Calocaris macandreae and polychaetes in offshore circalittoral mud and sandy mud

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

Dr Harvey Tyler-Walters

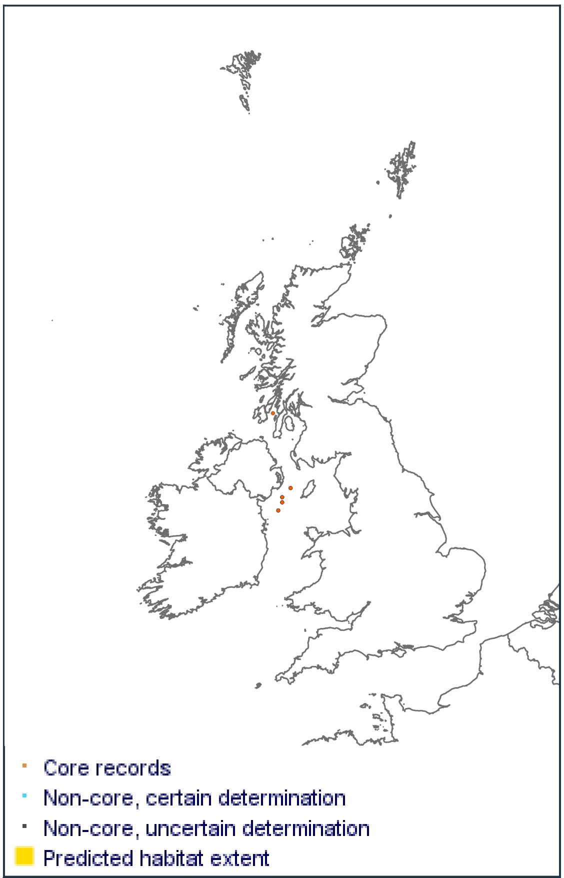
2022-09-06

A report from:
The Marine Life Information Network, Marine Biological Association of the United Kingdom.

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/1263]. All terms and the MarESA methodology are outlined on the website (https://www.marlin.ac.uk)

This review can be cited as:
Tyler-Walters, H., 2022. *Calocaris macandreae* and polychaetes in offshore circalittoral mud and sandy mud. In Tyler-Walters H. *Marine Life Information Network: Biology and Sensitivity Key Information Reviews*, [on-line]. Plymouth: Marine Biological Association of the United Kingdom.
DOI https://dx.doi.org/10.17031/marlinhab.1263.1

(page left blank)



Biotope distribution data provided by the JNCC (mhc.jncc.gov.uk)

Researched by Dr Harvey Tyler-Walters **Refereed by** Admin

Summary

UK and Ireland classification

EUNIS 2008	A5.377TMP	None (TBC)
JNCC 2022	SS.SMu.OMu.CalPol	*Calocaris macandreae* and polychaetes in offshore circalittoral mud and sandy mud
JNCC 2015	None	None
JNCC 2004	None	None
1997 Biotope	None	None

Description

Sublittoral mud and sandy mud plains characterized by a wide range of infauna including polychaetes, a few crustaceans and molluscs. This biotope has been found in the Irish Sea, the Minches, and Western Scotland. The description of this biotope is based on infauna recorded from the above location but could be found in other areas with similar environmental conditions. The characteristic infaunal species include *Calocaris macandreae* and polychaetes *Glycera unicornis*, *Mediomastus fragilis*, *Levinsenia gracilis* and oligochaete *Tubificoides amplivastus*. The other characterizing taxa include polychaetes *Nephtys incisa*, *Kirkegaardia dorsbranchialis* (previously *Monticellina*) and bivalve *Nucula sulcata*. The echinoid *Brissopsis lyrifera*, cumacean *Eudorella emarginata*, and *Nephrops norvegicus* are also present in small numbers. This biotope was described using Day grab infaunal data and the characterizing species listed will partly reflect the method used to collect data. (Information from JNCC, 2022).

Depth range

50-150 m

Additional information

-

Listed By

- none -

Further information sources

Search on:

G G G JNCC

Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

This biotope (SS.SMu.OMu.CalPol) is found on sublittoral mud and sandy mud plains and is characterized by a wide range of infauna including polychaetes, a few crustaceans and molluscs. The most important characterizing species are the mud shrimp *Calocaris macandreae*, the polychaetes *Glycera unicornis*, *Mediomastus fragilis*, *Levinsenia gracilis* and oligochaete *Tubificoides amplivastus*.

The mud shrimp *Calocaris macandreae* burrows in organically rich soft muds. It forms characteristic U-shaped burrows, with three-way junctions, and typically three openings at the surface, usually in two-tiers or levels at ca 9-18 cm and 14-21.5 cm below the surface (Buchanan, 1963; Nash *et al.*, 1984; Hughes, 1998; Atkinson & Taylor, 2005; Pinn & Atkinson, 2010). It is found in the Atlantic and the Mediterranean, at ca 30-1100 m in depth, and in the UK is most known from the Irish Sea, the Clyde Sea, the Firth of Lorne and the Northumberland coast (Buchannan, 1963, 1974, Buchanan & Warwick, 1974; Buchanan *et al.*, 1974; Nash *et al.*, 1984; Hughes, 1998). *Calocaris macandreae* is a deposit feeder (consuming organic material, bacteria and diatoms) and omnivore and possible carnivore that supplements its diet with scavenged animal (e.g. polychaetes, or molluscs) or plant material that it consumes directly and/or uses to farm bacteria (microbial gardening) and organic material with the walls of its burrows (Buchannan, 1963; Pinn *et al.*, 1998, 1998b; Atkinson & Taylor, 2005; Pinn & Atkinson, 2010; Fanelli *et al.*, 2011). Pinn *et al.* (1998) noted that its diet varied with food abundance and became less selective as food became scarce.

Mud shrimps, such as *Calocaris macandreae* are important bioturbators and influence the chemical, physical and biochemical properties of the sediment, and burrow irrigation draws oxygenated waters into the sediment while denitrification circulates nitrogen within the system and overlying waters above the sediment (Atkinson & Taylor, 2005; Pinn & Atkinson, 2010). For example, Gagnon *et al.* (2013) reported that *Calocaris templemani* reworked sediment to a depth of 15 cm at a rate of 8 $L/m^2/yr$ in a mesocosm study. Norling *et al.* (2007) noted that oxygen, ammonia and silicon fluxes were higher in mesocosms in the presence of *Calocaris macandreae*. Widdicombe & Austen (2003) noted that the presence of *Calocaris macandreae* decreased the abundance of burrowing spionid polychaetes and deposit-feeding polychaetes (e.g. *Heteromatus filiformis*) and the bivalve *Nuculoma tenuis* compared with controls. They suggested that spionids were excluded due to the reworking of the sediment and resultant smothering by sediment, while deposit feeders may be less abundant because deposit feeding by mud shrimp decreased the availability of organic matter in the sediment. They noted that species tolerant of smothering, i.e. *Chaetozone setosa* and *Cossura longicirrata* had higher abundances in mesocosms with low densities of mud shrimp (Widdicombe & Austen, 2003). However, while *Calocaris macandreae* significantly affected the community it did not significantly affect diversity (Widdicombe & Austen, 2004). Although they rarely leave their burrows, *Calocaris macandreae* are preyed upon by demersal fish (e.g. cod and haddock) and large decapods (e.g. *Nephrops*) (Buchanan, 1963; Hughes, 1998).

The important characteristic polychaetes *Mediomastus fragilis*, *Levinsenia gracilis* and oligochaete *Tubificoides amplivastus* are relatively widespread across habitats and sediment types. For example, *Mediomastus fragilis*, *Tubificoides amplivastus* are characteristic of coarse, mixed, sandy muds and muddy sediment biotopes, while *Levinsenia gracilis* is limited to sandy mud and mixed sediment biotopes (JNCC, 2022) and are widespread around the coasts of the UK and in the North Sea. *Glycera unicornis* is only recorded in one other sandy mud biotope (as *Glycera rouxii*) but is also widespread in UK waters. *Glycera* spp. are predators, *Mediomastus* are tube-dwelling deposit feeders and *Levinsenia* and *Tubificoides* are deposit feeders (MESL, 2008).

Overall, *Calocaris macandreae* is probably the structuring species in this biotope. Its burrowing activity alters the oxygen and nutrient flux between the sediment and the water column while its bioturbation can affect the local infaunal community. Therefore, *Calocaris macandreae* is the focus of the sensitivity assessment. The potential sensitivity of other species in the biotope is mentioned where relevant.

Resilience and recovery rates of habitat

Buchanan (1963, 1974) examined the population dynamics of *Calocaris macandreae* off the Northumberland coast. *Calocaris macandreae* is a protandrous hermaphrodite with both testes and ovaries at 1-3 years of age, after which the testes degenerate. Ovaries continue to mature through 4 - 5 years of age and the first eggs are laid in January-February at five years old. A small number of eggs (an average of 38 eggs but a range of 1 to 111 eggs) are attached to the pleopods and are carried for nine months until September to October of the sixth year. However, only ca 20% of the population attaches eggs to their pleopods successfully. 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. The eggs hatch into large larvae that remain on the bottom with no apparent pelagic phase (Buchanan, 1963). Growth is rapid in the early years (ca 1-3 years) with several moults a year, followed by annual moults after the 4th or 5th year, in July-September. Heavy mortality in a year group is almost wholly confined to the ninth and tenth years, probably due to senescence rather than mortality. 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, 1963, 1974).

Buchanan (1974) noted that the population of *Calocaris macandreae* of the Northumberland coast had remained stable with a mean density of 17.95 /m^2 for 10 years. Buchanan (1974) suggested that its long lifespan, low number of eggs but advanced non-pelagic larvae with high survivorship and reduced predation due to deep burrowing contributed to this stability (Buchanan, 1963, 1974; Hughes, 1998). Similarly, Buchanan *et al.* (1974) reported that *Calocaris macandreae*, together with *Chaetozone, Spiophanes,* and *Lumbrineris* were stable species in detailed community studies of Northumberland benthic macrofauna between 1971 and 1974. Fluctuations in other species, including *Glycera rouxi*, were attributed to interspecific competition. Buchanan (1963) estimated that the Northumberland population would only need to recruit slightly more than two individuals per year to maintain a density of 18 /m^2, based on three years of observations. However, Buchanan & Warwick (1974) reported that while *Calocaris macandreae* was the dominant single species in terms of biomass, polychaetes represented the bulk of the biomass in this Northumberland community.

The polychaete species present in the biotope can be broadly characterized as either opportunist species that rapidly colonize disturbed habitats and increase in abundance, or species that are larger and longer-lived and that may be more abundant in an established, mature assemblage. Species with opportunistic life strategies (small size, rapid maturation and short lifespan of 1-2 years with production of large numbers of small propagules), include the characterizing polychaete *Mediomastus fragilis.* These are likely to recolonize disturbed areas first, although the actual pattern will depend on the recovery of the habitat, season of occurrence and other factors. *Tubicoides* spp. are also considered opportunistic but have a relatively long lifespan (ca 2 years), internal fertilization and larvae develop in a cocoon so dispersal is probably poor (MES, 2008). However, they can form dense communities. Bolam & Whomersley (2003) found that tubificid oligochaetes began colonizing sediments from the first week following a beneficial use scheme involving the placement of fine-grained dredged material on a salt marsh in southeast England. The abundance of *Tubificoides benedii* recovered slowly in the recharge stations and required 18 months to match reference sites. *Glycera* spp. are longer-lived. *Glycera spp.* are monotelic having a single breeding period towards the end of their life but may recover through migration and may persist in disturbed sediments through their ability to burrow (Klawe & Dickie, 1957). *Glycera* spp. have a high potential rate of recolonization of sediments, but the relatively slow growth rate and long lifespan suggest that recovery of biomass following initial recolonization by post-larvae is likely to take several years (MES, 2008). Following dredging of subtidal sands in summer and autumn to provide material for beach nourishment in the Bay of Blanes, northwest Mediterranean, Spain, recovery was tracked by Sardá *et al.* (2000). Recolonization in the dredged habitats was rapid, with high densities of *Owenia fusiformis* in the spring following dredging, although most of these recruits did not survive summer. However, *Glycera* spp. and *Protodorvillea kefersteini* had not recovered within two years (Sardá *et al.*, 2000).

Resilience assessment. No evidence was found for recovery rates following disturbance. *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 (i.e. resistance is Low), then resilience is likely to be Low (10-25 years). The polychaete community is likely to recover quickly, and may well vary over time (see Buchanan *et al.*, 1974). 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 assessed as '**Medium'**. However, where the community suffers significant mortality (resistance is at least 'Low') then recovery is likely to be prolonged and resilience is assessed as '**Low'**. 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 are also ranked as Medium.

Hydrological Pressures

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

Calocaris macandreae is abundant in muddy sediments around the British east and west coasts, extending from North Norway to West Africa and the Mediterranean (Buchanan, 1963; Christiansen, 2000; Ingle & Christiansen 2004; Pinn & Atkinson, 2010). OBIS (2022) includes records of *Calocaris macandreae* where sea surface temperatures ranged in temperate from 0-25°C, although the majority of records were reported at 10-15°C. Hughes (1998) noted that shallow sea lochs, where burrowed mud megafauna are abundant, usually experience seasonal changes in temperature of 10°C, i.e. between ca 5 and 15°C. The stability of the population of *Calocaris macandreae* off the coast of Northumberland, over a 10-year period suggests it can withstand long-term seasonal changes in temperature. Also, the depth of the biotope (>50 m) combined with the *Calocaris macandreae* burrowed habit probably buffers its exposure to fluctuations in the temperature of the surface water (Hughes, 1998).

Sensitivity assessment. *Calocaris macandreae* is recorded from the north and south of the UK from northern Norway to the Adriatic in the Mediterranean. Short-term acute changes in temperature and long-term chronic changes in temperature at the pressure benchmark are unlikely to adversely this biotope as its distribution suggests that *Calocaris macandreae* and the dominant polychaetes can potentially adapt to a wide range of temperatures experienced in both northern and southern waters. Therefore, resistance is assessed as **'High'**, albeit at Low confidence due to the lack of direct evidence. Hence, resilience is assessed as **'High'** and sensitivity as **'Not sensitive'** at the benchmark level.

Temperature decrease (local)	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low

Calocaris macandreae is abundant in muddy sediments around the British east and west coasts, extending from North Norway to West Africa and the Mediterranean (Buchanan, 1963; Christiansen, 2000; Ingle & Christiansen 2004; Pinn & Atkinson, 2010). OBIS (2022) includes records of *Calocaris macandreae* where sea surface temperatures ranged in temperate from 0-25°C, although the majority of records were reported at 10-15°C. Hughes (1998) noted that shallow sea lochs, where burrowed mud megafauna are abundant, usually experience seasonal changes in temperature of 10°C, i.e. between ca 5 and 15°C. The stability of the population of *Calocaris macandreae* off the coast of Northumberland, over a 10-year period suggests it can withstand long-term seasonal changes in temperature. Also, the depth of the biotope (>50 m) combined with the *Calocaris macandreae* burrowed habit probably buffers its exposure to fluctuations in the temperature of the surface water (Hughes, 1998).

Sensitivity assessment. *Calocaris macandreae* is recorded from the north and south of the UK from northern Norway to the Adriatic in the Mediterranean. Short-term acute changes in temperature and long-term chronic changes in temperature at the pressure benchmark are unlikely to adversely this biotope as its distribution suggests that *Calocaris macandreae* and the dominant polychaetes can potentially adapt to a wide range of temperatures experienced in both northern and southern waters. Therefore, resistance is assessed as **'High'**, albeit at Low confidence due to the lack of direct evidence. Hence, resilience is assessed as **'High'** and sensitivity as **'Not sensitive'** at the benchmark level.

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 the salinity tolerance of *Calocaris macandreae*. This biotope is found in fully marine conditions (JNCC, 2022), while *Calocaris macandreae* is recorded from sites where sea surface salinity ranged from 15-35 psu although most records were from 30-35 psu (OBIS, 2022).

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 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 could 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 sensitivity may be '**High'.**

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

No direct evidence was found to assess the salinity tolerance of *Calocaris macandreae*. This biotope is found in fully marine conditions (JNCC, 2022), while *Calocaris macandreae* is recorded from sites where sea surface salinity ranged from 15-35 psu although most records were from 30-35 psu (OBIS, 2022).

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 their 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 at 25 psu and 100% mortality at 21 psu (Harris & Ulmestrand, 2004).

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. This *Calocaris macandreae* dominated biotope is only recorded from full (30-35) saline conditions as are most habitats in which it is abundant (Buchanan, 1974; Hughes, 1998; JNCC, 2022). The evidence for the similar species *Nephrops* shows that short, acute reductions in salinity result in mortality but also that reduced salinity results in mortality. Therefore, a reduction in salinity for a year may cause significant mortality. Therefore, a resilience of '**Low'** is recorded but with 'Low' confidence due to the lack of direct evidence. Resilience would probably be '**Low'**, so sensitivity may be '**High'**.

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

Calocaris macandreae was restricted to the muddier bottom areas at 70-100 m of the coast of Northumberland, where silt and clay content was greater than 20%, mixed with fine sand, but reached its highest density where silt and clay were >60% (Buchanan, 1963; Hughes, 1998). This biotope is recorded from weak (<0.5 m/s) tidal streams on mud and muddy sands, typical of low flow, wave-sheltered conditions. A further decrease in flow is unlikely. 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 the Hjulstrom-Sundborg diagram (Wright *et al.*, 2001). However, given the depth of mud that characterizes the biotope only the surface of the mud may be removed within a year (the benchmark). Hence, the deep burrowing community may remain intact but the surface infauna may reduce in abundance. Therefore, a resistance of '**High'** is recorded but with Low confidence. Hence, resilience is probably **High** and sensitivity is assessed as '**Not sensitive' at the benchmark level.** However, greater changes in water flow e.g. due to storms may reduce the area of mud or muddy sand, or temporarily deposit coarse sediment, which would alter the character of the biotope.

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

This biotope occurs at 50 - 150 m so emergence is '**Not relevant**'.

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

This biotope (SS.SMu.OMu.CalPol) occurs in low-energy environments, very sheltered from wave exposure (JNCC, 2022), a prerequisite for the muddy sediments that characterize the biotope (JNCC, 2022). In addition, the biotope is found to considerable depths, at which, wave action is unlikely to be significant. Therefore, a decrease in wave exposure is 'Not relevant'. 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 the removal or modification of the sediment. However, a change of 3-5% in significant wave height (the benchmark) 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	Low Q: High A: Medium C: Medium	Low Q: Medium A: Medium C: Medium	High Q: Medium A: Medium C: Medium

Rygg (1985) examined benthic macrofauna communities in areas of Norwegian fjords with different levels of heavy metal pollution. While Pb and Zn gave a weak negative correlation with diversity, Cu showed a strong negative correlation due to its toxicity to a large number of species. Rygg (1985) identified 20 of the 50 most common species as significantly missing from stations where the Cu concentration was >200 ppm. These non-tolerant species included *Calocaris macandreae*, *Glycera unicornis (syn. rouxii)* and *Nucula sulcata*, which characterize this biotope (OMu.CalPol). Tolerant species were all polychaetes. Atkinson & Taylor (2005) noted that bioturbation of sediments by thalassinideans has been shown to redistribute radionuclides in the Red Sea, a Pacific lagoon and the Irish Sea, although no effects on the species were given.

Sensitivity assessment. The evidence suggests that copper (Cu) pollution could result in a significant reduction in the abundance of *Calocaris macandreae* and possibly other members of the community and, hence, a reduction in the extent of the biotope. Therefore, resistance is assessed as **'Low'** although only a single metal was implicated. Hence, resilience is assessed as **'Low'** and sensitivity as **'High'**.

Hydrocarbon & PAH contamination	Low Q: Low A: NR C: NR	Low Q: Medium A: Medium C: Medium	High Q: Low A: Low C: Low

Daan *et al.* (1992) found that *Callianassa subterranea* decreased in density towards drilling sites contaminated by oil-based muds in the North Sea. For example, Daan *et al.* (1992) reported that at 1 km, where the oil concentration of the sediment was 16 mg/kg the abundance of *Callianassa subterranea* was significantly reduced. They suggested that it was one of the more sensitive species in the sediment fauna, and experienced environmental stress even at distances of 1 - 2 km from the contaminant (Daan *et al.*, 1992; Hughes, 1998).

Sensitivity assessment. Although no evidence of the effects of hydrocarbons on *Calocaris* spp. was found, the evidence from the similar species *Callianassa* spp. suggests that *Calocaris* spp. may be affected in a similar way. Therefore, resistance is assessed as **'Low'** but with 'Low' confidence. Hence, resilience is assessed as **'Low'** and sensitivity as **'High'**.

Synthetic compound contamination	None Q: High A: Medium C: Medium	Low Q: Medium A: Medium C: Medium	High Q: Medium A: Medium C: Medium

Hughes (1998) noted that the pesticide Ivermectin (once used in salmon farming to control sea lice) was reported to be highly toxic to sediment-dwelling polychaetes (Black *et al.*, 1997; Thain *et al.*, 1997) and epibenthic shrimps (Burridge & Haya, 1993), and suggested that it might be toxic to burrowing crustaceans.

Feldman *et al.* (2000) reviewed the use of pesticides to control burrowing thalassinidean shrimp (the ghost shrimp *Neotrypaea californiensis* and the mud shrimp *Upogebia puggettensis*) on oyster grounds in Willapa Bay and Grays Harbor, Washington State. The aerial application of the pesticide Carbaryl (1-Naphthalenol methylcarbamate) to mudflats at 11.02 kg/ha between 1963 and 1984 was shown to kill 90-95% of the targeted shrimp on treated beds. Ghost shrimp areas could be treated 'effectively' at 2-5 kg/ha for 2-5 hours while mud shrimp grounds required 7-9 kg/ha for 1.5-3 hours. They also reported that mud shrimp sediments (silty muds) could remain toxic to juveniles for 28 days while ghost shrimp sites remained toxic for 12 days. Stewart *et al.* (1967) reported an 1-day LC_{50} (death or irreversible paralysis) of 0.03- 0.16 mg/l Carbaryl and a 1-day LC_{50} of 6.2-13.7 mg/l of 1-naphthol (the pesticide precursor) larval *Upogebia pugettensis;* and a 1-day LC50 of 0.13 mg/l Carbaryl and 1-day LC50 of 6.6 mg/l of 1-naphthol in adult *Neotrypaea californiensis.* Dumbauld *et al.* (1997) reported a 1-day LC_{90} (90% mortality) of 7.0 kg/ha in *Upogebia pugettensis* in the field, and a LOEC of 5.6 kg/ha after 30.4 days based on changes in population abundance.

Sensitivity assessment. Although no direct evidence of the effects of synthetic compounds on *Calocaris* spp. was found, the above evidence suggests that pesticides (e.g. insecticides) have the potential to cause significant or severe (>75% mortality) on thalassinidean shrimp depending on the type of pesticide, the amount applied and duration of application, and its behaviour in the environment (e.g. retention by sediment). Therefore, resistance is assessed as **'None'** as a precaution. Hence, resilience is assessed as **'Low'** and sensitivity as **'High'**.

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

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. Atkinson & Taylor (2005) noted that bioturbation of sediments by thalassinideans has been shown to redistribute radionuclides in the Red Sea, a Pacific lagoon and the Irish Sea, although no effects on the species were given.

Introduction of other substances	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.

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

Low oxygen concentration, reduced pH and sulphide are probably typical of crustacean burrows (Atkinson & Taylor, 2005). For example, the oxygen concentration in *Calocaris macandreae* was reported to be between 20 and 40 Torr (ca 1.17 and 2.34 mg O_2/l) (Anderson *et al.*, 1991; Atkinson & Taylor, 2005). *Calocaris macandreae* irrigates its burrow for short intermittent periods of time. However, a significant increase in irrigations only occurs once the oxygen partial pressure (PO_2) has fallen to low levels (Anderson *et al.*, 1991; Atkinson & Taylor, 2005).

Mud shrimps are highly tolerant of hypoxia and the critical PO_2 below which normal oxygen consumption cannot occur is lower in thalassinideans than other decapods not normally exposed to hypoxia (Atkinson & Taylor, 2005). For example, the critical PO_2 of *Calocaris macandreae* was reported to be 10-20 Torr (ca 0.58-1.17 mg O_2/l). Their ability to maintain oxygen consumption under hypoxia is aided by the high oxygen affinities of their haemocyanins. As oxygen levels fall, especially in the presence of sulphide, mud shrimp can switch to anaerobic respiration resulting in the formation of lactate. For example, *Calocaris macandreae* switched to anaerobic respiration when PO_2 fell to =<10 Torr (ca =<0.58 mg O_2/l) (Anderson *et al.*, 1994; Atkinson & Taylor, 2005). Sufficient concentrations of sulphide only occur in anoxic conditions but thalassinideans are able to metabolise sulphide to thiosulphate in the presence of oxygen, i.e. in hypoxia. For example, in *Calocaris macandreae* more thiosulphate is produced under normoxic than hypoxic conditions but *Calocaris macandreae* is able to maintain aerobic metabolism under hypoxia (20 Torr) when exposed to 25 µM sulphide (Johns *et al.*, 1997). At higher concentrations of sulphide, it switched to anaerobic metabolism (Johns *et al.*, 1997; Atkinson & Taylor, 2005). Johns *et al.* (1997) reported an LT_{50} of 28 hours at 1 mM sulphide in *Calocaris macandreae*.

Sensitivity assessment. The evidence suggests that *Calocaris macandreae and* mud shrimps in general are highly tolerant of hypoxic and anoxic conditions. Therefore, a decrease in oxygen levels to below 2 mg/l for a week is unlikely to affect the abundance of the dominant mud shrimp in this biotope significantly. Hence, resistance and resilience are assessed as **'High'**, and sensitivity as **'Not sensitive' at the benchmark level**.

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

Burrowing megafauna, e.g mud shrimps, flourish in areas where the sediments are naturally high in organic matter, such as sheltered sea lochs (Hughes, 1998). Mud shrimps such as *Calocaris macandreae* are adapted to conditions associated with organic-rich muds and eutrophication such as hypoxia, anoxia and sulphide contamination but their burrowing activities oxidise the sediment, cycle nutrients to the overlying water and can moderate the effects of organic enrichment (Atkinson & Taylor, 2005).

No information on the effect of eutrophication was found. However, Stachowitsch (1984) recorded individuals of *Upogebia tipica*, *Jaxea nocturna* and *Axius stirhynchus* abandoning their burrows during a severe episode of oxygen depletion, possibly due to a halocline, in the Gulf of Trieste, northern Adriatic, although

Calocaris macandreae is more tolerant of hypoxia than *Upogebia* or *Jaxea* spp. (Hughes, 1998; Atkinson & Taylor, 2005). Pinn & Atkinson (2010) reported that the levels of nitrite, phosphate and ammonia in *Calocaris macandreae* burrows were higher than the overlying water in mesocosm studies, although only phosphate levels were significant. They reported average values of ca 0.1 mg/l N (nitrite), ca 0.4 mg/l N (nitrate), ca 0.4 mg/l N (ammonia), and ca 0.6 mg/l phosphate in their burrows (values extrapolated from Pinn & Atkinson, 2010; Figure 2).

Sensitivity assessment. No evidence was found to compare against the benchmark. However, mud shrimps such as *Calocaris macandreae* are adapted to conditions associated with eutrophication such as hypoxia, anoxia and sulphide contamination. Therefore, resistance is assessed as **'High'**, resilience as **'High'** and sensitivity as **'Not sensitive'** at the benchmark but with 'Low' confidence.

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

Burrowing megafauna, e.g mud shrimps, flourish in areas where the sediments are naturally high in organic matter, such as sheltered sea lochs (Hughes, 1998). 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, indicating 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.

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, 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 rubsecens*) were abundant where organic content was <4% but absent where the organic content exceeded 6% (Smith, 1988, cited in Hughes, 1998). *Calocaris macandreae* did not extend as far into the gradient as *Nephrops norvegicus* or *Lumpenus lampraetiformis* (Smith, 1988, cited in Hughes, 1998). Similarly, Feder & Pearson (1988) reported that *Calocaris macandreae* was present in Loch Eil in 1980 and 1982 after 16-18 years of pulp and paper mill effluent but not in the prior survey in 1963. Nevertheless, *Calocaris macandreae* was recorded at 6.3 and 9.2 km from the outfall but not at 3.3 km from the outfall (Feder & Pearson, 1988).

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. However, the size of the individuals of *Maxmuelleria lankesteri*, *Callianassa subterranean* suggested that they had survived the loch basin during the peak of enrichment (Hughes, 1998). Stachowitsch (1984) recorded individuals of *Upogebia tipica*, *Jaxea nocturna* and *Axius stirhynchus* abandoning their burrows during a severe episode of oxygen depletion in the Gulf of Trieste, northern Adriatic, although *Calocaris macandreae* is more tolerant of hypoxia than *Upogebia* or *Jaxea* spp. (Hughes, 1998; Atkinson & Taylor, 2005).

Sensitivity assessment. Mud shrimps such as *Calocaris macandreae* are adapted to conditions associated with organic-rich muds such as hypoxia, anoxia and sulphide contamination but their burrowing activities oxidise the sediment, cycle nutrients to the overlying water and can moderate the effects of organic enrichment (Atkinson & Taylor, 2005). Gitterberger & Van Loon (2011) ranked the mud shrimp *Callianassa subterranea* as a 'species tolerant to excess organic matter enrichment' and *Upogebia deltaura* as a 'species indifferent to enrichment'. The above evidence suggests that mud shrimp can survive all but gross organic enrichment but the absence of *Calocaris macandreae* from the centre of Garoch Head sludge dumping grounds suggests that its resistance has limits. Therefore, resistance is assessed as **'Medium'** as a precaution and, as resilience is probably **'Medium'**, sensitivity is assessed as **'Medium'.**

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. 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: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High

The mud shrimp *Calocaris macandreae* burrows in organically rich soft muds. *Calocaris macandreae* was restricted to the muddier bottom areas at 70-100 m of the coast of Northumberland, where silt and clay content was greater than 20%, mixed with fine sand, and reached its highest density where silt and clay were >60% but is not found in sandy sediments (Buchanan, 1963; Hughes, 1998). It is a deposit feeder and omnivore (Buchanan, 1963; Atkinson & Taylor, 2005; Pinn & Atkinson, 2010). In addition, this biotope is only recorded from mud and sandy mud (JNCC, 2022). A change in sediment type of one Folk class (see benchmark) to sand and muddy sand or to mixed sediments would result in the loss of the biotope and its community. Therefore, resistance is assessed as **'None',** resilience as **'Very low'** (permanent change) and sensitivity 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: Low C: Low

No direct evidence was found to assess the impacts of this pressure. *Calocaris macandreae* creates burrows with a total depth of 21 cm in muddy sediments with a high silt content (Buchanan, 1963; Hughes, 1998a). Based on burrow depths extraction (of 30 cm of sediment) is likely to disturb and remove the majority of the population of *Calocaris macandreae* within the affected area. Therefore, resistance is assessed as '**None'** (removal of >75% of individuals) and resilience is assessed as '**Low**'. Hence, sensitivity is assessed as '**High'**. Confidence in the quality of evidence for this assessment is Low as it is based on expert judgement, informed by the 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 large body size, low dispersal, late maturation and long lifespan are considered sensitive to physical disturbance (Bolam *et al.*, 2014; 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) suggested that the abundance of most stocks in the North Sea had declined to the MSY Biomass trigger point but remain above the F_{MSY} trigger point. However, in West Scotland, most stocks were 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).

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 bycatch 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 is 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 in the surrounding area.

Based on burrow depths surface abrasion is unlikely to likely to disturb or remove the majority of the population of *Calocaris macandreae*, *Callianassa subterranea*, or *Nephrops norvegicus* within the affected area. The burrow openings may be damaged but observations from Loch Sween suggest that they are re-established soon after disturbance (Marrs *et al.*, 1998; Hughes, 1998). 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 with stable populations and low recruitment rates. Therefore, resilience is assessed as **'Medium'** and sensitivity is assessed as '**Medium'**.

Penetration or disturbance of the substratum subsurface	Low Q: Medium 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 large body size, low dispersal, late maturation and long lifespan are considered sensitive to physical disturbance (Bolam *et al.*, 2014; 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) suggested that the abundance of most stocks in the North Sea had declined to the MSY Biomass trigger point but remain above the F_{MSY} trigger point. However, in West Scotland, most stocks were 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).

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 is 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 in the surrounding area.

Based on burrow depths surface abrasion is unlikely to likely to disturb or remove the majority of the population of *Calocaris macandreae*, *Callianassa subterranea*, or *Nephrops norvegicus* within the affected area. The burrow openings may be damaged but observations from Loch Sween suggest that they are re-established soon after disturbance (Marrs *et al.*, 1998; Hughes, 1998). 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 shallow burrowed specimens of the burrowing megafauna, especially juveniles, 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. *Calocaris macandreae* may take longer to recover due to its benthic larvae and lower fecundity and 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

Mud shrimps, such as *Calocaris macandreae* are important bioturbators and influence the chemical, physical and biochemical properties of the sediment, and burrow irrigation draws oxygenated waters into the sediment while denitrification circulates nitrogen within the system and overlying waters above the sediment (Atkinson & Taylor, 2005; Pinn & Atkinson, 2010). Mud shrimp burrows expel suspended sediment during excavation, and due to feeding and respiratory currents (Atkinson & Taylor, 2005). For example, Gagnon *et al.* (2013) reported that *Calocaris templemani* reworked sediment to a depth of 15 cm at a rate of 8 $L/m^2/yr$ in a mesocosm study. Gittenberger & Van Loon (2011) ranked the mud shrimp *Callianassa subterranea* and *Upogebia deltaura* as 'species insensitive to higher amounts of sedimentation'.

Sensitivity assessment. The biotope occurs in sheltered areas, in fine sediments, and subject to high suspended sediment loads. Therefore, the important characteristic species are unlikely to be impacted by an increase in suspended sediments. *Calocaris macandreae* lives in deep burrows and only emerges for short periods of time (Nash et al., 1984) and is unlikely to be affected by the resultant increase in turbidity. Therefore, resistance is, assessed as **'High'** based on its burrowing habit, resilience as **'High',** 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 *Calocaris macandreae* is unlikely to be affected adversely as it is an active borrower and important bioturbator. *Calocaris macandreae* and *Callianassa subterranea* were reported within the Garroch Head (Firth of Clyde) sludge dumping ground (Smith, 1988; cited in Hughes, 1998). In addition, if the deposited sediment occludes burrow openings, then they would be reopened quickly. Observations from Loch Sween suggest that burrows are re-established soon after experimental disturbance (Hughes, 1998). This biotope (OMu.CalPol) occurs in deep, sheltered muddy habitats where the accretion rates are potentially high. Therefore, it is probable that the deposition of 5 cm of fine sediment will have little effect other than to temporarily suspend feeding and the energetic cost of burrowing. Therefore, resistance is assessed as '**High', r**esilience as '**High'** and sensitivity assessed as '**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

The important characteristic burrowing megafauna *Calocaris macandreae* is unlikely to be affected adversely as it is an active borrower and important bioturbator. *Calocaris macandreae* and *Callianassa subterranea* were reported within the Garroch Head (Firth of Clyde) sludge dumping ground (Smith, 1988; cited in Hughes, 1998). In addition, if the deposited sediment occludes burrow openings, then they would be reopened quickly. Observations from Loch Sween suggest that burrows are re-established soon after experimental disturbance (Hughes, 1998). This biotope (OMu.CalPol) occurs in deep, sheltered muddy habitats where the accretion rates are potentially high. Therefore, it is probable that the deposition of 30 cm of fine sediment will have little effect other than to temporarily suspend feeding and the energetic cost of burrowing. Therefore, resistance is assessed as '**High', r**esilience as '**High'** and sensitivity assessed as '**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	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

Most of the species are infaunal and unlikely to respond to noise disturbance at the benchmark level. Therefore, this pressure is probably **Not relevant** in this biotope.

Introduction of light or shading	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

Calocaris macandreae rarely or infrequently emerges from its burrow system (Nash *et al.*, 1984; Hughes, 1998; Gagnon *et al.*, 2013). Light is probably not relevant in the deep examples of this biotope. Pinn & Atkinson (2010) observed their behaviour in mesocosms under 'subdued' lighting while Gagnon *et al.* (2013) observed the behaviour of *Calocaris templemani* in situ under low-intensity red light. These precautions suggest that the behaviour of *Calocaris macandreae* may be affected by bright light or sudden shading (similar to the approach of a predator) but no information on the response of *Calocaris macandreae* to light was found.

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, larvae or other propagules but propagule 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

Calocaris macandreae rarely or infrequently emerges from its burrow system (Nash *et al.*, 1984; Hughes, 1998; Gagnon *et al.*, 2013). Pinn & Atkinson (2010) observed their behaviour in mesocosms under 'subdued' lighting while Gagnon *et al.* (2013) observed the behaviour of *Calocaris templemani* in situ under low-intensity red light. These precautions suggest that the behaviour of *Calocaris macandreae* may be affected by bright light or sudden shading (similar to the approach of a predator) but no information on the response of *Calocaris macandreae* to light was found. It is unlikely to have the visual acuity or range to respond to visual disturbance from passing boats or divers etc, especially at depth. Therefore, this pressure is probably **'Not relevant'**.

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 burrowing mud shrimps 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

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 of the effect of non-native species on burrowing mud shrimp was found. However, this assessment should be revisited in light of new evidence.

Introduction of microbial pathogens	Medium Q: Low A: NR C: NR	Medium Q: Medium A: Medium C: Medium	Medium Q: Low A: Low C: Low

Mud shrimp are parasitized by parasitic isopods called bopyrids. The parasite lives in the gills and reduces reproductive output (Hughes, 1998). 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, 1998). Calderon-Perez (1986) reported the presence of larval nematodes (*Ascarophis* sp., *Proleptus obtusus* and *Hysterothylacium aduncum*) in *Calocaris macandreae* from the Irish Sea. However, no effect on host mortality was observed.

The bryozoan *Triticella flava* grows as a dense 'furry' covering on the antennae, mouthparts and legs of burrowing crustaceans. It occurs most commonly on *Calocaris macandreae* but has also been found on *Nephrops norvegicus*, *Goneplax rhomboides*, *Jaxea nocturna* and *Upogebia* spp (Hughes, 1998). On *Calocaris macandreae*, its coverage is densest in late summer but it is shed when the mud shrimp moults in September-October (Buchanan, 1963). However, the reproductive cycle of *Triticella* is synchronized with the moult cycle of its host and larvae are available to recolonize the crustacean body after the moult (Eggleston, 1971; Hughes, 1998).

Sensitivity assessment. As bopyrids could result in a decrease in reproduction and recruitment, resistance is assessed as **'Medium'** albeit with 'Low' confidence. Hence, resilience is assessed as **'Medium'** and sensitivity as **'Medium'.**

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

Calocaris macandreae is not part of a targeted fishery so this pressure is 'Not relevant' technically, although the species may be taken as bycatch.

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

Large bioturbating or bio-irrigating species may be especially sensitive to physical disturbance 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.

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 bycatch 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 is 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 in the surrounding area.

Based on burrow depths surface abrasion is unlikely to likely to disturb or remove the majority of the population of *Calocaris macandreae*, *Callianassa subterranea*, or *Nephrops norvegicus* within the affected area. The burrow openings may be damaged but observations from Loch Sween suggest that they are re-established soon after disturbance (Marrs *et al*., 1998; Hughes, 1998). 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), although *Calocaris macandreae* was not included in their study.

Mud shrimps, such as *Calocaris macandreae* are important bioturbators and influence the chemical, physical and biochemical properties of the sediment, and burrow irrigation draws oxygenated waters into the sediment while denitrification circulates nitrogen within the system and overlying waters above the sediment (Atkinson & Taylor, 2005; Pinn & Atkinson, 2010). For example, Gagnon *et al.* (2013) reported that *Calocaris templemani* reworked sediment to a depth of 15 cm at a rate of 8 $L/m^2/yr$ in a mesocosm study. Norling *et al.* (2007) noted that oxygen, ammonia and silicon fluxes were higher in mesocosms in the presence of *Calocaris macandreae.* Widdicombe & Austen (2003) noted that the presence of *Calocaris macandreae* decreased the abundance of burrowing spionid polychaetes and deposit-feeding polychaetes (e.g. *Heteromatus filiformis*) and the bivalve *Nuculoma tenuis* compared with controls. They suggested that spionids were excluded due to the reworking of the sediment and resultant smothering by sediment, while deposit feeders may be less abundant because deposit feeding by mud shrimp decreased the availability of organic matter in the sediment. They noted that species tolerant of smothering, i.e. *Chaetozone setosa* and *Cossura longicirrata* had higher abundances in mesocosms with low densities of mud shrimp (Widdicombe & Austen, 2003). However, while *Calocaris macandreae* significantly affected the community it did not significantly affect diversity (Widdicombe & Austen, 2004). Although they rarely leave their burrows, *Calocaris macandreae* are preyed upon by demersal fish (e.g. cod and haddock) and large decapods (e.g. *Nephrops*) (Buchanan, 1963; Hughes, 1998).

Sensitivity assessment. The above evidence suggests that the populations have been depleted by fisheries in some sites but not others. But this pressure examines the effect of the removal of the characteristic species on the community present in the biotope. Hughes (1998) suggested that there was no evidence that any single species of megafaunal burrower was dominant or determined the structure or functioning of the burrowing mud communities (see SS.SMu.CFiMu.MegMax). However, this biotope is defined by the abundance of *Calocaris macandreae* and a few dominant polychaetes. The evidence suggests that *Calocaris macandreae* is an important bioturbator in this biotope and its community, affects oxygen penetration into the sediment, denitrification and nutrient cycling, and influences community structure within the sediment (e.g. of the associated polychaete species), but not diversity (Widdicombe & Austen, 2003, 2004; Atkinson & Taylor, 2005). Therefore, the loss of a significant proportion of the *Calocaris macandreae* population could alter the community and the classification of the biotope. Therefore, resistance is assessed as **'Low'**. Hence, resilience is assessed as **'Low'** and sensitivity is assessed as **'High'**.

Bibliography

Abed-Navandi, D., Koller, H. & Dworschak, P.C., 2005. Nutritional ecology of thalassinidean shrimps constructing burrows with debris chambers: The distribution and use of macronutrients and micronutrients. *Marine Biology Research*, **1** (3), 202-215. DOI https://doi.org/10.1080/17451000510019123

Anderson, S.J., Atkinson, R.J.A. & Taylor, A.C., 1991. Behavioural and respiratory adaptations of the mud-burrowing shrimp *Calocaris macandreae* Bell (Thalassinidea, Crustacea) to the burrow environment. *Ophelia*, **34**, 143-156. DOI https://doi.org/10.1080/00785326.1991.10429702

Anderson, S.J., Taylor, A.C. & Atkinson, R.J.A., 1994. Anaerobic metabolism during anoxia in the burrowing shrimp *Calocaris macandreae* Bell (Crustacea: Thalassinidea). *Comparative Biochemistry and Physiology*, **108A** (4), 515-522. DOI https://doi.org/10.1016/0300-9629(94)90335-2

Atkinson, R.J.A. & Taylor, A.C., 2005. Aspects of the physiology, biology and ecology of thalassinidean shrimps in relation to their burrow environment. Oceanography and Marine Biology - an Annual Review, Vol. 43, pp. 173-210.

Atkinson, R.J.A., 1989. Baseline survey of the burrowing megafauna of Loch Sween, proposed Marine Nature Reserve, and an investigation of the effects of trawling on the benthic megafauna. *Report to the Nature Conservancy Council, Peterborough, from the University Marine Biological Station, Millport*, pp.1-59.

Ball, B.J., Fox, G. & Munday, B.W., 2000. Long- and short-term consequences of a *Nephrops* trawl fishery on the benthos and environment of the Irish Sea. *ICES Journal of Marine Science*, **57**, 1315-1320.

Bergmann, M., Wieczorek, S.K., Moore, P.G. & Atkinson, R.J.A., 2002a. Discard composition of the *Nephrops* fishery in the Clyde Sea area, Scotland. *Fisheries Research*, **57**, 169-183.

Black, K.D., Fleming, S. Nickell, T.D. & Pereira, P.M.F. 1997. The effects of ivermectin, used to control sea lice on caged farmed salmonids, on infaunal polychaetes. *ICES Journal of Marine Science*, **54**, 276-279.

Bolam, S. & Whomersley, P., 2003. Invertebrate recolonization of fine-grained beneficial use schemes: An example from the southeast coast of England. *Journal of Coastal Conservation*, **9** (2), 159-169.

Bolam, S.G., Coggan, R.C., Eggleton, J., Diesing, M. & Stephens, D., 2014. Sensitivity of macrobenthic secondary production to trawling in the English sector of the Greater North Sea: A biological trait approach. *Journal of Sea Research*, **85**, 162-177.

Buchanan, J.B. & Warwick, R.M., 1974. An estimate of benthic macrofaunal production in the offshore mud of the Northumberland coast. *Journal of the Marine Biological Association of the United Kingdom*, **54**, 197-222. DOI https://doi.org/10.1017/S0025315400022165

Buchanan, J.B., 1963. The biology of *Calocaris macandreae* (Crustacea: Thalassinidea). *Journal of the Marine Biological Association of the United Kingdom*, **43**, 729-747. DOI https://doi.org/10.1017/S0025315400025650

Buchanan, J.B., Kingston, P.F. & Sheader, M., 1974. Long-term population trends of the benthic macrofauna in the offshore mud of the Northumberland coast. *Journal of the Marine Biological Association of the United Kingdom*, **54** (4), 785-795. DOI https://doi.org/10.1017/S002531540005757X

Burridge, L.E. & Haya, K., 1993. The lethality of Ivermectin, a potential agent for treatment of salmonids against sea lice, to the shrimp *Crangon septemspinosa*. *Aquaculture*, **117**, 9-14.

Calderon-Perez, J.A., 1986. Occurrence of nematode parasites in *Calocaris macandreae* (Crustacea, Decapoda) from an Irish Sea population. *Journal of the Marine Biological Association of the United Kingdom*, **66** (2), 293-301. DOI https://doi.org/10.1017/S0025315400042934

Cartes, J. E., Company, J. B. & Maynou, F., 1994. Deep-water Decapod crustacean communities in the Northwestern Mediterranean - influence of submarine canyons and season. *Marine Biology*, **120** (2), 221-229. DOI https://doi.org/10.1007/bf00349682

Cartes, J. E., Maynou, F., Fanelli, E., Papiol, V. & Lloris, D., 2009. Long-term changes in the composition and diversity of deep-slope megabenthos and trophic webs off Catalonia (western Mediterranean): Are trends related to climatic oscillations? *Progress in Oceanography*, **82** (1), 32-46. DOI https://doi.org/10.1016/j.pocean.2009.03.003

Christiansen, M.E., 2000. On the occurrence of Thalassinidea (Decapoda) in Norwegian waters. *Journal of Crustacean Biology*, **20** (2), 230-237. DOI https://doi.org/10.1163/1937240x-90000024

Daan, R., Groenewould Van Het, H., Jong De, S.A. & Mulder, M., 1992. Physico-chemical and biological features of a drilling site in the North Sea, 1 year after discharges of oil-contaminated drill cuttings. *Marine Ecology Progress Series*, **91**, 37-45.

Duineveld, G.C.A., Bergman, M.J.N. & Lavaleye, M.S.S., 2007. Effects of an area closed to fisheries on the composition of the benthic fauna in the southern North Sea. *ICES Journal of Marine Science: Journal du Conseil*, **64**(5), 899-908.

Dumbauld, B.R., Armstrong, D.A. & Skalski, J., 1997. Efficacy of the pesticide carbaryl for thalassinid shrimp control in Washington state oyster (*Crassostrea gigas*, Thunberg, 1793) aquaculture. *Journal of Shellfish Research*, **16**, 503-518.

Eggleston, D., 1971. Synchronization between moulting in *Calocaris macandreae* Decapoda and reproduction in its epibiont *Tricella koreni* Polyzoa Ectoprocta. *Journal of the Marine Biological Association of the United Kingdom*, **51** (2), 409-410. DOI https://doi.org/10.1017/s0025315400031878

Fanelli, E., Cartes, J. E., Papiol, V. & Lopez-Perez, C., 2013. Environmental drivers of megafaunal assemblage composition and biomass distribution over mainland and insular slopes of the Balearic Basin (Western Mediterranean). *Deep-Sea Research Part I-Oceanographic Research Papers*, **78**, 79-94. DOI https://doi.org/10.1016/j.dsr.2013.04.009

Fanelli, E., Papiol, V., Cartes, J. E., Rumolo, P., Brunet, C. & Sprovieri, M., 2011. Food web structure of the epibenthic and infaunal invertebrates on the Catalan slope (NW Mediterranean): Evidence from delta C-13 and delta N-15 analysis. *Deep-Sea Research Part I-Oceanographic Research Papers*, **58** (1), 98-109. DOI https://doi.org/10.1016/j.dsr.2010.12.005

Feder, H.M. & Pearson, T.H., 1988. The benthic ecology of Loch Linnhe and Loch Eil, a sea-loch system on the west coast of Scotland. 5. Biology of the dominant soft-bottom epifauna and their interaction with the infauna. *Journal of Experimental Marine Biology and Ecology*, **116**, 99-134. DOI https://doi.org/10.1016/0022-0981(88)90050-0

Feldman, K.L., Armstrong, D.A., Dumbauld, B.R., DeWitt, T.H. & Doty, D.C., 2000. Oysters, crabs, and burrowing shrimp: review of an environmental conflict over aquatic resources and pesticide use in Washington State's (USA) coastal estuaries. *Estuaries*, **23**, 141-176. DOI https://doi.org/10.2307/1352824

Gagnon, J. M., Beaudin, L., Silverberg, N. & Mauviel, A., 2013. Mesocosm and in situ observations of the burrowing shrimp *Calocaris templemani* (Decapoda: Thalassinidea) and its bioturbation activities in soft sediments of the Laurentian Trough. *Marine Biology*, **160** (10), 2687-2697. DOI https://doi.org/10.1007/s00227-013-2262-0

GBNNSIP, 2011. Red King Crab, *Paralithodes camtschaticus.* Factsheet. [online]. York, GB Nonnative Species Secretariat. Available from: http://www.nonnativespecies.org/factsheet/factsheet.cfm?speciesId=2533 [Accessed 05/05/2016]

Gittenberger, A. & Van Loon, W.M.G.M., 2011. Common Marine Macrozoobenthos Species in the Netherlands, their Characterisitics and Sensitivities to Environmental Pressures. GiMaRIS report no 2011.08. DOI: 10.13140/RG.2.1.3135.7521

Harris, R.R. & Ulmestrand, M., 2004. Discarding Norway lobster (*Nephrops norvegicus* L.) through low salinity layers – mortality and damage seen in simulation experiments. *ICES Journal of Marine Science: Journal du Conseil*, **61**(1), 127-139.

Hinz, H., Prieto, V. & Kaiser, M.J., 2009. Trawl disturbance on benthic communities: chronic effects and experimental predictions. *Ecological Applications* **19** (3), 761-773.

Hughes, D.J. & Atkinson, R.J.A., 1997. A towed video survey of megafaunal bioturbation in the north-eastern Irish Sea. *Journal of the Marine Biological Association of the United Kingdom*, **77**, 635-653.DOI https://doi.org/10.1017/s0025315400036122

Hughes, D.J., 1998a. Sea pens & burrowing megafauna (volume III). An overview of dynamics and sensitivity characteristics for conservation management of marine SACs. *Natura 2000 report prepared for Scottish Association of Marine Science (SAMS) for the UK Marine SACs Project.*, Scottish Association for Marine Science. (UK Marine SACs Project). Available from: http://ukmpa.marinebiodiversity.org/uk_sacs/pdfs/seapens.pdf

Ingle, R.W. & Christiansen, M.E., 2004. *Lobsters, Mud Shrimps and Anomuran Crabs: Keys and Notes for the Identification of the Species.* Shrewsbury: Fields Studies Council for the Linnean Society of London and the Estuarine and Coastal Sciences Association. [Synopses of the British Fauna (New Series) No. 55].

Johns, A.R., Taylor, A.C., Atkinson, R.J.A. & Grieshaber, M.K., 1997. Sulphide metabolism in thalassinidean Crustacea. *Journal of the Marine Biological Association of the United Kingdom*, **77**, 127-144. DOI https://doi.org/10.1017/S0025315400033828

Johnson, M.P., Lordan, C. & Power, A.M., 2013. Habitat and ecology of *Nephrops norvegicus.* In Johnson, M.L. and Johnson, M.P. (eds.). T*he Ecology and Biology of Nephrops norvegicus. Advances in Marine Biology*, **64,** 27-63. Academic Press.

Kaiser, M., Clarke, K., Hinz, H., Austen, M., Somerfield, P. & Karakassis, I., 2006. Global analysis of response and recovery of benthic biota to fishing. *Marine Ecology Progress Series*, **311**, 1-14.

Klawe, W.L. & Dickie, L.M., 1957. Biology of the bloodworm, *Glycera dibranchiata* Ehlers, and its relation to the bloodworm fishery of the Maritime Provinces. *Bulletin of Fisheries Research Board of Canada*, **115**, 1-37.

Marine Scotland, 2016. *Fish and Shellfish stocks, 2016 edn*. Marine Scotland Science, pp 53. Available from http://www.gov.scot/Topics/marine/Publications/publicationslatest/farmedfish/fishandshellfishstocks/2016

Marrs, S.J., Atkinson, R.J.A. & Smith, C.J., 1998. The towed underwater TV technique for use in stock assessment of *Nephrops norvegicus*. *International Council for the Exploration of the Sea Study Group on Life Histories of* Nephrops *La Coruña 4-8 May 1998*, CM 1998/G:9, pp. 88-98.

Marine Ecological Surveys Limited (MES), 2008. *Marine Macrofauna Genus Trait Handbook*. Marine Ecological Surveys Limited: Bath.

Nash, R. D. M., Chapman, C.J., Atkinson, R.J.A. & Morgan, P.J.,1984. Observations on the burrows and burrowing behaviour of *Calocaris macandreae* (Crustacea: Decapoda: Thalassinoidea). *Journal of Zoology*, **202**(3), 425-439. DOI https://doi.org/10.1111/j.1469-7998.1984.tb05093.x

Nickell, L.A. & Atkinson, R.J.A., 1995. Functional morphology of burrows and trophic modes of three thalassinidean shrimp species, and a new approach to the classification of thalassinidean burrow morphology. *Marine Ecology Progress Series*, **128**, 181-197.

Norling, K., Rosenberg, R., Hulth, S., Grémare, A. & Bonsdorff, E., 2007. Importance of functional biodiversity and species-specific traits of benthic fauna for ecosystem functions in marine sediment. *Marine Ecology Progress Series*, **332**, 11-23. DOI https://doi.org/10.3354/meps332011

OBIS (Ocean Biodiversity Information System), 2024. Global map of species distribution using gridded data. Available from: Ocean Biogeographic Information System. www.iobis.org. Accessed: 2024-01-04

Olsgard, F., Schaanning, M.T., Widdicombe, S., Kendall, M.A. & Austen, M.C., 2008. Effects of bottom trawling on ecosystem functioning. *Journal of Experimental Marine Biology and Ecology*, **366** (1-2), 123-133. DOI http://dx.doi.org/10.1016/j.jembe.2008.07.036

OSPAR Commission, 2010. Background document for Seapen and Burrowing Megafauna communities. *OSPAR Commission Biodiversity Series*. OSPAR Commission: London. Available from: http://qsr2010.ospar.org/media/assessments/Species/P00481_Seapen_and_burrowing_megafauna.pdf

Pinn, E.H. & Atkinson, R.J.A., 2010. Burrow development, nutrient fluxes, carnivory and caching behaviour by *Calocaris macandreae*

(Crustacea: Decapoda: Thalassinidea). *Journal of the Marine Biological Association of the United Kingdom*, **90** (2), 247-253. DOI http://dx.doi.org/10.1017/S002531540999066X

Pinn, E.H., Atkinson, R.J.A. & Rogerson, A., 1998. The diet of two mud-shrimps, *Calocaris macandreae* and *Upogebia stellata* (Crustacea: Decapoda: Thalassinidea). *Ophelia*, **48** (3), 211-223. DOI https://doi.org/10.1080/00785236.1998.10426967

Pinn, E.H., James, R., Atkinson, A. & Rogerson, A., 1998b. Particle size selectivity and resource partitioning in five species of Thalassinidea (Crustacea: Decapoda). *Marine Ecology Progress Series*, **169**, 243-250. DOI https://doi.org/10.3354/meps169243

Pommer, C.D., Olesen, M. & Hansen, J.L.S., 2016. Impact and distribution of bottom trawl fishing on mud-bottom communities in the Kattegat. *Marine Ecology Progress Series*, **548**, 47-60

Roberts, D.A., Johnston, E.L. & Knott, N.A., 2010b. Impacts of desalination plant discharges on the marine environment: A critical review of published studies. *Water Research*, **44** (18), 5117-5128.

Rosenberg, R., Nilsson, H.C., Hellman, B. & Agrenius, S., 2000. Depth correlated benthic faunal quantity and infaunal burrow structures on the slopes of a marine depression. *Estuarine Coastal and Shelf Science*, **50** (6), 843-853. DOI https://doi.org/10.1006/ecss.2000.0614

Rowden, A.A. & Jones, M.B., 1994. A contribution to the biology of the burrowing mud shrimp, *Callianassa subterreanea* (Decapoda: Thalassinidea). *Journal of the Marine Biological Association of the United Kingdom*, **74**, 623-635.

Ruso, Y.D.P., la Ossa Carretero, J.A.D., Casalduero, F.G. & Lizaso, J.L.S., 2007. Spatial and temporal changes in infaunal communities inhabiting soft-bottoms affected by brine discharge. *Marine environmental research*, **64** (4), 492-503.

Rygg, B., 1985. Effect of sediment copper on benthic fauna. *Marine Ecology Progress Series*, **25**, 83-89.

Sardá, R., Pinedo, S., Gremare, A. & Taboada, S., 2000. Changes in the dynamics of shallow sandy-bottom assemblages due to sand extraction in the Catalan Western Mediterranean Sea. *ICES Journal of Marine Science*, **57** (5), 1446-1453.

Smith, C.J., Papadopoulou, K.N. & Diliberto, S., 2000. Impact of otter trawling on an eastern Mediterranean commercial trawl fishing ground. *ICES Journal of Marine Science*, **57** (5), 1340-1351. DOI http://dx.doi.org/10.1006/jmsc.2000.0927

Stewart, N.E., Millemann, R.E. & Breese, W.P., 1967. Acute toxicity of the insecticide Sevin® and its hydrolytic product 1-naphthol to some marine organisms. *Transactions of the American Fisheries Society*, **96** (1), 25-30.

Taylor, A.C., Astall, C.M. & Atkinson, R.J.A., 2000. A comparative study of the oxygen transporting properties of the heamocyanin of five species of thalassinidean mud-shrimps. *Journal of Experimental Marine Biology and Ecology*, **244**, 265-283.

Taylor, A.C., Johns, A.R., Atkinson, R.J.A. & Bridges, C.R., 1999. Effects of sulphide and thiosulphate on the respiratory properties of the haemocyanin of the benthic crustaceans *Calocaris macandreae* Bell, Nephrops norvegicus (L.) and *Carcinus maenas* (L.). *Journal of Experimental Marine Biology and Ecology*, **233** (2), 163-179. DOI https://doi.org/10.1016/s0022-0981(98)00108-7

Thain, J.E., Davies, I.M., Rae, G.H. & Allen, Y.T., 1997. Acute toxicity of ivermectin to the lugworm *Arenicola marina*. *Aquaculture*, **159**, 47-52.

Tuck, I.D., Hall, S.J., Robertson, M.R., Armstrong, E. & Basford, D.J., 1998. Effects of physical trawling disturbance in a previously unfished sheltered Scottish sea loch. *Marine Ecology Progress Series*, **162**, 227-242.

Ungfors, A., Bell, E., Johnson, M.L., Cowing, D., Dobson, N.C., Bublitz, R. & Sandell, J., 2013. Nephrops Fisheries in European Waters. In Johnson, M.L. and Johnson, M.P. (eds.). *The Ecology and Biology of Nephrops norvegicus. Advances in Marine Biology*, vol. 64, Academic Press, pp. 247-314.

Vergnon, R. & Blanchard, F., 2006. Evaluation of trawling disturbance on macrobenthic invertebrate communities in the Bay of Biscay, France: Abundance Biomass Comparison (ABC method). *Aquatic Living Resources*, **19** (3), 219-228. DOI https://doi.org/10.1051/alr:2006022

Widdicombe, S. & Austen, M.C., 2003. The effects of bioturbation by the burrowing shrimp *Calocaris macandreae* on a subtidal macrobenthic community: Further evidence for the importance of function over identity. *Vie Et Milieu-Life and Environment*, **53** (4), 163-169.

Widdicombe, S., Austen, M.C., Kendall, M.A., Olsgard, F., Schaanning, M.T., Dashfield, S.L. & Needham, H.R., 2004. Importance of bioturbators for biodiversity maintenance: indirect effects of fishing disturbance. *Marine Ecology Progress Series*, **275**, 1-10. DOI https://doi.org/10.3354/meps275001

Wright, J., Colling, A., Park, D. & Open University Oceanography Course Team, 2001. *Waves, Tides, and Shallow-water Processes*. Oxford: Butterworth-Heinemann.