Acrocnida brachiata with *Astropecten irregularis* and other echinoderms in circalittoral muddy sand

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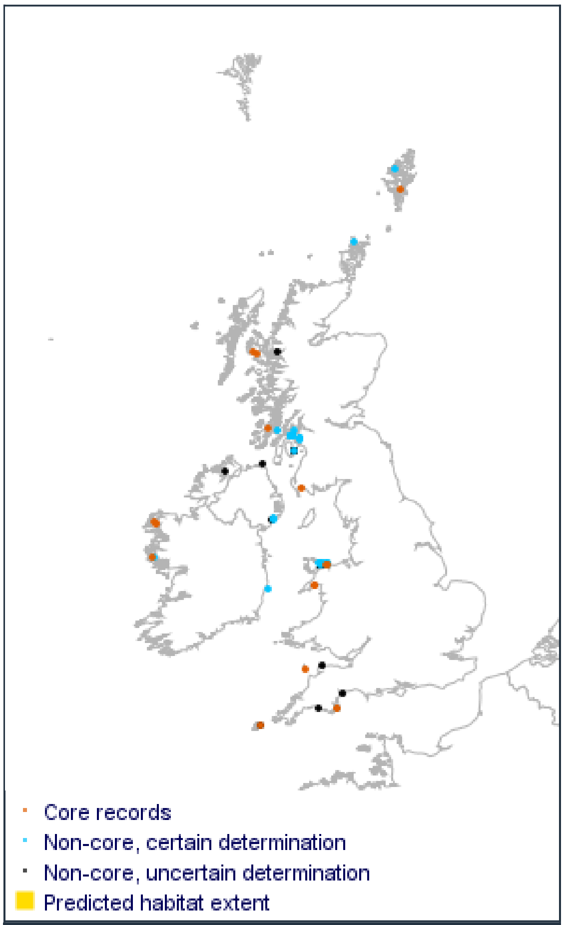

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Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

Researched by Eliane De-Bastos **Refereed by** Admin

Summary

UK and Ireland classification

EUNIS 2008	A5.262	*Amphiura brachiata* with *Astropecten irregularis* and other echinoderms in circalittoral muddy sand
JNCC 2015	SS.SSa.CMuSa.AbraAirr	*Acrocnida brachiata* with *Astropecten irregularis* and other echinoderms in circalittoral muddy sand
JNCC 2004	SS.SSa.CMuSa.AbraAirr	*Amphiura brachiata* with *Astropecten irregularis* and other echinoderms in circalittoral muddy sand
1997 Biotope		

Description

In shallow, circalittoral non-cohesive muddy sand (typically less than 20% silt/clay) abundant populations of the brittlestar *Acrocnida brachiata* may occur with other echinoderms such as *Astropecten irregularis*, *Asterias rubens*, *Ophiura ophiura* and *Echinocardium cordatum*. Other infaunal species typically include *Kurtiella bidentata*, *Lanice conchilega* and *Magelona filiformis*. This biotope is likely to form part of the non-cohesive/cohesive muddy sand communities, which make up the 'off-shore muddy sand association' described by other workers (Jones, 1951; Mackie, 1990). It is possible that in some areas this biotope forms an epifaunal overlay which may cover a range of biotopes in years of good recruitment but does not develop into a settled or established community. (Information taken from Connor *et al*., 2004). **Please note** that *Acrocnida brachiata* is now synonymous with *Acrocnida brachiata*.

Depth range

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

Additional information

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Listed By

- none -

Further information sources

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Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

SS.SSa.CMuSa.AbraAirr occurs in shallow, circalittoral, non-cohesive muddy sand (typically less than 20% silt/clay). The biotope occurs in a range of hydrographic regimes, including wave exposures ranging from very sheltered to sheltered, moderately exposed and exposed sites, with weak of very weak tidal streams (Connor *et al.*, 2004). Abundant populations of the brittlestar *Acrocnida brachiata* (syn. *Amphiura brachiata*) may occur, with other echinoderms such as *Astropecten irregularis*, *Asterias rubens*, *Ophiura ophiura* and *Echinocardium cordatum*. Other infaunal species typically include *Kurtiella bidentata*, *Lanice conchilega* and *Magelona filiformis*. This biotope is likely to form part of the non-cohesive/cohesive muddy sand communities, which make up the 'offshore muddy sand association' described by other workers (Jones, 1951; Mackie, 1990). Records of the community, such as those provided by Jones (1951) suggested that although there seemed to occur a gradual transition in the community from shallow outwards towards deeper depth, a sufficient number of species was common to the whole to characterize the community, suggesting that the denominated species in this biotope, *Acrocnida brachiata*, *Astropecten irregularis* and other echinoderms such as *Asterias rubens*, *Ophiura ophiura* and *Echinocardium cordatum* consistently occurred throughout. For this reason, these species are considered the key characterizing species in this biotope and are the focus of this sensitivity assessment. In addition, *Acrocnida brachiata* has been recorded in all examples of the biotope, often in abundance (up to >780 individuals/m^2 (Keegan & Könnecker, 1980)), with *Astropecten irregularis* reported as a potential predator (Fish & Fish, 1996). *Astropecten* generally tends to be found partially or completely buried in the sediment, but when foraging, they roam the sediment and are known to be voracious predators, behaviour which can have a profound influence in the structure of benthic communities (Freeman *et al.*, 2001). As a result, *Astropecten* is considered as key functional species of SS.SSa.CMuSa.AbraAirr.

SS.SSa.OSa.OfusAfil here is considered to represent an offshore example of SS.SSa.CMuSa.AbraAirr. However, no records have been found and this sensitivity assessment is based upon the description of the biotope given by Connor *et al.* (2004). SS.SSa.OSa.OfusAfil occurs in areas of slightly muddy sand (generally <20% mud) in offshore waters and may be characterized by high numbers of the tube building polychaete *Owenia fusiformis* often with the brittlestar *Amphiura filiformis*, both of which are associated with and live buried in muddy sands. Whilst *Owenia fusiformis* is also found in other circalittoral or offshore biotopes, such as SS.SSa.OSa.MalEdef, it usually occurs in lower abundances than in SS.SSa.OSa.OfusAfil. This suggests that the occurrence of *Owenia fusiformis* and *Amphiura filiformis* in offshore muddy substrata define this biotope. For this reason, these are considered the characterizing species of this biotope and will be the focus of this sensitivity assessment. Furthermore, as an infaunal tube building polychaete, *Owenia fusiformis* are known to be good ecosystem engineers as a result of building their tubes for protection from hydrodynamics and predators, which in turn provide stability to the benthic soft sediment, and influence the structure of the benthic community with regard to diversity, abundances and spatial distribution (Dauer *et al.*, 1982; Zuhlke, 2001, cited in Noffke *et al.*, 2009). Other species found in this community are the polychaetes *Goniada maculata*, *Pholoe inornata*, *Diplocirrus glaucus*, *Chaetozone setosa* and *Spiophanes kroyeri* with occasional bivalves such as *Timoclea ovata* and *Thyasira equalis*. The sea cucumber *Labidoplax buskii* (syn. *Labidoplax buski*) and the cumacean *Eudorella truncatula* are also commonly often found in this biotope.

Resilience and recovery rates of habitat

The fauna characterizing these biotopes occur buried in muddy sands. Brittlestar *Acrocnida brachiata* displays the characteristic brittlestar body plan with a flat central disc (up to 12 mm diameter) and five very long, slender arms, up to 15 times the diameter of the disc (Fish & Fish, 1996). *Acrocnida brachiata* is known to spawn during summer and it has been suggested that it has a brief pelagic phase (Fish & Fish, 1996). Zakadjian (1990) studied the reproductive strategy of *Acrocnida brachiata* from the Bay of Seine and suggested a well-defined annual reproductive cycle, with gonad development beginning in late summer to autumn and spawning occurring in May and June. The authors also suggested that individuals did not reach sexual maturity until the second or third year of life with most individuals spawning at least two or three times in their lifetimes of up to 4-5 years (Zakadjian, 1990). Reproduction did not seem to coincide with annual temperature peak. *Acrocnida brachiata*, like other brittlestars, has been reported to be able to tolerate a significant level of sub-lethal predation, with large portions of populations having been observed to be regenerating arms (Bourgoin & Guillou, 1994). *Acrocnida brachiata* may benefit from the buried position it occupies in the sediment to strategically rotate arms between suspension feeding and burial in the sediment to allow arm regeneration (Makra & Keegan, 1999).

Astropecten irregularis has a stiff flattened body and can grow up to 20 cm in diameter. The sexes are separate and breeding apparently takes place during the summer months. It has a bipinnaria larva but no brachiolaria in the life-cycle (Fish & Fish, 1996). Freeman *et al.* (2001) studied the seasonal trends in abundance, spatial distribution, spawning and growth of a population of *Astropecten irregularis* of the coast of North Wales. The authors observed that *Astropecten irregularis* population varied seasonally, with maximum and minimum abundances in summer and winter respectively, suggesting that the starfish might migrate offshore to deeper, more stable waters during winter. The higher densities in the summer may coincide with spawning aggregations, which on the study site occur during late spring, early summer. In north-eastern Europe, *Astropecten irregularis* displays a marked annual reproductive cycle, with frequent spawning episodes throughout the summer months. Like most starfish, fertilization takes places externally, which is likely to benefit from population aggregations and synchronized spawning (Freeman *et al.*, 2001). The authors suggested a lifespan of approx. 3.5 years, although under laboratory conditions *Astropecten irregularis* have been reported to live for up to about 10 years (Christensen, 1970, cited in Freeman *et al.*, 2001).

Owenia fusiformis lives in a tough, flexible tube, which it builds by selectively collecting grain particles from its environment (Noffke *et al.*, 2009). The sexes are separate and the larvae have a planktonic life of about four weeks. On the south coast of England, breeding occurs during June and July. Length of life is four years, with breeding occurring every year (Fish & Fish, 1996; Rouse & Pleijel, 2001). *Owenia fusiformis* has a polymodal population structure of three to five year classes (Menard *et al.*, 1990). The mortality rate increases gradually with age but suddenly increases in the fourth year of life (Menard *et al.*, 1990). Growth is rapid in summer, slows in the autumn and is negligible in winter, resuming in April each year. The maximum recorded density was 4660 individuals/m□ but this fluctuated over each year with mortality and massive larval settlement (Menard *et al.*, 1990). Maturity is size-dependent and all worms 6 cm long or more are mature but some individuals reach maturity at 2.4 cm. Some individuals may breed in their first year if they can grow fast enough (Gentil *et al.*, 1990). In the southern North Sea, spatfall occurs from spring to early summer (Hartmann-Schöder, 1996, cited in Noffke *et al.*, 2009) and in the English Channel the maximum of spat is in mid-May (Thiebaut *et al.*, 1992). Larval settlement depends on the portion of fine sediment (mud) in the sediment (Wilson, 1932), with juvenile settlement strongly decreasing where mud portion was <5%. Furthermore, if the fine fraction is missing in the sediment, initial tube building is strongly restricted and the survival of the juveniles is thus negatively influenced (Pinedo *et al.*, 2000; Noffke *et al.*, 2009). These post-settlement processes are thought to have more influence on the macrobenthic community than processes in the pelagic phase.

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 *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.

R***esilience assessment:*** Minor damage to individual brittlestars, such as *Acrocnida brachiata* and *Amphiura filiformis*, and starfish *Astropecten irregularis* is likely to be repaired, and recovery from impacts with a small spatial footprint may occur through migration of adults. Where the majority of the population remain (resistance is **High** or **Medium**), and/or recruitment by adult mobility is possible recovery (resilience) is likely to be **High**. Where populations are removed or significantly reduced over large areas then recovery will be through recruitment of juveniles and will depend on the supply of new larvae. The characterizing species in these biotopes reproduce annually, so recovery through juvenile recruitment may occur within two years. However, recruitment rates may be low in places and are dependent on favourable hydrodynamic conditions that allow settlement of new recruits. So where impacts remove a significant proportion of the population (resistance is **Low** or **None**), recovery is likely to be **Medium** (2-10 years). Within this time period it is likely that most species could have re-established biomass and age structured populations.

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

Hydrological Pressures

	Resistance	Resilience	Sensitivity

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

The characterizing species in these biotopes are widely distributed, from Norway to Morocco and the Mediterranean (Fish & Fish, 1996; Sabatini, 2008; Neil & Avant, 2008; Hill & Wilson, 2008). Kröncke *et al.* (2011) reported the increase in abundance and regional changes in the distribution of various species with a southern distribution in the North Sea in 2000, suggesting 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 was of about 1.1°C. Brittlestar *Acrocnida brachiata* was reported to be amongst these species, suggesting the brittlestar may benefit from warmer sea temperatures. On the other hand, *Amphiura filiformis* was among the species observed to have decreased. Zakadjian (1990) studied the reproductive strategy of *Acrocnida brachiata* from the Bay of Seine, where the annual temperature variations in the study site were from 6 to 22°C, with no link suggested between reproduction and temperature.

Freeman *et al.* (2001) observed that spawning in *Astropecten irregularis* in theirs studies coincided with an increase in seawater temperature from approx. 8°C to 15°C. Furthermore, the authors noted that, in the laboratory, the shallow burrowing species adjusted the depth at which they burrowed into the sediment to seawater temperature, burrowing deeper at lower temperatures.

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.

Owenia fusiformis is found in waters from -1 to 30°C (Dauvin & Thiebaut, 1994) globally. In the Bay of Seine, where there is a large population of *Owenia fusiformis*, the temperature varies between 5 and 20°C (Gentil *et al.*, 1990).

Sensitivity assessment: The characterizing species of these biotopes are widely distributed and likely to occur both north and south of the British Isles. Furthermore, the evidence presented suggests that these species are likely to potentially benefit from an increase in temperature at the pressure benchmark level, with increased distribution range, growth and fecundity. Resistance and resilience are therefore assessed as **High** and the biotopes considered **Not Sensitive** to an increase in temperature at the benchmark level.

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

The characterizing species in these biotopes are widely distributed, from Norway to Morocco and the Mediterranean (Fish & Fish, 1996; Sabatini, 2008; Neil & Avant, 2008; Hill & Wilson, 2008). Zakadjian (1990) studied the reproductive strategy of *Acrocnida brachiata* from the Bay of Seine, where the annual temperature variations in the study site were from 6 to 22°C, with no link suggested between reproduction and temperature. Holme (1967) reported the absence of *Acrocnida brachiata* 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). Abundance of *Amphiura filiformis* was also reported to have decreased.

Freeman *et al.* (2001) observed that, in the laboratory, *Astropecten irregularis* adjusted the depth at which it burrowed into the sediment to seawater temperature, burrowing deeper at lower temperatures. Furthermore, the authors noted that locomotory activity in *Astropecten irregularis* was inhibited at low seawater temperatures (<6°C), and that temperature is likely to be an important factor influencing the abundance and distribution of the species in coastal waters, as it has been suggested that individuals migrate offshore during the winter (Freeman *et al*., 2001)

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. However, echinoderms, including *Amphiura filiformis*, of 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 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.

Owenia fusiformis is found in waters from -1 to 30°C (Dauvin & Thiebaut, 1994) globally. In the Bay of Seine, where there is a large population of *Owenia fusiformis*, the temperature varies between 5 and 20°C (Gentil *et al*., 1990).

Sensitivity assessment: The characterizing species of these biotopes are widely distributed and likely to occur both north and south of the British Isles. However, the evidence presented suggests that low temperatures are likely to be a limiting factor for activity and breeding of the characterizing species. Furthermore, the species seem to be affected by extreme low temperatures and some mortality in shallower examples of the biotopes may occur as a result of a temperature change in winter at the benchmark level. Resistance is therefore assessed a **Low** and resilience as **Medium** and the biotopes considered to have **Medium** sensitivity to a decrease in temperature at the benchmark level.

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

Echinoderms 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 occurs in hypersaline conditions. Pagett (1981) suggested that localised physiological adaption to reduced or variable salinities may occur in nearshore areas subject to freshwater runoffs. Records indicate that SS.SSa.CMuSa.AbraAirr mainly occurs in full (30-35 ppt) salinity, but that it may also be found in variable (18-35 ppt) salinity (Connor *et al*., 2004). This suggests that the species in this biotope may experience variable salinities, and resident species perhaps may be adapted to variation in salinity, as suggested by the results given by Pagett (1981). On the other hand, records indicate that SS.SSa.OSa.OfusAfil only occurs in full salinity and is a circalittoral habitat, so is less likely to experience variable salinities, and resident species, therefore, less likely to be adapted to variation in salinity, as suggested by the results given by Pagett (1981).

Sensitivity assessment: There is little direct evidence of the effects of hypersaline conditions on the characterizing species of these biotopes. However, echinoderms are generally considered to be stenohaline (Stickle & Diehl, 1987; Russell, 2013). The biotopes mainly experience full salinity conditions (Connor *et al.*, 2004) and the species found are unlike to be adapted to increases in salinity. Therefore, an increase in salinity to >40 psu is likely to result in mortality of the characterizing species. Resistance is assessed as **Low** but with low confidence. Resilience is probably **Medium** so that sensitivity is therefore assessed as **Medium**.

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

Echinoderms 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, there are examples where characterizing species in these biotopes have been recorded in hyposaline conditions. For example, *Amphiura filiformis* was recorded in the Sado estuary in Portugal (Monteiro-Marques, 1982 cited in Russell, 2013) where the salinity is 25.5‰, and in the Black Sea where it tolerated 8.9‰ (Russell, 2013). Furthermore, adult and juvenile *Astropecten irregularis* were exposed to varying salinities of 16-32‰ and mortality was observed to have occurred at 26‰ (Russell, 2013). Pagett (1981) suggested that localised physiological adaption to reduced or variable salinities may occur in nearshore areas subject to freshwater runoffs. Records indicate that SS.SSa.CMuSa.AbraAirr mainly occurs in full (30-35 ppt) salinity, but that it may also be found in variable (18-35 ppt) salinity (Connor *et al.*, 2004). This suggests that the species in this biotope may experience variable salinities, and resident species perhaps may be adapted to variation in salinity, as suggested by the results given by Pagett (1981). On the other hand, records indicate that SS.SSa.OSa.OfusAfil only occurs in full salinity and is a circalittoral habitat, so is less likely to experience variable salinities, and resident species, therefore, less likely to be adapted to variation in salinity, as suggested by the results given by Pagett (1981).

Owenia fusiformis is found in front of river outlets in the Mediterranean (Somaschini, 1993) and English Channel (Gentil *et al.*, 1990) so is, therefore, likely to experience variable salinities.

Sensitivity assessment: Echinoderms are generally considered to be stenohaline (Stickle & Diehl, 1987; Russell, 2013). However, the evidence suggests that the characterizing species in these biotopes are likely to resist a decrease in salinity to 18-30 psu. *Astropecten irregularis* is the only characterizing species that may suffer some mortality so resistance is therefore assessed as **Medium** and resilience as **High**. Sensitivity is therefore assessed as **Low**.

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

Tyler & Banner (1977) studied coastal hydrodynamics and echinoderm distributions in Oxwich Bay in the Bristol Channel. The authors suggested a positive correlation between the distribution of *Acrocnida brachiata* and the percentage of fine sediments, and that wave and tidal-current energy played a major role in determining the distribution of echinoderms on the seabed by influencing the composition of the sediment. *Acrocnida brachiata* occurred mainly in the muddier areas of the bay, where maximum bottom spring-tidal flood currents of 0.41 m/s were recorded. *Owenia fusiformis* was also common in the study site.

Amphiura filiformis respond rapidly to currents by extending their arms into the water column to 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 will change to deposit feeding in stagnant water or areas of very low water flow (Ockelmann & Muus, 1978). *Acrocnida brachiata* and *Amphiura filiformis* have been recorded in biotopes experiencing moderately strong (<0.5 -1.5 m/s), and very weak to moderately strong (negligible - 1.5m/s) water flow strengths, respectively (Connor *et al*., 1997a&b, 2004). Food requirements probably set a lower limit on the current regime of areas able to support brittlestars.

Astropecten irregularis has been reported to migrate offshore during winter, probably to avoid being displaced during storm surges, which has been observed, suggesting that *Astropecten irregularis* is probably likely to be displaced by increased tidal streams (Freeman *et al*., 2001).

Noffke *et al.* (2009) reported that *Owenia fusiformis* occurred in abundance in a study site characterized by highly variable flow velocity and direction due to tides. It was reported to have adapted feeding strategies depending on the flow conditions (Dales, 1957, cited in Noffke *et al*., 2009) and sediment dynamics. *Owenia fusiformis* is found in front of river outlets in the Mediterranean and can be subject to a wide range of water velocities. Increase in water flow rate will most likely cause winnowing of the sediment, but the tubes of *Owenia fusiformis* can stabilize the sediment and reduce water movement related stresses on the benthos (Somaschini, 1993).

Both *Amphiura filiformis* and *Owenia fusiformis* have been reported in the Northumberland coast, the UK, where tidal currents ranged between 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: The biotopes are found in weak to very weak tidal streams (Connor *et al*., 2004). The evidence presented suggests the characterizing species of these biotopes appear to have behavioural adaptations to changes in water flow. An increase in water flow rate may inhibit suspension feeding in the biotopes and alter the character of the soft-sediment but species may be able to switch to deposit feeding. A decrease in water flow may result in increased siltation, which could be associated with deposition of organic particles. The characterizing species are likely to be able to utilize the additional deposits and burrow up through the deposited sediment. A change in water flow rate at the pressure benchmark level is considered to fall within the range of flow speeds experienced by mid-range populations. Resistance and resilience are therefore assessed as **High** and the biotope considered **Not Sensitive** to a change in water flow at the pressure benchmark level.

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

Changes in emergence are **Not Relevant** to the 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 Q: High A: Medium C: Medium	High Q: High A: High C: High	Not sensitive Q: High A: Medium C: Medium

The brittlestar species that characterize these biotopes, *Acrocnida brachiata* and *Amphiura filiformis*, occur in a range of wave exposures from very sheltered to extremely exposed, and extremely sheltered to moderately exposed, respectively (Tillin & Tyler-Walters, 2014). Tyler & Banner (1977) studied coastal hydrodynamics and echinoderm distributions in Oxwich Bay in the Bristol

Channel. The authors suggested a positive correlation between the distribution of *Acrocnida brachiata* and the percentage of fine sediments, and that wave and tidal-current energy played a major role in determining the distribution of echinoderms on the seabed by influencing the composition of the sediment. *Acrocnida brachiata* occurred mainly in the muddier areas of the bay. *Owenia fusiformis* was also common in the study site.

Astropecten irregularis have been suggested to migrate offshore in the winter to avoid storms, and have been reported being washed ashore during strong wave surges (Rees *et al*., 1977, cited in Freeman *et al*., 2001). The communities described by Jones (1951) which are thought to represent SS.SSa.CMuSa.AbraAirr (Connor *et al*., 2004), occurred in fairly exposed conditions, with the author suggesting the wave action was felt at the depth of 45 m (25 fm), depth at which the community was reported to occur.

Wells *et al.* (1981) reported that *Owenia fusiformis* in the intertidal and shallow subtidal are likely to be buried as a result of wave action but can survive this by working its way up through the sediment in its flexible tube. However, the effect of being washed out of the sediment by wave action was not commented on. In this situation, *Owenia fusiformis* would probably have to rebury in the sediment and construct a new tube. However, *Owenia fusiformis* only builds one tube in its lifespan (Noffke *et al*., 2009). Although tube building by polychaetes is normally a relatively fast process of a few hours (Ziegelmeier, 1952; Hempel, 1957; Myers, 1972), this is unlikely to occur quickly enough to avoid predation by flatfish and opportunistic predators. A decrease in wave exposure is likely to cause increased siltation which adult *Owenia fusiformis* can probably survive (Dauvin & Gillet, 1991; Wells *et al*., 1981). However, juveniles cannot construct tubes in sediments with a grain size <63 µm (mud). Therefore, if there is a lot of clay and silt deposited around a population of *Owenia fusiformis* recruits will not be able to construct tubes, and juvenile mortality is likely to be high.

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 re-suspend the sediment and break up and scatter *Amphiura filiformis*. However, the species is able to burrow further into the sediment and is able to re-burrow if displaced.

Sensitivity assessment: SS.SSa.CMuSa.AbraAirr occurs at shallower depths than SS.SSa.OSa.OfusAfil (Connor *et al*., 2004) hence it is more likely to experience variable wave exposure. However, the ranges of wave exposures at which the biotopes occur are unlikely to be severe enough as to compromise the maintenance of the sediment composition of less than 20% silt/clay (Connor *et al*., 2004). The benchmark refers to a change in nearshore significant wave height. Assuming an offshore representation of SS.SSa.OSa.OfusAfil, it is likely this biotope will be less affected than SS.SSa.CMuSa.AbraAirr. Nevertheless, a change in nearshore significant wave height >3% but <5% is likely to fall within the range of wave exposures in which the biotopes occur. Resistance and resilience are therefore assessed as **High** and the biotopes considered **Not Sensitive** at the pressure benchmark level.

Chemical Pressures

	Resistance	Resilience	Sensitivity

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

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

Information about the effects of heavy metals on echinoderms is limited and no details specific to any brittlestars was found. However, Bryan (1984) 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. LC50 concentrations exceeding 0.1 mg copper per litre, 1 mg zinc per litre and 10 mg chromium per litre for a duration between 4 -14 days of exposure have been reported for echinoderm species (Crompton, 1997). 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. More recent 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.

Owenia fusiformis from the south coast of England were found to have loadings of 1335 µg copper per gram bodyweight and 784 µg zinc per gram bodyweight. The metals were bound in spherules within the cells of the gut (Gibbs *et al*., 2000). No mention was made of any ill effects of these concentrations of metal within the body and it is presumed that *Owenia fusiformis* is resistant of heavy metal contamination.

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.

Oil spills resulting from tanker accidents can cause large-scale deterioration of communities in intertidal and shallow subtidal sedimentary systems. The key species and many other species in the biotopes are likely to be affected. For example, after the West Falmouth, *Florida* spill of 1969 the entire benthic fauna was eradicated immediately following the spill and populations of the opportunistic polychaete *Capitella capitata* increased to abundances of over 200,000/m^2 (Sanders, 1978). 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). Exposure to 30,000 ppm oil reduces the bacterial load by 50% and brittlestars begin to die (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).

A few *Owenia fusiformis* were recorded in the subtidal sediments of the Pembrokeshire coast after the *Sea Empress* oil spill but whether densities had increased, decreased or remained the same was not recorded (Rutt *et al*., 1998). Different polychaetes have the reported as having varying levels of resistance to oil pollution (Kingston *et al*., 1997).

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.

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 will 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

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 not-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.

Other 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) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) 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.

Sensitivity assessment: Although species in these biotopes are likely to bio-accumulate radionuclides with potential impacts on the biological community, information concerning the effects of such bioaccumulation was found.

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

This pressure is **Not assessed**.

De-oxygenation	Low Q: High A: Medium C: High	Medium Q: High A: Medium C: Medium	Medium Q: High 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 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*. *Amphiura filiformis* has been 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 (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 has also been observed following large increases in eutrophication and subsequent reductions in oxygen (Vistisen & Vismann, 1997). At oxygen concentrations between 0.85 mg/l and 1.0 mg/l, Rosenberg *et al.* (1991) observed the species was able to survive for several weeks. However, the regeneration rate of arms is significantly decreased at low oxygen concentrations (1.8-2.2 mg/l) (Nilsson, 1999), 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. *Owenia fusiformis* is very resistant of anoxia and can resist anaerobic conditions for up to 21 days by becoming quiescent (Dales, 1958). In the Gullmarsfjord a hypoxia event in 1980/1981, of ca 0.3 mg/l eliminated all the macrobenthic fauna below 115 m depth. The recovery sequence was slow and communities were not re-established eighteen months after the collapse (Josefson & Widbom, 1988). No specific information the resistance of *Acrocnida brachiata* and *Astropecten irregularis* to decreased oxygen was found.

Sensitivity assessment: A decrease in oxygenation at the pressure benchmark level is likely to result in significant (25-75%) mortality of the characterizing species of these biotopes. With the loss of these species, the biotopes would likely be lost. Community composition would likely become dominated by fewer species that are resistant of hypoxic conditions, such as some polychaete worms, so that the overall species richness would decline significantly. Resistance is therefore assessed as **Low** and resilience as **Medium,** and the biotopes are judged as having **Medium** sensitivity to de-oxygenation at the pressure benchmark level.

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

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 impact upon 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 sea bed may also be enhanced.

Owenia fusiformis has been reported as not resistant of changes in nutrients, and *Amphiura* spp. as probably favoured by Hiscock *et al.* (2005a). However, interface feeders such as *Owenia fusiformis* and *Amphiura filiformis* that occur in these biotopes, 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). Furthermore, Noffke *et al.* (2009) suggested that the data reported by Reiss *et al.* (2006) of a mass occurrence of *Owenia fusiformis* (>11,000 ind./m^2) could be associated to the close proximity of an estuary with a zone of permanent haline stratification, concluding that the increased abundance was directly linked to the nutrient supply in the estuary, resulting in higher productivity and consequent food available to the polychaetes.

Quillien *et al.* (2015) investigated the effects of green tides on macrotidal exposed and semi-exposed sandy beaches and found that mean abundance and species richness of macrozoobenthic invertebrates were higher where green tides occurred and that the communities in the two types of beach analysed responded differently to eutrophication seen as green tides. In terms of mean abundance and species richness, *Owenia fusiformis* and *Acrocnida cf. spatulispina* were amongst the species positively affected by the presence of green tides in exposed sandy beaches. Nutrient enrichment that leads to eutrophication is recognised as a major and worldwide pollution threat, and a direct symptom is mass development of opportunistic macroalgae, which can have negative impacts of sediment and water quality, hence of benthic community, particularly in low energy environments (Quillien *et al.*, 2015).

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 good status as defined by the WFD.

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

Organic enrichment is likely to promote pelagic productivity and increase the amount of organic matter reaching the sea bed, 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.

Al-Farraj *et al.* (2012) analysed polychaete community structures within important sewage treatment stations in Saudi Arabia and found that the control stations, situated farther from the stations had the highest species diversity, richness and evenness, dominated by polychaetes *Owenia fusiformis* and *Lumbrineris garcilis*. These species were not dominant in sites within close proximity of the sewage treatment stations.

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 on 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 as a result of seasonal variations. *Owenia fusiformis* was one of the most abundant species three months after cessation close to the disposal site, but its abundance became stable thereafter, suggesting the opportunistic polychaete may benefit from organic enrichment by taking advantage of the of the diminished competition in the early stages of community succession.

Borja *et al*. (2000) and Gittenberger & van Loon (2011) in the development of an AMBI index to assess disturbance (including organic enrichment) both assigned *Amphiura filiformis* and *Owenia fusiformis* 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)'. However, for *Acrocnida brachiata*, while Borja *et al.* (2000) assigned the species to Ecological Group I 'species very sensitive to organic enrichment and present under unpolluted conditions', Gittenberger & van Loon (2011) assigned the species to Ecological Group II 'species indifferent to enrichment, always present in low densities with non-significant variations with time (from initial state, to slight unbalance)'. *Astropecten irregularis* has not been assigned an AMBI category. Although the Gittenberger & van Loon (2011) report is an update on Borja *et al.* (2000), the former is a peer reviewed publication. Given that the evidence used in both cases is unclear, confidence in the evidence is assessed as medium.

Sensitivity assessment: The evidence presented based on the AMBI scores conflicts and is considered with caution. 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%) and resilience as **Medium**. Thus, the biotopes are considered to have **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 muddy sand that characterizes these biotopes was replaced with soft or hard rock substrata, this would represent a fundamental change to the physical character of the biotopes. Additionally, the biological community that occurs and characterizes the biotopes would no longer be supported. The biotopes would therefore be lost.

Sensitivity assessment: Resistance to the pressure is considered **None**, and resilience **Very low**. Sensitivity has been assessed as **High**.

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

Records indicate that SS.SSa.CMuSa.AbraAirr and SS.SSa.OSa.OfusAfil occur in muddy sands, typically with less than 20% silt/clay (Connor *et al.*, 2004). *Acrocnida brachiata* is generally associated with fine sands (Barnes, 2008). *Astropecten irregularis* inhabits a variety of substrata ranging from coarse gravel to fine mud, although it's more commonly found in sand (Freeman *et al.*, 2001). *Owenia fusiformis* occurs in fine clean sand, muddy sand, sandy mud (Neal & Avant, 2008), and *Amphiura filiformis* has been recorded in range of sediment types from silty mud to mixed sediment (with stones and shells) (Tillin & Tyler-Walters, 2014).

Owenia fusiformis actively selects coarse particles for tube building, a process which occurs immediately after the transition from pelagic to benthic life (Noffke *et al*., 2009). A linkage between the induction of metamorphosis of *Owenia fusiformis* larvae and the fine sand portion of the sediment was observed (Wilson, 1932). If the fine fraction is missing in the sediment, initial tube building is strongly restricted and the survival of the juveniles is thus negatively influenced (Noffke *et al*., 2009).

Sensitivity assessment: The characterizing species of these biotopes are likely to be resistant to a change in one Folk class from, for example, muddy sand to sandy mud. 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** (the pressure is a permanent change) and the biotopes are considered to have **High** sensitivity to a change in sediment type by one Folk class.

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

Muddy sand communities are unlikely to be resistant of substratum loss because most species are infaunal and extraction of substratum to 30 cm is likely to result in the removal of the biological community along with substrata, including the characterizing species. For example, 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). Newell *et al*. (1998) stated that removal of 0.5 m (50 cm) depth of sediment is likely to eliminate benthos from the affected area. Shallow and deep disturbance can injure, kill and displace benthic organisms and, in the case of fisheries, target and non-target species can be removed from the habitat. Through these effects, fisheries can alter the biomass, production and species richness of benthic invertebrate communities (Hiddink *et al*., 2006).

Sensitivity assessment. Due to the nature of this pressure it is highly likely that a large amount of the sediment would be removed along with the biological community, resulting in the removal of the biotopes. Disturbance effects may be particularly apparent in more sheltered, stable habitats, than in more disturbed mobile sediments (Kaiser & Spencer, 1996). Resistance is, therefore, assessed as **None** and resilience as **Medium** with a sensitivity of **Medium** to extraction of substratum to 30 cm.

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

The brittlestars *Acrocnida brachiata* and *Amphiura filiformis* that occur and characterize these biotopes are shallow burrowers. By extending their fragile arms from the sediment to feed, individuals 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). Bourgoin & Guillou (1994) observed that the frequency of arm regeneration in population of *Acrocnida brachiata* in the Bay of Douarenez, France was extensive (nearly 70% of total arm population of the study site). Observations of *Acrocnida brachiata* populations from the west coast of Ireland, where all individuals exhibited scar or ongoing regeneration of damage. This suggests that this species can withstand high levels of arm damage, and is adapted to rotate the arms for feeding with most damaged arms staying buried in the sediment (Makra & Keegan, 1999). 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. 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. Up to 55% of the starfish *Astropecten irregularis* had lost arms in a heavily beam-trawled area of the Irish Sea, compared with only 7% in a less intensively fished area (Kaiser, 1996). Starfish have been reported to be relatively resistant of fishing activities (Bergman & van Santbrink, 2000).

Owenia fusiformis can be up to 10 cm in length (Hayward & Ryland, 1990) and its tubes up to 30 cm in length (Rouse & Pleijel, 2001). Therefore, a passing scallop dredge is likely to remove the anterior end, which can be regenerated (Gibbs *et al*., 2000), but not the whole worm.

The infaunal position occupied by species in these biotopes may provide some protection from abrasion at the surface only. Kaiser *et al.* (2006) undertook a meta-analysis of different fishing gears on a range of habitats. The authors concluded that the footprint of the impact and the recovery of communities varied with gear and habitat types. For example, beam trawling and scallop dredging had significant negative short-term impacts in sand and muddy-sand habitats; and mud habitats were shown to have substantial initial impacts by otter trawling but the effects tended to be short lived (recovery initiated within weeks after impact) with an apparent long-term positive post-trawl disturbance response from the increase of small bodied fauna.

Furthermore, SS.SSa.CMuSa.AbraAirr and SS.SSa.OSa.OfusAfil occur in silty muds (Connor *et al*., 2004). Abrasion events caused by a passing fishing gear, or scour by objects on the seabed surface are likely to have marked impacts on the substratum and 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).

Hinz *et al*. (2009) investigated the chronic effects of otter-trawling in soft-sediment benthic communities and suggested that impacts are cumulative and can lead to profound changes in benthic community composition, with far reaching implication for marine food webs.

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 they 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 Q: High A: High C: High	Medium Q: High A: Medium C: Medium	Medium Q: High A: Medium C: Medium

The key species in the biotopes are shallow burrowers, found close to the sediment surface. 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% (Bergman & van Santbrink, 2000).

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). 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).

Sensitivity assessment: The biotopes could be lost or severely damaged, depending on the scale of the activity (see abrasion pressure). Therefore, a resistance of **Low** is suggested. Resilience is probably **Medium**, and therefore the biotopes' sensitivity to this pressure if likely to be **Medium**.

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

The biotopes are found in weak to very weak tidal streams (Connor *et al*., 2004). Of the characterizing species, *Acrocnida brachiata* seems to be the only obligate suspension feeder, so clogging of feeding apparatus by suspended sediment is not a major consideration for the characterizing species of the biotopes. *Amphiura filiformis* feed on suspended material in flowing water, but will change to deposit feeding in stagnant water or areas of very low water flow (Ockelmann & Muus, 1978). *Astropecten irregularis* is carnivorous (Fish & Fish, 1996). Noffke *et al.* (2009) reported that *Owenia fusiformis* occurred in abundance in a study site characterized by highly variable flow velocity and direction due to tides, being reported to have adapted feeding strategies depending on the flow conditions (Dales 1957, cited in Noffke *et al*., 2009) and sediment dynamics. 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 as a result 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 SS.SSa.CMuSa.AbraAirr and SS.SSa.OSa.OfusAfil. Resistance and resilience are assessed as **High** and the biotopes therefore considered **Not Sensitive** to a change in suspended solids at the pressure benchmark level.

Smothering and siltation rate changes (light)	Medium Q: High A: High C: High	High Q: High A: Medium C: Medium	Low Q: High 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 (1.2-2.0 mm diameter), medium fine (0.25-0.95 mm diameter) and fine (0.1-0.25 mm 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. However, as a suspension feeder, brittlestar *Acrocnida brachiata* 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.

Under laboratory conditions, Christensen (1970) found that *Astropecten irregularis* was unable to re-surface once it had been buried beneath 4 cm of sediments, although it has been suggested that it buries deeper in the winter to avoid the cold and storms (Freeman *et al*., 2001).

Noffke *et al.* (2009) suggested that *Owenia fusiformis* may equally be found up to 3 cm below the sediment or protruding above the sediment surface. Furthermore, *Owenia fusiformis* is not obliged to compensate for sand covering resulting from disturbance caused by storms by elongation of the tube above the sediment surface but will move upward with its tube to maintain feeding (Watson, 1901, cited in Noffke *et al*., 2009), as it can migrate up through the sediment in their flexible tube (Wells *et al*., 1981). However, deposition of sediment with grain sizes <63 µm (mud) is likely to cause high mortality amongst recruits which cannot construct tubes in this sort of sediment.

Therefore, if a lot of clay and silt was deposited around a population of *Owenia fusiformis* recruits will not be able to construct tubes, juvenile mortality will be high. *Owenia fusiformis* also occurs in areas where dredging spoil is deposited (Dauvin & Gillet, 1991).

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 de-oxygenation. Furthermore, the biotopes occur within a range of wave exposure conditions from very sheltered to exposed, with weak and very weak tidal streams (Connor *et al*., 2004). Dispersion of fine sediments may be rapid, and this could mitigate the magnitude of this pressure by reducing the time exposed, as 'light' deposition of sediments is likely to be cleared in a few tidal cycles in areas of higher water flow.

Sensitivity assessment: The characterizing species in these biotopes are burrowers and therefore likely to be able to move within the sediment deposited as a result of a deposition of 5 cm of sediment. However, Christensen (1970) suggested 4 cm as the maximum burden *Astropecten irregularis* is able to migrate through. Resistance is therefore assessed as **Medium** (<25% loss) and resilience as **High** and the biotope is considered to have **Low** sensitivity to this pressure at the benchmark level.

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

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 (1.2-2.0 mm diameter), medium fine (0.25-0.95 mm diameter) and fine (0.1-0.25 mm 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. However, as a suspension feeder, brittlestar *Acrocnida brachiata* may not persist in areas of excessive sedimentation. Material in suspension can affect the efficiency of filter and suspension feeding (Sherk, 1971; Morton, 1977). Effects can include abrasion and clogging of gills, impaired respiration, clogging of filter mechanisms, and reduced feeding and pumping rates.

Under laboratory conditions, Christensen (1970) found that *Astropecten irregularis* was unable to re-surface once it had been buried beneath 4 cm of sediments, although it has been suggested that it buries deeper in the winter to avoid the cold and storms (Freeman *et al*., 2001).

Noffke *et al.* (2009) suggested that *Owenia fusiformis* may equally be found up to 3 cm below the sediment or protruding above the sediment surface. Furthermore, *Owenia fusiformis* is not obliged to compensate for sand covering resulting from disturbance caused by storms by elongation of the tube above the sediment surface but will move upward with its tube to maintain feeding (Watson, 1901, cited in Noffke *et al*., 2009), as it can migrate up through the sediment in their flexible tube (Wells *et al*., 1981). However, deposition of sediment with grain sizes <63 µm (mud) is likely to cause high mortality amongst recruits which cannot construct tubes in this sort of sediment. Therefore, if a lot of clay and silt was deposited around a population of *Owenia fusiformis* recruits will not be able to construct tubes, juvenile mortality will be high. *Owenia fusiformis* also occurs in areas where dredging spoil is deposited (Dauvin & Gillet, 1991).

Furthermore, the biotopes occur within a range of wave exposure conditions from very sheltered to exposed, with weak and very weak tidal streams (Connor *et al*., 2004). In the more exposed examples of the biotopes dispersion of fine sediments may be rapid, and this could mitigate the magnitude of this pressure by reducing the time exposed, as 'heavy' deposition of sediments is likely to be cleared in a few tidal cycles in areas of higher water flow.

Studies by Maurer *et al*. (1986) analysed the ability to vertically migrate and survival responses of three major taxa (polychaetes, crustacean and molluscs) when exposed to simulated disposition of dredged materials (0-40 cm). Their results suggested that there was evidence of synergistic effects on burrowing activity and mortality with changes in time of burial sediment depth, sediment type and temperature. Significant mortality was observed among all taxa under the maximum overburden by sand or fine sediment with varying contents of silt-clay.

Sensitivity assessment: The characterizing species in these biotopes are burrowers and therefore likely to be able to move within deposited sediment. However, a deposition of 30 cm of fine sediment is likely to result in a significant overburden of the infaunal species and, as a result, there may be some mortality of the characterizing species. Resistance is therefore assessed as **Low (**25-75% loss) and resilience as **Medium** and the biotopes are considered to have **Medium** sensitivity to this pressure at the benchmark level.

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

Not assessed.

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

N**o Evidence** was available on which to assess this pressure.

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

N**o Evidence** was available on which to assess this pressure.

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

SS.SSa.CMuSa.AbraAirr and SS.SSa.OSa.OfusAfil are circalittoral biotopes (Connor *et al*., 2004) and therefore, not directly dependent on sunlight. **Not Relevant.**

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

Not Relevant to biotopes restricted to open waters.

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

Not Relevant to seabed habitats.

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

Brittlestars are likely to have poor facility for visual perception and consequently are probably not sensitive to visual disturbance. Movement of a hand near to *Ophiothrix fragilis*, for example, elicits no escape response (Sköld, 1998). *Owenia fusiformis* has very simple eyes for light perception and therefore will not be affected by visual disturbance. Therefore, this pressure is considered **Not Relevant.**

Biological Pressures

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

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) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (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) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) 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). So far, no information of SS.SSa.CMuSa.AbraAirr and SS.SSa.OSa.OfusAfil been affected was found, but epidemic disease should be considered as having the potential to significantly affect echinoderm dominated populations, such as these biotopes. 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). No information was found on microbial pathogens affecting *Owenia fusiformis.*

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.

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

SS.SSa.CMuSa.AbraAirr and SS.SSa.OSa.OfusAfil are currently not targeted by commercial fisheries and hence not directly affected by this pressure. This pressure is therefore considered **Not Relevant**.

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

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, *Acrocnida brachiata*, *Astropecten irregularis*, *Owenia fusiformis* and *Amphiura filiformis*, may be damaged or directly removed by static or mobile gears that are targeting other species (see abrasion and penetration pressures).

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

Sensitivity assessment. The evidence suggests that some loss of the characterizing species is likely to occur as a result of unintentional removal. Removal of the characterizing species would result in the biotopes being lost. Thus, the biotopes are considered to have **Low** resistance to this pressure and to have **Medium** resilience, resulting in the sensitivity being judged as **Medium**.

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