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Marine Information Network

Information on the species and habitats around the coasts and sea of the British Isles

Seapens, including *Funiculina quadrangularis*, and burrowing megafauna in undisturbed circalittoral fine mud

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

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Please note. This MarESA report is a dated version of the online review. Please refer to the website for the most up-to-date version [<https://www.marlin.ac.uk/habitats/detail/239>]. All terms and the MarESA methodology are outlined on the website (<https://www.marlin.ac.uk>)

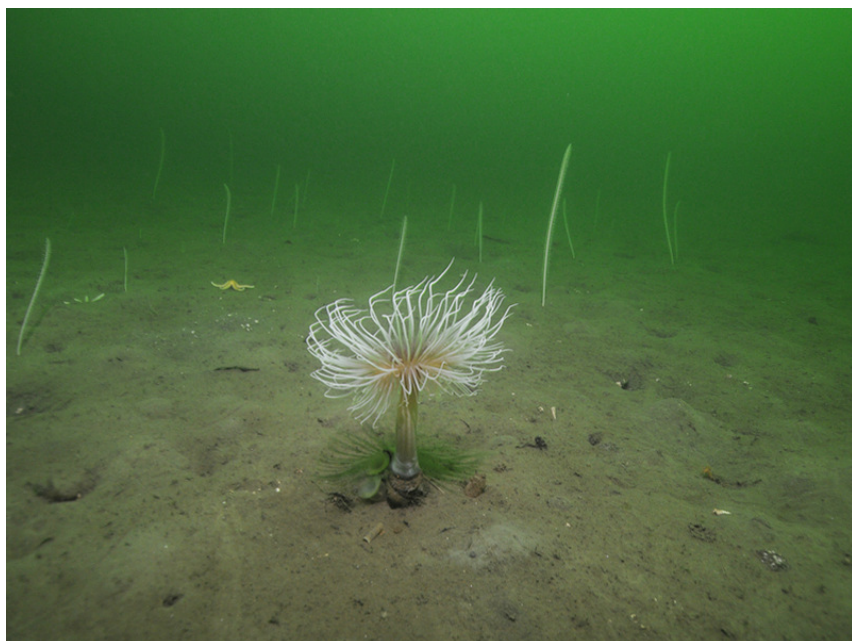
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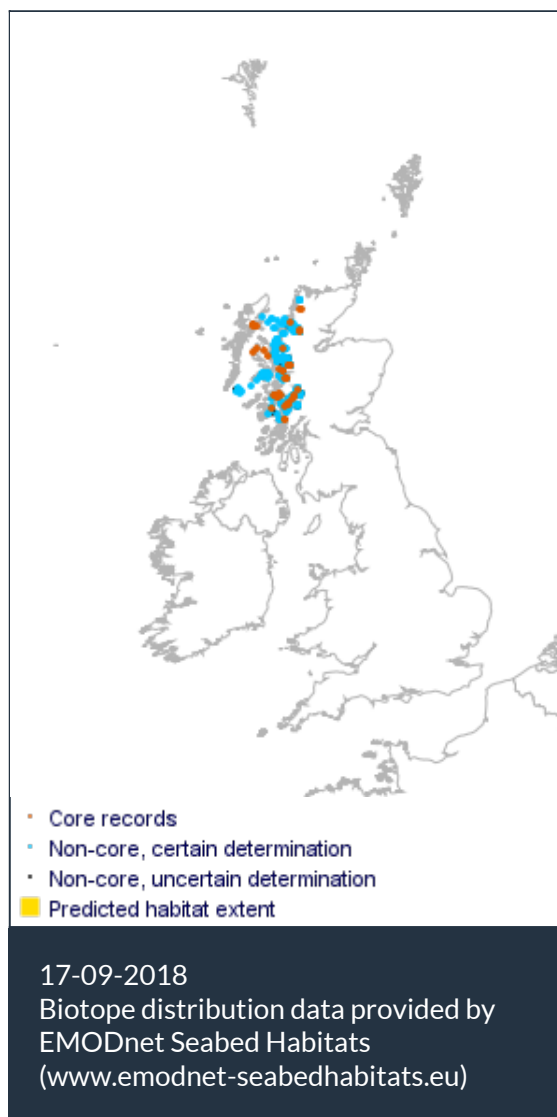


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Seapens, including *Funiculina quadrangularis*, and burrowing megafauna in undisturbed circalittoral fine mud
 Photographer: Keith Hiscock
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Researched by Dr Harvey Tyler-Walters

Refereed by Dr Clare Greathead

Summary

☰ UK and Ireland classification

EUNIS 2008 A5.3611

Seapens, including *Funiculina quadrangularis*, and burrowing megafauna in undisturbed circalittoral fine mud

JNCC 2015 SS.SMu.CFiMu.SpMmeg.Fun

Seapens, including *Funiculina quadrangularis*, and burrowing megafauna in undisturbed circalittoral fine mud

JNCC 2004 SS.SMu.CFiMu.SpMmeg.Fun

Seapens, including *Funiculina quadrangularis*, and burrowing megafauna in undisturbed circalittoral fine mud

1997 Biotope SS.CMU_.SpMmeg.Fun

Seapens, including *Funiculina quadrangularis*, and burrowing megafauna in undisturbed circalittoral soft mud

🔍 Description

Deep muds, especially in sea lochs, which support populations of sea pens such as *Virgularia mirabilis* and *Pennatula phosphorea*, but sometimes also with forests of the nationally scarce *Funiculina quadrangularis*. The sediment is usually extensively burrowed by crustaceans, the most common of which is *Nephrops norvegicus*, but *Callianassa subterranea* may also be present (the latter is likely to be under-recorded by grab sampling because it is deep burrowing). *Lesueurigobius friesii* is present at many sites. *Amphiura* spp. are usually present in high densities. (Information from Connor *et al.*, 2004; JNCC, 2015).

↓ Depth range

10-20 m, 20-30 m, 30-50 m

Additional information

Funiculina quadrangularis is also recorded in the Fladen Ground in the North Sea, and in the Minch, west Scotland (Greathead *et al.*, 2007, 2011, 2015).

✓ Listed By

- none -

Further information sources

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Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

CFiMu.Spnmeg and CFiMU.Spnmeg.Fun are similar to CFiMU.MegMax (Connor *et al.*, 2004) but differ in the relative abundance of sea pens (Spnmeg) and burrowing megafauna (MegMax). Connor *et al.* (2004) noted that MegMax often occurs in deeper water than Spnmeg but that the environmental factors that separate the biotopes are unclear. Hughes (1998a) suggested that the sea pen and burrowing megafauna communities exhibit a mosaic of patches of megafaunal communities depending on the level of disturbance. Hughes (1998a) also noted that the interaction between burrowing megafauna and sea pens was unknown, although they clearly co-exist.

Spnmeg and MegMax support a rich infauna of polychaetes, bivalves, burrowing sea urchins, brittlestars, and sea cucumbers, and a mobile epifauna of crabs and starfish. While the infaunal species composition varies between the biotopes, the infaunal and mobile epifaunal community is probably found across a range of circalittoral mud and deep mud habitats. Spnmeg.Fun is found in slightly deeper waters, typical of the fjordic sea lochs and the Minch, and is characterized by the presence of *Funiculina quadrangularis*. Spnmeg and Spnmeg.Fun may both support local populations of the rare burrowing anemone *Pachycerianthus multiplicatus* and occasional *Cerianthus lloydii*. Although *Pachycerianthus multiplicatus* is rare in the UK, loss of either burrowing anemone would not lead to a loss of the biotope.

Therefore, the sensitivity assessment of Spnmeg.Fun concentrates on the epifaunal, suspension feeding, sea pens because a significant reduction in their abundance, especially *Funiculina quadrangularis*, would result in the loss of the Spnmeg.Fun biotope. The sensitivity of burrowing megafauna and other species is discussed where relevant.

Resilience and recovery rates of habitat

Recent studies of oogenesis in *Funiculina quadrangularis* and *Pennatula phosphorea* in Loch Linnhe, Scotland, demonstrated that they were dioecious, with 1:1 sex ratios, highly fecund, with continuous prolonged oocyte development and annual spawning (Edwards & Moore 2008; Edwards & Moore, 2009). In *Funiculina quadrangularis* fecundity was high, expressed as 500-2000 per 1 cm midsection, but not correlated with size, and only a small proportion of the oocytes (<10%) matured. Unlike *Pennatula phosphorea*, annual spawning occurred in autumn or winter (between October and January). Also, the mature oocytes were very large (>800 µm), which suggested a lecithotrophic larval development (Edwards & Moore, 2009). In *Pennatula phosphorea*, oogenesis exceeded 12 months in duration, with many small oocytes of typically 50 per polyp giving an overall fecundity of ca 40,000 in medium to large specimens, depending on size. However, <30% matured (synchronously) and were spawned in summer (July-August). Mature oocytes were large (>500 µm) which suggested a lecithotrophic larval development (Edwards & Moore, 2008).

The lecithotrophic larval stage of *Funiculina quadrangularis* may result in a relatively long period of time in the water column and high potential dispersal ability and may explain the high gene flow observed between colonies of *Funiculina quadrangularis* in two Scottish sea lochs (Wright *et al.*, 2015). Wright *et al.* (2015) found limited genetic population subdivision within and between populations of *Funiculina quadrangularis* in Loch Linnhe and Loch Duich. However, the high genetic diversity and unique genotypes supported the absence of asexual reproduction in this species

(Wright *et al.*, 2015). No similar studies were available for *Virgularia mirabilis*, but Edwards & Moore (2009) noted that many sea pens exhibited similar characteristics. In a study of the intertidal *Virgularia juncea*, fecundity varied with length (46,000 at 50 cm and 87,000 at 70 cm), eggs reached a maximum size of 200-300 μm in May and were presumed to be spawned between August and September (Soong, 2005). Birkland (1974) found the lifespan of *Ptilosarcus gurneyi* to be 15 years, reaching sexual maturity between the ages of 5 and 6 years; while Wilson *et al.* (2002) noted that larger specimens of a tall sea pen (*Halipteris willemoesi*) in the Bering Sea were 44 years old, with a growth rate of 3.6 - 6.1 cm/year.

Sea pens were shown to recover rapidly from displacement and removal from the seabed. *Funiculina quadrangularis* and *Pennatula phosphorea* were found to right themselves when dislodged, with all *Pennatula phosphorea* individuals re-established and 50% of *Funiculina quadrangularis* after 72 hours (Eno *et al.*, 2001). *Virgularia mirabilis* was found to withdraw into its burrow rapidly (ca 30 seconds) and could not be uprooted by dragged creels (Hoare & Wilson 1977; Eno *et al.*, 2001; Ambroso *et al.* 2013). *Pennatula phosphorea* and *Funiculina quadrangularis* recovered with 72-96 hours after experimental smothering for 24 hours by pot or creel and after 96-144 hours of smothering for 48 hours (Kinnear *et al.* 1996; Eno *et al.* 2001). In summary, all three sea pen species have been found to recover rapidly from the effects of dragging, uprooting and smothering (Eno *et al.*, 2001). However, a later study of the effects of experimental trawling damage in the sea whip *Halipteris willemoesi* suggests that recovery in *Funiculina quadrangularis* may have been over-estimated. *Halipteris willemoesi* is a functionally similar species to *Funiculina quadrangularis*, as it is tall, thin, and cannot withdraw into the sediment. Malecha & Stone (2009) simulated trawl damage in field populations in Alaskan waters, by abrading the sea whip with rubber disks (similar to rubber tire punch-outs used on the footrope of many trawls), dislodging them from the sediment and breaking the axial rod manually. All the specimens abraded repaired tissue damage and survived the experimental period. However, the authors noted that the experimental abrasion probably underestimated the effect of trawls as it did not include the mechanical force of the mobile gear and that even the smallest amount of tissue damage probably decreased the sea whip's ability to reproduce. Fifty percent of the dislodged sea whips were able to rebury and become erect within 18 days. Only 42% of the fractured sea whips were erect 18 days after treatment. However, only one specimen was erect after the 372 days of the experiment. There was no evidence to suggest that specimens could repair their damaged axial rods. After 372 days, 92% of the dislodged and 100% of the fractured specimens had substantial tissue loss and perished. Tissue loss was exaggerated by predation from nudibranchs, which appeared to be attracted to the experimental area, possibly due to the tissue damage suffered by the sea whips (Malecha & Stone, 2009).

Recovery from effects that remove a proportion of the sea pen population (e.g. bottom gears, hydrographic changes) will depend on recruitment processes and little is known about the life history and population dynamics of sea pens (Hughes, 1998a). Hughes (1998a) suggested that patchy recruitment, slow growth and long lifespan were typical of sea pens. Larval settlement is likely to be patchy in space and highly episodic in time with no recruitment to the population taking place for some years. Greathead *et al.* (2007) noted that patchy distribution is typical for sea pen populations. In Holyhead harbour, for example, animals show a patchy distribution, probably related to larval settlement (Hoare & Wilson, 1977). However, no information on larval development, settlement behaviour or dispersal was found.

Buchanan (1963) examined the population dynamics of *Calocaris macandreae* off the Northumberland coast. The oldest individuals in that population appeared to be 9 years old and it was suggested that an age of almost ten years may be attained by a few (Buchanan, 1974).

Calocaris macandreae are hermaphrodites and eggs are produced at five years old. Around 50 eggs are attached to the pleopods and are carried for nine months until September to October of the sixth year. Annual moults follow but the next batch of eggs takes two years to mature and the second laying is at the end of the seventh year with occasionally a third at the end of the ninth year. Mortality of a year group is almost wholly confined to the ninth and tenth years (Buchanan, 1974). Hughes (1998a) noted that age at maturity (5 years), low fecundity (producing only two to three batches of eggs in their lifetime) and long lifespan contributed to the stability of the population studied, which was very stable in numbers over a 10-year period. No evidence was found for recovery rates following disturbance.

Callianassa subterranea is sexually dimorphic in that the mature male bears an enlarged major chela. In the North Sea, females were found bearing eggs from April to September, and planktonic larvae were most abundant in August. Larvae spent about four weeks in the plankton before settlement. Large females may have a secondary breeding period in late winter. Their lifespan was 2-3 years (Rowden & Jones, 1994; Hughes, 1998a).

Nephrops norvegicus reach sexual maturity at 2.5-3 years of age in females and after three years in males (Hughes, 1998a). In the Irish Sea, *Nephrops norvegicus* individuals are not thought to live more than 8 or 9 years and sexually mature at about 2.5 - 3 years. However, in deeper waters such as the Porcupine Bank, they may survive over 15 years (Marine Institute, 2001). In Scottish waters, eggs are spawned and fertilized between August and November and carried by the females until the larvae hatch in April to August (Hughes, 1998a). Local populations of *Nephrops norvegicus* may vary considerably in density, size and growth rate (Tuck *et al.*, 1997) with fecundity also varying geographically (Eiriksson, 1970; Tuck *et al.*, 1997). The percentage of eggs lost during development can range from 32 - 51% with larval mortalities as high as 87% (Garrod & Harding, 1980) which could reduce recovery rates. As a result, *Nephrops norvegicus* do not produce large numbers of offspring. The pelagic larval stage lasting up to 50 days (Hughes, 1998a; Johnson *et al.*, 2013; Powell and Eriksson, 2013). This may support long-range dispersal and recolonization of depleted populations, but water currents may prevent larvae reaching locations away from source populations and may remove larvae from populations preventing self-recruitment in small stocks (Johnson *et al.*, 2013). Recolonization of depleted populations may also be limited by the requirement for existing burrows for successful recruitment (Tuck *et al.*, 1994, cited in Johnson *et al.*, 2013). Adults are essentially sedentary as tagging studies have revealed movements of no more than 100 m from their burrow in adult life (Chapman & Rice, 1971). Therefore, potential recruitment from other populations of *Nephrops norvegicus* is low as larvae do not have a high dispersal potential and adults show no evidence of migration (Marine Institute, 2001). The resilience of *Nephrops* populations is assessed as 'Medium' (2-10 years) although confidence in the quality of evidence for recovery is low as this assessment is based on expert judgement, taking into consideration the apparent long-term stability of *Nephrops* fishing grounds (Ungfors *et al.*, 2013).

Resilience assessment. In SpnMeg.Fun (and SpnMeg) the resilience assessment is based on the recovery rates of the sea pens epifauna as the important characterizing species within the biotope. The characteristic burrowing megafauna is likely to recover more quickly, with perhaps the exception of *Calocaris macandreae*.

Where the sea pens survive impact undamaged, that is resistance is 'High', recovery is rapid; a resilience of 'High' (<2 years). Where a proportion of the population is removed or killed, then the species has a high dispersal potential and long-lived benthic larvae, but larval recruitment is probably sporadic and patchy and growth is slow, suggesting that recovery will take many years: a resilience of 'Low' (>10 years). The assessment is based on literature on the life history of the

three sea pen species but not their population dynamics or information inferred from on other species. Therefore, the quality, applicability and concordance of the evidence are '**Medium**'.

The recovery rates for mud shrimp and *Nephrops* are likely to be dependent on the spatial scale of impact and the ability of adults to survive exposure and provide a potential supply of colonists. *Callianassa subterranea* is short lived but produces numerous offspring with a high potential dispersal range, which suggests that recolonization and recovery may be rapid, e.g. within a few years. The evidence from fishing grounds indicates that *Nephrops norvegicus* can persist in areas where they are subject to targeted removal, which suggests that the population can withstand and recover from repeated disturbances, but it is not clear what proportion of the population is removed and hence what the recovery rate to an undisturbed state would be. The evidence above suggests that the mud shrimp and *Nephrops* component of the biotope would probably recover within 2-10 years; a resilience of **Medium**, depending on the scale of removal. *Calocaris macandreae* may be an exception. *Calocaris macandreae* is long-lived, reaches sexual maturity only after five years, has a low fecundity and lacks a pelagic stage. Therefore, local recruitment may be good, where a population remains but recovery of the abundance and age structure of a significantly reduced population would probably be prolonged and where the population experienced a significant reduction in abundance (e.g. resistance is Low), then resilience is likely to be **Low** (10-25 years).

Hydrological Pressures

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

In shallow sea lochs, sedimentary biotopes typically experience seasonal changes in temperature between 5°C and 15°C (10°C) (Hughes, 1998a). Although unusually warm summers or cold winters may change the temperatures outside this range, benthic burrowing species will be buffered from extremes by their presence in the sediment. The sea pens typical of CFiMu.SpMeg (except *Funiculina quadrangularis*) can also withdraw into their burrows for protection. No information was found on the upper limit of sea pens tolerance to temperature. *Virgularia mirabilis* is recorded from western Europe, the Mediterranean, from Norway and Iceland to Africa in the North Atlantic, and to the Gulf of Mexico in North America (Hughes, 1998a; OBIS, 2016). *Pennatula phosphorea* is recorded in the North Sea and western British coasts but is absent from southern Britain (Hughes, 1998a). Hughes (1998a) suggested that records from the Mediterranean and North Atlantic are confused with other species. *Funiculina quadrangularis* is only recorded from north and west coasts of Scotland and Ireland in the British Isles (Hughes, 1998a), but is also recorded in the North Atlantic, the Mediterranean, North and South America, Japan and New Zealand (Manual 1981 cited in Hughes 1998a; OBIS, 2016).

The distribution of sea pens suggests that they are probably resistant to a 2°C change in temperature. However, sea pens are subtidal and occur at depth where wide and rapid variations in temperature are not common and so may be less resistant of a short-term increase of 5°C. Therefore, a resistance of '**Medium**' is suggested but with Low confidence. Resilience is probably '**Low**' so that sensitivity is assessed as '**Medium**'.

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

None

Q: Low A: NR C: NR

Low

Q: Medium A: Medium C: Medium

High

Q: Low A: Low C: Low

No information on the salinity tolerance of the three sea pens was found. Jones *et al.* (2000) suggested that *Virgularia mirabilis* was more tolerant of reduced salinity due to its distribution in shallower waters. MNCR data recorded *Virgularia mirabilis* and *Pennatula phosphorea* species from biotopes (SS.SMu.IFiMu.PhiVir; SS.SMu.CFiMu.SpnMeg) that occur in full and variable salinity but *Funiculina quadrangularis* was only recorded in biotopes at full salinity. Analysis of survey data by Greathead *et al.* (2007), demonstrated that *Virgularia mirabilis* was the most ubiquitous of all three of the sea pens in Scotland, found in habitats nearer coastal areas and inner sea lochs. For example, *Virgularia mirabilis* is characteristic of the SS.SMu.IFiMu.PhiVir biotope, which can occur at depths of only 0-5 m. Greathead *et al.* (2007) suggested that *Pennatula phosphorea* was found in areas further from coastal areas and inner sea lochs, except in Loch Broom. *Funiculina quadrangularis* demonstrated a preference for deeper waters rather than any other physicochemical factor (Greathead *et al.*, 2007).

Pennatula phosphorea occurs in SS.SMu.CFiMu.SpnMeg at depths of >10 m, while *Funiculina quadrangularis* prefers deeper water (ca >20 m) where it is probably unexposed and hence intolerant to changes in salinity while *Virgularia mirabilis* is the most likely of the three sea pens to be exposed to variable salinity. Nevertheless, an increase in salinity to hypersaline conditions (>40 psu) for a year is probably detrimental to the sea pens and other epifauna, while deep burrowing species may be protected by their depth in the substratum. Therefore, *Funiculina quadrangularis* and *Pennatula phosphorea* probably have a resistance of '**None**' but the resistance of *Virgularia mirabilis* is probably '**Low**'. Resilience is likely to be at least '**Low**' and the resultant sensitivity is '**High**' for all three species. Due to the lack of direct evidence the assessment in resistance is made with Low confidence.

Salinity decrease (local)**None**

Q: Medium A: Low C: Medium

Low

Q: Medium A: Medium C: Medium

High

Q: Medium A: Low C: Medium

No information on the salinity tolerance of the three sea pens was found. Jones *et al.* (2000) suggested that *Virgularia mirabilis* was more tolerant of reduced salinity due to its distribution in shallower waters. MNCR data recorded *Virgularia mirabilis* and *Pennatula phosphorea* species from biotopes (SS.SMu.IFiMu.PhiVir; SS.SMu.CFiMu.SpnMeg) that occur in full and variable salinity but *Funiculina quadrangularis* was only recorded in biotopes at full salinity. Analysis of survey data by Greathead *et al.* (2007), demonstrated that *Virgularia mirabilis* was the most ubiquitous of all three of the sea pens in Scotland, found in habitats nearer coastal areas and inner sea lochs. For example, *Virgularia mirabilis* is characteristic of the SS.SMu.IFiMu.PhiVir biotope, which can occur at depths of only 0-5 m. Greathead *et al.* (2007) suggested that *Pennatula phosphorea* was found in areas further from coastal areas and inner sea lochs, except in Loch Broom. *Funiculina quadrangularis* demonstrated a preference for deeper waters rather than any other physicochemical factor (Greathead *et al.*, 2007).

Overall, the evidence suggests that *Virgularia mirabilis* is the most likely of the three sea pens to be exposed to variable salinity and its presence in shallow water biotopes suggests that it can tolerate occasionally reduced salinity while *Funiculina quadrangularis* is probably unexposed and hence intolerant to changes in salinity. *Pennatula phosphorea* occurs in SS.SMu.CFiMu.SpnMeg at depths of >10m where it is probably unexposed and hence intolerant to changes in salinity. Therefore, *Virgularia mirabilis* is probably resistant of variable salinity. But a decrease from full to reduced salinity for a year (the benchmark) e.g. from 32-35 units to 22-25 units for a year is probably more extreme. Therefore, *Funiculina quadrangularis* and *Pennatula phosphorea* probably have a resistance of **None** but the resistance of *Virgularia mirabilis* is probably **Low**. Resilience is likely to be at least **Low** and the resultant sensitivity is '**High**' for all three species.

Water flow (tidal current) changes (local)**Low**

Q: High A: High C: Medium

Low

Q: Medium A: Medium C: Medium

High

Q: Medium A: Low C: Medium

Sea pen biotopes (e.g. SS.SMu.CFiMu.SpnMeg) occur in low energy environments with weak (<0.5 m/sec) to very weak tidal streams (Connor *et al.*, 2004), which are a prerequisite for the fine mud sediments in which the sea pens occur (Hughes, 1998a). Of the three sea pens, *Virgularia mirabilis* occurs in coarser sandier muds with small stones and shell fragments e.g. SS.SMu.CSaMu.VirOphPmax (Hughes, 1998a; Greathead *et al.* 2007), and is probably more tolerant of current or wave induced flow than *Funiculina quadrangularis* and *Pennatula phosphorea* but the entire group is probably intolerant of increased flow. For example, Hiscock (1983) examined the effects of water flow on *Virgularia mirabilis*. As water flow rates increase, *Virgularia mirabilis* first responds by swinging polyps around the axial rod to face away from the current (at 0.12 m/s), then polyps face downstream. With further increase in flow, the stalk bends over and the pinnae are pushed together to an increasing amount with increasing velocity of flow (at 0.33 m/s). Finally, tentacles retract and at water speeds greater than 0.5 m/s (i.e. 1 knot) the stalk retracts into the mud (Hiscock, 1983). Best (1988) noted similar behaviour in the sea pen *Ptilosarcus gurneyi* and noted that filter efficiency, and hence feeding, increased with increased flow but then decreased once flow began to deform the shape of the sea pen. If water speeds remain at this level or above the sea-pen will be unable to extend above the sediment, unable to feed and could die. *Pennatula phosphorea* has a larger surface area due to its width, while *Funiculina quadrangularis* is larger and less flexible, suggesting both species may be less tolerant of increased flow than *Virgularia mirabilis*.

Greathead *et al.* (2015) suggested that the large surface area of *Funiculina quadrangularis* (compared to the other two sea pens) was a hindrance in strong currents but a potential competitive advantage in deeper quiescent waters as the amount of organic matter in the water column decreases with depth. In addition, long-term increases in water flow are likely to modify the sediment, removing the fine sediments the sea pens require in favour of sandier, coarser sediments. A change in sediment type could also affect the burrowing megafauna (see a change in sediment type below).

Sensitivity assessment. The biotope occurs in weak to negligible flow, so that a decrease in flow is not relevant. An increase in flow is probably directly detrimental to sea pens and may alter the sediment type in the long-term. An increase in water flow of 0.1-0.2 m/s for a year is may result in an increase in overall flow outside the preferred range for the sea pens, depending on location. Therefore, an increase in water flow may result in the removal or death of a proportion of the population of *Virgularia mirabilis*, and as the other sea pens are probably less tolerant of change, a resistance of '**Low**' is suggested, with a resilience of '**Low**', resulting in a sensitivity of '**High**'.

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 biotope, which is restricted to circalittoral below 10 metres. The pressure benchmark is relevant only to littoral and shallow sublittoral fringe biotopes.

Wave exposure changes (local)

High

Q: High A: High C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: High

Sea pen biotopes (e.g. SS.SMu.CFiMu.SpnMeg) occur in low energy environments, extremely sheltered to sheltered from wave exposure (Connor *et al.*, 2004), a prerequisite for the fine mud sediments in which the sea pens occur (Hughes, 1998a). While *Virgularia mirabilis* occurs in coastal areas and inner sea lochs, these areas are still sheltered from wave action, and in sandier muds (e.g. the biotope SS.SMu.CSaMu.VirOphPmax) wave exposure was not recorded to be more than 'sheltered'. Therefore, it is likely that all of the sea pens, characteristic of this biotope, are intolerant of an increase in wave action. *Virgularia mirabilis* is probably the most tolerant of the three species while *Funiculina quadrangularis* is probably the most intolerant as wave exposure is attenuated by depth and *Funiculina quadrangularis* prefers deeper waters than the other sea pens.

A decrease in wave exposure is unlikely in the sheltered habitats they inhabit. However, a decrease in wave exposure elsewhere may be beneficial by providing additional habitat for colonization and hence an increase in their distribution.

Sensitivity assessment. An increase in wave exposure is likely to affect all three species adversely, limiting or removing the shallower proportion of the population, and potentially modifying sediment and therefore habitat preferences in the longer-term. In some cases, areas suitable for *Pennatula phosphorea* and *Funiculina quadrangularis* may become more suitable for *Virgularia mirabilis*. However, a 3-5% increase in significant wave height (the benchmark) is unlikely to be significant. The benchmark level of change may be no more than expected during winter storms even in the sheltered waters favoured by this biotope. Alternatively, such a small change in wave action may not penetrate to the depths at which this biotope occurs. Therefore, resistance is recorded as '**High**' at the benchmark level. Hence, resilience is '**High**' and the biotope is assessed as '**Not sensitive**' at the benchmark level.

Chemical Pressures

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

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

In Norwegian fjords, Rygg (1985) found a relationship between species diversity in benthic fauna communities and sediment concentrations of the heavy metals Cu, Pb and Zn. Cu, in particular, showed a strong negative correlation and the author suggested a cause-effect relationship. Those species not present at sites where Cu concentrations were greater than ten times higher than the background level, such as *Calocaris macandreae*, *Amphiura filiformis* and several bivalves including *Nucula sulcata* and *Thyasira equalis*, were assessed as non-tolerant species. The tolerant species were all polychaete worms. Therefore, increased heavy metal contamination in sediments may change the faunal composition of the community and decrease overall species diversity. Some burrowing crustaceans, brittlestars and bivalves may disappear from the biotope and lead to an increasing dominance of polychaetes. But no information was found on the effect of heavy metals on sea pens.

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

There was no information found on the effect of hydrocarbon pollution on the biotope. The best documented oil spill for protected habitats with soft mud/sand substrata is the West Falmouth, Florida spill of 1969. Immediately after the spill virtually the entire benthic fauna was eradicated following the incident and populations of the opportunistic polychaete *Capitella capitata* increased to abundances of over 200,000/m² (Sanders, 1978). Persistent toxicity of Amoco Cadiz oil in sediment prevented the start of the recovery period (Clark, 1997). *Callinanassa subterranea* appears to be highly intolerant of sediment contaminated by oil-based drilling muds (Daan *et al.*, 1992). Oil from spills would have to be dispersed deep into the water column to affect the biotope and since the biotope occurs in very sheltered conditions this is unlikely to occur. However, should the sediment become contaminated with oil there is likely to be the loss of many species.

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**. There was no information found on the effect of chemical pollutants on the biotope, probably because burrowing megafauna are generally too difficult to sample to be included in standard pollution monitoring studies. And there is no information available on the possible consequences of chemicals to British sea pens.

However, effects on some of the individual species in the biotope have been reported. 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/g) and contained the following fauna: *Amphiura* spp.,

Brissopsis lyrifera, the bivalve *Abra alba* and several species of polychaete. Within two days of treatment with a TBT concentration above 13.7 $\mu\text{mol}/\text{m}^3$ all species except the polychaetes had crept up to the surface and after six weeks these fauna had started to decay. Thus, increased contamination from TBT is likely to result in the death of some intolerant species such as brittlestars and heart urchins. Bryan & Gibbs (1991) report that crabs appear to be relatively resistant to TBT although some deformity of regenerated limbs has been observed. However, arthropods are very intolerant of the insecticide carbaryl (1-naphthol n-methyl carbamate; sold under the trade name Sevin®), which has been used to control burrowing shrimp in oyster farms (Feldman *et al.*, 2000). Ivermectin, an anti-louse treatment that was used in the salmon fish farming industry, has been shown to be highly toxic to sediment dwelling polychaetes (Hughes, 1998b). Different species will be affected by different chemicals but a general trend in areas of increasing pollution is a reduction in species diversity with habitats becoming dominated by pollution tolerant polychaete worms.

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

In an investigation of bioturbation in the north-eastern Irish Sea, Hughes & Atkinson (1997) surveyed several sites close to the Sellafield (now Windscale) nuclear reprocessing plant. At a station immediately offshore from the Sellafield outfall pipeline a community similar to the CMU.SpMeg biotope was present. Burrow openings and shafts indicated the presence of the burrowing crustaceans *Callianassa subterranea*, *Goneplax rhomboides* and *Upogobia deltaura*. Epifauna were abundant, particularly *Ophiura ophiura* and *Asterias rubens*. The sea pen *Virgularia mirabilis* occurred at high density. Dragonets and small gobies were also common. Other species in the biotope such as *Nephrops norvegicus* and the echiuran worm *Maxmuelleria lankesteri* were also present at sites close to the outfall pipeline. Thus, the biotope occurs in bottom sediments that contain particles of long half-life radionuclides derived from the liquid effluent released from the reprocessing plant at Sellafield (now Windscale). 'No obvious effects' of the radionuclide effluent were observed (Hughes & Atkinson, 1997; Hughes, 1998a) but no information on the level of radiation was provided. Therefore, the biotope is may be resistant of such effluent but there is insufficient evidence to assess this pressure against the benchmark.

Introduction of other substances

Not Assessed (NA)

Q: NR A: NR C: NR

Not assessed (NA)

Q: NR A: NR C: NR

Not assessed (NA)

Q: NR A: NR C: NR

This pressure is **Not assessed**.

De-oxygenation

Medium

Q: Low A: NR C: NR

Low

Q: Medium A: Medium C: Medium

Medium

Q: Low A: Low C: Low

Virgularia mirabilis is often found in sea lochs so may be able to tolerate some reduction in oxygenation. However, Jones *et al.* (2000) reported that sea pen communities were absent from areas which are deoxygenated and characterized by a distinctive bacterial community and Hoare & Wilson (1977) reported that *Virgularia mirabilis* was absent from sewage related anoxic areas of Holyhead harbour.

Large active animals with high respiratory demands will be most affected by oxygen depletion. In moderately hypoxic conditions (1 mg/l) *Nephrops norvegicus* compensates by increasing production

of haemocyanin (Baden *et al.*, 1990). In the laboratory, this compensation lasted one week so at the level of the benchmark, the species will not be killed. However, at levels of about 0.6 mg/l the species died within 4 days. Catches of *Nephrops norvegicus* have been observed to be high when oxygenation in the water is low, probably because animals are forced out their burrows (Hughes, 1998a). Thalassinidean mud-shrimps are very resistant to oxygen depletion and enriched sulphide levels and many species can withstand total anoxia for several days (Hughes, 1998a).

Sensitivity assessment. The evidence suggests that severe hypoxic or anoxic conditions are likely to be detrimental to sea pen communities. However, sea pens may be resistant of short-term hypoxia due to their presence at depth in sheltered sea lochs. Nevertheless, Cole *et al.* (1999) suggested that most species would be affected at an oxygen concentration below 2 mg/l. Therefore, a precautionary resistance of '**Medium**' is suggested to represent to loss of a small proportion of the population but at 'Low' confidence as the evidence is limited to a single observation, on only one of the British sea pen species. Resilience is probably '**Low**' so that sensitivity is assessed as '**Medium**' but also with Low confidence.

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

Hoare & Wilson (1977) noted that *Virgularia mirabilis* was absent from part of the Holyhead Harbour heavily affected by sewage pollution. However, the species was abundant near the head of Loch Harport, Skye, close to a distillery outfall discharging water enriched in malt and yeast residues and other soluble organic compounds (Nickell & Anderson, 1977; cited in Hughes, 1998a), where the organic content of the sediment was up to 5%. *Virgularia mirabilis* was also present in Loch Sween in Scotland in sites where organic content was as high as 4.5% (Atkinson, 1989). Wilding (2011) noted that the abundance of *Pennatula phosphorea* was inversely correlated with predicted Infaunal Trophic Index (a predicted estimate of organic waste build-up) around salmon farms in Scotland, but that the effect only extended for 50 m from the cages. No information on the potential effect of nutrient enrichment on *Funiculina quadrangularis* was found.

Burrowing megafauna flourish in areas where the sediments are naturally high in organic matter, such as sheltered sea lochs (Hughes, 1998a). An increasing gradient of organic enrichment (e.g. in the vicinity of point sources of organic-rich effluent or sewage sludge dump sites) 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). The effects of organic enrichment on burrowing megafauna and other infauna depended on the degree of enrichment and any resultant hypoxia, which depend on the sediment type and local hydrology.

Sensitivity assessment. Sublittoral muds may be expected to be high in organic matter and nutrients, and the presence of *Virgularia mirabilis* in areas of up to 4.5% organic carbon (Atkinson, 1989) and distillery effluent suggest a resistance to nutrient enrichment. Similarly, the characteristic burrowing megafauna are probably resistant of all but gross enrichment. Nevertheless, this biotope is recorded as **Not sensitive** at the pressure benchmark that assumes compliance with good status as defined by the WFD.

Organic enrichment

Medium

Q: Medium A: Low C: Low

Low

Q: Medium A: Medium C: Medium

Medium

Q: Medium A: Low C: Low

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Harbour heavily affected by sewage pollution. However, the species was abundant near the head of Loch Harport, Skye, close to a distillery outfall discharging water enriched in malt and yeast residues and other soluble organic compounds (Nickell & Anderson, 1977; cited in Hughes, 1998a), where the organic content of the sediment was up to 5%. *Virgularia mirabilis* was also present in Loch Sween in Scotland in sites where organic content was as high as 4.5% (Atkinson, 1989). Wilding (2011) noted that the abundance of *Pennatula phosphorea* was inversely correlated with predicted Infaunal Trophic Index (a predicted estimate of organic waste build-up) around salmon farms in Scotland, but that the effect only extended for 50 m from the cages.

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For example, in a survey of Garoch Head sludge dumping grounds, Firth of Clyde, the burrowing megafauna (*Nephrops norvegicus*, *Callianassa subterranean*, *Calocaris macandreae*, *Lumpenus lampraetiformis* and *Cepola rubescens*) were abundant where organic content was <4% but absent where the organic content exceeded 6% (Smith, 1988, cited in Hughes, 1998a). *Calocaris macandreae* did not extend as far into the gradient as *Nephrops norvegicus* or *Lumpenus lampraetiformis* (Smith, 1988, cited in Hughes, 1998a). In Caol Scotnish, Loch Sween, bacterial mats of *Beggiatoa* were reported in the immediate vicinity of salmon cages in 1987. The burrowing megafauna (*Maxmuelleria lankesteri*, *Callianassa subterranea* and *Jaxea nocturna*) were abundant in unimpacted areas. But by 1988, the bacterial mats covered most of the seabed in the basin, the sediment was close to anoxic, and the burrows of megafauna were restricted to small areas free of *Beggiatoa*. After the removal of salmon cages in 1989, some recovery was apparent by 1990 with more burrows apparent, although the size of the individuals of *Maxmuelleria lankesteri*, *Callianassa subterranea* suggested that they had survived the loch basin during the peak of enrichment (Hughes, 1998a).

Sensitivity assessment. Sublittoral muds may be expected to be high in organic nutrients, and the presence of *Virgularia mirabilis* in areas of up to 4.5% organic carbon (Atkinson, 1989) suggest a resistance to organic enrichment at the benchmark level. Similarly, the characteristic burrowing megafauna are probably resistant of all but gross enrichment. Therefore, a precautionary resistance of 'Medium' is suggested, and as resilience is probably 'Low', a sensitivity of 'Medium' is recorded. However, *Pennatula phosphorea*, and by inference *Funiculina quadrangularis*, may be more sensitive.

A 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 sedimentary substrata were replaced with rock substrata the biotope would be lost, as it would no longer be a sedimentary habitat and would no longer support sea pens and burrowing megafauna.

Sensitivity assessment. Resistance to the pressure is considered 'None', and resilience 'Very low' or 'None' (as the pressure represents a permanent change) and the sensitivity of this biotope is assessed as 'High'.

Physical change (to another sediment type)

None

Q: High A: Medium C: Medium

Very Low

Q: High A: High C: High

High

Q: Medium A: Low C: Medium

Virgularia mirabilis occurs in a number of biotopes, on substrata ranging from mud, sandy mud, and gravelly mud, with or with shell fragments or stones (Connor *et al.*, 2004). Greathead *et al.* (2007) suggested that the muscular peduncle of *Virgularia mirabilis* allowed it to occupy coarser muds than the other sea pens, and explained its presence in the Moray Firth and Firth of Forth, and its wider distribution in Scotland. Greathead *et al.* (2007) noted that *Pennatula phosphorea* was absent in the North Minch while *Funiculina quadrangularis* and *Virgularia mirabilis* were present, but that *Pennatula phosphorea* was abundant in soft, adhesive mud with high silt-clay content in Loch Broom. This may suggest a preference for fine muds. The MNCR only recorded *Pennatula phosphorea* from biotopes in 'mud'. Greathead *et al.* (2007) also noted that *Funiculina quadrangularis* had the most restricted distribution, probably due to a preference of depth and soft deep muds of sheltered loch basins, where it was abundant. Again, the MNCR only recorded *Funiculina quadrangularis* from biotopes in 'mud'. However, it was also recorded from areas of muddy sand in the South and North Minches and in the Fladen Grounds but in deep water. In addition, a 'mud' substratum was the most important factor in a habitat suitability index model for sea pens developed by Greathead *et al.* (2015). In their model, habitat suitability for *Funiculina quadrangularis* increased with mud content up to a maximum at 90-100% mud. *Pennatula phosphorea* and *Virgularia mirabilis* also had their maximum habitat suitability at 100% mud. All three species had zero habitat suitability at 0% mud. However, gravel content was also important. *Virgularia mirabilis* was the most tolerant of gravel content and was still recorded at 50% gravel while there were no records of *Pennatula phosphorea* and *Funiculina quadrangularis* above 40% and 30% gravel respectively (Greathead *et al.*, 2015).

Callianassa subterranea creates a complex lattice of galleries at 30-40 cm below the surface in the fine muds but burrows less deeply (9-23 cm) in coarse sediments (Rowden & Jones, 1995; Hughes, 1998a). *Calocaris macandreae* creates burrows with a total depth of 21 cm in muddy sediments with a high silt content but is not found in sandy sediments (Buchanan, 1963; Hughes, 1998a). *Nephrops norvegicus* burrows to 20-30 cm and is found in soft mud sediments. The large echinuran *Maxmuelleria lankesteri* burrows up to 80 cm into the sediment and is found in fine muds and muddy sands in deep water (10-80 m) (Nickell *et al.*, 1995; Hughes, 1998a).

A change in sediment type by one Folk class (see benchmark) is likely to adversely affect the sea pens. A change from 'mud and sandy mud' to 'sand and muddy sand' or 'mixed' would probably

exclude *Pennatula phosphorea* and *Funiculina quadrangularis* (except where *Funiculina quadrangularis* occurs in deep basins) but not adversely affect *Virgularia mirabilis*, based on their reported distribution. It is also likely to result in a reduction in the abundance of most of the characteristic burrowing megafauna. Conversely, a change of sediment from coarse or sandy sediments to 'mud and sandy mud' will not affect *Virgularia mirabilis* but may allow the other sea pens to colonise. In all cases, a change in the sediment type is likely to change the associated community and result in loss of the sea pen population.

Sensitivity assessment. Sea pens have a narrow range of sediment type preferences, so their resistance to this pressure is '**None**' for the *Funiculina quadrangularis* and *Pennatula phosphorea* but '**Low**' for *Virgularia mirabilis* and, as resilience is '**Very low**' (the pressure is a permanent change), sensitivity is, therefore, '**High**'.

Habitat structure changes - removal of substratum (extraction)

None

Q: Medium A: Low C: Medium

Low

Q: Medium A: Low C: Medium

High

Q: Medium A: Low C: Medium

Benthic trawls (e.g. rock hopper ground gear, otter trawls) will remove and capture sea pens (Tuck *et al.*, 1998; Kenchington *et al.*, 2011), albeit with limited efficiency. Nevertheless, dredging and suction dredging penetrates to greater depth and are likely to remove sea pens. Although *Virgularia mirabilis* and *Pennatula phosphorea* can withdraw into the sediment, they will not be able to avoid activities that penetrate into the sediment. Assuming their burrows are only deep enough to hold the entire animal (see Greathead *et al.*, 2007 for sizes), then *Virgularia mirabilis* burrows are up to 40 cm deep while *Pennatula phosphorea* burrows are only up to 25 cm. *Funiculina quadrangularis* can grow up to 150 cm in height above the sediment surface but cannot withdraw into a burrow.

Sensitivity assessment. Extraction of sediment to 30 cm (the benchmark) could remove most of the resident sea pens present. Hence, their resistance is probably '**None**', and their resilience is at least '**Low**', resulting in a sensitivity of '**High**'.

Abrasion/disturbance of the surface of the substratum or seabed

Low

Q: High A: High C: Low

Low

Q: Medium A: Medium C: Medium

High

Q: Medium A: Low C: Low

In experimental studies (Kinnear *et al.* 1996; Eno *et al.* 2001), sea pens were found to be largely resilient to smothering, dragging or uprooting by creels or pots. In both *Pennatula phosphorea* and *Funiculina quadrangularis*, the pressure wave caused by approaching pots/creels bent the sea pen away, so that they were laid flat before contact. Kinnear *et al.* (1996) noted that *Pennatula phosphorea* and *Funiculina quadrangularis* were occasionally removed from the substratum by creels/pots. *Virgularia mirabilis* withdrew very quickly into the sediment when exposed to pots or creels, and so it was difficult to determine their response. However, all sea pens recovered from being dragged over by pots or creels within 24-72 h, with the exception of one individual *Funiculina quadrangularis*. Both *Pennatula phosphorea* and *Funiculina quadrangularis* were able to reinsert themselves into the sediment if removed as long as the peduncle remained in contact with the sediment surface, except in one specimen in which the peduncle was damaged. *Pennatula phosphorea* and *Funiculina quadrangularis* recovered with 72-96 hours after experimental smothering for 24 hours by pot or creel and after 96-144 hours of smothering for 48 hours (Kinnear *et al.* 1996; Eno *et al.* 2001).

However, a later study of the effects of experimental trawling damage in the sea whip *Halipteris willemoesi* suggests that recovery in *Funiculina quadrangularis* may have been over-estimated. *Halipteris willemoesi* is a functionally similar species to *Funiculina quadrangularis*, as it is tall, thin, and cannot withdraw into the sediment. Malecha & Stone (2009) simulated trawl damage in field populations in Alaskan waters, by abrading the sea whip with rubber disks (similar to rubber tire punch-outs used on the footrope of many trawls), dislodging them from the sediment and breaking the axial rod manually. All the specimens abraded repaired tissue damage and survived the experimental period. However, the authors noted that the experimental abrasion probably underestimated the effect of trawls as it did not include the mechanical force of the mobile gear and that even the smallest amount of tissue damage probably decreased the sea whip's ability to reproduce. Fifty percent of the dislodged sea whips were able to rebury and become erect within 18 days. Only 42% of the fractured sea whips were erect 18 days after treatment. However, only one specimen was erect after the 372 days of the experiment. There was no evidence to suggest that specimens could repair their damaged axial rods. After 372 days, 92% of the dislodged and 100% of the fractured specimens had substantial tissue loss and perished. Tissue loss was exaggerated by predation from nudibranchs, which appeared to be attracted to the experimental area, possibly due to the tissue damage suffered by the sea whips (Malecha & Stone, 2009).

Funiculina quadrangularis cannot withdraw into the sediment but both *Virgularia mirabilis* and *Pennatula phosphorea* can withdraw into tubes in the sediment. In *Virgularia mirabilis* withdrawal from a physical stimulus is rapid (ca 30 seconds) (Hoare & Wilson, 1977; Ambroso *et al.*, 2013). Birkland (1974) maintained that the only way to capture all of the sea pens in an area (quadrat) was to remove them slowly by hand until no more emerged. But several studies note that their ability to withdraw into the sediment in response to bottom towed or dropped gear (e.g. creels, pots, camera/video mounted towed sleds, experimental grab, trawl, or dredge) means that sea pen abundance can be difficult to estimate (Birkland, 1974; Eno *et al.*, 2001; Greathead *et al.*, 2007; Greathead *et al.*, 2011). The ability to withdraw also suggests that sea pens can avoid approaching demersal trawls and fishing gear. This was suggested as the explanation for the similarity in the densities of *Virgularia mirabilis* in trawled and untrawled sites in Loch Fyne, and the lack of change in sea pen density observed after experimental trawling (using modified rock hopper ground gear) over an 18 month period in Loch Gareloch (Howson & Davies, 1991; Hughes, 1998a; Tuck *et al.*, 1998). Kenchington *et al.* (2011) estimated the gear efficiency of otter trawls for sea pens (*Anthoptilum* and *Pennatula*) to be in the range of 3.7 – 8.2%, based on estimates of sea pen biomass from (non-destructive) towed camera surveys. However, species obtained by dredges were invariably damaged (Hoare & Wilson, 1977).

Hoare & Wilson (1977) noted that *Virgularia* was absent for areas of Holyhead Harbour disturbed by dragging or boat mooring, although no causal evidence was given (Hughes, 1998a). Sea pens are potentially vulnerable to long lining. Munoz *et al.* (2011) noted that small numbers of Pennatulids (inc. *Pennatula* sp.) were retrieved from experimental long-lining around the Hatton Bank in the North East Atlantic, presumably either attached to hooks or wrapped in line as it passed across the sediment. Hixon & Tissot (2007) noted that sea pens (*Stylatula* sp.) were four times more abundant in untrawled areas relative to trawled areas in the Coquille Bank, Oregon, although no causal relationship was shown. Greathead *et al.* (2011) noted that *Funiculina quadrangularis* was largely absent from Fladen fishing grounds in the northern North Sea, possibly due to its patchy distribution or fishing activities. Murillo *et al.* (2016) noted that species richness of the deep mud (>500m) communities (that included sea pens *Funiculina quadrangularis* and *Anthoptilum grandiflorum*) off the Tail of the Grand Bank and Flemish Cap, in the north-west Atlantic was negatively correlated with fishing intensity. In the southern Barents Sea, Buhl-Mortensen *et al.* (2016) reported that 70 of the 97 most common taxa (including *Funiculina*

quadrangularis) from the shelf (50-400 m) and slope (400-2000 m) were negatively correlated with fishing intensity.

Trawl caught *Nephrops* females were reported to have fewer eggs on average than creel caught females from the same area, during an experimental study, and that it was likely that the eggs may be lost due to physical abrasion (Chapman & Ballantyne, 1980). The proportion of eggs lost to abrasion ranged from 11-22 % in samples taken from the Clyde and West of Kintyre (Chapman & Ballantyne, 1980). *Nephrops* burrows are also likely to be damaged by abrasion. However, Marrs *et al.* (1998) reported that burrows were re-established within 2 days providing that the occupant had remained unharmed (Marrs *et al.*, 1998). The depth of the burrows constructed by characterizing megafauna (mud-shrimps and *Maxmuelleria lankesteri*) probably protects the species from surface abrasion and fishing activities. The burrow opening may be damaged (as above) but observations from Loch Sween suggest that they are re-established soon after experimental disturbance (Hughes, 1998a). Atkinson (1989) suggested that trawling was unlikely to affect burrowing megafauna (other than *Nephrops*) to 'any great extent'. Nevertheless, burrow density was lower in frequently trawled areas of Loch Fyne except in areas protected from trawling by submarine obstructions (Howson & Davies, 1991; Hughes, 1998a)

Sensitivity assessment. Overall, surface abrasion by pots and creels is unlikely to affect the three characterizing sea pens adversely. Towed gear is likely to remove a proportion of sea pens from the sediment, and if damaged they are likely to die, but if undamaged displaced and/or returned to suitable sediment they can recover relatively quickly. *Virgularia mirabilis* and *Pennatula phosphorea* can avoid abrasion by withdrawing into the sediment, but a frequent disturbance will probably reduce feeding time and hence viability. However, *Funiculina quadrangularis* cannot withdraw and is the tallest of all three of the sea pens (up to 2 m) and is the most likely to be displaced or removed by surface abrasion and towed gear, a resistance of '**Low**' is suggested where it is a dominant member of the community, as in CFiMu.SpMg.Fun. As the resilience is probably '**Low**', the sensitivity CFiMU.SpMg.Fun is probably '**High**'.

Penetration or disturbance of the substratum subsurface

Low

Q: High A: Medium C: Low

Low

Q: Medium A: Medium C: Medium

High

Q: Medium A: Low C: Low

The relevant evidence on the effects of fishing activities is present above under abrasion. Penetrative gear is likely to remove a greater proportion of the sea pen population, as it may remove them from their burrows, within the footprint of the activity. Therefore, resistance is assessed as '**Low**' for all three sea pen species. As resilience is probably '**Low**', sensitivity is assessed as '**High**'.

Changes in suspended solids (water clarity)

High

Q: Medium A: Low C: Medium

High

Q: High A: High C: High

Not sensitive

Q: Medium A: Low C: Medium

The characteristic sea pen species live in sheltered areas, in fine sediments, subject to high suspended sediment loads. The effect of increased deposition of fine silt is uncertain but it is possible that feeding structures may become clogged. When tested, *Virgularia mirabilis* quickly seized and rejected inert particles (Hoare & Wilson, 1977). Hiscock (1983) observed *Virgularia mirabilis* secretes copious amounts of mucus which could keep the polyps clear of silt. Kinnear *et al.* (1996) noted that *Funiculina quadrangularis* was quick to remove any adhering mud particles by the production of copious quantities of mucus. *Virgularia mirabilis* is also likely to be able to self-clean

(Hiscock, 1983). No indication of the suspended sediment load was given in any evidence found.

If feeding is reduced by increases in suspended sediment the viability of the population will be reduced. Once siltation levels return to normal, feeding will be resumed therefore recovery will be immediate. Similarly, burrowing megafauna are unlikely to be affected adversely by changes in suspended sediment in the water column. Overall, resistance is probably **High**, hence, resilience is also **High**, and the sea pens are probably **Not sensitive** at the benchmark level.

Smothering and siltation rate changes (light)

High

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

Pennatula phosphorea and *Funiculina quadrangularis* were found to recover within 72-96 hours after experimental smothering by pots or creels for 24 hours and after 96-144 hours after 48 hours of smothering by pots or creels (Kinnear *et al.*, 1996; Eno *et al.*, 2001). However, smothering by a pot or creel differs significantly from 30 cm of fine sediment, which could clog feeding apparatus and exclude oxygen. Kinnear *et al.* (1996) noted that *Funiculina quadrangularis* was quick to remove any adhering mud particles by the production of copious quantities of mucus, once the source of smothering (in this case potting) was removed. Similarly, Hiscock (1983) observed *Virgularia mirabilis* secretes copious amounts of mucus, which could keep the polyps clear of silt and is also likely to be able to self-clean.

Where present, the characteristic burrowing megafauna (mud-shrimp and *Nephrops*) are unlikely to be affected adversely as they are active burrowers and *Nephrops norvegicus*, *Calocaris macandreae* and *Callianassa subterranea* were reported within the Garroch Head (Firth of Clyde) sludge dumping ground (Smith, 1988; cited in Hughes, 1998a). In addition, if the deposited sediment occludes burrow openings, then they would be reopened quickly. Observations from Loch Sween suggest that they are re-established soon after experimental disturbance (Hughes, 1998a).

All three species occur in deep, sheltered muddy habitats where the accretion rates are potentially high. Both *Pennatula phosphorea* and *Virgularia mirabilis* can burrow and move into and out of their own burrows. It is probable therefore that deposition of 5 cm of fine sediment will have little effect other than to temporarily suspend feeding and the energetic cost of burrowing. *Funiculina quadrangularis* cannot withdraw into a burrow but can stand up to two metres above the substratum, and so will probably not be affected adversely. However, no direct evidence was found. Therefore, a resistance of **High** is suggested, resulting in a resilience of **High** and sensitivity of **Not sensitive** at the benchmark level.

Smothering and siltation rate changes (heavy)

High

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

Pennatula phosphorea and *Funiculina quadrangularis* were found to recover within 72-96 hours after experimental smothering by pots or creels for 24 hours and after 96-144 hours after 48 hours of smothering by pots or creels (Kinnear *et al.*, 1996; Eno *et al.*, 2001). However, smothering by a pot or creel differs significantly from 30 cm of fine sediment, which could clog feeding apparatus and exclude oxygen. Kinnear *et al.* (1996) noted that *Funiculina quadrangularis* was quick to remove any adhering mud particles by the production of copious quantities of mucus, once the source of smothering (in this case potting) was removed. Similarly, Hiscock (1983) observed *Virgularia mirabilis* secretes copious amounts of mucus, which could keep the polyps clear of silt and is also

likely to be able to self-clean.

Where present, the characteristic burrowing megafauna (mud-shrimp and *Nephrops*) are unlikely to be affected adversely as they are active burrowers and *Nephrops norvegicus*, *Calocaris macandreae* and *Callianassa subterranea* were reported within the Garroch Head (Firth of Clyde) sludge dumping ground (Smith, 1988; cited in Hughes, 1998a). In addition, if the deposited sediment occludes burrow openings, then they would be reopened quickly. Observations from Loch Sween suggest that they are re-established soon after experimental disturbance (Hughes, 1998a).

All three species occur in deep, sheltered muddy habitats where the accretion rates are potentially high. Both *Pennatula phosphorea* and *Virgularia mirabilis* can burrow and move into and out of their own burrows. It is probable therefore that deposition of 30 cm of fine sediment will have little effect other than to temporarily suspend feeding and the energetic cost of burrowing. *Funiculina quadrangularis* cannot withdraw into a burrow but can stand up to two metres above the substratum, and so will probably not be affected adversely. However, no direct evidence was found. Therefore, a resistance of **High** is suggested, resulting in a resilience of **High** and sensitivity of **Not sensitive** 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

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

No evidence (NEv)

Q: NR A: NR C: NR

No evidence was found

Underwater noise changes

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Some of the important characterizing species associated with this biotope, in particular, the sea pens, may respond to sound vibrations and can withdraw into the sediment. Feeding will resume once the disturbing factor has passed. However, most of the species are infaunal and unlikely respond to a noise disturbance at the benchmark level. Therefore, this pressure is probably **Not relevant** in this biotope.

Introduction of light or shading

High

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

Hughes (1998a) suggested that sea pens were insensitive to light. In shallow water, *Nephrops* only forages outside their burrows at night, but in deeper waters (ca 100 m) *Nephrops* are active during the day (Hughes, 1998a). while *Maxmuelleria lankesteri* is highly averse to light and its proboscis is only extended to the surface in the shallow waters of Loch Sween (Hughes, 1998a). Therefore, shading at the surface may alter the response of burrowing megafauna to daylight in the shaded area only but is otherwise unlikely to be detrimental. It is unlikely that artificial illumination would penetrate deep enough to affect the megafauna, except in the most shallow examples. However,

the important characterizing sea pens are unlikely to be affected. Therefore, the biotope is probably **Not sensitive** to changes in light.

Barrier to species movement

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant–this pressure is considered applicable to mobile species, e.g. fish and marine mammals rather than seabed habitats. Physical and hydrographic barriers may limit the dispersal of seed. But seed dispersal is not considered under the pressure definition and benchmark.

Death or injury by collision

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

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

Visual disturbance

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Most species within the biotope are burrowing and have no or poor visual perception and are unlikely to be affected by visual disturbance such as shading. Epifauna such as crabs have well developed visual acuity and are likely to respond to movement in order to avoid predators. However, it is unlikely that the species will be affected by visual disturbance at the benchmark level.

Biological Pressures

Resistance

Resilience

Sensitivity

Genetic modification & translocation of indigenous species

No evidence (NEv)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

No evidence (NEv)

Q: NR A: NR C: NR

No evidence of genetic modification, breeding, or translocation in sea pens or burrowing megafauna was found.

Introduction or spread of invasive non-indigenous species

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

Sternopsis scutata is a non-native polychaete that has extended its range in inshore muddy sediments in the south west of the UK (Shelley *et al.*, 2008). However, in mesocosm experiment, little effect on biological functioning was detected after the introduction of the polychaete and a doubling of its biomass (Shelley *et al.*, 2008). The red king crab *Paralithodes camtschaticus* is a voracious, omnivorous benthic predator that has spread from the Barents Sea to the coast of Norway, where it is a threat to shellfisheries and demersal fisheries. It has not been recorded in UK waters to date (GBNNSIP, 2011).

No direct evidence on the effect of non-native species on sea pen and burrowing megafauna communities was found. However, this assessment should be revisited in the light of new evidence.

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

The only major disease causing organism found in the biotope is the dinoflagellate parasite, *Hematodinium* sp. found in *Nephrops* populations from the west of Scotland, Irish Sea and North Sea (Hughes, 1998b). The parasite occurs in the blood and connective tissue spaces and appears to cause death by blocking the delivery of oxygen to the host's tissues (Taylor *et al.*, 1996). Infection is at its highest in the spring and early summer when a dense concentration of parasite cells in the blood give *Nephrops* an abnormal bright orange body and milky white ventral abdomen. Heavily infected animals become moribund, spend more time out of their burrows than healthy individuals making them more vulnerable to predation and fishing gear. Heavy infestation is fatal. The ecological consequences of *Hematodinium* infection and host mortality in *Nephrops* populations are unknown, but there are potential economic implications since the disease adversely affects meat quality. However, so far the *Nephrops* fishery has not suffered any serious decline. The infection appears to be cyclical. In the Clyde Sea, infection peaked in 1991-92 at 70% and had declined to 10 - 20% by 1996-7 (Hughes, 1998a).

However, no evidence was found on pathogen or parasite-mediated disease in sea pens.

Removal of target species	High	High	Not sensitive
	Q: Low A: NR C: NR	Q: High A: High C: High	Q: Low A: Low C: Low

Nephrops norvegicus is a characterizing species and *Nephrops* fisheries are of major economic importance. The species is fished throughout most of the geographic range of the biotopes in which it occurs including CMU.SpMeg. In trawled areas it is likely that the density of *Nephrops norvegicus* has been reduced but Hughes (1998b) reports that most stocks have the potential to recover even after heavy fishing pressure. Atkinson (1989) concluded that trawling for *Nephrops* was unlikely to affect other megafaunal burrowers to any great extent. The upper section of burrows will be disrupted by trawling but observations in Loch Sween have shown that surface openings are soon re-established (Hughes, 1998b).

Sensitivity assessment. This pressure considers any biological effects resulting from the removal of target species. Sea pens are not targeted by commercial fisheries and hence are not directly affected by this pressure. Although *Nephrops* is targeted the ecological relationships between sea pens and burrowing megafauna are unclear (Hughes, 1998a). Direct effects of static or mobile gears that are targeting other species are assessed in under abrasion and penetration of the seabed pressures. Therefore, the biotope is considered to be **Not sensitive** (to the ecological effects only) of targeted removal of other species.

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

Sea pens are not targeted by commercial or recreational fisheries but may be damaged or removed as by-catch and loss of the sea pens would change the biological character of the biotope. In observations of the impact of creeling activities, all three British species proved able to re-anchor

themselves provided the basal peduncle remained in contact with the sediment surface (Kinnear *et al.*, 1996; Eno *et al.*, 2001) (see abrasion above). *Virgularia mirabilis* was found to withdraw into its burrow rapidly (ca 30 seconds) and could not be uprooted by dragged creels (Hoare & Wilson 1977; Eno *et al.*, 2001; Ambroso *et al.* 2013). *Pennatula phosphorea* and *Funiculina quadrangularis* recovered with 72-96 hours after experimental smothering for 24 hours by pot or creel and after 96-144 hours of smothering for 48 hours (Kinnear *et al.* 1996; Eno *et al.* 2001).

The ability to withdraw also suggests that sea pens can avoid approaching demersal trawls and fishing gear. This was suggested as the explanation for the similarity in the densities of *Virgularia mirabilis* in trawled and untrawled sites in Loch Fyne, and the lack of change in sea pen density observed after experimental trawling (using modified rock hopper ground gear) over a 18 month period in Loch Gareloch (Howson & Davies, 1991; Hughes, 1998a; Tuck *et al.*, 1998). Kenchington *et al.* (2011) estimated the gear efficiency of otter trawls for sea pens (*Anthoptilum* and *Pennatula*) to be in the range of 3.7 – 8.2%, based on estimates of sea pen biomass from (non-destructive) towed camera surveys. However, species obtained by dredges were invariably damaged (Hoare & Wilson, 1977).

It should be noted that *Funiculina quadrangularis* cannot withdraw into the sediment. A study of the effects of experimental trawling damage in the sea whip *Halipteris willemoesi* suggests that recovery from dislodging and abrasion in *Funiculina quadrangularis* may have been over-estimated. *Halipteris willemoesi* is a functionally similar species to *Funiculina quadrangularis*, as it is tall, thin, and cannot withdraw into the sediment. Malecha & Stone (2009) simulated trawl damage in field populations in Alaskan waters, by abrading the sea whip with rubber disks (similar to rubber tire punch-outs used on the footrope of many trawls), dislodging them from the sediment and breaking the axial rod manually. All the specimens abraded repaired tissue damage and survived the experimental period. However, the authors noted that the experimental abrasion probably underestimated the effect of trawls as it did not include the mechanical force of the mobile gear and that even the smallest amount of tissue damage probably decreased the sea whip's ability to reproduce. Fifty percent of the dislodged sea whips were able to rebury and become erect within 18 days. Only 42% of the fractured sea whips were erect 18 days after treatment. However, only one specimen was erect after the 372 days of the experiment. There was no evidence to suggest that specimens could repair their damaged axial rods. After 372 days, 92% of the dislodged and 100% of the fractured specimens had substantial tissue loss and perished. Tissue loss was exaggerated by predation from nudibranchs, which appeared to be attracted to the experimental area, possibly due to the tissue damage suffered by the sea whips (Malecha & Stone, 2009).

Hoare & Wilson (1977) noted that *Virgularia* was absent for areas of Holyhead Harbour disturbed by dragging or boat mooring, although no causal evidence was given (Hughes, 1998a). Sea pens are potentially vulnerable to long lining. Munoz *et al.* (2011) noted that small numbers of Pennatulids (inc. *Pennatula* sp.) were retrieved from experimental long-lining around the Hatton Bank in the north east Atlantic, presumably either attached to hooks or wrapped in line as it passed across the sediment. Hixon & Tissot (2007) noted that sea pens (*Stylatula* sp.) were four times more abundant in untrawled areas relative to trawled areas in the Coquille Bank, Oregon, although no causal relationship was shown. Greathead *et al.* (2011) noted that *Funiculina quadrangularis* was largely absent from Fladen fishing grounds in the northern North Sea, possibly due to its patchy distribution or fishing activities. Murillo *et al.* (2016) noted that species richness of the deep mud (>500m) communities (that included sea pens *Funiculina quadrangularis* and *Anthoptilum grandiflorum*) off the Tail of the Grand Bank and Flemish Cap, in north west Atlantic was negatively correlated with fishing intensity. In the southern Barents Sea, Buhl-Mortensen *et al.* (2016)

reported that 70 of the 97 most common taxa (including *Funiculina quadrangularis*) from the shelf (50-400 m) and slope (400-2000 m) were negatively correlated with fishing intensity.

Sensitivity assessment. The removal of a proportion of the sea pen population as by-catch would change the character of the biotope. Therefore, a resistance of '**Medium**' is suggested for *Pennatula phosphorea* and *Virgularia mirabilis*. However, as *Funiculina quadrangularis* cannot withdraw and is more likely to be removed by bottom gears, a resistance of '**Low**' is suggested in CFiMu.Spnmeg.Fun. As the resilience is probably '**Low**', the sensitivity of Spnmeg.Fun is assessed as '**High**'.

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