis and could certainly hamper serpulid feeding & cause increased drag. However, this biotope is assessed as **'Not sensitive' at the pressure benchmark** that specifies compliance with good status as defined by the WFD as, by that definition, the biotope is not exposed to potentially adverse effects.

**Organic enrichment**

| | | |
|---|---|---|
| No evidence (NEv) | Not relevant (NR) | No evidence (NEv) |
| Q: NR A: NR C: NR | Q: NR A: NR C: NR | Q: NR A: NR C: NR |

Organic enrichment leads to organisms no longer being limited by the availability of organic carbon. The consequent changes in ecosystem function can lead to the progression of eutrophic symptoms (Bricker *et al.*, 2008), changes in species diversity and evenness (Johnston & Roberts, 2009) and decreases in dissolved oxygen and uncharacteristic microalgal blooms (Bricker *et al.*, 1999, 2008). Indirect adverse effects associated with organic enrichment include increased turbidity, increased suspended sediment and the increased risk of deoxygenation. Johnston & Roberts (2009) undertook a review and meta-analysis of the effect of contaminants on species richness and evenness in the marine environment. Of the 49 papers reviewed relating to sewage as a contaminant, over 70% found that it had a negative impact on species diversity, <5% found increased diversity, and the remaining papers finding no detectable effect. Due to the 'remarkably consistent' effect of marine pollutants on species diversity, this finding is probably relevant to this biotope (Johnston & Roberts, 2009). It was found that any single pollutant reduced species richness by 30-50% within any of the marine habitats considered (Johnston & Roberts, 2009).

Throughout their investigation, there were only a few examples where species richness was increased due to the anthropogenic introduction of a contaminant. These examples were almost entirely from the introduction of nutrients, either from aquaculture or sewage outfalls.

Organic effluent from an alginate factory in Loch Creran, Scotland appeared to be responsible for the exclusion of *Serpula vermicularis* reefs along a 1 km stretch of the coast, centred on the discharge and may have reduced reef development at greater distances (Moore *et al*., 1998b). The affected area was covered in a bacterial mat of *Beggiatoa* spp. and no reefs were present even though suitable substrata was present. However, this level of organic pollution was extreme and does not give any indication of the intolerance of *Serpula vermicularis* reefs to an increase in organic enrichment at the benchmark. Species diversity may decline but the overall impact on reefs is unknown.

**Sensitivity assessment.** Little empirical evidence was found to support an assessment of this biotope at this benchmark. The lack of direct evidence for the characterizing species has resulted in this pressure being assessed as 'No evidence'.

## Physical Pressures

| | Resistance | Resilience | Sensitivity |
|---|---|---|---|
| **Physical loss (to land or freshwater habitat)** | None<br>Q: High A: High C: High | Very Low<br>Q: High A: High C: High | High<br>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<br>Q: High A: High C: High | Very Low<br>Q: High A: High C: High | High<br>Q: High A: High C: High |

*Serpula vermicularis* requires a hard substratum on which to construct its tube. The most common substratum for settlement is bivalve shells. In Loch Creran, it was particularly common on shells of *Pecten*, *Aequipecten* and *Modiolus*. Reefs form predominantly in areas where there is suitable substratum scattered throughout a muddy sand bottom (Moore *et al*., 1998b, 2009; Chapman *et al*., 2007). In Loch Creran, reefs were found growing in bedrock, boulders, stones, shells and man-made substrata (Moore *et al*., 1998b). Large reefs were only rarely found growing on rock (Moore *et al*., 1998b, 2009).

**Sensitivity assessment.** If the sediment was replaced with rock, this would represent a fundamental change to the physical character of the biotope and the species would be unlikely to recover. The biotope would be lost. Therefore, resistance to the pressure is assessed as **'None'**, resilience as **'Very low'** and sensitivity assessed as **'High'.**

| | Resistance | Resilience | Sensitivity |
|---|---|---|---|
| **Physical change (to another sediment type)** | Low<br>Q: Medium A: Medium C: Medium | Very Low<br>Q: High A: Medium C: Medium | Not sensitive<br>Q: Medium A: Medium C: Medium |

In Loch Teacuis, *Serpula vermicularis* reefs were recorded to grow on rocks and amongst the *Laminaria saccharina* holdfasts (Dodd *et al.*, 2009). In Loch Creran, *Serpula vermicularis* grows mainly on bivalve shells on muddy sand (Moore *et al.*, 1998b, 2009; Chapman *et al.*, 2007; Dodd *et al.*, 2009). *Serpula vermicularis* typically grow up from a shell, cobble or boulder substratum on muddy sand to produce patch reefs (Chapman *et al.*, 2007, 2012). The species needs to be able to attach to a hard substratum, and can't settle on to soft sediment alone. In Loch Creran, Moore *et al.* (1998b, 2009) noted that reefs were mainly restricted to muddy sands with 'low representation' in muddy areas even when suitable substratum was present. Moore *et al.* (2009) suggested that the distribution of fine muds in Loch Creran defined the lower limit of the reefs and explained their absence from the head of the loch but the cause (siltation, suspended sediment etc.) was unknown. Bosence (1979b) suggested that raised levels of suspended mud defined the lower limit of the reefs in Ardbear Lough, Ireland. Chapman *et al.* (2007) suggested that the lower reef boundary in Loch Creran resulted from a depth-correlated settlement response rather than lack of suitable substratum or depth-correlated mortality and that light or another factor was more important in determining the depth distribution of settlement than siltation.

**Sensitivity assessment.** A change in sediment type from muddy sand to 'mud and sandy muds' may reduce the abundance or extent of the serpulid reef, based on their habitat preferences in Loch Creran and Ardbear Logh. The effect of a change from muddy sand to coarse, gravel dominated sediments is unclear as no records of reefs on this habitat was found, presumably as their preference for sheltered environments favours finer sediments. Therefore, resistance is assessed as **'Low'** based on their possible response to a change to muddy sediments. Hence, resistance is assessed as **'Very low'** and sensitivity as **'High'**.

| | | | |
|---|---|---|---|
| **Habitat structure changes - removal of substratum (extraction)** | None<br>Q: Low A: NR C: NR | Very Low<br>Q: High A: Medium C: Medium | High<br>Q: Low A: Low C: Low |

*Serpula vermicularis* reefs are always attached to a hard substratum as the larvae have to be able to settle on a stable anchor point. However, these solid anchor points can be bivalve shells, pebbles, cobbles, and boulders, all of which could be extracted under this pressure. The removal of this substratum would remove all of the characterizing species, *Serpula vermicularis*, as well as a large majority of the other species found in this biotope. Therefore, the resistance of this biotope to this pressure is assessed as **'None',** resilience as **'Very low'**, and sensitivity is assessed as **'High'.**

| | | | |
|---|---|---|---|
| **Abrasion/disturbance of the surface of the substratum or seabed** | None<br>Q: High A: Medium C: Medium | Very Low<br>Q: High A: Medium C: Medium | High<br>Q: High A: Medium C: Medium |

*Serpula vermicularis* aggregations and reefs are fragile and can be easily damaged. For example, in Loch Creran severe damage, although on a local scale, was caused by the movement of mooring blocks and chains (Moore, 1996; Moore *et al.*, 2009, Figure 8). Although the effects were localized, mooring had reduced colonies to rubble within a radius of 10 m in one instance, and extensive damage was reported within 50 m of salmon cages (Holt *et al.*, 1998). Although individual worms survived and were seen to continue feeding, the reefs were broken up so that the value of the habitat was greatly diminished. Moore *et al.* (2009, Figure 7) also detected single and double tracks through the reef at Rubha Mor in Loch Creran using side-scan sonar. The single tracks were ca 3 m wide. Diver survey revealed the tracks consisted of scattered reef rubble through the dense area of reef, and estimated the tracks had removed ca 11% of the reef in Rubha Mor (Moore *et al.*, 2009).

**Sensitivity assessment.** *Serpula vermicularis* aggregations and reefs are considered to be extremely fragile (Holt *et al.*,1998; Moore *et al.*, 1998b, 2009; Chapman *et al.*, 2017, 2012). The evidence suggests that physical disturbance from mooring chains and bottom gear would remove the majority of the reef within the affected area. While some individual worms and fragments may remain, the aggregates, reefs, and the biodiversity they host would be lost within the affected area. Therefore, the resistance of this biotope to this pressure is assessed as **'None'**, resilience as **'Very low',** and sensitivity is assessed as **'High'.**

| | | | |
|---|---|---|---|
| **Penetration or disturbance of the substratum subsurface** | None<br>Q: High A: Medium C: Medium | Very Low<br>Q: High A: Medium C: Medium | High<br>Q: High A: Medium C: Medium |

Due to the epifaunal nature of the characterizing species within this biotope, the physical effect of penetration will be extremely similar to the effects of abrasion and disturbance. Therefore, the resistance of this biotope to this pressure is assessed as **'None'**, resilience as **'Very low',** and sensitivity is assessed as **'High'.**

| | | | |
|---|---|---|---|
| **Changes in suspended solids (water clarity)** | No evidence (NEv)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | No evidence (NEv)<br>Q: NR A: NR C: NR |

Siltation can have a negative impact on site selection by serpulid larvae (Rodriguez *et al.*, 1993). Bosence (1979b) suggested from observations and transplant experiments, that the lower depth limit of *Serpula vermicularis* was probably determined by suspended sediment and deoxygenation. In contrast, Moore *et al.* (1998b) found no horizontal layers of suspended mud in Loch Creran, and although the authors do not rule out the possibility that storm-generated, suspended mud may inhibit reef development, the lower limit of reefs could also be due to inadequate current velocities for suspension feeding. Chapman *et al.* (2007) suggested that the lower reef boundary resulted from a depth-correlated settlement response rather than lack of suitable substratum or depth-correlated mortality and that light or another factor was more important in determining the depth distribution of settlement than siltation. A supply of suspended sediment may be important to *Serpula vermicularis* because the species requires a supply of particulate matter for suspension feeding.

**Sensitivity assessment.** There is a lack of empirical evidence to suggest how the pressure at the benchmark might affect this biotope. An increase in suspended sediment may affect the ability of *Serpula vermicularis* larvae to settle. In addition, an increase in suspended sediment may change the rate at which *Serpula vermicularis* has to clean its branchial plume. A decrease in the level of suspended sediment could reduce the amount of particulate food in the water column and consequently reduce food availability. However, due to the lack of information a sensitivity assessment of 'No evidence' is given.

| | | | |
|---|---|---|---|
| **Smothering and siltation rate changes (light)** | Medium<br>Q: Low A: NR C: NR | Low<br>Q: High A: Medium C: Medium | Medium<br>Q: Low A: Low C: Low |

*Serpula vermicularis* is attached permanently to the substratum by a calcareous tube, which in aggregating reef-forming individuals extends above the substratum as new worms are added to old tubes. For example, in Loch Creran individual reefs were reported to reach a height of about 50- 100 cm (Moore *et al.*, 2009). The reef structure is also open, creating cracks and crevices where sediment could collect. Therefore, many individuals of *Serpula vermicularis*, and the associated fauna of sponges, ascidians and hydroids, may avoid 5 cm of smothering material. Some of the mobile species in the biotope may be able to avoid the factor. The deposition of silt is thought to create unfavourable conditions for the settlement of *Serpula vermicularis* larvae (Cotter *et al.*, 2003).

**Sensitivity assessment.** At the level of the benchmark, a portion of the reef may be lost due to the sediment deposition. In addition, it is also likely that too much sediment on the surface of rocks or tubes would prevent settlement of larvae (Holt *et al.*, 1998; Cotter *et al.*, 2003) and so may also reduce the long-term growth of the reef. Therefore, resistance is assessed as **'Medium',** resilience as **'Low'**, and sensitivity is assessed as **'Medium'.**

| | | | |
|---|---|---|---|
| **Smothering and siltation rate changes (heavy)** | None<br>Q: Low A: NR C: NR | Very Low<br>Q: High A: Medium C: Medium | High<br>Q: Low A: Low C: Low |

The mean height of *Serpula vermicularis* reefs in Loch Teacuis was 26 ± 9 cm (Dodd *et al.*, 2009). In other reefs, such as those in Loch Creran, reefs have been recorded to have a maximum height often exceeding 50 cm (Moore *et al.*, 2003). This difference in reef height will mean that the effect of this pressure will vary depending on the reef which is going to be affected. Therefore, each reef should be assessed on a case by case basis. Taking into consideration the reef in Loch Teacuis, the pressure at the benchmark would smother a vast majority of the reef, causing the worms to asphyxiate as gaseous exchange would be inhibited and the worms would also not be able to feed.

**Sensitivity assessment.** A large proportion of the biotope could be smothered by a 30 cm deposit of fine material. Therefore, resistance is assessed as **'None'**, resilience as assessed as **'Very low'**, and the sensitivity of this biotope is assessed as **'High'.**

| | | | |
|---|---|---|---|
| **Litter** | Not Assessed (NA)<br>Q: NR A: NR C: NR | Not assessed (NA)<br>Q: NR A: NR C: NR | Not assessed (NA)<br>Q: NR A: NR C: NR |

**Not assessed.**

| | | | |
|---|---|---|---|
| **Electromagnetic changes** | No evidence (NEv)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | No evidence (NEv)<br>Q: NR A: NR C: NR |

No evidence.

| | | | |
|---|---|---|---|
| **Underwater noise changes** | Not relevant (NR)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR |

Species characterizing this habitat do not have hearing perception but vibrations may cause an impact, however, no studies exist to support an assessment.

| | | | |
|---|---|---|---|
| **Introduction of light or shading** | No evidence (NEv)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | No evidence (NEv)<br>Q: NR A: NR C: NR |

No evidence.

| | | | |
|---|---|---|---|
| **Barrier to species movement** | Not relevant (NR)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>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 propagule dispersal. But propagule dispersal is not considered under the pressure definition and benchmark.

| | | | |
|---|---|---|---|
| **Death or injury by collision** | Not relevant (NR)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>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 propagule dispersal. But propagule dispersal is not considered under the pressure definition and benchmark.

| | | | |
|---|---|---|---|
| **Visual disturbance** | Not relevant (NR)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR |

Not relevant.

## Biological Pressures

| | Resistance | Resilience | Sensitivity |
|---|---|---|---|
| **Genetic modification & translocation of indigenous species** | No evidence (NEv)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | No evidence (NEv)<br>Q: NR A: NR C: NR |

No evidence for the effect of this pressure on the characterizing species within this biotope was found.

| | | | |
|---|---|---|---|
| **Introduction or spread of invasive non-indigenous species** | No evidence (NEv)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | No evidence (NEv)<br>Q: NR A: NR C: NR |

Although several species of serpulid polychaetes have been introduced into British waters none are reported to compete with *Serpula vermicularis* (Eno *et al*., 1997). The reefs in Loch Creran were monitored for the smothering ascidian *Didemnum vexillum* which was confirmed at an intertidal oyster farm in the loch but have not yet found any on the reefs (D. Harries, *pers. comm*., 2018). The red seaweed *Heterosiphonia japonica* was also present in the loch but no evidence of impacts on the reefs was observed (D. Harries, *pers. comm*., 2018).

**Sensitivity assessment.** There is a chance that an INIS might be able to invade this biotope. Depending on which INIS species is introduced, this biotope may remain, but with reduced species richness due to the loss of some species. However, at present, there is insufficient evidence to support an assessment of this pressure. Due to the constant risk of new invasive species, the literature for this pressure should be revisited.

| | | | |
|---|---|---|---|
| **Introduction of microbial pathogens** | No evidence (NEv)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | No evidence (NEv)<br>Q: NR A: NR C: NR |

No information on diseases of *Serpula vermicularis* was found. The species is known to be parasitized by the protozoan *Haplosporidium parisi* (Ormieres, 1980) but the effects of this infestation are unknown. There are no reports of loss of the biotope from the disease. There is insufficient evidence to assess the effect of the pressure on this biotope, therefore, an assessment of 'No evidence' has been given.

| | | | |
|---|---|---|---|
| **Removal of target species** | Not relevant (NR)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR | Not relevant (NR)<br>Q: NR A: NR C: NR |

The characterizing species (*Serpula vermicularis*) are not known to be targeted by commercial fisheries.

| | | | |
|---|---|---|---|
| **Removal of non-target species** | None<br>Q: Low A: NR C: NR | Very Low<br>Q: High A: Medium C: Medium | High<br>Q: Low A: Low C: Low |

Direct, physical impacts from harvesting are assessed through the abrasion and penetration of the seabed pressures. The characterizing species within this biotope could easily be incidentally removed from this biotope as by-catch when other species are being targeted. The loss of these species and other associated species would decrease species richness and negatively impact on the ecosystem function.

**Sensitivity assessment.** Removal of a large percentage of the characterizing species would alter the character of the biotope. The resistance to removal is **'Low'** due to the easy accessibility of the biotopes location and the inability of these species to evade the effects of collection or harvesting. Resilience is assessed as **'Very low'**, with recovery only being able to begin when the harvesting pressure is removed altogether. Therefore, sensitivity is assessed as **'High'.**

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