Paramphinome jeffreysii, *Thyasira* spp. and *Amphiura filiformis* in offshore circalittoral sandy mud

MarLIN – Marine Life Information Network
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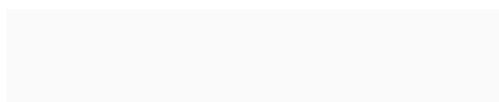
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Researched by Eliane De-Bastos   **Refereed by** Admin

Summary

≡ UK and Ireland classification

EUNIS 2008	A5.376	*Paramphinome jeffreysii, Thyasira* spp. and *Amphiura filiformis* in offshore circalittoral sandy mud
JNCC 2015	SS.SMu.OMu.PjefThyAfil	*Paramphinome jeffreysii, Thyasira* spp. and *Amphiura filiformis* in offshore circalittoral sandy mud
JNCC 2004	SS.SMu.OMu.PjefThyAfil	*Paramphinome jeffreysii, Thyasira spp.* and *Amphiura filiformis* in offshore circalittoral sandy mud
1997 Biotope		

🏷 Description

Deep, offshore cohesive sandy mud communities characterized by the polychaete *Paramphinome jeffreysii*, bivalves such as *Thyasira equalis* and *Thyasira gouldi* and the brittlestar *Amphiura filiformis*. Other taxa may include *Laonice cirrata*, the sea cucumber *Labidoplax buskii* (syn. *Labidoplax buski*)

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and the polychaetes Goniada maculata, Spiophanes kroyeri and *Aricidea (Acmira) catherinae* (syn. *Aricidea catherinae*). *Amphiura chiajei* may be occasional in this biotope as may *Hermania scabra* (syn. *Philine scabra*), *Levinsenia gracilis* and *Pholoe inornata*. This biotope along with SS.SMu.CSaMu.ThyNten, SS.SMu.CSaMu.AfilMysAnit, SS.SMu.CSaMu.AfilNten and SS.SSa.OSa.OfusAfil may comprise the *Amphiura* dominated components of the 'off-shore muddy sand association' (Jones, 1951; Mackie, 1990) and the infralittoral etage described by Glemarec (1973). (Information taken from Connor *et al.*, 2004)

↓ Depth range

-

🏛 Additional information

-

✔ Listed By

- none -

🔗 Further information sources

Search on:

G 🎓 G JNCC

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Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

SS.SMu.CSaMu.AfilMysAnit, SS.SMu.CSaMu.ThyNten, SS.SMu.CSaMu.AfilNten, SS.SMu.OMu.LevHet, SS.SMu.OMu.PjefThyAfil and SS.SMu.OMu.MyrPo are circalittoral biotopes characterized by low energy hydrographic conditions that allow the development of stable sandy muds, and support rich and diverse infaunal communities. The biotopes SS.SMu.OMu.PjefThyAfil, SS.SMu.CSaMu.ThyNten, SS.SMu.CSaMu.AfilMysAnit, SS.SMu.CSaMu.AfilNten and SSA.OfusAfil, may comprise the *Amphiura* dominated components of the 'off-shore muddy sand association' (Jones, 1951; Mackie, 1990) and the infralittoral étage described by Glemarec (1973, cited in Connor *et al.*, 2004). Little evidence on the polychaete fauna of the offshore sandy mud biotopes SS.SMu.OMu.LevHet, SS.SMu.OMu.PjefThyAfil and SS.SMu.OMu.MyrPo was found.

Therefore, the sensitivity of these A*mphiura* dominated biotopes is assessed as a group, on the assumption that their sensitivity is very similar in terms of substratum and functional groups present. Any differences in species or biotope response to pressures are highlighted. Although the biotopes also support diverse communities of other polychaete worms, bivalves, echinoderms and others, which contribute to species richness and diversity, these are not considered important characterizing, defining or structuring species and are not considered within the assessments. More information on these species can be found in other biotope assessments available on this website.

SS.SMu.CSaMu.AfilMysAnit occurs on cohesive sandy muds off wave exposed and moderately exposed deep waters with weak tidal streams. The biotope is characterized by super-abundant *Amphiura filiformis* with *Kurtiella bidentata* (syn. *Mysella bidentata*) and *Abra nitida* (Connor *et al.*, 2004).

SS.SMu.CSaMu.ThyNten also occurs on cohesive sandy muds with small quantities of gravel, off sheltered or moderately exposed coasts with very weak tidal streams. The biotope may support populations characterized by *Thyasira* spp. and in particular *Thyasira flexuosa*, which may occur with *Ennucula tenuis* (syn. *Nuculoma tenuis*). Whilst moderately diverse, animal abundances are often low and it is possible that the biotope is the result of sedimentary disturbance e.g. from trawling, becoming an impoverished version of SS.SMu.CSaMu.AfilNten (Connor *et al.*, 2004).

SS.SMu.CSaMu.AfilNten occurs in cohesive and non-cohesive sandy muds, off moderately exposed coasts in deep waters with very weak tidal streams. The biotope supports dense populations of *Amphiura filiformis* with the bivalve *Ennucula tenuis* (syn. *Nuculoma tenuis*) (Connor *et al.*, 2004).

SS.Smu.Omu.LevHet, SS.Smu.Omu.PjefThyAfil and SS.Smu.Omu.MyrPo occur in deep offshore muds and sandy muds, and communities are characterized by the polychaetes *Levinsenia gracilis* and *Heteromastus filiformis*; polychaete *Paramphinome jeffreysii*, bivalves such as *Thyasira* spp. And the brittlestar *Amphiura filiformis*; and bivalve *Myrtea spinifera* with infaunal polychaetes respectively. However, no records have been found of these biotopes so the sensitivity assessments are largely based upon the description of the biotopes given by Connor *et al.* (2004).

Resilience and recovery rates of habitat

Amphiura filiformis is a small brittlestar, disc up to 10 mm in diameter, with very long arms (10x disc diameter) which lives buried in muddy sand. Muus (1981) showed the mortality of new settling

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Amphiura filiformis to be extremely high with less than 5% contributing to the adult population in any given year. Sköld *et al.* (1994) also commented on the high mortality and low rates of recruitment in this species. In Galway Bay populations (O'Connor *et al.*, 1983), small individuals make up ca 5% of the population in any given month, which also suggests the actual level of input into the adult population is extremely low. Muus (1981) estimated the lifespan of *Amphiura filiformis* to be 25 years based on oral width (which does not change with gonadal growth) with recruitment taking place at the 0.3 mm disc size. In very long-term studies of *Amphiura filiformis* populations in Galway Bay, a lifespan of some 20 years is possible (O'Connor *et al.*, 1983). *Amphiura filiformis* reaches sexual maturity after 2 years, breeds annually and, in the UK, one period of recruitment occurs in the autumn (Pedrotti, 1993). The species is thought to have a long pelagic life. Sköld *et al.* (1994) estimated the time lag between full gonads and settlement to be 88 days. This duration is comparable to the time period when pelagic larvae have been recorded in the plankton from July to November in one prior study, and August to December in another prior study (Fosshagen, 1965; Thorson, 1946, respectively, cited in Sköld *et al.*, 1994). A long planktonic life stage means this species is predicted to disperse over considerable distances.

Kurtiella bidentata is a very small bivalve, up to 3 mm in length (Carter, 2008). The bivalve is often found in muddy sand or fine gravel, and associated with other species (e.g. brittlestar *Acrocnida brachiata* and other ophiurids) (Ockelmann & Muus, 1978; Carter, 2008). This is a viviparous species, with larvae retained in the gill pouch until an early shelled veliger stage, which then live for some time in the sea, common in summer and autumn (Lebour, 1938). *Kurtiella bidentata* produce planktonic larvae during a prolonged spawning season (Larsen *et al.*, 2007), so are considered to have a high dispersal potential. Recruitment occurred during August-October and three year-classes were identified (O'Foighil *et al.*, 1984). It is not known at what age this species becomes sexually mature, although both males and hermaphrodites can be found in their first year (Marshall, 2005). *Kurtiella bidentata* (studied as *Mysella bidentata*) was reported to be fast growing and have a lifespan of 5-6 years in the North Sea (Künitzer, 1989).

Abra nitida is considered to be an opportunistic bivalve species (Josefson, 1982) capable of exploiting newly disturbed substratum through larval recruitment, secondary settlement of post-metamorphosis juveniles, or redistribution of adults (Rees & Dare, 1993). *Abra nitida* recruitment tends to be episodic and may be negatively affected by the presence of predators and inhibited by high densities of adults (Josefson, 1982). *Abra nitida* has a larval planktonic phase indicating a high dispersal potential. In addition to dispersal via the plankton, dispersal of post-settlement juveniles in *Abra* spp. may occur via byssus drifting (Sigurdsson *et al.*, 1976) and probably bed load transport (Emerson & Grant, 1991). Usually this species occurs in dense aggregations that undergo subsequent decline and then recover through dense settlement (Josefson, 1982).

Little information was available for bivalve *Thyasira flexuosa*. The larval development of the congener *Thyasira equalis* is lecithotrophic and the pelagic stage is very short or suppressed (Tillin & Tyler-Walters, 2014). This agrees with the reproduction of other *Thyasira* sp., and in some cases (e.g. *Thyasira gouldi*) no pelagic stage occurs at all (Thorson 1946, 1950). This means that larval dispersal is limited. Sparks-McConkey & Watling (2001) found that a population of *Thyasira flexuosa* in Penobscot Bay, Maine recovered rapidly (within 3.5 months) following trawler disturbance that resulted in a decrease in the population. Benthic reproduction allows re-colonization of nearby disturbed sediment and leads to rapid recovery where a large proportion of the population remains to re-populate the habitat.

Ennucula tenuis (syn. *Nuculoma tenuis*) is a small bivalve typically 1-2 cm in length and is free-living within sediments (MES, 2010). Harvey & Gage (1995) investigated reproduction and recruitment

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of the species from the Loch Etive, Scotland. They observed that synchronized spawning occurred in the winter, although no recruitment peak was evident, with benthic post-larvae present throughout the year. The authors also noted that there was spatial segregation occurring between adults and post-larvae, and suggested that high densities of adults could inhibit successful settlement and growth of post-larvae. Spawning of nuculids was restricted to a few months of the year (Harvey & Gage, 1995), and appeared to be controlled by endogenous factors, as well as environmental factors, such as temperature, salinity, light, tidal period and food available. In *Nucula nitidosa* from the German Bight, the timing of spawning in the summer and autumn was attributed to the seasonal rise in temperature during the summer months. At Plymouth, however, the same species appeared to breed in winter when bottom temperatures are falling, as is the case in *Pronucula tenuis* from Loch Etive (Harvey & Gage, 1995). The availability of a suitable food supply during the months prior to spawning may be a more potent determinant of spawning time (Berry, 1989; Tyler *et al.*, 1992, both cited in Harvey & Gage, 1995), with annual variation in the availability and quality of food determining the exact time of spawning in any one year. The remaining evidence is based on related species *Nucula nitidosa*. The lifespan of *Nucula nitidosa* ranges from 7-10 years (Wilson, 1992). It takes 2-3 years for *Nucula nitidosa* to reach sexual maturity (Davis & Wilson, 1983b), and reproduce in high numbers. Once hatched *Nucula nitidosa* larvae spend a short time in the water column (a few days), which reduces the risk of predation. However, juveniles do not have a high dispersal potential as they settle in the vicinity of the adults (Thorson, 1946).

Levinsenia gracilis tends to be found in deep water so little is known about the species. *Levinsenia gracialis* is a polychaete of the small Paraonidae family, which are known to be gonochoric. Larvae have been found in the plankton with up to 60 segments (Bhaud, 1983, cited in Rouse & Pleijel, 2001). This family is found in almost all deep-water regions of the world, and are only found on the surface of sandy or silty sediments or burrowing into the deeper layers of such sediments. Individuals tend to be non-selective surface or burrowing deposit feeders (Rouse & Pleijel, 2001).

Heteromastus filiformis is a medium-sized tube-dwelling polychaete belonging to the family Capitellidae. The body length is about 10 cm and the worm lives in a vertical tube extending to a depth of about 15 cm into muddy sands (Shaffer, 1983). *Heteromastus filiformis* has a lifespan of 2 years and reproduces once within 2 years. Several authors (cited in Shaffer, 1983) have suggested that it reproduces in spring. Lo Bianco (1909) in Italy and Fauvel (1927) in France reported that breeding and spawning occurred from September to April. Linke (1939), in the Bay of Jadebusen, Germany and Rasmussen (1956) in the Isefjord, Denmark both observed spawning in spring. Cazaux (1970) reported breeding and spawning in the early summer in the Bay of Arcahon, France. In the North Atlantic Ocean to the North Sea, recruitment also appears to be in spring (Gillet & Gorman, 2002). After spawning, the eggs are fertilized externally and released as a planktotrophic larva that spends up to 4 months in the plankton (Shaffer, 1983). Settlement is generally from April-May. Little is known of the fecundity of this genus. The planktonic larval phase allows significant recolonization from surrounding deposits, and the short lifespan allows relatively rapid restoration of biomass following colonization. Buchanan & Warwick (1974) concluded that *Heteromastus filiformis* spawned at the end of its second year, sometime between January and April, off the coast of England, followed by high mortality. Predators have a large effect on the mortality rate of *Heteromastus* juveniles, but not on the adults, and disturbance has a moderate effect on juvenile mortality (Shaffer, 1983).

No information regarding the longevity and life cycle of *Paramphionome jeffreysii* or *Myrtea spinifera* was found. *Paramphionome jeffreysii* is a polychaete of the Amphimonidae sub-family, which mainly occur in warm littoral waters. The group is known to be gonochoric with external fertilization. As

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far as it is known, the group are slow active predators, mainly on sessile animals, such as sponges, cnidarians, hydroids and ascidians (Rouse & Pleijel, 2001).

Myrtea spinifera is a small bivalve up to 2.5 cm long found in mud and muddy sands from the western coasts from south Devon to Shetland Isles, rarely elsewhere but is also recorded from Norway to Mediterranean (Hayward & Ryland, 1995b). Gamete production in most bivalves seems to involve the planktonic larvae strategy, characterized by high fecundity and high metabolic cost (Vance, 1973; Bayne, 1976 cited in Dame, 1996), with bivalves often considered as having variable recruitment success, likely to vary with environmental conditions.

Resilience assessment: Recovery of habitats following a disturbance is dependent on physical, chemical and biological processes and can be a more rapid process than in other areas (Bishop *et al.*, 2006; cited in Fletcher *et al.*, 2011). However, recovery times after physical disturbance have been found to vary for different sediment types (Roberts *et al.*, 2010). Dernie *et al.* (2003) found that muddy sand habitats had the longest recovery times, compared to mud and clean sand habitats. Population recovery rates will be species specific. Removal of the characterizing species would result in the biotopes being lost and/or reclassified. Furthermore, these are stable biotopes, unlikely to be adapted to deal with disturbance. Brittlestar *Amphiura filiformis* is able to repair arms, has long dispersal potential, but is slow growing and takes two years to reach maturity. Bivalves *Kurtiella bidentata*, *Abra nitida*, *Thyasira* spp., *Myrtea spinifera* have fragile shells that are vulnerable to damage, are thought to be slow growing, have high dispersal potential, but recruitment tends to be sporadic. The polychaete species, including *Levinsenia gracilis*, *Heteromastus filiformis* and *Paramphinome jeffreysii* are often characterized by short lifespans and likely to have high recovery rates. So where the majority of the population remain (resistance is High or Medium), and/or recruitment by adult mobility is possible, resilience is likely to be **High** for all biotopes under assessment. However, where recovery through juvenile recruitment is required, this may be low in places and are dependent on favourable hydrodynamic conditions that allow settlement of new recruits. Although polychaetes tend to have high recovery rates, the low energy environments where the biotopes occur are likely to slow the time for most species to re-established biomass and age structured populations. Therefore, where impacts remove a significant proportion of the population (resistance is Low or None), recovery is likely to be **Medium** (2-10 years). Given that no information was found for some of the characterizing species of these biotopes, confidence in this assessment is 'Low'.

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

The characterizing species in these biotopes are widely distributed in the British Isles, north-east Atlantic and beyond, from Norway to the Mediterranean, west and South Africa (Hayward & Ryland, 1995b). However, *Thyasira* populations in the British Isles are restricted to areas where the bottom waters remain cool all year round (Jackson, 2007). Additionally, *Paramphinome jeffreysii* seems to reach its southerly limit in UK waters suggesting a possible susceptibility to a long-term rise in summer water temperatures (Tillin & Tyler-Walters, 2014), although the sub-family to which it belongs, seems to mainly occur in warm littoral waters (Rouse & Pleijel, 2001). On the other hand, it is has been suggested that growth rates of *Heteromastus filiformis* are very rapid in warmer environments, with no growth occurring during winter (Shaffer, 1983).

Kröncke *et al.* (2011) reported an increase in abundance and regional changes in distribution of various species with a southern distribution in the North Sea in 2000, and suggested the changes were largely associated with an increase in sea surface temperature, primary production and, thus, food supply. The authors suggested that the increase of annual average temperature was of about 1.1°C. *Amphiura filiformis* was among the species observed to have decreased. In Galway Bay, long-term recordings of water temperature at a site of high density aggregations of *Amphiura filiformis* showed the species is subject to annual variations in temperature of about 10°C (O'Connor *et al.*, 1983). Increases in temperature may affect growth and fecundity. Muus (1981) showed that juvenile *Amphiura filiformis* are capable of much higher growth rates in experiments with temperatures between 12 and 17°C.

Temperature not only limits the spatial distribution of bivalves, but also is a major controlling factor in many physiological rate processes like feeding and growth (Dame, 1996). For example, no spawning occurred in June in the wild, but specimens of *Pronucula tenuis* (studied as *Nucula tenuis*) held in laboratory at elevated temperature of 23°C were observed to spawn in July (Rachor, 1976, cited in Harvey & Gage, 1995). Furthermore, Wilson (1981) investigated temperature tolerances of six bivalve species from Dublin Bay. The author concluded that species variations in tolerance to increased temperature varied seasonally and with distribution along tidal height. Lethal temperatures for all six bivalve species in the study varied greatly and were, in most cases, well above 20°C. The maximum sea surface temperatures around the British Isles rarely exceed 20°C (Hiscock, 1998). *Kurtiella bidentata* (studied as *Mysella bidentata*) was recorded in Kinsale Harbour at temperatures ranging from 7.7-18.8°C (O'Brien & Keegan, 2006), and Künitzer (1989) reported that the main factor affecting the growth rate of *Kurtiella bidentata* (studied as *Mysella bidentata*) was temperature.

Sensitivity assessment: The characterizing species of the biotopes are widely distributed and likely to occur both north and south of the British Isles, where typical surface water temperatures vary seasonally from 4-19°C (Huthnance, 2010). No information was found on the maximum temperature tolerated by the characterizing species. Elevated temperatures may affect growth of some of the characterizing species, but no mortality is expected. It is therefore likely that the characterizing species are able to resist a long-term increase in temperature of 2°C. However, *Thyasira* spp. may suffer some mortality because of an acute increase in temperature. So resistance is therefore assessed as **Medium** (loss <25%) for SS.SMu.CSaMu.ThyNten, and **High** for the remaining biotopes. Resilience is likely to be **High** so SS.SMu.CSaMu.ThyNten is considered to have **Low** sensitivity to an increase in temperature at the pressure benchmark level, whereas the remaining biotopes are considered **Not Sensitive**.

Temperature decrease (local)	Low	Medium	Medium
	Q: Medium A: Medium C: Medium	Q: Low A: NR C: NR	Q: Low A: NR C: NR

The characterizing species in these biotopes are widely distributed in the British Isles, north-east Atlantic and beyond, from Norway to the Mediterranean and west and South Africa (Hayward & Ryland, 1995b). However, *Thyasira* populations in the British Isles are restricted to areas where the bottom waters remain cool all year round (Jackson, 2007). Additionally, *Paramphinome jeffreysii* seems to reach its southerly limit in UK waters (Tillin & Tyler-Walters, 2014), although the sub-family to which it belongs, seems to mainly occur in warm littoral waters (Rouse & Pleijel, 2001). On the other hand, *Heteromastus filiformis* occur in the North Sea, English Channel, north-east Atlantic and Mediterranean (Hayward & Ryland, 1995b), and it has been suggested that no growth occurs during winter (Shaffer, 1983), suggesting intolerance to decreases in temperature.

Holme (1967) reported the absence of *Amphiura filiformis* from samples taken from Weymouth Bay and Poole Bay, England, after severe winter temperatures (4 and 5°C, respectively, below the mean for about a month). In Galway Bay, long-term recordings of water temperature at a site of high density aggregations of *Amphiura filiformis* showed the species is subject to annual variations in temperature of about 10°C (O'Connor *et al.*, 1983). However, echinoderms, including *Amphiura filiformis*, in the North Sea, seem periodically affected by winter cold. A population at 27 m depth off the Danish coast was killed by the winter of 1962-63 (Muus, 1981) and a population at 35-50 m depth in the inner German Bight was killed in the winter of 1969-1970 and a new population was not re-established until 1974 (Gerdes, 1977). Ursin (1960, cited in Gerdes, 1977) suggests that *Amphiura filiformis* does not occur in areas with winter temperatures below 4 °C although in Helgoland waters it can tolerate temperatures as low as 3.5 °C.

Temperature not only limits the spatial distribution of bivalves, but also is a major controlling factor in many physiological rate processes like feeding and growth, with short-term acute periods of extreme cold and icing conditions considered likely to cause stress and some mortality in bivalve populations (Dame, 1996). For example, *Kurtiella bidentata* (studied as *Mysella bidentata*) was among the species that suffered high losses that could be related to low temperatures in the Wadden Sea area in 1979, where temperature was 3 degrees below average for 3 months (Beukema, 1979). During the 1978/79 winter, which was very cold with severe ice conditions, water temperature in the outer Weser estuary, Germany, remained below 0 °C on 45 successive days. Populations of the characteristic species of the benthos, including *Abra* spp. were considerably damaged (Buhr, 1981).

Coyle *et al.* (2007) analysed temporal differences in benthic infaunal samples from the south-eastern Bering Sea shelf. Significant differences were observed for specific functional groups, namely carnivores, omnivores and surface detritivores, which suggested a mechanistic link between temperature changes and infaunal biomass, with exclusion of benthic predators on infaunal invertebrates by the cold bottom water on the shelf.

In studies of the effects of cold winters on macrofauna communities in the North Sea, Kröncke *et al.* (2013) suggested that the overall trend was towards decreased abundance and biomass, including polychaetes, as a result of temperature anomalies of about 2°C below normal. However, Holte *et al.* (2005) investigated the variations in soft bottom macrofauna from stratified Norwegian basins. *Heteromastus filiformis* occurred at the study sites, which experienced temperatures between 0.5-14°C.

Sensitivity assessment: The characterizing species of the biotope are widely distributed and likely

to occur both north and south of the British Isles, where typical surface water temperatures vary seasonally from 4-19°C (Huthnance, 2010). Although it is likely that the characterizing species are able to resist a long-term decrease in temperature of 2°C, species may suffer some mortality as a result of an acute decrease in temperature. Therefore, resistance is assessed as **Low** (25-75% loss) and resilience is likely to be **Medium,** so the biotopes are considered to have **Medium** sensitivity to a decrease in temperature at the pressure benchmark level.

Salinity increase (local)

Low
Q: Low A: NR C: NR

Medium
Q: Low A: NR C: NR

Medium
Q: Low A: NR C: NR

The biotopes are found within fully marine subtidal locations (Connor *et al.*, 2004). Therefore, it is highly unlikely that the biotopes would experience conditions of hypersalinity.

Echinoderms, such as *Amphiura filiformis*, are stenohaline owing to the lack of an excretory organ and a poor ability to osmo- and ion-regulate (Stickle & Diehl, 1987; Russell, 2013). A review by Russell (2013) confirmed that none of the echinoderm species relevant in this assessment occur in hypersaline conditions. Pagett (1981) suggested that localised physiological adaption to reduced or variable salinities may occur in nearshore areas subject to freshwater runoffs. However, individuals in these biotopes are unlikely to experience variable salinities, and resident species unlikely to be adapted to variation in salinity, as suggested by the results given by Pagett (1981).

The capitellid polychaete *Heteromastus filiformis* has been recorded in the Homa lagoon, eastern Aegean Sea, where salinity exceeded 40 psu all year round, and negative effects on the species density were reported as a result of salinity increases to 59-61.5 psu (Can *et al.*, 2012), which is higher than the benchmark level.

The minimum and maximum recorded ranges of salinities for the remaining characterizing species found are 18.6 - 38.6 pps for *Kurtiella bidentata*, 17.8 - 39.1 pps for *Abra nitida*, 31.8-39.1 pps for *Thyasira flexuosa*, 32.3 - 38.6 pps for *Paramphinome jeffreysii*, and 33.4 - 39.0 for *Myrtea spinifera* (OBIS, 2014). Similar data was not available for *Levinsenia gracilis* and *Pronucula tenuis.*

Sensitivity assessment: There is little direct evidence of the effects of hypersaline conditions on the characterizing species of these biotopes. However, based on the information presented, all key species except for *Heteromastus filiformis*, are likely to suffer significant (25-75%) mortality as a result of an increase in salinity to >40 psu. Resistance is assessed as **Low** but with low confidence. Resilience is probably **Medium,** so sensitivity is therefore assessed as **Medium**.

Salinity decrease (local)

Low
Q: Low A: NR C: NR

Medium
Q: Low A: NR C: NR

Medium
Q: Low A: NR C: NR

The biotopes are found within fully marine subtidal locations (Connor *et al.*, 2004). Therefore, it is highly unlikely that the biotopes would experience conditions of hyposalinity.

Echinoderms, such as *Amphiura filiformis*, are stenohaline owing to the lack of an excretory organ and a poor ability to osmo- and ion-regulate (Stickle & Diehl, 1987; Russell, 2013). However, *Amphiura filiformis* was recorded in hyposaline conditions in the Sado estuary in Portugal (Monteiro-Marques, 1982 cited in Russell, 2013) where the salinity was 25.5‰, and in the Black Sea where it tolerated 8.9‰ (Russell, 2013). Pagett (1981) suggested that localised physiological adaption to reduced or variable salinities may occur in nearshore areas subject to freshwater

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runoffs. However, individuals in these biotopes are unlikely to experience variable salinities, and resident species are unlikely to be adapted to variation in salinity, as suggested by the results given by Pagett (1981).

Salinity may affect the structural and functional properties of bivalve organisms through changes in total osmotic concentration, relative proportion of solutes, coefficients of adsorption and saturation of dissolved gases and density and viscosity (Kinne, 1964, cited in Dame, 1996). There are records of *Kurtiella bidentata* (studied as *Mysella bidentata*) in Kinsale Harbour at salinities ranging from 19.3-35.0 (O'Brien & Keegan, 2006). However, Gogina *et al.* (2010a) reported that *Kurtiella bidentata* (studied as *Mysella bidentata*) showed a strong positive correlation with salinity varying at a factor of 8.30-27.10 psu, which suggested that the species was affected adversely at the low end of the range. According to Budd (2007), the change would be likely to cause inhibition of growth and reproduction and exposure to low salinity may result in some mortality of *Abra* spp.. *Thyasira* spp. inhabit waters of reduced salinity with 25-30 psu being optimal. However, adults exposed to lower than optimal salinities produced non-viable or slow developing eggs (Jackson, 2007). There is insufficient information regarding the effects of salinity on adults.

Furthermore, the minimum and maximum recorded ranges of salinities for the characterizing species found are 18.6 - 38.6 pps for *Kurtiella bidentata*, 17.8 - 39.1 pps for *Abra nitida*, 31.8-39.1 pps for *Thyasira flexuosa*, 32.3 - 38.6 pps for *Paramphinome jeffreysii*, and 33.4 - 39.0 for *Myrtea spinifera* (OBIS, 2014), although the source of the data is unclear. Similar data was not available for *Levinsenia gracilis* and *Pronucula tenuis.*

Sensitivity assessment: The evidence presented suggests that not all characterizing species of the biotopes are likely to resist a decrease in salinity at the pressure benchmark level. Resistance is, therefore, assessed as **Low** (loss of 25-75%) but with low confidence. Once prior conditions are resumed, resilience is probably **Medium,** so sensitivity is therefore assessed as **Medium**.

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

The hydrographic regime, including flow rates, is an important structuring factor in sedimentary habitats. The low energetic environments where the biotopes occur are therefore likely to be important in allowing for the development of the sandy mud substrata which characterize the biotopes. The most damaging effect of increased flow rate (above the pressure benchmark) would be the erosion of the substratum as this could eventually lead to loss of the habitat. Increased water flow rates are likely to change the sediment characteristics in which the species live, primarily by resuspending and preventing deposition of finer particles (Hiscock, 1983). Furthermore, increased water flow rate may prevent settlement of larvae and therefore reduce recruitment. Mature adults buried at depth are likely to be unaffected as muddy substrata are particularly cohesive. Additionally, the consequent lack of deposition of particulate matter at the sediment surface would reduce food availability.

Decreased water movement would result in increased deposition of suspended sediment (Hiscock, 1983). An increased rate of siltation resulting from a decrease in water flow may result in an increase in food availability for the characterizing species and therefore growth and reproduction may be enhanced, but only if food was previously limiting. Nevertheless, a decrease in water flow rates is unlikely to be relevant in the low energy environments where the biotopes occur.

Amphiura filiformis respond rapidly to currents by extending their arms into the water column to

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feed. Under laboratory conditions, they were shown to maintain this vertical position at currents of 0.3 m/s (Buchanan, 1964). *Amphiura filiformis* feed on suspended material in flowing water but change to deposit feeding in stagnant water or areas of very low water flow (Ockelmann & Muus, 1978). Food requirements probably set a lower limit on the current regime of areas able to support brittlestars. *Amphiura filiformis* has also been reported in the Northumberland coast, UK where tidal currents ranged, with surface speeds of 0.65 m/s at springs to 0.4 m/s at neaps, on a flood tide. Bottom residual currents were much weaker than near-surface, reaching a maximum of 0.7 m/s (Jones, 1979, cited in Birchenough & Frid, 2009).

Sensitivity assessment: Sand particles are most easily eroded and likely to be eroded at about 0.20 m/s (based on Hjulström-Sundborg diagram, Sundborg, 1956). Although having a smaller grain size than sand, silts and clays require greater critical erosion velocities because of their cohesiveness. The biotopes occur in stable areas of very weak (negligible) and weak (>0.5 m/s) tidal streams (Connor *et al.*, 2004). Although changes in water flow (above the benchmark) would be likely to change the sedimentary regime in the biotopes, the cohesive nature of the sandy muds that characterize the biotopes is likely to provide some protection to changes in water flow at the pressure benchmark. Additionally, the characterizing species are likely to resist an increase in water flow at the benchmark level. Resistance and resilience are, therefore, assessed as **High** and the biotopes considered **Not Sensitive** to a change in water flow at the pressure benchmark level.

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

The biotopes are circalittoral (Connor *et al.*, 2004). Changes in emergence are **Not Relevant** to biotopes which are restricted to fully subtidal/circalittoral conditions. The pressure benchmark is relevant only to littoral and shallow sublittoral fringe biotopes.

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

Potentially the most damaging effect of increased wave heights would be the erosion of the fine sediment substratum as this could eventually lead to loss of the habitat that characterizes the biotopes. Decreased exposure will probably lead to increased siltation and reduced grain size (muddy sediment). Changes in wave exposure may therefore influence the supply of particulate matter for tube building and feeding activities of the characterizing species. Food supplies may also be reduced affecting growth and fecundity of the species. Strong wave action may cause damage or withdrawal of the siphons and delicate feeding structures, resulting in loss of feeding opportunities and compromised growth for the characterizing species. Additionally, individuals may be dislodged by scouring from sand and gravel mobilized by increased wave action (Budd, 2007). During winter gales along the North Wales coast, large numbers of *Abra* spp. were cast ashore and over winter survival rate was as low as 7% in the more exposed locations (Rees *et al.*, 1977). Additionally, changes in wave exposure may also interfere with larval dispersal of the characterizing species. Olivier *et al.* (1996) reported that the post-larvae and juveniles of *Abra alba* were most abundant in the near-bottom water stratum at flood tides. Therefore, increased wave action could result in enhanced resuspension and dispersal of early life stages, whereas a reduction in wave exposure may lead to a decrease in dispersal.

Amphiura filiformis is found in sheltered habitats characterized by fine muddy sandy sediments and low wave exposure. The species is unlikely to be resistant of increases in wave exposure because

strong wave action can resuspend the sediment and break up and scatter *Amphiura filiformis*. However, the species is able to burrow further into the sediment and if displaced is able to reburrow (Hill & Wilson, 2008).

Thyasira gouldi lives in rather wave sheltered areas at the heads of sea lochs (Jackson, 2007). Increases in wave exposure may disrupt the sediment in which they live, cause continual displacement and physical damage to the shells which are thin and fragile.

Sensitivity assessment: No direct evidence of the specific tolerances of the characterizing species to changes in wave exposure was found. Hiscock (1983) suggested that a Force 8 Gale could result in oscillatory wave induced water flow at 80 m of 0.09 m/s or ca 0.4 m/s at 50 m. A change in significant wave height of 3-5% is roughly equivalent to a change from force 3-4. Therefore, it is unlikely to be significant in deep water biotopes. Except for SS.SMu.CSaMu.AfilMysAnit, the biotopes under assessment occur at depths (>20 m), which are likely to protect the biotopes from anything other than the most severe change in wave action. However, SS.SMu.CSaMu.AfilMysAnit is the least sheltered of the biotopes, occurring in exposed and moderately conditions (Connor *et al.*, 2004), and a change at the benchmark level is likely to fall within the range experienced by this particular biotope. Resistance and resilience are, therefore, assessed as **High**, and the biotopes are considered **Not Sensitive** at the benchmark level.

⚗ Chemical Pressures

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

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

There is little or no information on the resistance of the characteristic species in the biotopes. Experimental studies with various species suggest that polychaete worms are quite tolerant of heavy metals (Bryan, 1984). Bryan (1984) also reports that early work has shown that echinoderm larvae are intolerant of heavy metals, e.g. the intolerance of larvae of sea urchin *Paracentrotus lividus* to copper (Cu) had been used to develop a water quality assessment. Adult echinoderms are known to be efficient concentrators of heavy metals including those that are biologically active and toxic (Hutchins *et al.*, 1996). However, there is no information available regarding the effects of this bioaccumulation. Studies by Deheyn & Latz (2006) at the Bay of San Diego found that heavy metal accumulation in brittlestars occurs both through dissolved metals as well as through diet, to the arms and disc, respectively. Similarly, Sbaihat *et al.* (2013) measured concentrations of heavy metals (Cu, Ni, Cd, Co, Cr and Pb) in the body of *Ophiocoma scolopendrina* collected from the Gulf of Aqaba, and found that most concentration was found in the central disc rather than arms and no simple correlations could be found between contaminant and body length.

Abra spp. can live in polluted sediments (Dauvin, pers. comm.), for example, near Calais where high densities of *Abra alba* were found in sediment containing 8 mg/g iron and 4 mg/g titanium (Dewarumez *et al.*, 1976). The capacity of bivalves to accumulate heavy metals in their tissues, far in excess of environmental levels, is well known. Bryan (1984) states that Hg is the most toxic metal to bivalve molluscs while Cu, Cd and Zn seem to be most problematic in the field. In bivalve molluscs Hg was reported to have the highest toxicity, mortalities occurring above 0.1-1 g/l after

4-14 days exposure (Crompton, 1997), toxicity decreasing from Hg > Cu and Cd > Zn > Pb and As > Cr (in bivalve larvae, Hg and Cu > Zn > Cd, Pb, As, and Ni > to Cr).

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.

Invertebrate communities respond to severe chronic oil pollution in much the same way. Initial massive mortality and lowered community diversity is followed by extreme fluctuations in populations of opportunistic mobile and sessile fauna (Suchanek, 1993). Infaunal communities, such as those characterizing these biotopes are highly likely to be adversely affected by an event of oil pollution, but the biological effects of accumulation of PAHs are likely to depend on the length of time exposed (Viñas *et al.*, 2009). Oil contamination is likely to remain in the sediment for a long time after the pollution source is removed. Ingestion of contaminated sediments is likely to be a more important route of exposure for deposit feeders such as the characterizing species of these biotopes.

Echinoderms have not been found to be resistant to the toxic effects of oil, likely because of the large amount of exposed epidermis (Suchanek, 1993), and tend to be very sensitive to various types of marine pollution (Newton & McKenzie, 1995). In a study of the effects of oil exploration and production on benthic communities, Olsgard & Gray (1995) found *Amphiura filiformis* to be very intolerant of oil pollution. During monitoring of sediments in the Ekofisk oilfield, Addy *et al.* (1978) suggested that reduced abundance of *Amphiura filiformis* within 2-3 km of the site was related to discharges of oil from the platforms and to physical disturbance of the sediment. Brittlestars host symbiotic sub-cuticular bacteria (Kelly & McKenzie, 1995). After exposure to hydrocarbons, loadings of such bacteria were reduced indicating a possible sub-lethal stress to the host (Newton & McKenzie, 1995).

Suchanek (1993) reviewed the effects of oil spills on marine invertebrates and concluded that, in general, on soft sediment habitats, infaunal polychaetes, bivalves and amphipods were particularly affected. Sub-lethal concentrations may produce substantially reduced feeding rates and/or food detection ability, probably due to ciliary inhibition. Respiration rates may increase at low concentrations and decrease at high concentrations. Generally, contact with oil causes an increase in energy expenditure and a decrease in feeding rate, resulting in less energy available for growth and reproduction. However, the *Abra alba* population affected by the 1978 *Amoco Cadiz* benefited from the nutrient enrichment caused by the oil pollution. The biomass of the fine-sand community remained low in 1979, a year after the spill, owing to the decimation of the *Ampelisca* amphipod population, but the biomass then doubled as a result of an increase in *Abra alba* abundance in 1980 and *Abra alba* remained a dominant species over the 20 year duration over which recovery of the community was monitored (Dauvin, 1998).

Untreated oil (e.g. from oil spills) is not a risk, since it is concentrated mainly at the surface, and circalittoral biotopes are likely to be protected by their depth. If oil is treated by dispersant, the resulting emulsion may penetrate down the water column, especially under the influence of turbulence (Hartnoll, 1998).

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

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

Echinoderms tend to be very sensitive to various types of marine pollution (Newton & McKenzie, 1995) but there is no more detailed information than this broad statement. In laboratory experiments Smith (1968) found the concentration of BP1002 (the detergent used in the *Torrey Canyon* oil spill clean-up) needed to kill the majority of brittlestar *Ophiocomina nigra* was 5 ppm. Dahllöf *et al.* (1999) studied the long-term effects of tri-n-butyl-tin (TBT) on the function of a marine sediment system. TBT spiked sediment was added to a sediment that already had a TBT background level of approximately 27 ng/g (83 pmol TBT per g) and contained *Amphiura* spp., and several species of polychaete. Within two days of treatment with a TBT concentration above 13.7 µmol/m▯ all species except the polychaetes had crept up to the surface and after six weeks these fauna had started to decay. Thus, contamination from TBT is likely to result in the death of some non-resistant species such as brittlestars. However, Walsh *et al.* (1986) observed inhibition of arm regeneration in another brittlestar, *Ophioderma brevispina*, following exposure to TBT at levels between 10 ng/l and 100 ng/l. Loizeau & Menesguen (1993), found that 8-15% of the PCB burden in dab, *Limanda limanda*, from the Bay of Seine could be explained by ophiuroid consumption. Thus, *Amphiura* communities may play an important role in the accumulation, remobilization and transfer of PCBs and other sediment associated contamination to higher trophic levels.

Abra spp. demonstrated alterations of its behaviour in response to exposure to marine sediments contaminated with pesticides (6000 ppm parathion, 200 ppm methyl parathion, 200 ppm malathion). No burrowing occurred in the most contaminated sediment, whilst burrowing was impaired in the moderately contaminated sediment with a median effective burrowing time ($ET_{(50)}$) of 9.0 (±3.0 - 28) minutes in comparison to a control time of 4.5 (±2.8 - 7.2) minutes (Møhlenberg & Kiørboe, 1983). There is no evidence relating directly to the effects of synthetic chemicals on the remaining characterizing species.

Species in the biotopes, in particular polychaete worms, are generally more resistant of a range of marine pollutants so a change in the faunal composition may be expected if chemical pollution increases. Polluted areas would be characterized by biotopes with lower species diversity and a higher abundance and density of pollution resistant species such as polychaetes.

Radionuclide contamination	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

Adult echinoderms are known to be efficient concentrators of radionuclides (Hutchins *et al.*, 1996). However, no information concerning the effects of such bioaccumulation was found. Carvalho (2011) determined the concentrations of [210]Po and ^{210}Pb in marine organisms from the seashore to abyssal depths, as these two radioactive elements tend to be higher in the marine environment. The author's results showed that concentrations varied greatly, even between organisms of the same biota, mainly related with the trophic levels occupied by the species, suggesting that the more levels between a species and the bottom of the food chain, the more likely that the concentrations of radioactive elements were likely to be diluted. This may have great implications for the deposit feeders that characterize these biotopes. There was no information available about the effect of this bioaccumulation.

Sensitivity assessment: There is no substantial evidence available on which to assess this pressure. The pressure is therefore assessed as **No Evidence.**

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

This pressure is **Not assessed**.

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

Oxygen-deficient marine areas are characterized by a decline in the number and diversity of species. Cole *et al.* (1999) suggested possible adverse effects on marine species exposed to dissolved oxygen concentrations below 4 mg/l and probable adverse effects below 2 mg/l.

A number of animals have behavioural strategies to survive periodic events of reduced dissolved oxygen. These include shell closure and reduced metabolic rate in bivalve molluscs and either decreased burrowing depth or emergence from burrows for sediment dwelling crustaceans, molluscs and annelids. However, a decrease in oxygenation is likely to see the loss of the key species in the biotopes. During periods of hypoxia infaunal species migrate to the surface of the sediment (Diaz & Rosenberg, 1995). Stachowitsch (1984) observed a mass mortality of benthic organisms in the Gulf of Trieste, northern Adriatic Sea, caused by the onset of severe hypoxia in the near-bottom water. A wide variety of organisms were affected, including burrowing invertebrates, sponges, and the brittlestar *Ophiothrix quinquemaculata*. However, *Amphiura filiformis* was reported as a species resistant to moderate hypoxia (Diaz & Rosenberg, 1995). In experiments exposing benthic invertebrates to decreasing oxygen levels, *Amphiura filiformis* only left its protected position in the sediment when oxygen levels fell below 0.85 mg/l, and was able to survive for several weeks (Rosenberg *et al.*, 1991). This escape response increases predation risk. Mass mortality of *Amphiura filiformis* was observed during severely low oxygen events (<0.7 mg/l) (Nilsson, 1999). Mass mortality was observed following large increases in eutrophication and subsequent reductions in oxygen (Vistisen & Vismann, 1997). The regeneration rate of arms is significantly decreased at low oxygen concentrations (1.8-2.2 mg/l) (Nilsson, 1999), and growth rate is decreased in oxygen concentrations of <2.7 mg/l and spawning is restricted (Nilsson & Sköld, 1996).

Infaunal burrowers in the community live in close association with hypoxic and even anoxic muddy substrata, including the characterizing polychaetes. *Heteromastus filiformis* was recorded to occur in the Homa lagoon, eastern Aegean Sea, where high salinity was coupled with low oxygen concentrations (2.3-3.9 mg/l) with adverse negative effects on the abundance of the community (Can *et al.*, 2012). However, the study focused on the effects of hypersalinity (>50 psu) and the authors attributed mortality to increased salinity, leaving it unclear whether the hypoxic conditions also contributed to mortality of the population. This agrees with Hiscock *et al.* (2005a), who reported *Heteromastus filiformis* as a species resistant to severe hypoxia.

At oxygen concentrations below ca 0.4 mg O_2/l, *Kurtiella bidentata* eventually emerged from the substratum (Ockelmann & Muus, 1978). Nilsson & Rosenberg (1994) investigated hypoxic responses of benthic communities and reported *Kurtiella bidentata* (studied as *Mysella bidentata*) leaving the sediment at oxygen concentrations of 1.7 mg/l. According to the authors, this behaviour that occurs at hypoxic oxygen concentrations is slightly higher than those causing mortality, suggesting high levels of stress caused to the organisms.

Abra spp. are typically found in organically enriched sediments where it may be present in high

densities (Dauvin & Gentil, 1989). Experimental examination of the interactions between eutrophication and oxygen deficiency (2.4-3.5 mg O_2/l over a 93 day experimental period) revealed that *Abra alba* became inefficient in its use of the available organic matter under prolonged conditions of hypoxia (Hylland *et al.*, 1996). *Abra alba* was also reported to be sensitive to lowered oxygen concentrations off the Swedish west coast (Rosenberg & Loo, 1988; Weigelt & Rumohr, 1986, both cited in Rees & Dare, 1993).

López-Jamar *et al.* (1987) stated that *Thyasira flexuosa* was adapted to living in reduced sediments and also was found in organically enriched sediments. However, Dando & Spiro (1993) found that numbers of the congeners *Thyasira equalis* and *Thyasira sarsi* decreased rapidly following the de-oxygenation of bottom water in the deep basin of the Gullmar fjord in 1979-80.

In a meta-analysis study of hypoxia, median sub-lethal oxygen concentrations reported in experimental assessments. Although no specific data was reported for all the characterizing species of these biotopes, the thresholds of hypoxia for different benthic groups was LC50 1.42 mg/l for bivalves, and sub-lethal (SLC50) of 1.20 mg/l for annelids (Vaquer-Sunyer & Duarte, 2008). For *Kurtiella bidentata* (studied as *Mysella bidentata*), the median sub-lethal oxygen concentrations reported in experimental assessments was 1 mg/l, and for *Abra* spp. was 0.57 mg/l (Vaquer-Sunyer & Duarte, 2008).

Sensitivity assessment: Cole *et al.* (1999) suggest possible adverse effects on marine species below 4 mg/l and probable adverse effects below 2 mg/l. Based on the evidence presented, the characterizing species are likely to only be affected by severe deoxygenation episodes. However, some mortality of *Thyasira* spp. might occur in near anoxic (0% oxygen) conditions. So resistance is therefore assessed as **Medium** (loss <25%) for SS.SMu.CSaMu.ThyNten, and **High** for the remaining biotopes. Resilience is likely to be **High** so SS.SMu.CSaMu.ThyNten is considered to have **Low** sensitivity to exposure to dissolved oxygen concentration of less than or equal to 2 mg/l for 1 week, whereas the remaining biotopes are considered **Not Sensitive**.

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

Increased nutrients are most likely to affect abundance of phytoplankton which may include toxic algae (OSPAR, 2009). This primary effect resulting from elevated nutrients will affect other biological elements or features (e.g. toxins produced by phytoplankton blooms or de-oxygenation of sediments) and may lead to 'undesirable disturbance' to the structure and functioning of the ecosystem. With enhanced primary productivity in the water column, organic detritus that falls to the seabed may also be enhanced.

Interface feeders such as *Amphiura filiformis* have been reported to respond rapidly to increased primary production that may result from increased nutrient availability (Pearson & Mannvik, 1998, cited in Schückel *et al.*, 2010).

In a sewage dumping region of the North Sea, a great increase in the abundance of *Abra* spp. occurred in much of the dumping area because of the ecological adaptations of the species enabled it to exploit the greatly increased supply of nutrients (Caspers, 1981). The *Amoco Cadiz* oil spill in March 1978 caused vast disturbance to the fine-sand communities of the Bay of Morlaix, France (Dauvin, 1982). Drastic qualitative and quantitative changes in species abundance, diversity, and biomass were recorded after the spill. However, the *Abra alba* population persisted in the disturbed environment under eutrophic conditions and, as an 'opportunistic species' (Hily & Le

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Bris, 1984), rapidly adapting its reproductive strategy to three spawnings per year. Increased growth and abundance were attributable to increased food availability and vacant ecological niches (Dauvin & Gentil, 1989).

Enrichment from pulp mills is believed to have been the cause of the death of two populations of *Thyasira* spp. in west Scotland sea lochs. *Thyasira flexuosa* has been recorded at densities of up to 4000 per square metre in enriched areas (Jackson, 2007).

In a report to identify seabed indicator species to support implementation of the EU habitats and water framework directives, *Amphiura* spp., *Kurtiella bidentata*, *Levinsenia gracilis*, *Heteromastus filiformis* and *Thyasira* spp. were reported as likely to be favoured by nutrient enrichment, whereas *Abra* spp. were assessed as intolerant (Hiscock *et al.*, 2005a).

Sensitivity assessment: The overall species diversity in these biotopes is likely to decline given the varying responses of the species occurring here to nutrient enrichment (Hiscock *et al.*, 2005a). The community, and hence the biotopes, may change to one dominated by nutrient enrichment resistant species, in particular polychaete worms. However, these changes generally refer to gross nutrient enrichment. A decrease in nutrient availability may result in impaired growth and fecundity although species diversity is not likely to be affected significantly. Nevertheless, the biotopes are considered to be **Not Sensitive** at the pressure benchmark that assumes compliance with WFD good status.

Organic enrichment	Low	Medium	Medium
	Q: Low A: NR C: NR	Q: Low A: NR C: NR	Q: Low A: NR C: NR

Organic enrichment is likely to promote pelagic productivity and increase the amount of organic matter reaching the seabed, which may be beneficial to deposit feeders as a direct source of food. Nilsson (1999) investigated the effects of organic enrichment (control 0 gC/m^2, medium 27 gC/m^2 and high 55 gC/m^2) on arm regeneration of *Amphiura filiformis* over a two month period. *Amphiura filiformis* responded positively to increased organic enrichment (Nilsson, 1999). In the Skagerrak in the North Sea, a massive increase in abundance and biomass of the brittlestar between 1972 and 1988 was attributed to organic enrichment (Josefson, 1990; Hernroth *et al.*, 2012). Rosenberg *et al.* (1997) also reported that *Amphiura filiformis* appeared to be more densely packed in the sediment when food occurred superabundantly compared to when food was less common. Sköld & Gunnarsson (1996) reported enhanced growth and gonad development in response to short-term enrichment of sediment cores containing *Amphiura filiformis* maintained in laboratory mesocosms. However, if increased organic input resulted in almost complete oxygen depletion, mortality of individuals was likely to occur (see de-oxygenation pressure). Mcleod *et al.* (2008) investigated the recovery of soft sediment benthic invertebrate community following removal of high levels of organic enrichment from fish farming in Tasmania. The authors observed that *Amphiura* species were associated with areas least impacted by organic enrichment.

Birchenough & Frid (2009) analysed the succession of the macrobenthic community in the three years following cessation of sewage sludge disposal of the Northumberland coast, UK after 18 years of dumping. The authors reported a continued localized increase of individuals and species in the disposal area that was followed by a decline in the two sites close to the disposal site (less than 1 km). The control stations did not show this fluctuation in species abundance other than what expected because of seasonal variations. Particularly relevant was the increase in abundance of the bivalve *Thyasira flexuosa*. Other studies have also identified elevated *Thysira flexuosa* inhabiting polluted or semi-polluted areas mainly in fine sediments with high organic content (Pearson &

Rosenberg, 1978; López-Jamar *et al.*, 1987; Parra, 2002, cited in Birchenough & Frid, 2009). Similarly, *Abra nitida* occurs in organically enriched areas such as sediments beneath fish farms (Kutti *et al.*, 2008).

Borja *et al.* (2000) and Gittenberger & Van Loon (2011) both assigned *Amphiura filiformis* to their Ecological Group II 'species indifferent to enrichment, always present in low densities with non-significant variations with time (from initial state, to slight unbalance)'; *Abra nitida* and *Thyasira flexuosa* were assigned to Ecological Group III 'species tolerant to excess organic matter enrichment); *Kurtiella bidentata* (referred to as *Mysella bidnetata*), *Pronucula* spp. and *Myrtea spinifera* were characterized as AMBI Group I – 'species very sensitive to organic enrichment and present under unpolluted conditions (initial state)'. *Heteromastus filiformis* was considered in both cases as an opportunistic species, tolerant to excess organic matter enrichment, although assigned to different levels (III by Borja *et al.*, 2000, and IV by Gittenberger & Van Loon, 2011).

Sensitivity assessment: No direct evidence of the characterizing species' specific tolerances to organic enrichment was found. Typically, an increasing gradient of organic enrichment results in a decline in the suspension feeding fauna and an increase in the number of deposit feeders, in particular polychaete worms (Pearson & Rosenberg, 1978), which could result in significant change in the community composition of sedimentary habitats. Forrest *et al.* (2009) identified that the recovery of muddy sediments beneath fish farms from enrichment can be highly variable and may be many years at poorly flushed sites, such as those where these biotopes tend to occur. In summary, some mortality of the characterizing species of these biotopes is likely to occur, either as a direct result of a deposit of 100 gC/m^2 over the period of one year, or indirect result of hypoxia. Resistance is therefore assessed as **Low** (loss of 25-75%), but with low confidence. Resilience is likely to be **Medium**, so the biotopes are assessed as **Medium** sensitivity to organic enrichment at the pressure benchmark level.

♒ Physical Pressures

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

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

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

If the sediment that characterizes the biotopes was replaced with rock substrata, this would represent a fundamental change to the physical character of the biotopes. The characterizing species would no longer be supported and the biotopes would be lost and/or reclassified.

Sensitivity assessment: Resistance to the pressure is considered **None**, and resilience **Very Low**, given the permanent nature of this pressure. Sensitivity has been assessed as **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 sediment type)	Low	Very Low	High
	Q: Medium A: Medium C: High	Q: High A: High C: High	Q: Medium A: Medium C: High

Records indicate that the biotopes occur in sandy muds (Connor *et al.*, 2004). The characterizing species within these biotopes have wide ranges of sediment preferences. For example, *Amphiura filiformis* has been recorded in silty mud to mixed sediment (with stones and shells) (Tillin & Tyler-Walters, 2014); *Kurtiella bidentata* lives in muddy sand or fine gravel (Carter, 2008); *Abra* spp. prefer mud, muddy gravel, muddy sand, sandy mud (Budd, 2007); and *Thyasira* spp. prefer mud, muddy sand, sandy mud (Jackson, 2007).

Sensitivity assessment: A change in Folk class from mud and sandy mud to sand or muddy sand (based on the Long, 2006 simplification) would probably not affect the characterizing species which appear to have habitats preferences that would fall within this range. However, this would probably represent a fundamental change in the character of the biotopes, and a change in the abundance of the characteristic species, resulting in the loss and/or re-classification of the biotopes. Resistance is therefore assessed as **None** and resilience as **Very Low** and the biotopes are considered to have **High** sensitivity to a change in seabed type by one Folk class.

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

Sedimentary communities are likely to be highly intolerant of substratum removal, which will lead to partial or complete defaunation, expose underlying sediment which may be anoxic and/or of a different character and lead to changes in the topography of the area (Dernie *et al.*, 2003). Any remaining species, given their new position at the sediment/water interface, may be exposed to unsuitable conditions. Newell *et al.* (1998) stated that removal of 0.5 m depth of sediment was likely to eliminate benthos from the affected area. Some epifaunal and swimming species may be able to avoid this pressure. Removal of 30 cm of sediment is likely to remove species that occur at the surface and within the upper layers of sediment, such as the characterizing species of this biotope. For example, *Abra* spp. are shallow burrowers and have fragile shells (Tebble, 1976). *Thyasira* species are found 2-8 cm below the sediment surface (Dando & Southward, 1986). *Heteromastus filiformis* was reported to occupy the top 15 cm of muddy sands and its limited mobility was considered to contribute to its vulnerability to dredging and to deposition of sediment mobilised by the dredging process by Shaffer (1983). Although no specific burial depths are provided for the remaining characterizing species, these are small and need to maintain contact with the surface of the sediment layer for feeding and respiration, suggesting species are unlikely to escape extraction of substratum to 30 cm. These environmental positions, together with shell fragility, are likely to render the species vulnerable to this pressure. Furthermore, dredging operations were shown to affect large infaunal and epifaunal species, decrease sessile polychaete abundance, and reduce the numbers of burrowing heart urchins (Eleftheriou & Robertson, 1992).

Sensitivity assessment: Extraction of 30 cm of sediment will remove the characterizing biological component of the biotopes so resistance is assessed as **None**. Newell *et al.* (1998) indicate that local hydrodynamics (currents and wave action) and sediment characteristics (mobility and supply)

strongly influence the recovery of soft sediment habitats. The biotopes occur in low energy environments, so resilience is therefore judged as **Medium** (see resilience section). Sensitivity has been assessed as **Medium**.

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

The characterizing species of the biotopes are infaunal and hence have some protection against surface disturbance. However, bivalves and other species require contact with the surface for respiration and feeding, so siphons and delicate feeding structures may be damaged or withdraw because of surface disturbance, resulting in loss of feeding opportunities and compromised growth.

By extending their fragile arms from the sediment to feed, characterizing species *Amphiura filiformis* become vulnerable to damage by abrasion. Brittlestars can resist considerable damage to arms and even the disk without suffering mortality and are capable of arm and even some disk regeneration (Sköld, 1998). Ramsay *et al.* (1998) suggested that *Amphiura* spp. may be less susceptible to beam trawl damage than other species like echinoids or tube dwelling amphipods and polychaetes. For example, Bergman & Hup (1992) found that beam trawling in the North Sea had no significant direct effect on small brittlestars. Holtmann *et al.* (1996) reported a decrease in the abundance of the fragile burrowing heart urchins and the brittlestar *Amphiura filiformis* in areas of the southern North Sea between 1990 and 1995. These trends suggest that fishing activity may have been the main cause of these changes. However, Bradshaw *et al.* (2002) noted that the brittlestars *Amphiura filiformis* had increased in abundance in a long-term study of the effects of scallop dredging in the Irish Sea.

Abra spp. are shallow burrowers with a fragile shell (Tebble, 1976), and have been considered amongst the list of bivalve species most vulnerable to trawling (Bergmann & Van Santbrink, 2000) who reported between <0.5% and 18% mortality of *Abra alba* due to trawling in the southern North Sea. However, the small size of *Abra* spp. relative to meshes of commercial trawls may ensure survival of at least a moderate proportion of disturbed individuals which pass through (Rees & Dare, 1993). This is likely to be the case for small infaunal bivalve *Kurtiella bidentata*. *Thyasira* spp., are small bivalves with thin fragile shells likely to be damaged and result in mortality within the population depending on the force (Jackson, 2007). Sparks-McConkey & Watling (2001) found that trawler disturbance resulted in a decline of *Thyasira flexuosa* in Penobscot Bay, Maine. *Heteromastus filiformis* occupied the top 15 cm of muddy sands and its limited mobility was considered to contribute to its vulnerability to dredging and to deposition of sediment mobilised by the dredging process by Shaffer (1983).

Rumohr & Kujawski (2000) compared qualitative historical benthos data (1902–1912) with recent data (1986) to find long-term trends in epifauna species composition in the southern North Sea that may be attributed to fishery-induced changes. In general, the frequency of occurrence of bivalve species declined, whereas scavenger and predator species (crustaceans, gastropods, and sea stars) were observed more frequently in 1986. The authors suggested that these shifts could be attributed not only to the physical fishery impact but also to the additional potential food for scavenging and predator species provided by the large amounts of discards and moribund benthos. The brittlestar *Amphiura filiformis* occurred in 1986 on only 5% of the stations while it was present in most of the historical stations. Also, virtually all bivalve species originally present had decreased

drastically, including *Nucula tenuis* (also less the 5% of the sites by 1986). Despite the problems with the historical data set, the comparison presented was considered the best illustration achievable of the changes in the benthos from a near-pristine situation to the present conditions after long-term disturbance.

In a meta-analysis of the impacts of different fishing activities on the benthic biota of different habitats, muddy sands were found to be vulnerable to the impacts of fishing activities, with recovery times predicted to take years (Kaiser *et al.*, 2006). The long recovery time for muddy sands is due to the fact that these habitats are mediated by a combination of physical, chemical and biological processes (compared to sand habitats which are dominated by physical processes and recovery time takes days-months).

Furthermore, abrasion events are likely to cause turbulent re-suspension of surface sediments. When used over fine muddy sediments, trawls are often fitted with shoes designed to prevent the boards digging too far into the sediment (M.J. Kaiser, pers. obs., cited in Jennings & Kaiser, 1998). The effects may persist for variable lengths of time depending on tidal strength and currents and may result in a loss of biological organization and reduce species richness (Hall, 1994; Bergman & Van Santbrink, 2000; Reiss *et al.*, 2009) (see change in suspended solids and smothering pressures). The effects of trawling on infauna are greater in areas with low levels of natural disturbance compared to areas of high natural disturbance (e.g. Hiddink *et al.*, 2006), and its cumulative impacts can lead to profound changes in benthic community composition, with far reaching implication for marine food webs (Hinz *et al.*, 2009).

Sensitivity assessment: Although burrowing life habits may provide some protection from damage by abrasion at the surface, a proportion of the population is likely to be damaged or removed. Significant impacts in population density would be expected if such physical disturbance were repeated at regular intervals. Furthermore, the nature of the soft sediment where the biotopes occur means that objects causing abrasion, such as fishing gears (including pots and creels) are likely to penetrate the surface and cause further damage to the characterizing species. Resistance is therefore assessed as **Low** and resilience as **Medium**, so sensitivity is assessed as **Medium**.

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

Activities that disturb the surface and penetrate below the surface would remove /damage infaunal species such as the characterizing species within the direct area of impact. The footprint of the impact will depend on the type of gear used (Hall *et al.*, 2008). The biotopes occur in muddy sands (Connor *et al.*, 2004) so penetrative activities (e.g. anchoring, scallop or suction dredging) and damage to the seabed's sub-surface is likely to remove and/or damage the infaunal community, including the characterizing species, given that bottom fishing gears penetrate deeper into softer sediments (Bergman & Van Santbrink, 2000). Direct mortality (percentage of initial density) of *Amphiura* species from a single pass of a beam trawl was estimated from experimental studies on sandy and silty grounds as 9%, 20-65% for bivalves and 5-40% for gastropods, starfish, small-medium sized crustaceans and annelid worms, including *Kurtiella bidentata* (studied as *Mysella bidentata*) as 4%. Some mortality was not caused directly by the passage of the trawl, but instead by disturbance, exposure and subsequent predation (Bergman & Van Santbrink, 2000). Ball *et al.* (2000b) reported on the short-term effects of fishing on benthos from a mud patch in the north western part of the Irish Sea investigated in 1994–1996 by means of samples taken both

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before and shortly after (ca 24 hr) fishing activity. *Kurtiella bidentata* (studied as *Mysella bidentata*) was one of the species that was common at the inshore site and for which estimates of mortality were calculated and was uncommon or totally absent on the offshore fishing ground. Direct mortality from passage of an otter trawl was estimated as 70%. The delicate shells of *Abra* spp. are vulnerable to physical damage (e.g. by otterboards), but its small size relative to meshes of commercial trawls may ensure survival of at least a moderate proportion of disturbed individuals which pass through (Rees & Dare, 1993). Equally, *Thyasira* spp. also have delicate shells and are likely to be vulnerable to physical disturbance. *Heteromastus filiformis* was reported to occupy the top 15 cm of muddy sands and its limited mobility was considered to contribute to its vulnerability to dredging and to deposition of sediment mobilised by the dredging process by Shaffer (1983).

Furthermore, penetrative events caused by a passing fishing gear are also likely to have marked impacts on the substratum and cause turbulent re-suspension of surface sediments (see abrasion pressure). When used over fine muddy sediments, trawls are often fitted with shoes designed to prevent the boards digging too far into the sediment (M.J. Kaiser, pers. obs., cited in Jennings & Kaiser, 1998). Trawling can create suspended sediment plumes up to 10 m above the bottom (Churchill, 1989 cited in Clarke & Wilber, 2000). The effects may persist for variable lengths of time depending on tidal strength and currents and may result in a loss of biological organization and reduce species richness (Hall, 1994; Bergman & Van Santbrink, 2000; Reiss *et al.*, 2009) (see change in suspended solids and smothering pressures). A meta-analysis of over 100 experimental fishing impact studies showed that beam trawling, scallop dredging and otter trawling all had significant short-term impacts in muddy sand habitats, with most severe effect on suspension feeders (Kaiser *et al.*, 2006). Jennings *et al.* (2001) found that trawling in the muddy sand region led to significant decreases in infaunal biomass and production in the North Sea, with the abundance of larger individuals depleted more than smaller ones.

Sensitivity assessment: A large proportion of the characterizing species in these biotopes is likely to be lost or severely damaged, depending on the scale of the activity (see abrasion pressure). Therefore, a resistance of **Low** is suggested. Muddy sand habitats have been reported as having the longest recovery times, whilst mud habitats had an 'intermediate' recovery time (compared to clean sand communities which had the most rapid recovery rate) (Dernie *et al.*, 2003). Resilience is probably **Medium**, and therefore the biotopes' sensitivity to this pressure is likely to be **Medium**.

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

The biotopes are found in weak and very weak tidal streams (Connor *et al.*, 2004). Clogging of feeding apparatus by suspended sediment is likely to be a major consideration for the characterizing species of the biotopes, which include a number of suspension feeders, such as brittlestar *Amphiura filiformis,* and bivalves *Kurtiella bidentata, Abra* spp., *Pronucula nitida* and *Thyasira* spp.. For example, according to Widdows *et al.* (1979) growth of filter-feeding bivalves may be impaired at suspended particulate matter (SPM) concentrations >250 mg/l. For instance, the abundance of *Abra alba* declined over two years within 1 km of an outfall pipe discharging fine-grained mineral waste from the china/clay industry at a rate of 450,000 tons per year to Mevagissey Bay, Cornwall. However, it was argued that persistent sediment instability was the more significant source of stress to the predominantly deposit-feeding community than the suspended sediment concentration (Probert, 1981).

Amphiura filiformi, Kurtiella bidentata and *Abra* spp. are able to switch between feeding methods

(Hill & Wilson, 2008; Carter, 2008; Budd, 2007) and are likely to change to deposit feeding in stagnant waters or areas of very low water flow (Ockelmann & Muus, 1978).

The characterizing polychaetes of the biotopes are thought to be predators or deposit feeders. For most benthic deposit feeders, food is suggested to be a limiting factor for body and gonad growth, at least between events of sedimentation of fresh organic matter (Hargrave, 1980; Tenore, 1988). Consequently, increased organic matter in suspension that is deposited may become incorporated into sediments via bioturbation and may enhance food supply. A decrease in the suspended sediment and hence siltation may reduce the flux of particulate material to the seabed. Since this includes organic matter the supply of food to the biotopes would probably also be reduced. While regenerating arms, the amount of food the brittlestars can feed on is decreased, meaning there is less energy to allocate to arm regeneration. If there is a change in the amount and quality of food available because of change in suspended solids in the biotopes, then this can have aggravated effects of the growth and development of brittlestars (Lawrence, 2010).

Where a change in suspended solids results in increased turbidity and change of light, the community is unlikely to be directly affected. The community is also unlikely to be directly affected by increased light penetration of the water column caused by a decrease in turbidity. Greater light penetration of the water column may improve primary production by phytoplankton in the water column and contribute to secondary productivity via the production of detritus from which the community may benefit.

Sensitivity assessment: An increase in the suspended matter settling out from the water column to the substratum may increase food availability. On the other hand, decreased siltation is unlikely to affect the mainly deposit feeding community that occur in the biotopes. Resistance of the biotopes is likely to be **High**, but with low confidence as no direct evidence was found. Resistance is likely to be **High** (by default) and the biotopes are, therefore, assessed as **Not Sensitive** to a change in suspended solids at the pressure benchmark level.

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

The biotopes are characterized by burrowing species that are likely to be able to burrow upwards and therefore unlikely to be adversely affected by smothering of 5 cm sediment.

Last *et al.* (2011) buried *Ophiura ophiura* individuals under three different depths of sediment; shallow (2 cm), medium (5 cm) and deep (7 cm). The results indicated that *Ophiura ophiura* is highly tolerant of short-term (32 days) burial events, with less than 10% mortality of all buried specimens. This is largely a reflection of the ability of the species to re-emerge from all depths across all sediment fractions tested. Survival of specimens that remained buried was low, with 100% mortality of individuals that remained buried after 32 days. The experiments utilized three different fractions of kiln dried, commercially obtained marine sediment: coarse (1.2-2.0mm diameter), medium fine (0.25-0.95mm diameter) and fine (0.1-0.25mm diameter). Trannum *et al.* (2010) investigated how sedimentation from water-bases drill cuttings could affect benthic communities, in comparison with natural sediment deposition. The authors concluded there was no effect of adding natural test sediment up to 2.4 cm but a significant reduction in number of taxa, abundance, biomass and diversity of fauna with increasing layer of thickness of drill cuttings (3-24 mm), suggesting other mechanisms affecting the fauna other than sedimentation, possibly lower contents of nutrients, toxicity and oxygen depletion. *Amphiura filiformis* was amongst the species to be absent from treatments under 6, 12 and 24 mm of artificial sediment, possibly due to its surface

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deposit feeding habits.

Characterizing suspension feeders may not persist in areas of excessive sedimentation. Material in suspension can affect the efficiency of filter and suspension feeding (Sherk & Cronin, 1970; Morton, 1976). Effects can include abrasion and clogging of gills, impaired respiration, clogging of filter mechanisms, and reduced feeding and pumping rates.

Hinchey *et al.* (2006) investigated the responses of estuarine benthic invertebrates to sediment burial and concluded that species-specific response to burial varied as a function of motility living position, and physiological tolerance of anoxic conditions while buried. Although the characterizing species were not included in the study, increased overburden stress did not significantly decrease survival and growth of the juvenile bivalve studied, *Limecola balthica*, but significantly caused decline juvenile *Streblospio benedicti*. The depth of sediment deposited varied between 0-24.6 cm and 0-8.4 cm, respectively.

Furthermore, a study of the ecological effects of dumping dredged sediments by Essink (1999) reported that resistance of mobile macrobenthos varied greatly with species. For polychaetes, the author reported tolerances of up to 50 cm of mud for species such as *Nepthys* and *Nereis,* and up to 80 cm of sand. Bijkerk (1988, results cited from Essink, 1999) indicated that the maximal overburden through which small bivalves could migrate was 20 cm in sand for *Donax* and approximately 40 cm in mud for *Tellina* sp. and approximately 50 cm in sand. Powilleit *et al.* (2009) studied responses to smothering for three bivalves; *Arctica islandica, Limecola balthica* and *Mya arenaria*. These successfully burrowed to the surface of a 32 – 41 cm deposited sediment layer of till or sand/till mixture and restored contact with the overlying water. These high escape potentials could partly be explained by the heterogeneous texture of the till and sand/till mixture with 'voids'. In comparison to a thick coverage, thin covering layers (i.e. 15 - 16 cm and 20 cm) increased the chance of the organisms to reach the sediment surface after burial. This suggests that characterizing species such as *Kurtiella bidentata, Abra* spp., *Thyasira* spp. and *Pronucula tenuis* are likely to be able to reborrow through similar overburdens, although sudden smothering with 5 cm of sediment would temporarily halt feeding and respiration, compromising growth and reproduction owing to energetic expenditure. Furthermore, *Thyasira flexuosa* have highly extensible feet (Dando & Southward, 1986) allowing them to construct channels within the sediment and to burrow to 8 cm depth.

Being adapted for burrowing means these species are likely to resist additional fine sediment. However, it should be remembered that smothering by impermeable or viscous materials are likely to have some effect upon the animals, e.g. by causing deoxygenation.

Sensitivity assessment: Beyond re-establishing burrow openings or moving up through the sediment, there is evidence of synergistic effects on burrowing activity of marine benthos and mortality with changes in time of burial, sediment depth, sediment type and temperature (Maurer *et al.,* 1986). However, the biotopes are likely to resist smothering at the benchmark level since the majority of associated fauna are burrowing infauna. Resistance is therefore assessed as **High**, and resilience is also **High** (by default) so the biotopes are considered **Not Sensitive** to a 'light' deposition of up to 5 cm of fine material added to the seabed in a single, discrete event.

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

The biotopes are characterized by burrowing species that are likely to be able to burrow upwards.

Last *et al.* (2011) buried *Ophiura ophiura* individuals under three different depths of sediment; shallow (2 cm), medium (5 cm) and deep (7 cm). The results indicated that *Ophiura ophiura* is highly tolerant of short-term (32 days) burial events, with less than 10% mortality of all buried specimens. This is largely a reflection of the ability of the species to re-emerge from all depths across all sediment fractions tested. Survival of specimens that remained buried was low, with 100% mortality of individuals that remained buried after 32 days. The experiments utilized three different fractions of kiln dried, commercially obtained marine sediment: coarse (1.2-2.0mm diameter), medium fine (0.25-0.95mm diameter) and fine (0.1-0.25mm diameter). Trannum *et al.* (2010) investigated how sedimentation from water-bases drill cuttings could affect benthic communities, in comparison with natural sediment deposition. The authors concluded there was no effect of adding natural test sediment up to 2.4 cm but a significant reduction in number of taxa, abundance, biomass and diversity of fauna with increasing layer of thickness of drill cuttings (3-24 mm), suggesting other mechanisms affecting the fauna other than sedimentation, possibly lower contents of nutrients, toxicity and oxygen depletion. *Amphiura filiformis* was amongst the species to be absent from treatments under 6, 12 and 24 mm of artificial sediment, possibly due to its surface deposit feeding habits.

Characterizing suspension feeders may not persist in areas of excessive sedimentation. Material in suspension can affect the efficiency of filter and suspension feeding (Sherk & Cronin, 1970; Morton, 1976). Effects can include abrasion and clogging of gills, impaired respiration, clogging of filter mechanisms, and reduced feeding and pumping rates.

Hinchey *et al.* (2006) investigated the responses of estuarine benthic invertebrates to sediment burial and concluded that species-specific response to burial varied as a function of motility living position, and physiological tolerance of anoxic conditions while buried. Although the characterizing species were not included in the study, increased overburden stress did not significantly decrease survival and growth of the juvenile bivalve studied, *Limecola balthica*, but significantly caused decline juvenile *Streblospio benedicti*. The depth of sediment deposited varied between 0-24.6 cm and 0-8.4 cm, respectively.

Furthermore, a study of the ecological effects of dumping dredged sediments by Essink (1999) reported that resistance of mobile macrobenthos varied greatly with species. For polychaetes, the author reported tolerances of up to 50 cm of mud for species such as *Nepthys* and *Nereis,* and up to 80 cm of sand. Bijkerk (1988, results cited from Essink, 1999) indicated that the maximal overburden through which small bivalves could migrate was 20 cm in sand for *Donax* and approximately 40 cm in mud for *Tellina* sp. and approximately 50 cm in sand. Powilleit *et al.* (2009) studied responses to smothering for three bivalves; *Arctica islandica, Limecola balthica* and *Mya arenaria.* These successfully burrowed to the surface of a 32 – 41 cm deposited sediment layer of till or sand/till mixture and restored contact with the overlying water. These high escape potentials could partly be explained by the heterogeneous texture of the till and sand/till mixture with 'voids'. In comparison to a thick coverage, thin covering layers (i.e. 15 - 16 cm and 20 cm) increased the chance of the organisms to reach the sediment surface after burial. This suggests that characterizing species such as *Kurtiella bidentata, Abra* spp., *Thyasira* spp. and *Pronucula tenuis* are likely to be able to reborrow through similar overburdens, although sudden smothering with 5 cm of sediment would temporarily halt feeding and respiration, compromising growth and reproduction owing to energetic expenditure. Furthermore, *Thyasira flexuosa* have highly extensible feet (Dando & Southward, 1986) allowing them to construct channels within the sediment and to burrow to 8 cm depth.

Being adapted for burrowing means these species are likely to resist additional fine sediment.

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However, it should be remembered that smothering by impermeable or viscous materials are likely to have some effect upon the animals, e.g. by causing deoxygenation.

Sensitivity assessment: Beyond re-establishing burrow openings or moving up through the sediment, there is evidence of synergistic effects on burrowing activity of marine benthos and mortality with changes in time of burial, sediment depth, sediment type and temperature (Maurer *et al.*, 1986). Bivalve and polychaete species have been reported to migrate through depositions of sediment greater that the benchmark (30 cm of fine material added to the seabed in a single discrete event) (Bijkerk, 1988; Powilleit *et al.*, 2009; Maurer *et al.*, 1982). However, it is not clear whether the characterizing species are likely to be able to migrate through a maximum thickness of fine sediment because muds tend to be more cohesive and compacted than sand. Some mortality of the characterizing species is likely to occur. Resistance is therefore assessed as **Low** (25-75% loss), but with low confidence. Resilience as **Medium** and the biotopes are considered to have **Medium** sensitivity to a 'heavy' deposition of up to 30 cm of fine material in a single discrete event.

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

Not assessed.

Electromagnetic changes	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

No Evidence is available on which to assess this pressure.

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

Species in the biotopes may respond to vibrations from predators or excavation by retracting their palps or by burrowing deeper into the sediment. However, the characterizing species are unlikely to be affected by noise pollution and so the biotopes are assessed as **Not Sensitive**.

Introduction of light or shading	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

The biotopes are circalittoral (Connor *et al.*, 2004) and therefore, not directly dependent on sunlight.

Sensitivity assessment. The biotopes are considered to have **High** resistance and, by default, **High** resilience and therefore is **Not Sensitive** to this pressure.

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

Not Relevant to biotopes restricted to open waters.

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

The characterizing species of the biotopes live infaunally, so are likely to have poor or no visual perception and unlikely to be affected by visual disturbance such as shading. For example, movement of a hand near brittlestar *Ophiothrix fragilis* elicits no escape response (Sköld, 1998).

🐚 Biological Pressures

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

The important characterizing species in the biotopes are not cultivated or likely to be translocated. This pressure is therefore considered **Not Relevant**.

Introduction or spread of invasive non-indigenous species	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

There are no records of the introduction or spread of non-indigenous species in these biotopes. This pressure is, therefore, considered **Not Relevant**.

Introduction of microbial pathogens	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

Introduced organisms (especially parasites or pathogens) are a potential threat in all coastal ecosystems. Several examples are known of echinoderm populations that have been massively reduced by sudden outbreaks of epidemic disease. Cases include the mass mortality of the sea urchin *Diadema antillarum* throughout the Caribbean as a result of infection by a water-borne pathogen (Lessios, 1988), and the decimation of urchin populations in the North Atlantic by parasitic amoebae and nematodes (Hagen, 1997). Brittlestars have symbiotic sub-cuticular bacteria. The host-bacteria association can be perturbed by acute stress and changes in bacterial loading may be used as an indicator of sub-lethal stress (Newton & McKenzie, 1995).

More than 20 viruses have been described for marine bivalves (Sinderman, 1990). Bacterial diseases are more significant in the larval stages and protozoans are the most common cause of epizootic outbreaks that may result in mass mortalities of bivalve populations. Parasitic worms, trematodes, cestodes and nematodes can reduce growth and fecundity within bivalves and may in some instances cause death (Dame, 1996). A viral infection of the mutualist bacterium living on the

gills of *Thyasira gouldi* was suggested as the reason for a major decline in the Loch Etive population (Jackson, 2007). However, no information specifically concerning the effects of microbial pathogens and parasites on the viability of the characterizing species was found.

Sensitivity assessment: No direct evidence of the biotopes being affected by the introduction of microbial pathogens was found as with which to assess this pressure. This pressure is therefore assessed as **No Evidence.**

Removal of target species	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

It is extremely unlikely that any of the species indicative of sensitivity would be targeted for extraction. This pressure is therefore considered **Not Relevant**.

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

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

Sensitivity assessment: Removal of the characterizing species would result in the biotopes being lost or reclassified. Thus, the biotopes are assessed to have a resistance of **Low** to this pressure and to have **Medium** resilience, resulting in the sensitivity being judged as **Medium**.

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