Burrowing megafauna and *Maxmuelleria lankesteri* in circalittoral mud

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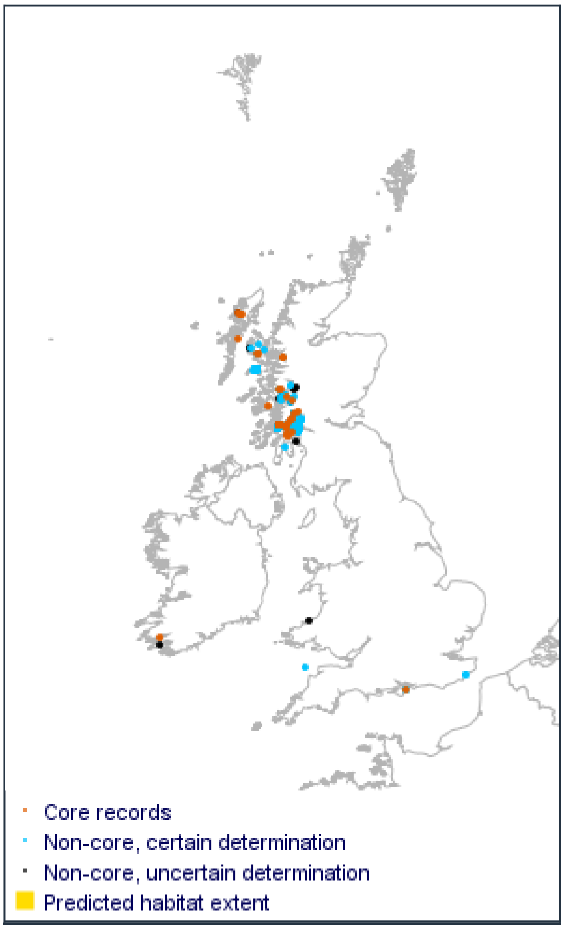

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Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

Researched by Olivia Durkin & Dr Harvey Tyler-Walters **Refereed by** Dr Clare Greathead

Summary

UK and Ireland classification

EUNIS 2008	A5.362	Burrowing megafauna and *Maxmuelleria lankesteri* in circalittoral mud
JNCC 2015	SS.SMu.CFiMu.MegMax	Burrowing megafauna and *Maxmuelleria lankesteri* in circalittoral mud
JNCC 2004	SS.SMu.CFiMu.MegMax	Burrowing megafauna and *Maxmuelleria lankesteri* in circalittoral mud
1997 Biotope		

Description

Distinctive populations of megafauna may be found in circalittoral stable mud. The megafauna typically include *Nephrops norvegicus*, *Calocaris macandreae* and *Callianassa subterranea*. Large mounds formed by the echiuran *Maxmuelleria lankesteri* are also frequent in this biotope. The seapen *Virgularia mirabilis* may occur occasionally in this biotope but not in the same abundance as SpnMeg to which MegMax is closely allied. Infaunal species may include *Nephtys hystricis*, *Chaetozone setosa*, *Amphiura chiajei* and *Abra alba*. (Information from Connor *et al*., 2004; JNCC, 2105).

Depth range

10-20 m, 20-30 m, 30-50 m, 50-100 m

Additional information

CFiMu.MegMax often occurs in slightly deeper water than CFiMu.SpnMeg but CFiMu.SpnMeg has a greater abundance of sea pens and is slightly less diverse (Connor *et al*., 2004).

Listed By

- none -

Further information sources

Search on:

G G JNCC

Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

CFiMU.MegMax is similar to CFiMu.SpnMeg and CFiMU.SpnMeg.Fun (Connor *et al.*, 2004) but differs 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.

MegMax and SpnMeg 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. The sea pen *Virgularia mirabilis* is recorded occasionally in MegMax but its loss from the biotope would not result in the loss of the biotope. However, the biotope is defined by the abundance of deep burrowing mud shrimps (*Calocaris macandreae* and *Callianassa subterranea*), Norway lobster *Nephrops norvegicus*, and the echiuran *Maxmuelleria lankesteri.*

Therefore, the sensitivity assessment of MegMax concentrates on the important characteristic burrowing megafauna because a significant reduction in their abundance would result in a change in the character or in the loss of the biotope. The sensitivity of surface infauna and epifauna (inc. *Virgularia mirabilis*) is discussed where relevant.

Resilience and recovery rates of habitat

Little is known about the reproduction and recruitment of *Maxmuelleria lankesteri*. Extreme sexual dimorphism is a characteristic of echiuran worms, with males being considerably smaller, attached to females or found within the female's nephridia (excretory glands). Presently, male *Maxmuelleria lankesteri* have not been recorded, possibly indicating that males are absent from the species (Hughes, 1998a). Hughes *et al.* (1996) suggest that reproduction could take place by parthenogenesis (asexual reproduction), which is a relatively rare process in marine invertebrates. Reproduction cycles have been inferred from collected samples; oocyte development occurs in spring/summer with mature eggs found within reproductive organs between October and December, suggesting a single, annual spawn in winter (Hughes *et al.*, 1996). The presence of large, yolky eggs suggests the planktonic stage is brief or entirely absent (Hughes, 1998a). *Maxmuelleria lankesteri* is a long-lived species with low recruitment rates; a similar echiuran worm species, *Urechis caupo*, is reported to live to 25 years old (Nickell *et al.*, 1995). Populations of *Maxmuelleria lankesteri* remain stable in density, with no wide fluctuations in abundance observed in Loch Sween over about ten years (Hughes, 1998a). Hughes (1998a) concluded that *Maxmuelleria lankesteri* is long-lived, with stable populations and low recruitment rates.

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 subterrranea 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. The proportion of ovigerous females declined during April and September, and no females with eggs were collected in October (Rowden & Jones, 1994). Larvae spent about four weeks in the plankton before settlement. Post-larvae were also relatively abundant in April, which supports evidence from Witbaard & Duineveld (1989) of a double reproductive cycle. Large females may have a secondary breeding period in late winter. Lindley (1987) found no *Callianassa subterranea* larvae in the North Sea plankton for late winter or early spring, which also supports the suggestion of a double reproductive cycle. However, Rowden & Jones (1994) suggest that the absence of larvae between the two peaks may be because *Callianassa subterranea* adopts an alternative life-history strategy of direct benthic development during this period. Such benthic larval development has been observed for *Callianassa kraussi* in South Africa. 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 lasts up to 50 days (Hughes, 1998a; Johnson *et al*., 2013; Powell & 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).

No information on reproduction and life history 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), and eggs reached a maximum size of 200-300 µm in May and were presumed to be spawned between August and September (Soong, 2005). Similarly, *Pennatula phosphorea* and *Funiculina quadrangularis* were highly fecund with prolonged oocyte development, spawned annually, and produced large eggs and potentially lecithotrophic larvae, although most oocytes did not reach maturity (Edwards

& Moore, 2008, 2009). A long-lived lecithotrophic larval stage and may explain the high gene flow observed between colonies of *Funiculina quadrangularis* in two Scottish sea lochs (Wright *et al*., 2015). 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.

Resilience assessment. In MegMax, the resilience assessment is based on the recovery rates of the burrowing megafauna. The evidence from fishing grounds indicates that *Nephrops norvegicus* can persist in areas where they are subject to targeted removal (Vergnon & Blanchard, 2006; OSPAR, 2010; Ungfors *et al*., 2013), which suggests that the population can withstand and recover from repeated disturbances.

European *Nephrops* fisheries are managed as separate fishing grounds, or Functional Units (FUs), which are smaller than the usual ICES sub-regions due to the limited dispersal abilities of *Nephrops* and the need to make stock assessments at a smaller scale. There were 34 FUs in European waters in 2012 (Ungfors *et al*., 2013). *Nephrops* is the only shellfishery managed under the Total Allowable Catch (TAC) scheme (Ungfors *et al*., 2013). Information on landings and fishing effort is combined with information on burrow density from underwater towed TV cameras to determine maximum sustainable yield (MSY). However, information on recruitment, the size of the spawning stock and age range of the population is lacking in most *Nephrops* stock. Therefore, the management uses proxies for estimates of fishing mortality (F_{MSY}), based on length cohort analysis averaged over a three-year period. Fishing mortality also varies between the sexes. Hence, estimates of abundance, recommended maximum sustainable yield (MSY), the related Biomass trigger points and fishing mortality (F_{MSY}), estimated harvest rates and ICES' recommended limits on landings and by-catch vary between FUs (Ungfors *et al*., 2013; Marine Scotland, 2016). For example, harvest rates (ratio of total catch to absolute abundance) varied from ca 5-25% between 2007 and 2015 in the Farn Deeps, and from ca 5-30% between 2005 and 2015 in South Minch (Marine Scotland, 2016). Marine Scotland (2016) suggest that the abundance of most stocks in the North Sea has declined to MSY Biomass trigger point but remain above the F_{MSY} trigger point. However, in West Scotland, most stocks are above the Biomass trigger point but fluctuate around the F_{MSY} (Marine Scotland, 2016). Nevertheless, landings of *Nephrops* in 2014 were 13,700 tonnes in the North Sea and 12,800 in West Scotland (Marine Scotland, 2016).

Callianassa subterrranea 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. *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). Similarly, populations of *Maxmuelleria lankesteri* may also take a long time to recover from a significant reduction in abundance or extent.

The evidence above suggests that the mud shrimp and *Nephrops* component of the biotope would probably recover within 2-10 years depending on the scale of removal. 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. However, 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).

Overall, where the pressure results in some mortality of the resident characteristic burrowing megafauna (resistance is 'Medium') then recovery is likely to take 2-10 years depending on the scale of the impact, and resilience is recorded as **Medium**. However, where the community suffers significant mortality (resistance is at least 'Low') then recovery is likely to be prolonged and a resilience of **Low** is recorded. As the assessment is based on a mixture of peer reviewed and grey literature, and expert judgement based on life-history characteristics, the confidence quality of the assessment is ranked as Medium, and its applicability and concordance also ranked as Medium.

Hydrological Pressures

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

In shallow sea lochs, sedimentary biotopes typically experience seasonal changes in temperature between 5°C and 15°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.

Callianassa subterranea is recorded from the Norwegian coasts of North Sea, south through the Bay of Biscay to the Mediterranean (OBIS, 2016). In the North Sea, *Callianassa subterranea* lives in water temperatures that vary between 6 and 15°C (Rowden *et al.*, 1998). *Calocaris macandreae* is abundant in muddy sediments around the British east and west coasts, extending from Scandinavia to West Africa and the Mediterranean (Ingle & Christiansen 2004; cited in Pinn & Atkinson, 2010). *Nephrops norvegicus* is distributed from Iceland to the eastern Mediterranean at temperatures between 6 and 17°C (Eriksson *et al.*, 2013; Johnson *et al.*, 2013). Hernroth *et al.* (2012) exposed individuals from a population found in the Skagerrak to temperature elevations 4°C above normal for the area for four months. No signs of oxidative stress were observed and mortality rates were not affected. *Maxmuelleria lankesteri* is recorded from the Irish Sea, Clyde Sea, Scottish sea lochs, the Kattegat and Skagerrak and north-west Spain (Hughes, 1998a).

Sensitivity assessment. Short-term acute changes in temperature and long-term chronic changes in temperature at the pressure benchmark are considered unlikely to adversely this biotope as global distribution suggest *Nephrops norvegicus*, *Calocaris macandreae* and *Callianassa subterranea* can potentially adapt to a wide range of temperatures experienced in both northern and southern waters. While *Maxmuelleria lankesteri* has a more limited distribution it would probably be able to avoid locally acute changes in temperature as they burrow deeply into the sediment. Therefore, resistance and resilience are assessed as **High.** This biotope is, therefore, considered to be **Not sensitive.**

	Resistance	Resilience	Sensitivity
Temperature decrease (local)	High Q: Medium A: Low C: Medium	High Q: High A: High C: High	Not sensitive Q: Medium A: Low C: Medium

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

No evidence was found to assess salinity tolerance of *Calocaris macandreae*. It is found in fully marine conditions. No habitat records from estuaries or brackish water were found. Similarly, *Callianassa subterranea* and *Maxmuelleria lankesteri* are only recorded from full (30-35) saline conditions.

Thompson & Ayers (1989) noted that *Nephrops* larvae were found at salinities of 34-35 ppt in the wild. Johnson *et al.* (2013) noted that *Nephrops* was generally restricted to full salinity waters, considered stenohaline, and was recorded by OBIS from 31.8 to 38.8 psu. Farmer (1975) reported that *Nephrops* occurred at salinities of 29-30 ppt in the Kattegat and 35.8-38.7 ppt in the Adriatic. However, Höglund (1942; cited in Farmer, 1975) suggested that the absence of *Nephrops norvegicus* in the Baltic Sea was due to its intolerance to very low salinities.

The effects of low salinity exposure and emersion were tested to simulate the conditions experienced by discarded *Nephrops* in the Kattegat area as these are transported through the halocline (Harris & Ulmestrand, 2004). *Nephrops* exposed to 15 psu (for <2 hr) suffered mortalities of 25-42% overall. Exposed animals gained mass rapidly as water was absorbed and showed delayed or absent responses to stimulation following return to waters of 33 psu.(Harris & Ulmestrand, 2004; Johnson *et al.*, 2013). In addition, *Nephrops* was reported to survive at 28 psu but experience 50% mortality 25 psu and 100% mortality at 21 psu (Harris & Ulmestrand, 2004).

An increase in salinity at the benchmark level, would result in a salinity of >40 psu, and as hypersaline water is likely to sink to the seabed, the biotope may be affected by hypersaline effluents. Ruso *et al.* (2007) reported that changes in the community structure of soft sediment communities due to desalinisation plant effluent in Alicante, Spain. In particular, in close vicinity to the effluent, where the salinity reached 39 psu, the community of polychaetes, crustaceans and molluscs was lost and replaced by one dominated by nematodes. Roberts *et al.* (2010b) suggested that hypersaline effluent dispersed quickly but was more of a concern at the seabed and in areas of low energy where widespread alternations in the community of soft sediments were observed. In several studies, echinoderms and ascidians were amongst the most sensitive groups examined (Roberts *et al*., 2010b).

Sensitivity assessment. An increase in salinity from full to >40 psu is probably detrimental to the important characteristic species of the biotope. Hypersaline water would probably sink to the seabed and potentially into the sediment via burrows. Although, there is no direct evidence of the effects of hypersaline water, the stenohaline nature of the community suggests that hypersaline conditions may cause mortality. Therefore, a resistance of **Low** is recorded but at Low confidence. Resilience would probably be **Low**, so that sensitivity may be **High**.

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

No evidence was found to assess salinity tolerance of *Calocaris macandreae*. It is found in fully marine conditions. No habitat records from estuaries or brackish water were found. Similarly, *Callianassa subterranea* and *Maxmuelleria lankesteri* are only recorded from full (30-35) saline conditions.

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Sensitivity assessment. A decrease in salinity from full to reduced (18-30 psu) is likely to be detrimental to most of the important characteristic species in the biotope. *Callianassa subterranea*, *Calocaris macandreae* and *Maxmuelleria lankesteri* are only recorded from full (30-35) saline conditions. The above evidence shows that short, acute reductions in salinity result in mortality in *Nephrops*, but also that reduced salinity results in mortality. Therefore, a reduction is salinity for a year is likely to either cause the mobile species to move out of the affected area or cause significant mortality. Therefore, a resilience of **Low** is recorded. Resilience would probably be **Low**, so that sensitivity may be **High**. It is noted that many Scottish sea lochs in which this biotope is recorded may experience variable salinity conditions but the hyposaline conditions probably do not occur at the depths this community occurs.

Water flow (tidal current) changes (local)	Medium Q: Low A: NR C: NR	Low Q: Medium A: Medium C: Medium	Medium Q: Low A: Low C: Low

This biotope occurs in weak to very weak (negligible) flow, in deep low energy environments. A further decrease in water flow is unlikely. *Nephrops* has been shown to walk in line with water flow between 0.07 and 0.2 m/s in flume experiments (Newell *et al*., 1988) but no other direct evidence of the effects of changes in water flow was found. Increased flow has the potential to modify the sediment, especially at the surface. A significant increase in water flow may winnow away mud surface or even remove the mud habitat and hence the biotope if prolonged. An increase of 0.2 m/s may begin to erode the mud surface where the site is already subject to flow (e.g. weak flow at the seabed), based on sediment erosion deposition curves (Wright, 2001). However, given the depth of mud that characterizes the biotope only the surface of the mud may be removed within a year. Hence, the deep burrowing community may remain intact but the surface infauna and erect epifauna may reduce in abundance. Therefore, a resistance of **Medium** is recorded but with Low confidence. Resilience is probably **Medium** and sensitivity of the biotope is assessed **Medium**.

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

SS.SMu.CFiMu.MegMax occurs in low energy environments, extremely sheltered to sheltered from wave exposure (Connor *et al*., 2004), a prerequisite for the fine mud sediments in the community is found (Hughes, 1998a). In addition, the biotope is found to considerable depths, at which, wave action in unlikely to be significant. Therefore, a decreased in wave exposure is not relevant. However, any activity or climatic effect that increased wave action or storminess could have a significant effect on the shallower examples of the biotope, due to removal or modification of the sediment. However, a change of 3-5% in significant wave height (the benchmark0 is unlikely to be significant. Therefore, the biotope is probably **Not sensitive** (resistance and resilience are High) 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.

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

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.

In the fish farming industry, a range of synthetic compounds has been used treat parasitic infestations in the past. Ivermectin, an anti-louse treatment, was shown to be highly toxic to sediment-dwelling polychaetes (Black *et al.*, 1997; Thain *et al.*, 1997), epibenthic shrimps (Burridge & Haya, 1993) and also thought to be toxic to burrowing megafauna (Hughes, 1998a). The pesticide carbamyl (1-naphthol n-methyl carbamate; trade name Sevin®) has been used to control populations of thalassinidean mud-shrimps in areas important for oyster cultivation (Feldman *et al.*, 2000).

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

Burrowing fauna probably have a major influence on the distribution of radionuclides within the sediments (Kershaw *et al.*, 1983). *Maxmuelleria lankesteri* burrows may act as sinks for surface-derived radionuclides and there is probably little return of deeply-buried material to the sediment surface (Hughes *et al.*, 1996). Plutonium is reported to accumulate in the linings of *Maxmuelleria lankesteri* burrows, this emphasises the role of bioturbation in the incorporation of radionuclides in deeper sediments (Kershaw *et al.*, 1984). Communities similar to this biotope containing abundant burrowing megafauna and sea pens were found to exist in areas heavily contaminated by radionuclides, in particular near Sellafield, Cumbria, due to the activities of the British Nuclear Fuels Plc reprocessing plant (Hughes & Atkinson, 1997) but no information on the level of radiation was provided. No reports on the effects on the fauna themselves were found. 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: High A: High C: Medium	Medium Q: Medium A: Medium C: Medium	Medium Q: Medium A: Medium C: Medium

Crustaceans are thought to be amongst the most susceptible group to the effects of hypoxia (Diaz

& Rosenberg, 1995; Vaquer-Sunyer & Duarte, 2008; Eriksson *et al.*, 2103). Large, active animals with high respiratory demands are likely to be most affected by oxygenation changes, whereas burrow-dwelling fauna may be less susceptible to hypoxic conditions. The oxygen concentrations in *Nephrops* grounds was reported to be between 6 and 9.4 mgO_2/l and in Scottish sea lochs has been reported to range from 1 -9.2 mgO_2/l (Gilibrand *et al.*, 2006; Eriksson et al., 2013). Oxygen depletion can occur naturally (warm temperatures combined with prolonged stratification of the water column), however, it can also be caused by human activities such as sewage disposal, cage aquaculture or eutrophication.

Diaz & Rosenberg (1995) suggested that *Nephrops norvegicus* was sensitive to hypoxia. *Nephrops norvegicus* is sensitive to extreme hypoxia (0.6 mg O_2/l), but in moderately hypoxic conditions (1 mg O_2/l) can compensate by increasing haemocyanin levels (Baden *et al.*, 1990).

In the laboratory, juvenile *Nephrops* behaviour and mortality changed with lowered oxygen concentrations; energetically costly activities were reduced, and activity in general declined. In normoxia, juveniles initially walked and then burrowed but when exposed to hypoxia they were mainly inactive with occasional outbursts of escape swimming. To increase oxygen availability the juveniles were observed to raise their bodies on stilted legs (similar to adults in hypoxic conditions) but an oxygen saturation of 25% (<2.5 mg O_2/l) were lethal within 24 h (Eriksson & Baden, 1997). Burrowing behaviour was tested in post-larvae at an oxygen saturation of >80% (<8 mg O_2/l) for 1 wk. The difference in time taken to complete a V-shaped depression or a U-shaped burrow was measured and showed a strong negative relationship between post larval age and burrowing time but all individuals made a burrow. Eriksson & Baden (1997) suggested that juveniles were, therefore, more sensitive to hypoxia than adults.

In moderately hypoxic conditions 38-43% saturation (3.8-4.3 mg O_2/l) adult *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 would not be killed. However in severe hypoxia, <20% saturation (<2 mg/l) *Nephrops* became less active and raised their bodies on their legs (Baden *et al.*, 1990). During laboratory studies at <15% O_2 (1.5mg O_2/l) specimens of *Nephrops norvegicus* stopped feeding even though there was available food suggesting that hypoxia induces starvation (Baden *et al.*, 1990). At 12% (<1.2 mg O_2/l) oxygen saturation some specimens of *Nephrops norvegicus* began to 'tip toe'. They supported themselves by elevating the body from the substratum with their claws and telson. The lobsters remained elevated until they became tired, sluggish, and barely moved when touched for 2-3 days after which they died (Baden *et al.*, 1990). At <10% (<1 mg O_2/l) adult *Nephrops* died within a few days (Baden *et al.*, 1990; Eriksson *et al.*, 2013).

Nephrops leave their burrows at <50% O_2 (at 1 m above the substratum) or <15% O_2 (at 0.5 m above the substratum) (Eriksson *et al.*, 2013). Catches of *Nephrops norvegicus* were found to be high in hypoxic conditions, probably because the animals are forced out of their burrows (Eriksson & Baden, 1997). Baden *et al.* (1990) reported that the *Nephrops* biomass declined from 10.8 kg/hr to zero from October 1984 to September 1989 in the SE Kattegat, an area affected by 1-3 month periods of low oxygen concentrations (< 2ml/l = 2.8 mg/l) during the 1980s. Eriksson *et al.* (2013) suggested that increased temperatures due to climate change may increase hypoxic stress on benthos as median lethal oxygen concentration increases with temperature.

The bioturbative activity of burrowing megafauna improves ventilation and oxygenation of burrows. Thalassinidean mud-shrimps are very resistant to oxygen depletion and many species can survive extended periods of anoxia of 50-60 hr at 10°C (Anderson *et al.*, 1994). *Callianassa* *subterranea* burrows are often hypoxic or even anoxic (Hughes, 1998a). In laboratory experiments, the species survived for up to five days under anoxic conditions at 6°C (Powilleit & Graf, 1996). The species has several adaptations that allow it to survive in low oxygen environments: a low rate of oxygen consumption, large gill areas and a respiratory pigment with a high oxygen affinity (Astall *et al*., 1997; Taylor *et al*., 2000). However, anoxic, sulphide-rich waters upwelling in a Norwegian fjord (Christiansen & Stene, 1998; cited in Hughes, 1998a) killed *Callianassa subterranea*.

Calocaris macandreae also in habitats burrows subject to severe hypoxia. In the laboratory, *Calocaris macandreae* was highly tolerant of anoxia, with a LT_{50} of 43 hr (although some specimens survived for 49.5 hrs), as it exhibited anaerobic metabolism at severe hypoxia (PO_2 <7 Torr, or ca 0.4 mg O_2/l) (Anderson *et al*., 1994).

Mud shrimps are among the few species to survive the low oxygen partial pressures and high sulphide levels in the vicinity of fish cages in sea lochs (Atkinson, 1989). 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. However, 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 subterranean* suggested that they had survived the loch basin during the peak of enrichment (Atkinson, 1989; Hughes, 1998a). Little other evidence on the tolerance of *Maxmuelleria lankesteri* to deoxygenation was found. However, it is thought to be tolerant of hypoxic conditions, as burrow conditions often become hypoxic (Hughes, 1998a).

In experiments exposing benthic invertebrates to decreasing oxygen levels, *Amphiura chiajei* only left its protected position in the sediment when oxygen levels fell below 0.54 mg O_2L^{-1} (Rosenberg *et al*., 1991). This escape response increases its risk to predators. Mass mortality in a superficially similar species of ophiuroid, *Amphiura filiformis* from the south-east Kattegat has been observed during severe hypoxic events (< 0.7 mg/l), while the abundance of *Amphiura chiajei* remained unchanged at the same site and time (Rosenberg & Loo, 1988).

Sensitivity assessment. Therefore, a decrease in oxygenation to 2 mg/l or below for a week (the benchmark), is likely result in mortality of *Nephrops* due to an increase in predation or fishing mortality, or direct mortality due to severe hypoxia. The mud shrimp fauna and *Maxmuelleria lankesteri* may survive severe hypoxia or even anoxia in a short period or one week (the benchmark). *Amphiura chiajei* abundance in the biotope may also not be affected adversely until exposed to severe hypoxic conditions. However, a reduction in the abundance of *Nephrops* is unlikely to change to the character of the biotope as the other important characteristic species are likely to remain. Therefore, a resistance of **Medium** is suggested. As the *Nephrops* population would probably recover within 2-10 year, resilience is likely to be **Medium**, and, hence, sensitivity is assessed as **Medium**.

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

Burrowing megafauna flourish is areas where the sediments are naturally high in organic matter and, hence nutrients, such as sheltered sea lochs (Hughes, 1998a). For example, *Nephrops* *norvegicus* was present in high densities in Loch Sween, Scotland where the organic content was about 5% and as high as 9% in some patches (Atkinson, 1989). *Callianassa subterranea* is found in sediments with a range of organic content. In the soft, organically enriched sediments (typical organic carbon values of 3.6 - 7.8%) of Loch Sween, a sea loch in Scotland, *Callianassa subterranea* was present as a significant megafaunal burrower (Atkinson, 1989). The maximum depth of the species burrows has been recorded as 86 cm, which Nickell & Atkinson (1995) suggest is an underestimate, indicates a nutritional requirement for sub-surface organic matter. In the North Sea, where sediments have a low organic content Rowden & Jones (1997) found *Callianassa subterranea* had to construct much more complex burrows to support their energetic costs.

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. For example, is a survey of Garoch Head sludge dumping grounds, Firth of Clyde, the burrowing megafauna (*Nephrops norvegicus*, *Callianassa subterranean*, *Calocaris macandreae*, *Lumpenus lampraetiformis* and *Cepola rubsecens*) 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 subterranean* suggested that they had survived the loch basin during the peak of enrichment (Hughes, 1998a).

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).

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: Medium C: Medium	Medium Q: Medium A: Medium C: Medium	Medium Q: Medium A: Medium C: Medium

Burrowing megafauna flourish is areas where the sediments are naturally high in organic matter, such as sheltered sea lochs (Hughes, 1998a). For example, *Nephrops norvegicus* was present in high densities in Loch Sween, Scotland where the organic content was about 5% and as high as 9% in some patches (Atkinson, 1989). *Callianassa subterranea* is found in sediments with a range of organic content. In the soft, organically enriched sediments (typical organic carbon values of 3.6 - 7.8%) of Loch Sween, a sea loch in Scotland, *Callianassa subterranea* was present as a significant megafaunal burrower (Atkinson, 1989). The maximum depth of the species burrows has been recorded as 86 cm, which Nickell & Atkinson (1995) suggest is an underestimate, indicates a nutritional requirement for sub-surface organic matter. In the North Sea, where sediments have a low organic content Rowden & Jones (1997) found *Callianassa subterranea* had to construct much more complex burrows to support their energetic costs.

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Sensitivity assessment. Sublittoral muds may be expected to be high in organic nutrients. 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 **Medium**, a sensitivity of **Medium** is recorded.

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)	Low Q: Medium A: Low C: Medium	Very Low Q: High A: High C: High	High Q: Medium A: Low C: Medium

Species creating permanent burrows typically have specific sediment requirements, relating to the maintenance of burrow structures. *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 as total depth of 21 cm in muddy sediments with as high silt content but is not found in sandy sediments (Buchanan, 1963; Hughes, 1998a). The large echiuran *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).

Nephrops norvegicus burrows to 20-30 cm and is found in soft mud sediments (Hughes, 1998a). *Nephrops* has been shown to be more frequent in sandy muds than muds off the southwest and south eastern grounds off Portugal (Leotte *et al.*, 2005; abstract only). In coarse, sandy sediments, population density is low because of the instability of the sediment and the tendency of burrows to collapse. In medium-grained mud sediments, *Nephrops* are able to construct stable burrows, and population density peaks. In very fine-grained, soft muds, *Nephrops* excavate extensive burrow complexes, and competition for space is a limiting factor on population density (Afonso-Dias, 1998).

The important characterizing burrowing megafauna occur in a relatively restricted range of sediment types, related to the burrowing life habit (and feeding for *Calocaris macandreae*). The species are, therefore considered, to have **'Low'** resistance to a change in sediment type of one Folk class for a year. However, resilience is **Very low** or 'None' (as the pressure represents a permanent change). Sensitivity is, therefore, assessed as **High**.

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

No direct evidence was found to assess the impacts of this pressure. *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 as high silt content (Buchanan, 1963; Hughes, 1998a); *Maxmuelleria lankesteri* burrows up to 80 cm into the sediment (Nickell *et al.*, 1995; Hughes, 1998a); and *Nephrops norvegicus* burrows to 20-30 cm and is found in soft mud sediments (Hughes, 1998a). Based on burrow depths (maximum depth 21 cm for

Calocaris macandreae and 30 cm for *Nephrops norvegicus*) extraction (of 30 cm of sediment) is likely to disturb and remove the majority of the population of *Calocaris macandreae and Nephrops norvegicus*, together with a proportion of the *Callianassa subterranea* population within the affected area. A proportion of the *Maxmuelleria lankesteri* population may remain, depending on their depth within the sediment. Resistance is assessed as **None** (removal of >75% of individuals) and recovery is assessed as **Low**. Sensitivity is, therefore, assessed as **High**. Confidence in the quality of evidence for this assessment is Low as it is based on expert judgement, informed by life habit of the species assessed.

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

Species living in deep subtidal mud habitats are considered to be more vulnerable to physical disturbance as they are adapted to stable conditions (Pommer *et al*., 2016). In general, species with a large body size, low dispersal, late maturation and long lifespan are considered sensitive to physical disturbance (Bolam *et al*., 2014; Pommer *et al*., 2016). Similarly, sessile epifauna and species that live at or near the sediment surface are likely to be more vulnerable to physical disturbance than deep-burrowing or mobile species (Pommer *et al*., 2016). Large bioturbating or bio-irrigating species may be especially sensitive and their loss may affect the community (Widdicombe *et al*., 2004; Pommer *et al*., 2016).

Hinz *et al*. (2009) noted that different studies on the effects of otter trawl disturbance in muddy sediments gave mixed results and that the effect on abundance, biomass and diversity at a community level were largely inconsistent between studies. For example, experimental studies on short-term effects showed modest changes in the benthic communities (e.g. Tuck *et al*., 1998) and meta-analysis suggested that otter trawling on muddy sediments had one of the least negative impacts on the benthos (Kaiser *et al*., 2006). However, other studies showed that areas of seabed protected by wrecks from Nephrops trawls had higher abundance and biomass of benthos (Ball *et al*., 2000), while Smith *et al*. (2000) showed significantly lower abundance, biomass and species richness of benthos in high-intensity trawling lanes. Hinz *et al*. (2009) suggested that the differences in results were the result of differences in statistical analysis, prior fishing intensity and duration of the studies. Hinz *et al*. (2009) reported that chronic otter trawling from a *Nephrops* fishery had significant negative effects on the benthic macrofauna. Hinz *et al*. (2009) concluded that while the initial impact of otter trawl on muddy sediments was modest, the long-term disturbance could lead to profound changes in the benthic communities, especially epifauna and shallow burrowing infauna.

Nephrops norvegicus fisheries could, therefore, affect burrowing megafauna and sea pen biotopes. *Nephrops* is a commercially targeted species that is harvested by static and mobile gears. Information on the European fisheries for this species is summarised by Ungfors *et al*. (2013). It is difficult to conduct stock assessments on *Nephrops*, which can only be harvested selectively by trawls and static gears. *Nephrops* cannot be aged directly. European *Nephrops* fisheries are managed as Functional Units (FUs), which are smaller than the usual ICES sub-regions due to the limited dispersal abilities of *Nephrops*. The estimates of abundance, and hence the recommended maximum sustainable yield (MSY), the related Biomass trigger points and fishing mortality (F_{MSY}), estimated harvest rates and ICES recommended limits on landings and by-catch vary between FUs, (Ungfors *et al*., 2013; Marine Scotland, 2016). For example, harvest rates (ratio of total catch to absolute abundance) vary from ca 5-25% between 2007 and 2015 in the Farn Deeps, to ca 5-30%

between 2005 and 2015 in South Minch (Marine Scotland, 2016). Marine Scotland (2016) suggest that the abundance of most stocks in the North Sea has declined to MSY Biomass trigger point but remain above the F_{MSY} trigger point. However, in West Scotland, most stocks are above the Biomass trigger point but fluctuate around the F_{MSY} (Marine Scotland, 2016). Nevertheless, landings of *Nephrops* in 2014 were 13,700 tonnes in the North Sea and 12,800 in West Scotland (Marine Scotland, 2016).

Nephrops trawls catch specimens that are foraging at the surface. 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). The entrances to *Nephrops* burrows are 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). 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). Video studies have found that only a low proportion (circa 5%) of *Nephrops* that approached creels enter them (Bjordal, 1986; Adey, 2007, cited in Ungfors *et al.*, 2013). Factors that govern emergence will influence catch rates as only individuals that have emerged from burrows will be caught by trawl hauls. The degree of emergence from burrows for feeding or mating appears to be mainly governed by light intensities and therefore depends on factors such as time of day and season and varies between populations at different depths (Katoh *et al.*, 2013). Experimental trawling (Bell *et al.*, 2008) to evaluate catch rates showed that catchability varied between vessels in the same area and that catch rates were strongly linked to tidal cycles with increased catch rates at spring rather than neap tides. Catch rates differ between genders (Ungfors *et al.*, 2013); berried females tend to stay within burrows and are rarely caught in trawls (Aguzzi and Sarda 2008, cited in Katoh *et al.*, 2013). The population of *Nephrops* in the Irish Sea, in muds between the Isle of Man and the Irish coast, may be an exception. The area is subject to a near-surface gyre that retains larvae in the vicinity of the adults, so that while the population is self-sustaining, it may be vulnerable to over-exploitation as it is unlikely to receive recruitment from the surrounding area (Hill *et al.*, 1996b, 1997b; Hughes, 1998a). Hughes (1998a) noted that areas that were unsuitable for trawling due to rocky outcrops or other obstacles were often exploited by creeling. Hughes (1998a) suggested that trawling could reduce the density of *Nephrops* in confined sea lochs but cited Atkinson's observation that the resilience of *Nephrops* populations to trawling is enhanced by the fact that juveniles and egg-bearing females remain in their burrows and are not caught by trawls.

Calocaris macandreae is suggested to rarely venture onto the surface (Nash *et al.* 1984). Bergmann *et al.* (2002) noted that small numbers of *Calocaris macandreae* were by-catch in *Nephrops* trawls in the Clyde Sea. Comparisons between grab samples collected at trawled and untrawled sites in the Oslofjord, a northern branch of the Skagerrak in the North Sea, showed that *Calocaris macandreae* were depleted at trawled sites. The mean abundance of *Calocaris macandreae* was 41.5 individuals per m^2 (ca ±9.91) in non-trawled areas and 14.5 individuals per m^2 (ci.±4.99) in trawled areas (Olsgard *et al.*, 2008). Trawled areas were visited by otter trawlers targeting *Pandalus montagui* between 50 and 100 times per year, and based on the size of the trawls and the boat speed, each part of these areas are trawled on average 2–3 times per year (Olsgard *et al.*, 2008). It is not clear whether the impact is cumulative with decreases in the population occurring incrementally or if the first pass removes the most vulnerable individuals, and those that remain are either new recruits or individuals that are more resistant due to factors such as burrow depth. However, Pommer *et al.* (2016) did not find a significant difference in the abundance of *Calocaris macandreae* with trawling intensity in the Kattegat. Duineveld *et al.* (2007) reported a higher species diversity and abundance of mud shrimps (*Callianassa subterranea* and *Upogebia deltura*) with a fisheries exclusion zone in the North Sea than the surrounding area.

Bolam *et al.* (2014) suggested that spoon worms (Echiura) of the family Bonellidae (the family to which *Maxmuelleria lankesteri* belongs) had a high sensitivity to trawling based on their average sensitivity score from eight traits (mainly body size, morphology, lack of mobility, longevity and low recruitment) in their biological traits analysis. However, the depth of the burrows constructed by characterizing megafauna (mud-shrimps and *Maxmuelleria lankesteri*) probably protects the species from surface abrasion and fishing activities. For example, *Maxmuelleria lankesteri* burrows up to 80 cm into the sediment (Nickell *et al.*, 1995; Hughes, 1998a); *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 (Buchanan, 1963; Hughes, 1998a); and *Nephrops norvegicus* burrows to 20-30 cm and is found in soft mud sediments (Rice and Chapman 1971; Nash *et al.* 1984; Hughes, 1998a). Based on burrow depths surface abrasion is unlikely to likely to disturb or remove the majority of the population of *Maxmuelleria lankesteri*, *Calocaris macandreae*, *Callianassa subterranea*, or *Nephrops norvegicus* within the affected area, although the proboscis of *Maxmuelleria lankesteri* could be damaged by passing gear at night.

The burrow opening may be damaged (as above) but observations from Loch Sween suggest that they are re-established soon after disturbance (Marrs *et al.*, 1998; Hughes, 1998a). Atkinson (1989) suggested that trawling was unlikely to affect burrowing megafauna (other than *Nephrops*) to 'any great extent'. Similarly, Vergnon & Blanchard, 2006; OSPAR, 2010) noted that burrowing megafauna (*Nephrops* and other non-commercial crustaceans) did not show any reduction in total biomass or abundance in highly exploited sites. In their study, *Nephrops norvegicus*, *Munida rugosa* and *Liocarcinus depurator* dominated highly exploited sites in the Bay of Biscay (Vergnon & Blanchard, 2006).

Sensitivity assessment. The burrowing habit of the important characterizing species probably confers some protection from direct impacts of surface abrasion. Therefore, resistance is assessed as **Medium** (loss of <25% of individuals) as some individuals may be exposed within the direct footprint when on the surface. Most *Nephrops* populations are reported to be resilient to fishing activity and the majority of the population will probably remain to support recovery. However, there is the potential for overfishing in populations enclosed by hydrology (e.g. in the Irish Sea) or in sea lochs. In addition, while *Callianassa subterranea* may recover quickly, *Calocaris macandreae* may take longer to recover due to its benthic larvae and lower fecundity and *Maxmuelleria lankesteri* is long-lived, with stable populations and low recruitment rates. Therefore, resilience is assessed as **Medium**, so that sensitivity is assessed as **Medium**.

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: Medium C: Low

Species living in deep subtidal mud habitats are considered to be more vulnerable to physical disturbance as they are adapted to stable conditions (Pommer *et al.*, 2016). In general, species with a large body size, low dispersal, latematuration and long lifespan are considered sensitive to physical disturbance (Bolam *et al.*, 2014; Pommer *et al.*, 2016). Similarly, sessile epifauna and species that live at or near the sediment surface are likely to be more vulnerable to physical disturbance than deep-burrowing or mobile species (Pommer *et al.*, 2016). Large bioturbating or bio-irrigating species may be especially sensitive and their loss may affect the community (Widdicombe *et al.*, 2004; Pommer *et al.*, 2016).

Hinz *et al.* (2009) noted that different studies on the effects of otter trawl disturbance in muddy sediments gave mixed results and that the effect on abundance, biomass and diversity at a community level were largely inconsistent between studies. For example, experimental studies on short-term effects showed modest changes in the benthic communities (e.g. Tuck *et al.*, 1998) and meta-analysis suggested that otter trawling on muddy sediments had one of the least negative impacts on the benthos (Kaiser *et al.*, 2006). However, other studies showed that areas of seabed protected by wrecks from Nephrops trawls had higher abundance and biomass of benthos (Ball *et al.*, 2000), while Smith *et al.* (2000) showed significantly lower abundance, biomass and species richness of benthos in high-intensity trawling lanes. Hinz et al. (2009) suggested that the differences in results were the result of differences in statistical analysis, prior fishing intensity and duration of the studies. Hinz *et al.* (2009) reported that chronic otter trawling from a *Nephrops* fishery had significant negative effects on the benthic macrofauna. Hinz *et al.* (2009) concluded that while the initial impact of otter trawl on muddy sediments was modest, the long-term disturbance could lead to profound changes in the benthic communities, especially epifauna and shallow burrowing infauna.

Nephrops norvegicus fisheries could, therefore, affect burrowing megafauna and sea pen biotopes. *Nephrops* is a commercially targeted species that is harvested by static and mobile gears. Information on the European fisheries for this species is summarised by Ungfors *et al.* (2013). It is difficult to conduct stock assessments on *Nephrops*, which can only be harvested selectively by trawls and static gears. *Nephrops* cannot be aged directly. European *Nephrops* fisheries are managed as Functional Units (FUs), which are smaller than the usual ICES sub-regions due to the limited dispersal abilities of *Nephrops*. The estimates of abundance, and hence the recommended maximum sustainable yield (MSY), the related Biomass trigger points and fishing mortality (F_{MSY}), estimated harvest rates and ICES' recommended limits on landings and by-catch vary between FUs (Ungfors *et al.*, 2013; Marine Scotland, 2016). For example, harvest rates (ratio of total catch to absolute abundance) vary from ca 5-25% between 2007 and 2015 in the Farn Deeps, to ca 5-30% between 2005 and 2015 in South Minch (Marine Scotland, 2016). Marine Scotland (2016) suggest that the abundance of most stocks in the North Sea has declined to MSY Biomass trigger point but remain above the F_{MSY} trigger point. However, in West Scotland, most stocks are above the Biomass trigger point but fluctuate around the F_{MSY} (Marine Scotland, 2016). Nevertheless, landings of *Nephrops* in 2014 were 13,700 tonnes in the North Sea and 12,800 in West Scotland (Marine Scotland, 2016).

Nephrops trawls catch specimens that are foraging at the surface. 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). The entrances to *Nephrops* burrows are 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). 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). Video studies have found that only a low proportion (circa 5%) of *Nephrops* that approached creels enter them (Bjordal, 1986; Adey, 2007, cited in

Ungfors *et al.*, 2013). Factors that govern emergence will influence catch rates as only individuals that have emerged from burrows will be caught by trawl hauls. The degree of emergence from burrows for feeding or mating appears to be mainly governed by light intensities and therefore depends on factors such as time of day and season and varies between populations at different depths (Katoh *et al.*, 2013). Experimental trawling (Bell *et al.*, 2008) to evaluate catch rates showed that catchability varied between vessels in the same area and that catch rates were strongly linked to tidal cycles with increased catch rates at spring rather than neap tides. Catch rates differ between genders (Ungfors *et al.*, 2013); berried females tend to stay within burrows and are rarely caught in trawls (Aguzzi and Sarda 2008, cited in Katoh *et al.*, 2013). The population of *Nephrops* in the Irish Sea, in muds between the Isle of Man and the Irish coast, may be an exception. The area is subject to a near-surface gyre that retains larvae in the vicinity of the adults, so that while the population is self-sustaining, it may be vulnerable to over-exploitation as it is unlikely to receive recruitment from the surrounding area (Hill *et al.*, 1996b, 1997b; Hughes, 1998a). Hughes (1998a) noted that areas that were unsuitable for trawling due to rocky outcrops or other obstacles were often exploited by creeling. Hughes (1998a) suggested that trawling could reduce the density of *Nephrops* in confined sea lochs but cited Atkinson's observation that the resilience of *Nephrops* populations to trawling is enhanced by the fact that juveniles and egg-bearing females remain in their burrows and are not caught by trawls.

Calocaris macandreae is suggested to rarely venture onto the surface (Nash *et al.* 1984). Bergmann *et al.* (2002) noted that small numbers of *Calocaris macandreae* were by-catch in *Nephrops* trawls in the Clyde Sea. Comparisons between grab samples collected at trawled and untrawled sites in the Oslofjord, a northern branch of the Skagerrak in the North Sea, showed that *Calocaris macandreae* were depleted at trawled sites. The mean abundance of *Calocaris macandreae* was 41.5 individuals per m^2 (ca ±9.91) in non-trawled areas and 14.5 individuals per m^2 (ci.±4.99) in trawled areas (Olsgard *et al.*, 2008). Trawled areas were visited by otter trawlers targeting *Pandalus montagui* between 50 and 100 times per year, and based on the size of the trawls and the boat speed, each part of these areas are trawled on average 2–3 times per year (Olsgard *et al.*, 2008). It is not clear whether the impact is cumulative with decreases in the population occurring incrementally or if the first pass removes the most vulnerable individuals, and those that remain are either new recruits or individuals that are more resistant due to factors such as burrow depth. However, Pommer *et al.* (2016) did not find a significant difference in the abundance of *Calocaris macandreae* with trawling intensity in the Kattegat. Duineveld *et al.* (2007) reported a higher species diversity and abundance of mud shrimps (*Callianassa subterranea* and *Upogebia deltura*) with a fisheries exclusion zone in the North Sea than the surrounding area.

Bolam *et al.* (2014) suggested that spoon worms (Echiura) of the family Bonellidae (the family to which *Maxmuelleria lankesteri* belongs) had a high sensitivity to trawling based on their average sensitivity score from eight traits, and high scores for body size, morphology, lack of mobility, longevity and low recruitment, in their biological traits analysis. However, the depth of the burrows constructed by characterizing megafauna (mud-shrimps and *Maxmuelleria lankesteri*) probably protects the species from surface abrasion and fishing activities. For example, *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 (Buchanan, 1963; Hughes, 1998a); *Maxmuelleria lankesteri* burrows up to 80 cm into the sediment (Nickell *et al.*, 1995; Hughes, 1998a); and *Nephrops norvegicus* burrows to 20-30 cm and is found in soft mud sediments (Rice and Chapman 1971; Nash *et al.* 1984; Hughes, 1998a). Based on burrow depths (maximum depth 21 cm for *Calocaris macandreae*, 30 cm for *Nephrops norvegicus* and up to 80 cm for *Maxmuelleria lankesteri*) the potential effect of penetrative gear will depend on the depth to which the gear penetrates the substratum and, hence, gear type.

The burrow opening may be damaged (as above) but observations from Loch Sween suggest that they are re-established soon after disturbance (Marrs *et al*., 1998; Hughes, 1998a). Atkinson (1989) suggested that trawling was unlikely to affect burrowing megafauna (other than *Nephrops*) to 'any great extent'. Similarly, Vergnon & Blanchard, 2006; OSPAR, 2010) noted that burrowing megafauna (*Nephrops* and other non-commercial crustaceans) did not show any reduction in total biomass or abundance in highly exploited sites. In their study, *Nephrops norvegicus*, *Munida rugosa* and *Liocarcinus depurator* dominated highly exploited sites in the Bay of Biscay (Vergnon & Blanchard, 2006).

Sensitivity assessment. The burrowing habit of the important characterizing species probably confers some protection from direct impacts depending on the depth of penetration of the passing fishing gear or other penetrative activity. Penetration of the substratum surface may damage the proboscis of *Maxmuelleria lankesteri* but more importantly remove shallow burrowed specimens of the burrowing megafauna, espeically junveniles, and disturb and damage the burrow network within the sediment. Therefore, resistance is assessed as **Low** (loss of 25%-75% of individuals) as some individuals may be exposed within the direct footprint on the surface or in shallow parts of their burrows. Most *Nephrops* populations are reported to be resilient to fishing activity and the majority of the population will probably remain to support recovery. However, there is the potential for overfishing in populations enclosed by hydrology (e.g. in the Irish Sea) or in sea lochs. In addition, while *Callianassa subterranea* may recover quickly, *Calocaris macandreae* may take longer to recover due to its benthic larvae and lower fecundity and *Maxmuelleria lankesteri* may take a long time to recover due to its low recruitment potential. Therefore, resilience is assessed as **Low** and sensitivity is assessed as **High**.

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

The eye of *Nephrops norvegicus* is well adapted to low levels of light at the sea bed and hence changes in clarity are unlikely to interfere with visual perception. *Nephrops norvegicus* emerge from burrows and, due to adaptations to ambient light, *Nephrops* in shallower waters emerge from burrows at dawn and dusk, whereas those from deeper waters emerge about midday (Ball *et al*., 2000b). Alteration in light intensity due to turbidity may, therefore, alter emergence rhythms. Aréchiga & Atkinson (1975) reported that the burrowing activity of *Nephrops norvegicus* is restricted to an optimum range of light intensity from about 10,000 to 10 m-c (meter/candles) (equivalent to approximately, 10% to 0.001% of natural daylight).

Calocaris macandreae are considered to rarely emerge from the burrow system and to mostly feed on organic material within the burrow deposits. *Callianassa subterranea* also feeds on organic matter within its burrow. *Maxmuelleria lankesteri* does not leave its burrow but extends its proboscis to the surface to feed, and is thought to be highly adverse to light (Hughes, 1998a).

Sensitivity assessment. The biotope occurs in sheltered areas, in fine sediments, subject to high suspended sediment loads. Therefore, the important characteristic species are unlikely to be impacted by an increase in suspended sediments. As they dwell in deep burrows (and only emerge for short periods of time, e.g *Nephrops*) they are unlikely to be affected by the resultant increase in turbidity and reduction in light. Resistance is, therefore, assessed as **High** based on its burrowing habit and resilience is **High** (based on no impact to recover from) and the biotope is assessed as

'Not sensitive'.

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

The important 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).

This biotope occurs in deep, sheltered muddy habitats where the accretion rates are potentially high. 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. Therefore, a resistance of **High** is suggested, resulting in a resilience of **High** and sensitivity of **Not sensitive.**

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

The important 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).

This biotope occurs in deep, sheltered muddy habitats where the accretion rates are potentially high. 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. Therefore, a resistance of **High** is suggested, resulting in a resilience of **High** and sensitivity of **Not sensitive.**

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

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 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 noise disturbance at the benchmark level. Therefore, this pressure is probably **Not relevant** in this biotope.

Introduction of light or shading	High Q: Medium A: Medium C: Medium	High Q: High A: High C: High	Not sensitive Q: Medium A: Medium C: Medium

Nephrops norvegicus emerge from burrows and, due to adaptations to ambient light, *Nephrops* in shallower waters emerge from burrows at dawn and dusk, whereas those from deeper waters emerge about midday (Ball *et al.*, 2000b). Alteration in light intensity due to turbidity may, therefore, alter emergence rhythms. Aréchiga & Atkinson (1975) reported that the burrowing activity of *Nephrops norvegicus* is restricted to an optimum range of light intensity from about 10,000 to 10 m-c (meter/candles) (equivalent to approximately, 10% to 0.001% of natural daylight). But *Nephrops* are more active by day in deeper waters (ca 100 m) (Hughes, 1998a). In the shallow waters of Loch Sween, *Maxmuelleria lankesteri* only extends its proboscis to the surface to feed at night, and then only for short periods (Hughes *et al.*, 1993). Hughes (1998a) this species would behave differently in deep water. *Calocaris macandreae* is considered to rarely emerge from its burrow system (Hughes, 1998a).

Sensitivity assessment. Light is probably not relevant in the deep examples of this biotope. In shallow examples of the biotope, shading may increase the time available for feeding by *Nephrops* or *Maxmuelleria lankesteri*, while an increase in ambient light might decrease feeding. Therefore, a resistance of **High** is recorded. Resilience is **High** (by default) so that the biotope is probably **Not sensitive** at the benchmark level.

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.

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

Sternapsis 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 experiments, 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 shell fisheries 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	Medium Q: High A: Medium C: Medium	Medium Q: Medium A: Medium C: Medium	Medium Q: Medium A: Medium C: Medium

The infection of *Nephrops norvegicus* by a parasitic dinoflagellate of the genus *Hematodinium* has been known since the mid-1980s (Field *et al*., 1992). Infected populations have been found in the Irish Sea, Scottish sites in the Clyde Sea area and the west and east coasts. *Hematodinium* has also been reported in *Nephrops* in the German Bight, the Skagerrak and Kattegat (Briggs & McAliskey, 2002). Infected animals are recognized by an opaque vivid body colouration, believed to be due to high densities of parasites in the haemolymph. The muscle of infected animals is said to have a bitter taste. The infection causes a general morbidity of the lobster and a reduction in swimming performance. Death usually occurs when the parasite bursts out of the haemolymph (Marrs, pers. comm.). Recovery of *Hematodinium* infected *Nephrops* has not been observed to date (Stentiford *et al*., 2001). Results from the Irish Sea and Scottish surveys show a seasonal pattern to the level of *Hematodinium* infection in *Nephrops norvegicus*, with peaks in spring (Stentiford *et al*., 2001; Briggs & McAliskey, 2002). There was also a marked spatial variability in infection rates in animals in the Irish Sea (Briggs & McAliskey, 2002). The prevalence of infection is higher in immature animals although the reasons for this are still unclear. High mortalities seen during some surveys although these values may be an artefact brought about by the increased catchability of infected *Nephrops* as swimming performance falls with the severity of infection (Stentiford *et al*., 2000). This may lead to overestimation of the actual prevalence of infection in fishing stocks. Briggs & McAliskey (2002) report that the disease has been present in populations of *Nephrops* at least since 1994 and despite inflicting juvenile mortality on the *Nephrops* stock, recent assessments indicated a stable situation.

Mud shrimp are parasitized by parasitic isopods called bopyrids. The parasite lives in the gills and reduces reproductive output (Hughes, 1998a). Rowden & Jones (1994) reported that 11% of

Callianassa subterranea in the southern North Sea were infected. Other than a reduction in reproduction, no other effects were reported (Hughes, 1998a).

Sensitivity assessment. As *Hematodinium* could result in increased mortality in *Nephrops*, a resistance of **Medium** is recorded. Resilience is probably **Medium** so that the sensitivity of the biotope is assessed as **Medium**.

Removal of target species	High Q: Medium A: Medium C: Medium	High Q: High A: High C: High	Not sensitive Q: Medium A: Medium C: Medium

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Hughes (1998a) suggested that the mix of megafaunal burrowers creates a continuously shifting mosaic of habitat patches that reflected different disturbance. He suggested that this 'patchiness' was a factor in the maintenance of the species diversity of these communities. Although the burrows of different megafaunal burrowers often interconnected, there was no evidence of any relationship between the species, and that the connections were probably accidental. In addition, there was no evidence that any single species of megafaunal burrower was dominant or determined the structure or functioning of the community (Hughes, 1998a).

Sensitivity assessment. The physical effects of *Nephrops* fisheries are discussed under the 'abrasion' and penetration' pressures above. However, there is no evidence to suggest that the targeted removal of *Nephrops* from the community would have any biological effect on the community. This conclusion is supported by Atkinson's (1989) observation that trawling was unlikely to affect other megafaunal burrowers to 'any great extent'. Similarly, Vergnon & Blanchard, 2006; OSPAR, 2010) noted that burrowing megafauna (*Nephrops* and other non-commercial crustaceans) did not show any reduction in total biomass or abundance in highly exploited sites. In their study, *Nephrops norvegicus*, *Munida rugosa* and *Liocarcinus depurator* dominated highly exploited sites in the Bay of Biscay (Vergnon & Blanchard, 2006). In mesocosm experiments, Widdicombe *et al.* (2004) noted that bioturbation of muddy sediments associated by burrow formation (by *Calocaris macandreae*) was less important for maintaining biodiversity than the bioturbation of bulldozing species (e.g. *Brissopsis lyrifera* and *Aphrodita aculeata*) in the surface 10 cm of the sediment. In addition, Sciberras *et al.*, (2016) concluded that the physical effects of trawling on the biogeochemistry of muds were larger than in sands but that these changes were not mediated by changes in the infauna. Therefore, a resistance of **High** is recorded, so that resilience is also **High** (by default) and the biotope is recorded as **Not sensitive**.

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

The physical effects of fisheries are discussed under the 'abrasion' and 'penetration' pressures above. Species living in deep subtidal mud habitats are considered to be more vulnerable to physical disturbance as they are adapted to stable conditions (Pommer *et al.*, 2016). In general, species with a large body size, low dispersal, late maturation and long lifespan are considered sensitive to physical disturbance (Bolam *et al.*, 2014; Pommer *et al.*, 2016). Similarly, sessile epifauna and species that live at or near the sediment surface are likely to be more vulnerable to physical disturbance than deep-burrowing or mobile species (Pommer *et al.*, 2016). Large bioturbating or bio-irrigating species may be especially sensitive and their loss may affect the community (Widdicombe *et al.*, 2004; Pommer *et al.*, 2016).

Hinz *et al.* (2009) noted that different studies on the effects of otter trawl disturbance in muddy sediments gave mixed results and that the effect on abundance, biomass and diversity at a community level were largely inconsistent between studies. For example, experimental studies on short-term effects showed modest changes in the benthic communities (e.g. Tuck *et al.*, 1998) and meta-analysis suggested that otter trawling on muddy sediments had one of the least negative impacts on the benthos (Kaiser *et al.*, 2006). However, other studies showed that areas of seabed protected by wrecks from Nephrops trawls had higher abundance and biomass of benthos (Ball *et al.*, 2000), while Smith *et al.* (2000) showed significantly lower abundance, biomass and species richness of benthos in high-intensity trawling lanes. Hinz *et al.* (2009) suggested that the differences in results were the result of differences in statistical analysis, prior fishing intensity and duration of the studies. Hinz *et al.* (2009) reported that chronic otter trawling from a *Nephrops* fishery had significant negative effects on the benthic macrofauna. Hinz *et al.* (2009) concluded that while the initial impact of otter trawl on muddy sediments was modest, the long-term disturbance could lead to profound changes in the benthic communities, especially epifauna and shallow burrowing infauna.

However, there is no evidence to suggest that the targeted removal of *Nephrops* or other megafaunal burrowers from the community would have any biological effect on the community. This conclusion is supported by Atkinson's (1989) observation that trawling was unlikely to affect other megafaunal burrowers to 'any great extent'. Similarly, Vergnon & Blanchard, 2006; OSPAR, 2010) noted that burrowing megafauna (*Nephrops* and other non-commercial crustaceans) did not show any reduction in total biomass or abundance in highly exploited sites. In their study, *Nephrops norvegicus*, *Munida rugosa* and *Liocarcinus depurator* dominated highly exploited sites in the Bay of Biscay (Vergnon & Blanchard, 2006). In mesocosm experiments, Widdicombe *et al.* (2004) noted that bioturbation of muddy sediments associated by burrow formation (by *Calocaris macandreae*) was less important for maintaining diversity than the bioturbation of bulldozing species (e.g. *Brissopsis lyrifera* and *Aphrodita aculeata*) in the surface 10 cm of the sediment. In addition, Sciberras *et al.*, (2016) concluded that the physical effects of trawling on the biogeochemistry of muds were larger than in sands but that these changes were not mediated by changes in the infauna.

Hughes (1998a) suggested that the mix of megafaunal burrowers creates a continuously shifting mosaic of habitat patches that reflected different disturbance. He suggested that this ‘patchiness’ was a factor in the maintenance of the species diversity of these communities. Although the burrows of different megafaunal burrowers often interconnected, there was no evidence of any relationship between the species, and that the connections were probably accidental. In addition, there was no evidence that any single species of megafaunal burrower was dominant or determined the structure or functioning of the community (Hughes, 1998a). Therefore, a resistance of **High** is recorded, so that resilience is also **High** (by default) and the biotope is recorded as **Not sensitive**.

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