Mytilus edulis and piddocks on eulittoral firm clay

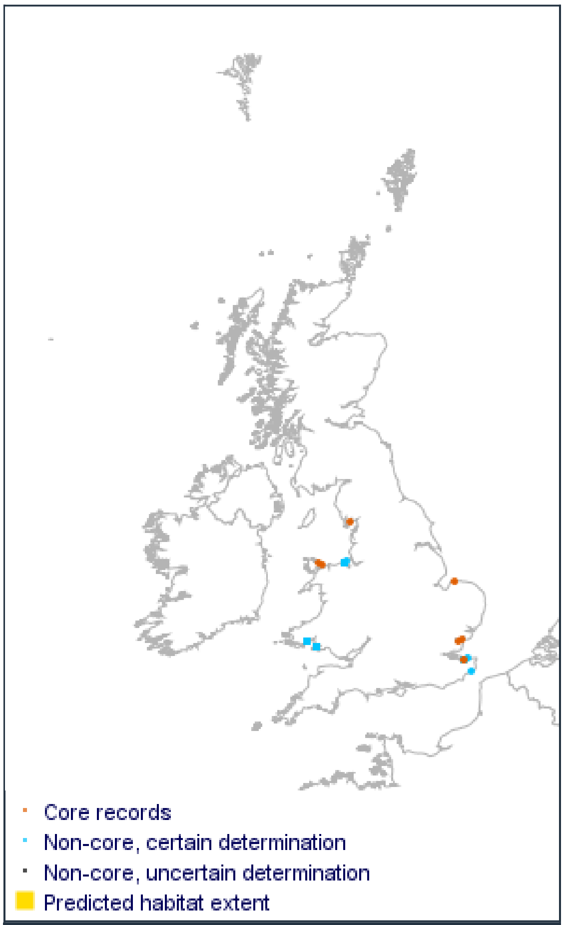
MarLIN – Marine Life Information Network
Marine Evidence–based Sensitivity Assessment (MarESA) Review

Dr Heidi Tillin & Charlotte Marshall

2016-02-05

This review can be cited as:
Tillin, H.M. & Marshall, C.M., 2016. [Mytilus edulis] and piddocks on eulittoral firm clay. In Tyler-Walters H. and Hiscock K. (eds) *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.95.1

(page left blank)



17-09-2018
Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

Researched by Dr Heidi Tillin & Charlotte Marshall **Refereed by** Admin

Summary

UK and Ireland classification

EUNIS 2008	A1.223	*Mytilus edulis* and piddocks on eulittoral firm clay
JNCC 2015	LR.MLR.MusF.MytPid	*Mytilus edulis* and piddocks on eulittoral firm clay
JNCC 2004	LR.MLR.MusF.MytPid	*Mytilus edulis* and piddocks on eulittoral firm clay
1997 Biotope	LR.MLR.MytPid	*Mytilus edulis* and piddocks on eulittoral firm clay

Description

Clay outcrops in the mid to lower eulittoral that are bored by a variety of piddocks including *Pholas dactylus*, *Barnea candida* and *Petricola pholadiformis*. The surface of the clay is characterized by small clumps of the mussel *Mytilus edulis*, the barnacle *Elminius modestus* and the winkle *Littorina littorea*. Seaweeds are generally sparse on the clay, although small patches of the red seaweeds *Mastocarpus stellatus*, *Halurus flosculosus* and *Ceramium* spp. can occur, usually attached to loose-lying cobbles or mussel shells. Also the green seaweeds *Ulva* spp. including *Ulva lactuca* may be present. The polychaete *Lanice conchilega* can sometimes be present in the clay, while the crustacean *Carcinus maenas* is present as well. More data required to validate this biotope. (Information from Connor *et al*., 2004, JNCC).

Depth range

Lower shore

Additional information

-

Listed By

- none -

Further information sources

Search on:

G G G JNCC

Habitat review

Ecology

Ecological and functional relationships

- Filter / suspension feeding organisms such as the piddocks *Barnea candida*, *Petricola pholadiformis* and *Pholas dactylus*, the mussel *Mytilus edulis* and the sand mason worm *Lanice conchilega*, are the dominant trophic group in the biotope. They feed on phytoplankton and detritus but also small zooplankton and dissolved organic material. Other associated suspension feeders may include the barnacles *Semibalanus balanoides* and *Elminius modestus*, mud shrimps *Corophium* spp. and the slipper limpet *Crepidula fornicata*. Inter and intra-specific competition for food may exist between the key structural species (see Species Composition) and other filter feeders within the biotope.
- The common shore crab *Carcinus maenas* is the predominant mobile species in the biotope, travelling through as it scavenges for food. It is a significant predator on both adult mussels and their spat.
- The algae that occur in small loose lying patches or attached to cobbles on the surface of the clay may provide shelter and possibly a source of food for the grazing prosobranchs *Littorina littorea*, which frequently occurs in the biotope. *Littorina littorea* feed within and around the mussel bed, grazing on benthic microalgae and macroalgae (sporeling and adult plants), and bulldozing newly settled invertebrate larvae (Hawkins & Hartnoll, 1983).

Predation

- Predation is the single most important source of mortality in *Mytilus edulis* populations (Seed & Suchanek, 1992; Holt *et al*., 1998). Many predators target specific sizes of mussels and, therefore influence population size structure. For example, *Carcinus maenas* was unable to consume mussels of ca. 70 mm in length and mussels >45 mm long were probably safe from attack (Davies *et al*., 1980; Holt *et al*., 1998).

  The lower limit of intertidal mussel populations may be limited by predation by *Carcinus maenas*.

- Birds are important predators of mussels. Oystercatchers, herring gulls, eider ducks and knot have been reported to be major sources of *Mytilus edulis* mortality. For example, in the Ythan estuary bird predation consumed 72% of mussel production, with oystercatchers and herring gulls being each responsible for 15%. Mussels are regarded as a staple food of oystercatchers (Dare, 1976; Holt *et al*., 1998). It is not known if birds are significant predators of the piddock species but the areas in which this biotope is found are often important sites for thousands of wildfowl and wading birds.

  ### Seasonal and longer term change

  - It is unlikely that piddock populations will be subject to significant seasonal changes in abundance. *Petricola pholadiformis*, for example, has a longevity of up to 10 years (Duval, 1963a) and its established populations may not exhibit significant seasonal changes, besides spawning in the summer. *Pholas dactylus* live to approximately 14 years of age, and spawning usually occurs between May and September with settlement and recruitment of juvenile piddocks occuring between November and February (Pinn *et al.*, 2005).

- *Mytilus edulis* spawns in spring and summer and in some areas again in August and September, with settlement occurring 1-4 weeks later. However, while recruitment can be annual, it is often sporadic and unpredictable. The species richness of the macro-invertebrate fauna associated with mussel patches was shown to fluctuate seasonally, probably reflecting random fluctuations in settlement and mortality typical of marine species with planktonic larvae (see Seed, 1996 for discussion). Winter storms can remove clumps of mussels, especially where the mussels are fouling by macroalgae or epifauna, due to wave action and drag, or direct impact by wave driven debris, e.g. logs (Seed & Suchanek, 1992).
- The *Carcinus maenas* population may migrate offshore in the winter, therefore reducing predation pressure on the mussels.
- Macroalgae populations are also likely to exhibit some seasonal differences with a general decline in abundance / biomass over the winter months.

Habitat structure and complexity

Clay platforms can support rich and diverse communities. Piddock burrowing creates a generally uneven surface on a small scale (5-15 cm) providing habitats for other animals that inhabit vacant burrows and crevices in the clay. Resident piddock populations can result in extensively burrowed clay and empty piddock burrows can influence the abundance of other species by providing additional habitats and refuges (Pinn *et al.*, in press). Wallace & Wallace (1983) reported densities of 30-60 *Barnea candida* siphon holes per square foot in Merseyside and burrows up to 6 inches deep. Duval (1977) found that the depth of the boring depended on the size of the animal. For example, an animal with a shell length of 1.2 cm could bore a 2.7 cm burrow whereas animals 4.8 cm long could bore burrows of 12 cm. Pinn *et al.* (in press) found a statistically significant increase in species diversity in areas where old piddock burrows were present compared to where they were absent. Empty shells protruding from the eroded surface are also an important settlement surface within this habitat. Due to the impervious nature of the clay, small depressions on the surface can retain water as the tide goes out. In the Swale, Kent, these areas of shallow water have been colonized by the suspension feeders *Crepidula fornicata* and *Hydrallmania falcata* and the red algae *Halurus flosculosus* (as *Griffithsia flosculosa*) and *Dictyota dichotoma* (Hill *et al.*, 1996).

Mussel beds can be divided into three distinct habitat components: the interstices within the mussel matrix; the biodeposits beneath the bed; and the substratum afforded by the mussel shells themselves (Suchanek, 1985; Seed & Suchanek, 1992). The sediments, shell fragments and byssal threads that form important components of the mussel patches are important for increasing the heterogeneity of the environments (Tsuchiya & Nishihira, 1986). After the settlement of mussel larvae, a monolayer is formed in the early stages of patch growth (Tsuchiya & Nishihira, 1986). As the patch grows, and the mussels require more space, mussels on the outside may be pushed outwards whilst those on the inside may be pushed up, resulting in the formation of a multi-layered mussel bed (Tsuchiya & Nishihira, 1986). If surface space is limited, as is likely if the sediment surface is extensively bored by the piddocks, mussels may be forced upwards rather than outwards in their patches. This will result in further increases to the heterogeneity of the substratum. Recent evidence suggests that the *Mytilus edulis* communities studied by Suchanek 1985 and Tsuchiya & Nishihira (1985, 1986) were probably *Mytilus trossulus* and *Mytilus galloprovincialis* respectively (Seed, 1992), although their community structure is probably similar to that of *Mytilus edulis*.

- The interstices between the mussels provide refuge from predation, and a humid environment protected from wave action, desiccation, and extremes of temperature.
- In the intertidal, *Mytilus* sp. Beds the species richness and diversity increases with the age and size of the bed (Suchanek, 1985; Tsuchiya & Nishihira, 1985,1986; Seed & Suchanek, 1992). However, the biotope is characterized by small clumps of mussels.
- Mussel faeces and pseudo-faeces, together with silt, build up organic biodeposits under the patches. In mussel beds the silt supports infauna such as sediment dwelling sipunculids, polychaetes and ophiuroids (Suchanek, 1978; Tsuchiya & Nishihira, 1985,1986; Seed & Suchanek, 1992).
- *Mytilus edulis* can use its prehensile foot to clean fouling organisms from its shell (Theisen, 1972). Therefore, the epizoan flora and fauna is probably less developed or diverse than found in beds of other mussel species but may include barnacles (e.g. *Austrominius modestus*) and tubeworms (e.g. *Spirobranchus* species)
- Mobile epifauna including *Littorina littorea* can obtain refuge from predators, especially birds, within the mussel matrix and emerge at high tide to forage (Suchanek, 1985; Seed & Suchanek, 1992).
- The mussels provide a substratum for the attachment of foliose and filamentous algae e.g. *Ceramium* species, *Mastocarpus stellatus* and *Ulva lactuca*. These algae in turn can provide a habitat for cryptic fauna such as amphipods.
- Piddocks increase the structural complexity of the habitat through their burrowing activities, which results in an increase in species diversity (Pinn *et al.*, in press).

Productivity

Dense beds of bivalve suspension feeders increase turnover of nutrients and organic carbon in estuarine (and presumably coastal) environments by effectively transferring pelagic phytoplanktonic primary production to secondary production (pelagic-benthic coupling) (Dame, 1996).

- Specific information about the productivity of the key structural species was not found. However, the piddocks together with the mussels mean that detritus will contribute the most to the productivity of the biotope.
- *Mytilus* spp. Communities are highly productive secondary producers (Seed & Suchanek, 1992; Holt *et al.*, 1998). Low shore mussels were reported to grow 3.5-4 cm in 30 weeks and up to 6-8 cm in length in 2 years under favourable conditions, although high shore mussels may only reach 2-3 cm in length after 15-20 years (Seed, 1976). Seed & Suchanek (1992) suggested that in populations of older mussels,

productivity may be in the region of 2000-14,500 kJ/m^2/yr. However, this biotope is characterized by patches of mussels, as opposed to mussel beds, and although mussel productivity is nevertheless important, it will not be as high as productivity from mussel beds. In Killary Harbour, western Ireland, the shore population of mussels contributed significantly to the larval population of the inlet. Kautsky (1981) reported that the release of mussel eggs and larvae from subtidal beds in the Baltic Sea contributed an annual input of 600 tons of organic carbon/yr. to the pelagic system. The eggs and larvae were probably an important food source for herring larvae and other zooplankton. The *Mytilus edulis* beds probably also provide secondary productivity in the form of tissue, faeces and pseudofaeces (Seed & Suchanek, 1992; Holt *et al.*, 1998). Maximum growth rates for the piddocks *Pholas dactylus*, *Barnea candida* and *Barnea parva* were found to be respectively about 7 mm, 10 mm and 4 mm per growth line.

- The small amount of macroalgae associated with this biotope including *Mastocarpus stellatus*, *Ceramium* species and *Ulva intestinalis* will contribute some dissolved organic carbon to the biotope. This is taken up readily by bacteria and may even be taken up directly by some larger invertebrates. Only about 10% of the primary production is directly cropped by herbivores (Raffaelli & Hawkins, 1996). Dissolved organic carbon, algal fragments and microbial film organisms are continually removed by the sea. This may enter the food chain of local, subtidal ecosystems, or be exported further offshore. Measurements of the productivity of benthic algae are relatively few, particularly for the Rhodophyta (Dixon, 1973). Blinks (1955) estimated the net production of red algae to be in the order of 11 to 54 g dry weight per m^2 per day.

Recruitment processes

Most of the characterizing species in the biotope are sessile or sedentary suspension feeders. Recruitment of adults of these species to the biotope by immigration is therefore unlikely. Consequently, recruitment occurs primarily through dispersive larval stages. However, recruitment in many bivalve species is sporadic with unpredictable recruitment episodes.

- The three piddock species *Pholas dactylus*, *Petricola pholadiformis* and *Barnea candida* spawn in the summer months of July, August and September respectively. Settlement and recruitment of juvenile piddocks into the population is known to occur over an extended period between the months of November and February (Pinn *et al.*, 2005). El-Maghraby (1955) showed that in southern England *Barnea candida* was unusual in that it started to spawn when the temperature fell at the beginning of the autumn (September).
- The fecundity of female *Petricola pholadiformis* is estimated to be between 3 - 3.5 million eggs per year (Duval, 1963a).
- *Mytilus edulis* recruitment is dependant on larval supply and settlement, together with larval and post-settlement mortality. Jørgensen (1981) estimated that larvae suffered a daily mortality of 13% in the Isefjord, Denmark but Lutz & Kennish (1992) suggested that larval mortality was approximately 99%. Larval mortality is probably due to adverse

environmental conditions, especially temperature, inadequate food supply (fluctuations in phytoplankton populations), inhalation by suspension feeding adult mytilids, difficulty in finding suitable substrata and predation (Lutz & Kennish, 1992). Widdows (1991) suggested that any environmental factor that increased development time, or the time between fertilization and settlement would increase larval mortality.

- Recruitment in many *Mytilus* sp. populations is sporadic, with unpredictable pulses of recruitment (Seed & Suchanek, 1992). *Mytilus* sp. is highly gregarious and final settlement often occurs around or in-between individual mussels of established populations. Persistent mussels beds can be maintained by relatively low levels of recruitment e.g. McGrorty *et al.*, (1990) reported that adult populations were largely unaffected by large variations in spat fall between 1976-1983 in the Exe estuary.
- The *Mytilus edulis* patch may act as a refuge for larvae or juveniles, however, the intense suspension feeding activity of the mussels is likely to consume large numbers of pelagic larvae.
- *Littorina littorea* can breed all through the year although the length and timing of the breeding period is dependent on climatic conditions. Large females can produce up to 100, 000 eggs during this time. The pelagic phase of the larvae can be as long as six weeks providing potential for dispersal.
- The breeding season in *Carcinus maenas* depends on geographic location and in general, the length of the breeding period increases further south in England with year round breeding possible on the south coast. Fecundity in females can exceed 100, 000 eggs.

Time for community to reach maturity

Little information was found concerning community development. However, piddocks, *Barnea candida*, *Pholas dactylus* and *Petricola pholadiformis* are likely to settle readily. These piddocks breed annually and produce a large number of gametes. Once established individuals may live for a considerable length of time; *Petricola pholadiformis* of length 5-6 cm are likely to be between 6-10 years old (Duval, 1963a). Pinn *et al.* (2005) estimated the maximum age of *Pholas dactylus*, *Barnea candida* and *Barnea parva* to be 14 years, 4 years and 6 years respectively. Duval (1977) proposed that it was as a result of the extensive borings of *Barnea candida* that facilitated the colonization of an area in the Thames Estuary by the introduced American piddock, *Petricola pholadiformis*. This suggests that *Barnea candida* is a more competitive colonizing species in clay environments than the American piddock and it is possible that this species will appear first on cleared substrates.

Mytilus spp. populations are considered to have a strong ability to recover from environmental disturbance (Seed & Suchanek, 1992; Holt *et al.*, 1998). Larval supply and settlement could potentially occur annually, however, settlement is sporadic with unpredictable pulses of recruitment (Lutz & Kennish, 1992; Seed & Suchanek, 1992). The presence of macroalgae in disturbance gaps in *Mytilus califorianus* populations, where grazers were excluded, inhibited recovery by the mussels. In New England, U.S.A, prior barnacle cover was found to enhance recovery by *Mytilus edulis* (Seed & Suchanek, 1992). While good annual recruitment is possible, recovery of the mussel population may take up to 5 years. However, recovery of the mussel population may be delayed by 1-7 years for the initial macroalgal cover to reduce and barnacle cover to increase. Therefore, the biotope may take between 5 -10 years to recover depending on local conditions. Once the patches of mussels have returned, colonization of the associated community is dependant on the development of a mussel matrix, younger beds exhibiting lower species richness and species diversity than older beds, and hence growth rates and local environmental conditions. Tsuchiya & Nishihira (1986) examined young and older patches of *Mytilus* (probably *Mytilus galloprovincialis*) in Japan. They noted that as the patches of mussels grew older, individuals increased in size, and other layers were added, increasing the space within the matrix for colonization, which also accumulated biogenic sediment. Increased space and organic sediment was then colonized by infauna and epiphytes and as the patches and mussels became older, eventually epizoic species colonized the mussel shells. Macroalgae could colonize at any time in the succession. Unfortunately, Tsuchiya & Nishihira (1986) did not suggest a timescale.

Additional information

-

Preferences & Distribution

Habitat preferences

Depth Range	Lower shore
Water clarity preferences	
Limiting Nutrients	Data deficient
Salinity preferences	Full (30-40 psu)
Physiographic preferences	
Biological zone preferences	Eulittoral
Substratum/habitat preferences	Clay, Cobbles
Tidal strength preferences	
Wave exposure preferences	Exposed, Moderately exposed
Other preferences	Clay

Additional Information

This biotope occurs in predominantly turbid waters which are vital for the suspension feeders, the dominant trophic group. The three piddock species are likely to be fairly specific with regard to substratum preferences. *Petricola pholadiformis*, for example, requires a fairly soft but firm and stable sediment in which to live and in Britain, its upper limit is usually determined by a change in substratum (Duval, 1963a), namely a lack of appropriate substrata. Richter & Sarnthein (1976) looked at the re-colonization of different sediments by various molluscs on suspended platforms in Kiel Bay, Germany. They found that *Barnea candida* was restricted to clay, and occasionally fine sand, and that substrate type was certainly the most important factor for this species, in contrast to depth that was the primary factor for all other piddock species. No information was found concerning the factors influencing the lower limits of their distribution.

The upper limit of mussel beds is often clear cut (see Lewis, 1964) and determined by physical factors such as temperature and desiccation, which may be synergistic, i.e. sudden mass mortalities at the upper limit of intertidal mussel beds are often associated with prolonged periods of unusually high temperatures and desiccation stress (Seed & Suchanek, 1992).

The lower limit of distribution is strongly influenced by predation, primarily from starfish but also dogwhelks and crabs. Tsuchiya & Nishihira (1985, 1986) noted that increase sediment or silt build up within the mussel bed matrix, reduced the available space within the matrix, changing species composition, presumably in favour of infaunal invertebrates, and reduced species richness.

The high silt deposition environment is also favourable for deposit feeders which may include the ragworm *Hediste diversicolor* and mud shrimps *Corophium* spp.

Species composition

Species found especially in this biotope

Rare or scarce species associated with this biotope

-

Additional information

The MNCR reported 42 species from this biotope, although not all species occur in all examples of the biotope (JNCC, 1999). Tsuchiya & Nishihira (1986) found more than 40 different species associated with mussel patches approximately 500 cm▯ in size.

Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

This biotope is formed where clay outcrops in the mid to lower eulittoral support a variety of piddocks including *Pholas dactylus*, *Barnea candida* and *Petricolaria pholadiformis* and small clumps of the mussel *Mytilus edulis*. This biotope provides a habitat for common shore species including the barnacle *Elminius modestus* and the winkle *Littorina littorea*. Seaweeds are generally sparse on the clay which provides a poor surface for attachment, although small patches of red seaweeds and green seaweeds can occur where loose-lying cobble or mussel shells provide suitable attachment space. The sand mason *Lanice conchilega* can sometimes be present in the clay, while the shore crab *Carcinus maenas* is present as well.

Development of this biotope is highly dependent on the presence of suitable substratum, the sensitivity assessments therefore specifically consider the sensitivity of the clay substratum to the pressures, where appropriate. The piddocks associated with the biotope are key characterizing species and if these were removed the biotope classification would change. Piddocks are also important structuring species as their empty holes can provide habitats for other species (Pinn *et al*., 2008) and they are bioeroders, destabilising the substratum through their burrowing activities, allowing it to be more easily eroded by water flow and wave action (Pinn *et al*., 2005; Evans 1968, Trudgill 1983, Trudgill & Crabtree, 1987). Pinn *et al*. (2005) estimated that over the lifespan of a piddock (12 years), up to 41% of the shore could be eroded to a depth of 8.5 mm).

The sensitivity of the mussels as a key characterizing and structuring species are considered within the assessments. The *Mytilus edulis* patches provide additional surface area for attachment for epibionts including algal species. Within the mussel matrix, associated fauna may find refuge.

Other species associated with the biotope are commonly found on many different shore types and are either mobile or rapid colonizers. Although these species contribute to the structure and function of the biotope they are not considered key species and are not specifically assessed.

Resilience and recovery rates of habitat

Hydrological Pressures

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

Little empirical evidence was found to assess the effects of increased temperature on piddocks and the assessment is based on distribution records and evidence for spawning in response to temperature changes.

More extensive evidence on thermal tolerance and physiological effects was found for *Mytilus edulis*.

The American piddock *Petricolaria pholadiformis* has a wide distribution and is found north as far as the Skaggerak, Kattegat and Limfjord (Jensen, 2010) and is also present in the Mediterranean, Gulf of Mexico and Caribbean (Huber & Gofas, 2015). *Pholas dactylus* occurs in the Mediterranean and the East Atlantic, from Norway to Cape Verde Islands (Micu, 2007). *Barnea candida* is distributed from Norway to the Mediterranean and West Africa (Gofas, 2015).

Temperature changes have been observed to initiate spawning by *Pholas dactylus*, which usually spawns between July and August. Increased summer temperatures in 1982 induced spawning in July on the south coast of England (Knight, 1984). Spawning of *Petricolaria pholadiformis* is initiated by increasing water temperature (>18 °C) (Duval, 1963a), so elevated temperatures outside of usual seasons may disrupt normal spawning periods. The spawning of *Barnea candida* was also reported to be disrupted by changes in temperature. *Barnea candida* normally spawns in September when temperatures are dropping (El-Maghraby, 1955). However, a rise in temperature in late June of 1956, induced spawning in some specimens of *Barnea candida* (Duval, 1963b). Disruption from established spawning periods, caused by temperature changes, may be detrimental to the survival of recruits as other factors influencing their survival may not be optimal, and some mortality may result. Established populations may otherwise remain unaffected by elevated temperatures.

Mytilus edulis is a eurytopic species found in a wide temperature range from mild, subtropical regions to areas which frequently experience freezing conditions and are vulnerable to ice scour (Seed & Suchanek 1992). In British waters 29°C was recorded as the upper sustained thermal tolerance limit for *Mytilus edulis* (Read & Cumming, 1967; Almada-Villela, et al., 1982), although it is thought that European mussels will rarely experience temperatures above 25°C (Seed & Suchanek, 1992).

Tsuchiya (1983) documented the mass mortality of *Mytilus edulis* in August 1981 due to air temperatures of 34°C that resulted in mussel tissue temperatures in excess of 40°C. In one hour, 50% of the *Mytilus edulis* from the upper 75% of the shore had died. It could not be concluded from this study whether the mortality was due to high temperatures, desiccation or a combination of the two. Lethal water temperatures appear to vary between areas (Tsuchiya, 1983) and it appears that tolerance varies, depending on the temperature range to which the individuals are acclimatised (Kittner & Riisgaard 2005). After acclimation of individuals of *Mytilus edulis* to 18°C, Kittner & Riisgaard (2005) observed that the filtrations rates were at their maximum between 8.3 and 20°C and below this at 6°C the mussels closed their valves. However, after being acclimated at 11°C for five days, the mussels maintained the high filtration rates down to 4°C. Hence, given time, mussels can acclimatise and shifting their temperature tolerance. Filtration in *Mytilus edulis* was observed to continue down to -1°C, with high absorption efficiencies (53-81%) (Loo, 1992).

At the upper range of a mussels tolerance limit, heat shock proteins are produced, indicating high stress levels (Jones *et al*., 2010). After a single day at 30°C, heat shock proteins were still present over 14 days later, although at a reduced level. Increased temperatures can also affect reproduction in *Mytilus edulis* (Myrand *et al*., 2000). In shallow lagoons mortality began in late July at the end of a major spawning event when temperatures peaked at >20°C. These mussels had a low energetic content post spawning and had stopped shell growth. It is likely that the high temperatures caused mortality due to the reduced condition of the mussels post spawning (Myrand *et al*., 2000). Gamete production does not appear to be affected by temperature (Suchanek, 1985).

Temperature changes may also lead to indirect effects For example, an increase in temperature increases the mussels' susceptibility to pathogens (*Vibrio tubiashii*) in the presence of relatively low concentrations of copper (Parry & Pipe, 2004). Increased temperatures may also allow for range expansion of parasites or pathogens which will have a negative impact upon the health of the mussels if they become infected.

Power stations have the potential to cause an increase in sea temperature of up to 15°C (Cole *et al*., 1999), although this impact will be localised. However, as mussels are of the most damaging biofouling organisms on water outlets of power stations, they are clearly not adversely affected (Whitehouse *et al*., 1985; Thompson *et al*., 2000).

Sensitivity assessment. Based on the wide range of temperature tolerance of *Mytilus edulis* and its limited effect on its physiology, it is concluded that the acute and chronic changes described by the benchmark would have limited effect. The global distribution of the piddock species suggest that these species can tolerate warmer waters than currently experienced in the UK and may therefore be tolerant of a chronic increase in temperature. Short-term chronic increases may, depending on timing, interfere with spawning cues which appear to be temperature driven. The effects will depend on seasonality of occurrence and the species affected. Adult populations may be unaffected and, in such long-lived species, an unfavourable recruitment may be compensated for in a following year. Based on the characterizing species, resistance to an acute change in temperature is therefore assessed as 'High' and recovery as 'High' (within two years) and the biotope is considered 'Not Sensitive'. For all characterizing species it should be noted that the timing of acute changes may lead to greater impacts, temperature increases in the warmest months may exceed thermal tolerances whilst changes in colder periods may stress individuals acclimated to the lower temperatures.

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

Little empirical evidence was found to assess the effects of decreased temperature on piddocks and the assessment is based on distribution records and evidence for spawning in response to temperature changes. More extensive evidence on thermal tolerance and physiological effects was found for *Mytilus edulis*.

The American piddock *Petricolaria pholadiformis* has a wide distribution and is found north as far as the Skaggerak, Kattegat and Limfjord (Jensen, 2010) (Huber & Gofas, 2015). *Pholas dactylus* occurs in the Mediterranean and the East Atlantic, from Norway to Cape Verde Islands (Micu, 2007). *Barnea candida* is distributed from Norway to the Mediterranean and West Africa (Gofas, 2015).

Temperature changes have been observed to initiate spawning by *Pholas dactylus*, which usually spawns between July and August. Increased summer temperatures in 1982 induced spawning in July on the south coast of England (Knight, 1984). Spawning of *Petricolaria pholadiformis* is initiated by increasing water temperature (>18 °C) (Duval, 1963a), so decreased temperatures may disrupt normal spawning periods where this coincides with the reproductive season. The spawning of *Barnea candida* was also reported to be disrupted by changes in temperature. *Barnea candida* normally spawns in September when temperatures are dropping (El-Maghraby, 1955). Disruption from established spawning periods, caused by decreased temperatures may be detrimental to the survival of recruits as other factors influencing their survival may not be optimal, and some mortality may result. Established populations may otherwise remain unaffected by decreased temperatures.

Mytilus edulis is a eurytopic species found in a wide temperature range from mild, subtropical regions to areas which frequently experience freezing conditions and are vulnerable to ice scour (Seed & Suchanek 1992). After acclimation of individuals of *Mytilus edulis* to 18°C, Kittner & Riisgaard (2005) observed that the filtrations rates were at their maximum between 8.3 and 20°C and below this at 6°C the mussels closed their valves. However, after being acclimated at 11°C for five days, the mussels maintained the high filtration rates down to 4°C. Hence, given time, mussels can acclimatise and shifting their temperature tolerance. Filtration in *Mytilus edulis* was observed to continue down to -1°C, with high absorption efficiencies (53-81%) (Loo, 1992).

Sensitivity assessment. Based on the wide range of temperature tolerance of *Mytilus edulis* and its limited effect on its physiology, it is concluded that the acute and chronic changes described by the benchmark would have limited effect. The global distribution of the piddock species suggest that these species can tolerate cooler waters than currently experienced in the UK and may therefore be tolerant of a chronic decrease in temperature at the benchmark level. Decreased temperatures may, depending on timing, interfere with spawning cues which appear to be temperature driven. The effects will depend on seasonality of occurrence and the species affected. Adult populations may be unaffected and, in such long-lived species, an unfavourable recruitment may be compensated for in a following year. Based on the characterizing species, resistance to an acute and chronic decrease in temperature at the pressure benchmark is therefore assessed as ‘High’ and recovery as ‘High’ (within two years) and the biotope is considered ‘Not Sensitive’.

Salinity increase (local)	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

No evidence for the range of physiological tolerances to salinity changes were found for piddocks. There is therefore no direct or indirect evidence for sensitivity to an increase in salinity. *Mytilus edulis* is found in a wide range of salinities from variable salinity areas (18-35ppt) such as estuaries and intertidal areas, to areas of more constant salinity (30-35ppt) in the sublittoral (Connor *et al*., 2004). Furthermore, mussels in rock pools are likely to experience hypersaline conditions on hot days. Newell (1979) recorded salinities as high as 42psu in intertidal rock pools, suggesting that *Mytilus edulis* can tolerate high salinities.

Sensitivity assessment. No evidence for the range of physiological tolerances to salinity changes were found for piddocks and sensitivity to this pressure is not assessed based on 'No evidence'.

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

Biotopes found in the intertidal will naturally experience fluctuations in salinity where evaporation increases salinity and inputs of rainwater expose individuals to freshwater. Species found in the intertidal are therefore likely to have some form of behavioural or physiological adaptations to changes in salinity. No direct empirical evidence was found to assess the sensitivity of piddocks to this pressure and the assessment is based on the reported distribution of characterizing species. *Barnea candida* is reported to extend in to estuarine environments in salinities down to 20 psu (Fish & Fish, 1996). *Petricolaria pholadiformis* is particularly common off the Essex and Thames estuary, e.g. the River Medway (Bamber, 1985) suggesting tolerance of brackish waters. Zenetos *et al.* (2009) suggest that at all sites where *Petricolaria pholadiformis* has been found there is some freshwater inflow into the sea. According to the literature, the species in its native range inhabits environments with salinities between 29 and 35ppt, while in the Baltic Sea it is reported from salinities 10-30 psu (Gollasch & Mecke, 1996, cited from Zenetos *et al.* 2009). According to Castagna & Chanley (1973, cited from Zenetos *et al.* 2009) the lower salinity tolerance of *Petricolaria pholadiformis* is 7.5-10 psu suggesting that reduced salinity facilitates its establishment(Zenetos *et al*., 2009). No information was found for the salinity tolerance of *Pholas dactylus.*

Mytilus edulis is found in a wide range of salinities from variable salinity areas (18-35ppt) such as estuaries and intertidal areas, to areas of more constant salinity (30-35ppt) in the sublittoral (Connor *et al*., 2004). In addition, *Mytilus edulis* thrives in brackish lagoons and estuaries, although, this is probably due to the abundance of food in these environments rather than the salinity (Seed & Suchanek, 1992). *Mytilus edulis* was recorded to grow in a dwarf form in the Baltic sea where the average salinity was 6.5psu (Riisgård *et al*., 2013).

Mytilus edulis exhibits a defined behavioural response to reducing salinity, initially only closing its siphons to maintain the salinity of the water in its mantle cavity, which allows some gaseous exchange and therefore maintains aerobic metabolism for longer. If the salinity continues to fall the valves close tightly (Davenport ,1979; Rankin & Davenport, 1981). In the long-term (weeks) *Mytilus edulis* can acclimate to lower salinities (Almada-Villela, 1984; Seed & Suchanek, 1992; Holt *et al*.,1998). Almada-Villela (1984) reported that the growth rate of individuals exposed to only 13 psu reduced to almost zero but had recovered to over 80% of control animals within one month. Observed differences in growth are due to physiological and/or genetic adaptation to salinity.

Decreased salinity has physiological effects on *Mytilus edulis*; decreasing the heart rate (Bahmet *et al*., 2005), reducing filtration rates (Riisgård *et al*., 2013), reducing growth rate (Gruffydd *et al*., 1984) and reducing the immune function (Bussell *et al*., 2008). Both Bahmet *et al*., (2005); Riisgård *et al*., (2013) noted that filtration and heart rates return to normal within a number of days acclimation or a return to the original salinity. However, Riisgard *et al*., (2013) did observe that mussels from an average of 17 psu found it harder to acclimate between the salinity extremes than those from an average of 6.5 psu. This observation may mean that mussels in a variable/ lower salinity environment are more able to tolerate change than those found at fully marine salinities.

Mytilus edulis is an osmoconformer and maintains its tissue fluids iso-osmotic (equal ionic strength) with the surrounding medium by mobilisation and adjustment of the tissue fluid concentration of free amino acids (e.g. taurine, glycine and alanine) (Bayne, 1976; Newell, 1989). But mobilizing amino acids may result in loss of protein, increased nitrogen excretion and reduced growth. However, Koehn (1983) and Koehn & Hilbish (1987) reported a genetic basis to adaptation to salinity.

In extreme low salinities, e.g. resulting from storm runoff, large numbers of mussels may be killed (Keith Hiscock pers comm. Tyler-Walters, 2008). However, Bailey *et al*., (1996) observed very few mortalities when exposing *Mytilus edulis* to a range of salinities as low as 0ppt for two weeks at a range of temperatures. It was also noted that there was a fast recovery rate.

Sensitivity assessment. Based on reported distributions of piddocks and *Mytilus edulis* and the results of experiments to assess salinity tolerance thresholds and behavioural and physiological responses in *Mytilus edulis* it is considered that the benchmark decrease in salinity would not result in mortality of these characterizing species in biotopes that were previously fully marine. Resistance is therefore assessed as 'High' and resilience as 'High', based on no effect to recover from and the biotope is considered to be

'Not sensitive'. In areas experiencing prolonged decreases in salinity, the ratio of *Petricolaria pholadiformis* to other piddock species may change as a result of its greater tolerance to reduced salinities, but this would not lead to re-classification of biotope type.

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

Established adult piddocks are, to a large extent, protected from direct effects of increased water flow, owing to their environmental position within the substratum. Increases or decreases in flow rates may affect suspension feeding by altering the delivery of suspended particles or the efficiency of filter feeding. Adult piddocks may become exposed should physical erosion associated with increase flow, occur at a greater rate than burrowing, and lost from the substratum. Increased scour, as a consequence of increased water flow may also inhibit settlement of juveniles. Changes in flow may lead to increased siltation through deposition or movement of mobile bedforms such as sand waves, these impacts are assessed separately through the siltation pressure. No direct evidence was found to inform the sensitivity assessment, other biotopes characterized by piddocks (EUNIS A3.2113; IR.MIR.KR.Ldig.Pid and A 4.231; CR.MCR.SfR.Pid) however, have been recorded in areas where tidal flows vary between 0.5 -1.5 m/s (Connor *et al.*, 2004), suggesting that changes in flow rates within this range will not negatively impact piddocks.

Increased flow rate increases the risk of mussel clumps being detached from the bed and transported elsewhere (Dare, 1976) although no evidence was found for mussel clumps on clay and much of the evidence on responses to flow rates is based on mussel beds on rock or sediments (Holt *et al.*, 1998; Widdows *et al.*, 2002). Widdows *et al.* (2002) found that low density mussel beds formed small clumps with a lower mass ratio of mussels attached to the substratum to increase anchorage.

Flow rate has been shown to influence the strength and number of byssus threads that are produced by *Mytilus edulis* and other *Mytilus* spp. with mussels in areas of higher flow rate demonstrating stronger attachment (Dolmer & Svane, 1994; Alfaro, 2006). Young (1985) demonstrated that byssus thread production and attachment increased with increasing water agitation. She observed the strengthening of byssal attachments by 25% within eight hours of a storm commencing and an ability to withstand surges up to 16 m/s. However, it was concluded that sudden surges may leave the mussels susceptible to being swept away (Young, 1985) as they need time to react to the increased velocity to increase the attachment strength.

Mytilus edulis are active suspension feeders generating currents by beating cilia and are therefore not entirely dependent on water flow to supply food (organic particulates and phytoplankton). Therefore, they can survive in very sheltered areas, but water flow (due to tides, currents or wave action) can enhance the supply of food, carried from outside the area or resuspended into the water column. Higher current speed brings food to the bottom layers of the water column, and hence near to the mussels, at a higher rate (Frechette *et al*., 1989). Widdows *et al*., (2002) found that there was no change in filtration rate of *Mytilus edulis* between 0.05 and 0.8 m/s and that above 0.8 m/s the filtration rate declined mainly because the mussels became detached from the substratum in the experimental flume tank. Widdows *et al*., (2002) noted that their results were consistent with field observations, as mussels show preferential settlement and growth in areas of high flow, They also reported that Jenner *et al*.,(1998; cited in Widdows *et al*., 2002) observed that biofouling of cooling water systems by mussels was only reduced significantly when mean current speeds reached 1.8-2.2 m/s and that mussels were absent at >2.9 m/s.

Water flow also affects the settlement behaviour of larvae. Alfaro (2005) observed that larvae settling in a low water flow environment are able to first settle and then detach and reattach displaying exploratory behaviour before finally settling and strengthening their byssus threads. However, larvae settling in high flow environments did not display this exploratory behaviour. Pernet *et al*., (2003) found that at high velocities, larvae of *Mytilus* spp. were not able to able to exercise much settlement preference. It was thought that when contact with suitable substratum is made the larvae probably secure a firm attachment. Movement of larvae from low shear velocities, where they use their foot to settle, to high shear velocities where they use their byssal thread to settle was observed by Dobretsov & Wahl (2008).

Potentially the most damaging effect of increased flow rate would be the erosion of the clay substratum as this could eventually lead to loss of the habitat. Increased erosion would lead to the loss of habitat and removal of piddocks and mussel clumps and macroalgae and other attached plants and animals. In general clays are cohesive and the consolidated nature of the sediment would reduce erodability. Laminar flows over smooth clay surfaces also reduce bed shear stress although flows may become more turbulent around clumps of mussels and macroalgae. However, at the benchmark this is considered unlikely to lead to significant erosion of the substratum.

Sensitivity assessment. No evidence was found to assess the water velocities at which erosion of clay occurs. Some erosion will occur naturally and storm events and wave action may be more significant in loss and damage of clay than surface water flow.

Based on the exposure of piddocks in other biotopes to water flows between 0.5 and 1.5 m/s, the piddocks are considered to be not sensitive to changes within this range as long as these do not lead to increased erosion of the substratum. *Mytilus edulis* biotopes are recorded from week (<0.5 m/s) to strong (up to 3 m/s) tidal streams. The sensitivity of beds on sedimentary biotopes to increased flow is dependent on the stability of the substratum and the degree of cover. Mussels in this biotope occur as clumps where more individuals anchor to the surface by byssus threads rather than multi-layered beds with less substratum attachment. Mussel clumps in this biotope may be naturally ephemeral based on the friability of the surface with periodic losses and recolonization. Resistance is therefore assessed as ‘High’ to changes (increase and decrease) in water flow at the pressure benchmark and resilience is assessed as ‘High’ and the biotope is considered to be ‘Not sensitve’.

Emergence regime changes	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low

Adult piddocks and the clumps of *Mytilus edulis* that characterize this biotope have no mobility and cannot therefore migrate up or down shore to adapt to changes in emergence. Within the clay substratum, adult piddocks will be afforded some protection by their burrows from desiccation and temperature increases, following increased emergence, by their burrows which will retain some moisture. During extended periods of exposure, *Pholas dactylus* squirt some water from their inhalant siphon and extend their gaping siphons into the air (Knight, 1984). This may result in increased predation by birds. The shells of piddocks do not completely enclose the animals, however , and therefore cannot be closed to prevent water loss. The tolerance of piddocks to increased and decreased emergence varies. *Pholas dactylus* inhabits the shallow sub-tidal and lower shore and *Barnea candida* and *Petricolaria pholadiformis* live slightly higher up the shore than *Pholas dactylus* (Duval, 1977) . Changes in emergence may therefore alter species abundances and ratios within the piddock population although the biotope will remain recognisable as a piddock biotope.

Mytilus edulis beds are found at a wide range of shore heights from in the strandline down to the shallow sublittoral (Connor et al., 2004). Their upper limits are controlled by temperature and desiccation (Suchanek, 1978; Seed & Suchanek 1992; Holt et al., 1998) while the lower limits are set by predation, competition (Suchanek, 1978) and sand burial (Daly & Mathieson 1977). Mussels found higher up the shore display slower growth rates (Buschbaum & Saier, 2001) due to the decrease in time during which they can feed and also a decrease in food availability. It has been estimated that the point of zero growth occurs at 55% emergence (Baird, 1966) although this figure will vary slightly depending on the conditions of the exposure of the shore (Baird, 1966; Holt et al., 1998). Increasing shore height does, however, increase the longevity of the mussels due to reduced predation pressures (Seed & Suchanek 1992; Holt et al., 1998), resulting in a wider age class of mussels found on the upper shore.

A decrease in emergence will reduce exposure to desiccation and extremes of temperature and allow the piddocks and *Mytilus edulis to* feed for longer periods and hence grow faster. Piddocks and mussels are therefore likely to be tolerant of a decrease in emergence and as a result, the biotope may be able to colonize further up the shore, providing a suitable substrate was available. No information was found on factors controlling the lower limit of piddock populations and it is possible, for example, that predation (predominantly siphon nipping by gobies, see Micu, 2007, and other species) may increase at the lower edge of the biotope. lower limit of *Mytilus* beds is mainly set by predation from *Asterias rubens* and *Carcinus maenas* which may increase with a decrease in emergence potentially reducing the lower limit or reducing the number of size classes and age of the mussels at the lower range of the bed (Saier, 2002). Competition for space with species better adapted to the changed conditions may also alter habitat suitability for this biotope. The Therefore, in the short-term, a decrease in emergence is likely to change the population structure of the mussel bed and, possibly, the piddock populations at their lower limits, probably reducing the species richness of the biotope. Although the mussel patches and piddock populations will effectively survive, the lower limit of the biotope as described may be lost although this biotope will probably colonize further up the shore , if the profile and substratum are suitable.

Sensitivity assessment. This biotope occurs in the eulittoral zone, where it experiences regular immersion and emersion. Species present are therefore tolerant of periods of emergence to some extent, however changes in emergence regime may alter habitat suitability and increase levels of predation and competition. Based on these considerations resistance to changes in emergence is assessed as 'Medium' as changes may alter the upper or lower margins of the biotope, recovery as 'Medium' (within 2-10 years) so that sensitivity is assessed as 'Medium'.

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

No direct evidence was found to assess sensitivity to this pressure. The biotope typically occurs in exposed or moderately wave exposed locations (Connor *et al*., 2004). The piddocks are unlikely to be directly affected by changes in wave exposure, owing to their environmental position within the clay substratum, which protects them. On clay substrates, it is possible however, that wave action actively erodes the substratum at a faster rate than the piddocks leading to exposure and displacement. At higher densities bioerosion by piddocks may destabilise the substratum increasing vulnerability to erosion. An increase in wave height may facilitate upward expansion of biotope margins where wave splash ameliorated effects of emergence and dessication but this is not considered significant at the pressure benchmark.

A number of studies and reports have assessed the effects of water flows on blue mussel beds however none of these were directly relevant to clumps of mussels on clay substrata. *Mytilus edulis* are able to increase the strength of their attachment to the substratum in more turbulent conditions (Price, 1982; Young, 1985). Young (1985) demonstrated an increase in strength of the byssal attachment by 25% within 8 hours of a storm commencing. When comparing mussels in areas of high flow rate and low flow rate those at a higher flow rate exhibit stronger attachments than those in the areas of lower flow (Dolmer & Svane, 1994; Alfaro, 2006). The growth of other organisms on the mussels themselves, will increase drag and hence increase the possibility of damage due to wave action.

Potentially the most damaging effect of increased wave heights on the biotope would be the erosion of the clay substratum as increased erosion would lead to the loss of habitat and removal of piddocks and the attached mussels. No evidence was found to link significant wave height to erosion. Some erosion will occur naturally and storm events may be more significant in loss and damage of clay substrata than changes in wave height at the pressure benchmark.

Sensitivity assessment. No direct evidence was found to assess this pressure at the benchmark and the assessment is based largely on the distribution of the biotope and characterizing species. Based on the occurrence of this biotope in exposed or moderately wave exposed habitats the piddocks and mussel clumps are considered to have 'High' resistance and 'High' resilience to changes (increase and decrease) at the pressure benchmark where these do not lead to increased erosion of the substratum. The biotope is therefore considered to be 'Not sensitive'.

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.

Hydrocarbon & PAH contamination	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

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

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.

Radionuclide contamination	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

No evidence.

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	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

Specific information concerning oxygen consumption and reduced oxygen tolerances were not found for piddocks. Cole *et al*. (1999) suggested possible adverse effects on marine species below 4 mg O_2/l and probable adverse effects below 2mg O_2/l. Duval (1963a) observed that conditions within the borings of *Petricolaria pholadiformis* were anaerobic and lined with a loose blue/black sludge, suggesting that the species may be relatively tolerant to conditions of reduced oxygen.

Mytilus edulis is regarded as euryoxic, tolerant of a wide range of oxygen concentrations including zero (Zandee *et al*., 1986; Wang & Widdows, 1991; Gosling, 1992; Zwaan de & Mathieu, 1992; Diaz & Rosenberg, 1995; Gray et al., 2002). Theede et al., (1969) reported LD50of 35 days for *Mytilus edulis* exposed to 0.21 mg/l O_2 at 10°C, which was reduced to 25 days with the addition of sulphide (50 mg/l $Na_2S.9H_2O$). Jorgensen (1980) observed, by diving, the effects of hypoxia (0.2 -1 mg/l) on benthic macrofauna in marine areas in Sweden over a 3-4 week period. Mussels were observed to close their shell valves in response to hypoxia and survived for 1-2 weeks before dying (Cole *et al*., 1999; Jorgensen, 1980).

All life stages show high levels of tolerance to low oxygen levels. *Mytilus edulis* larvae, for example, are tolerant down to 1.0ml/l, and although the growth of late stage larvae is depressed in hypoxic condition, the settlement behaviour does not seem to be affected (Diaz & Rosenberg 1995). Based on the available evidence *Mytilus edulis* are considered to be resistant to periods of hypoxia and anoxia although sub-lethal effects on feeding and growth may be expected.

Sensitivity assessment. *Mytilus edulis* is considered to be 'Not Sensitive' to de-oxygenation at the pressure benchmark. Resistance is therefore assessed as 'High' and resilience as 'High' (no effect to recover from), resulting in a sensitivity of 'Not sensitive'. However, as this biotope occurs in the intertidal, emergence will mitigate the effects of hypoxic surface waters as will the exposure to wave action and water flows and this pressure is considered to be 'Not relevant'.

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

This pressure relates to increased levels of nitrogen, phosphorus and silicon in the marine environment compared to background concentrations. The benchmark is set at compliance with WFD criteria for good status, based on nitrogen concentration (UKTAG, 2014).

No direct evidence was found to assess the sensitivity of piddocks to this pressure.

High levels of enrichment may stimulate algal blooms and macroalgal growth. The growth of macrophytes on the mussel clumps may result in increased drag on the mussel bed and hence increase susceptibility to damage from wave action and/or storms (see changes in wave exposure pressure). Algal blooms may die off suddenly, causing de-oxygenation (see de-oxygenation pressure) where the algae decompose on the seabed. The thresholds at which these blooms occur depend on site-specific conditions and be mitigated by the degree of mixing and tidal exchange. Some algae have been shown to negatively affect *Mytilus edulis* when present in high concentrations. For example, blooms of the algae *Phaeocystis* sp., have been observed to block the mussels gills when present in high concentrations reducing clearing rates, and at high levels they caused a complete cessation of clearance (Smaal & Twisk, 1997). Blockage of the gills is also likely to reduce ingestion rates, prevent growth and cause reproductive failure (Holt *et al*., 1998). Other species known to negatively impact Mytilus edulis are *Gyrodinium aureolum* (Tangen, 1977; Widdows et al., 1979b) and non-flagellated chrysophycean alga (Tracey, 1988). The accumulation of toxins from algal blooms has also been linked to out-breaks of paralytic shellfish poisoning resulting in the closure of shell fish beds (Shumway, 1990).

At low levels, nutrient enrichment may stimulate the growth of phytoplankton used as food - a potential beneficial effect. In the Wadden Sea, where fishing had caused the destruction of the local population of *Sabellaria spinulosa*, *Mytilus edulis* was able to colonize, partly because of the increase in coastal eutrophication (Maddock, 2008). However, Dinesen *et al*. (2011) observed that a reduction in nutrient loading to comply with the WFD resulted in a decrease of mussel biomass in estuaries.

Sensitivity assessment. The pressure benchmark is set at a level that is relatively protective and based on the evidence and considerations outlined above the biological assemblage, including the clumps of *Mytilus edulis*, are considered to be 'Not sensitive' at the pressure benchmark. Resistance and resilience are therefore assessed as 'High'.

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

Organic enrichment may lead to eutrophication with adverse environmental effects including deoxygenation, algal blooms and changes in community structure (see nutrient enrichment and de-oxygenation). No evidence was found for piddocks to support assessment of sensitivity to this pressure. *Mytilus edulis*, however, has been found to be generally insensitive to increased organic matter resulting from human activities. *Mytilus edulis* have been recorded in areas around sewage outflows (Akaishi *et al*. 2007; Lindahl & Kollberg, 2008; Nenonen *et al*. 2008; Giltrap *et al*. 2013) suggesting that they are highly tolerant of the increase in organic material that would occur in these areas. A number of studies have also highlighted the ability of *Mytilus edulis* to utilise the increased volume of organic material available at locations around salmon farms. Reid *et al*. (2010) noted that *Mytilus edulis* could absorb organic waste products from a salmon farm with great efficiency. Increased shell length, wet meat weight, and condition index were shown at locations within 200m from a farm in the Bay of Fundy allowing a reduced time to market (Lander *et al*., 2012). It has been shown that regardless of the concentration of organic matter *Mytilus edulis* will maintain its feeding rate by compensating with changes to filtration rate, clearance rates, production of pseudofaeces and absorption efficiencies (Tracey, 1988; Bayne *et al*., 1993; Hawkins *et al*., 1996).

The biotopes occurs in tide swept or wave exposed areas (Connor *et al*., 2004) preventing a build up of organic matter, so that the biotope is considered to have a low risk of organic enrichment at the pressure benchmark.

Sensitivity assessment. Based on the observation of *Mytilus edulis* thriving in areas of increased organic matter (Lander *et al*., 2012, Reid *et al*., 2010), it was assumed that *Mytilus edulis* clumps have a 'High' resistance to increased organic matter at the pressure benchmark. Resilience is therefore assessed as 'High' (no effect to recover from). No evidence was found to support an assessment for piddocks. As organic matter particles in suspension could potentially be utilised as a food resource or consumed by *Mytilus edulis* and other species present within the biotope with excess likely to be rapidly removed by wave action or coverall resistance of the biological assemblage within the biotope is considered to be 'High' and resilience was assessed as 'High', so that this biotope is judged to be 'Not sensitive'.

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

This biotope is characterized by the clay substratum which supports populations of burrowing piddocks. A change to a sedimentary, rock or artifical substratum will result in the loss of piddocks significantly altering the character of the biotope. The biotope is therefore considered to have 'No' resistance to this pressure, recovery of the biological assemblage (following habitat restoration) is considered to be 'Medium' (2-10 years) but see caveats in the recovery notes. The biotope is dependent on the presence of clay, when lost natural habitat restoration is unlikely and recovery is therefore categorised as 'Very low'. Biotope sensitivity is therefore assessed as 'High', based on the lack of recovery of clay substratum. Although no specific evidence is described, confidence in this assessment is 'High', due to the incontrovertible nature of this pressure.

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

This biotope is characterized by the clay substratum which supports populations of burrowing piddocks. A change in sedimentary substratum would result in the loss of piddocks significantly altering the character of the biotope. The biotope is therefore considered to have 'No' resistance to this pressure, recovery of the biological assemblage (following habitat restoration) is considered to be 'Medium' (2-10 years). The biotope is dependent on the presence of clay, when lost restoration would not be feasible and recovery is therefore categorised as 'Very low'. Sensitivity is therefore assessed as 'High', based on the lack of recovery on clay substratum. Although no specific evidence is described confidence in this assessment is ‘High’, due to the incontrovertible nature of this pressure.

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

The removal of substratum down to 30cm depth will remove the biological assemblage and the substratum. Resistance is therefore assessed as ‘None’, recovery of the biological assemblage (following habitat restoration) is considered to be 'Medium' (2-10 years). The biotope is dependent on the presence of clays, when lost habitat restoration is unlikely and recovery is, therefore, categorised as 'Very low'. Sensitivity is therefore assessed as 'High', based on the lack of recovery of clay substratum. Although no specific evidence is described confidence in this assessment is ‘High’, due to the incontrovertible nature of this pressure.

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

Within this biotope surface abrasion could damage and remove *Mytilus edulis* clumps, surface dwelling fauna, and the seaweeds. Some species protruding from the surface, e.g. *Lanice conchilega*, may also be removed. No evidence directly relating to this pressure was found for piddocks. Although piddocks are afforded some protection from surface abrasion by living in their burrows, the clay is relatively soft which leaves many individuals, especially those near the surface of the clay, vulnerable to damage and death through exposure, sediment damage and compaction. Micu (2007) for example, observed that after storms in the Romanian Black Sea, the round goby, *Neogobius melanostomus*, removed clay from damaged or exposed burrows to be able to remove and eat piddocks.

Activities resulting in abrasion and disturbance can either directly affect the mussel by crushing them, or indirectly affect them by the weakening or breaking of their byssus threads making them vulnerable to displacement (Denny, 1987) where they are unlikely to survive (Dare, 1976). In addition, abrasion and sub-surface damage may attract mobile scavengers and predators including fish, crabs, and starfish to feed on exposed, dead and damaged individuals and discards (Kaiser & Spencer, 1994; Ramsay *et al*., 1998; Groenewold & Fonds, 2000; Bergmann *et al*., 2002). This effect will increase predation pressure on surviving damaged and intact *Mytilus edulis* when submerged. A number of activities or events that result in abrasion and disturbance and their impacts on mussel beds are described below, based on the review by Mainwaring *et al*. (2014).

Large declines of the *Mytilus californianus* from mussel beds due to trampling have been reported (Brosnan, 1993; Brosnan & Crumrine, 1994; Smith & Murray, 2005). Brosnan & Crumrine (1994) recorded the loss of 54% of mussels from a single experimental plot on one day. Mussels continued to be lost throughout the experimental period, forming empty patches larger than the experimental plots. The empty patches continued to expand after trampling had ceased, due to wave action. Brosnan (1993) also reported a 40% loss of mussels from mussel beds after three months of trampling and a 50% loss within a year. Van de Werfhorst & Pearse (2007) examined *Mytilus californianus* abundance at sites with differing levels of trampling disturbance. The highest percentage of mussel cover was found at the undisturbed site while the severely disturbed site showed low mussel cover.

Smith & Murray (2005) examined the effects of low level disturbance on an extensive bed of *Mytilus californianus* (composed of a single layer of mussels) in southern California. Smith & Murray (2005) reported that in experimental plots exposed to trampling, mussel loss was 20-40% greater than in untreated plots. A decrease in mussel mass, density, cover and maximum shell length where recorded even in low intensity trampling events (429 steps/m^2). However, only 15% of mussel loss was as a direct result of trampling, with the remaining loss occurring during intervals between treatment applications. Brosnan & Crumrine (1994) suggested that trampling destabilizes the mussel bed, making it more susceptible to wave action, especially in winter. Smith & Murray (2005) suggested that an indirect effect of trampling was weakening of byssal threads, which increases mussel susceptibility to wave disturbance (Denny, 1987). Brosnan & Crumrine (1994) observed recruitment within experimental plots did not occur until after trampling had ceased, and no recovery had occurred within 2 years

Brosnan and Crumrine (1994) noted that mussels that occupied hard substrata but did not form beds were also adversely affected. Although only at low abundance (2.5% cover), all mussels were removed by trampling within 4 months. Brosnan & Crumrine (1994) noted that mussels were not common and confined to crevices in heavily trampled sites. Similarly, the mussel bed infauna (e.g. barnacles) were adversely affected and were crushed or lost with the mussels to which they were attached. However, Beauchamp & Gowing (1982) did not observe any differences in mussel density between sites that differed in visitor use.

Paine & Levine (1981) examined natural patch dynamics in a *Mytilus californianus* bed in the USA. They suggested that it may take up to seven years for large barren patches to recover. However, chronic trampling may prevent recovery altogether. This would result in a shift from a mussel dominated habitat to one dominated by an algal turf or crust (Brosnan & Cumrine, 1994), completely changing the biotope. However, a small period of trampling could allow communities to recover at a similar rate to that of natural disturbance as the effects are similar. The associated epifauna and epiflora suffer the greatest amount of damage as they are the first organisms that a foot makes contact with (Brosnan & Crumrine, 1994). The loss of epifauna and epiflora could initially be of benefit to the mussel bed, despite the obvious decrease in species diversity, as there will be a decrease in drag for the mussels reducing the risk of dislodgement (Witman & Suchanek 1984) and freeing up more energy for growth and reproduction. However, it is likely that after continued trampling this effect will be minimal compared with the increased risk of dislodgement caused by trampling.

The collision of objects with the bed, such as wave driven logs (or similar flotsam), is known to cause the removal of patches of mussels from mussel beds (Seed & Suchanek, 1992; Holt et al., 1998). When patches occur in mussel beds a good recruitment could result in a rapid recovery or the patch may increase in size through a weakening of the byssus threads of the remaining mussels leaving them vulnerable to erosion from storm damage (Denny, 1987). Damage in areas of high wave exposure is likely to result in increased erosion and a patchy distribution although recruitment may be high. In sheltered areas damage may take a lot longer due to limited larval supply although the frequency of destruction through wave driven logs would be less than in high wave exposure. Similar effects could be observed through the grounding of a vessel, the dropping of an anchor or the laying of a cable, although the scale of damage clearly differs.Shifting sand is known to limit the range of Mytilus edulis through burial and abrasion (Daly & Mathieson, 1977).

Various fishing methods also result in abrasion of the mussel beds. Bait collection through raking will cause surface abrasion and the removal of patches of mussel resulting in the damage and recovery times described above. Holt et al., (1998) reported that hand collection, or using simple hand tools occurs in small artisanal fisheries. They suggested that moderate levels of collection by experienced fishermen may not adversely affect the biodiversity of the bed. But they also noted that even artisanal hand fisheries can deplete the mussel biomass on accessible beds in the absence of adequate recruitment of mussels. Smith & Murray (2005) observed a significant decrease in mussel mass (g/m^2), density (no./m^2), percentage cover and mean shell length due to low-intensity simulated bait-removal treatments (2 mussels / month) for 12 months (Smith & Murray, 2005). They also stated that the initial effects of removal were 'overshadowed' by the loss of additional mussels during time periods between treatments, probably due to the indirect effect of the weakening of byssal threads attachments between the mussel leaving them more susceptible to wave action (Smith & Murray, 2005). The low-intensity simulated bait-removal treatments had reduced percentage cover by 57.5% at the end of the 12 month experimental period. Smith & Murray (2005) suggested that the losses occurred from collection and trampling are far greater than those that occur by natural causes. This conclusion was reached due to significant results being displayed for human impact despite the experiment taking place during a time of high natural disturbance from El Niño–Southern Oscillation (ENSO).

A significant impact resulting from this pressure may be removal and damage of the clay resulting in the clay being more vulnerable to erosion. Natural erosion processes are, however, likely to be on-going within this habitat type. Where abundant the boring activities of piddocks contribute significantly to bioerosion, which can make the substratum habitat more unstable and can result in increased rates of coastal erosion (Evans 1968, Trudgill 1983, Trudgill & Crabtree, 1987). Pinn et al. (2005) estimated that over the lifespan of a piddock (12 years), up to 41% of the shore could be eroded to a depth of 8.5 mm.

Sensitivity assessment. Surface abrasion may remove mussel clumps and algae and surface infauna and may result in the loss of some piddocks and damage to the clay substratum. Resistance is therefore assessed as 'Low' for mussels and surface infauna and algae and 'Medium' for piddocks and substratum. The mussels are predicted to recover within 2 -10 years, so that resilience is considered to be 'Medium' and sensitivity is 'Medium'. As the substratum cannot recover, resilience is assessed as 'Very Low' . The overall sensitivity of the biotope is considered to be 'Medium'.

Penetration or disturbance of the substratum subsurface	None Q: Low A: NR C: NR	Very Low Q: High A: High C: High	High Q: Low A: Low C: Low

Penetration and disturbance below the surface of the substratum may damage and remove the *Mytilus edulis* clumps, surface dwelling fauna and could damage and expose piddocks depnding on depth of penetration and burrow depth. Duval (1977) found that the depth of the piddock burrow depended on the size of the animal. For example, an animal with a shell length of 1.2 cm could bore a 2.7 cm burrow whereas animals 4.8 cm long could bore burrows of 12 cm.

Piddocks in damaged burrows or those that are removed from the substratum are unlikely to be able to rebury (Duval, 1963a; Barnes, 1980) and will be predated by fish and other mobile species (Micu, 2007).

Mytilus edulis lives on the surface of the substratum held in place by byssus threads that either attach to the substratum or to other mussels in the bed. Activities resulting in penetration and disturbance can either directly affect the mussel by crushing or removal, or indirectly affect them by the weakening or breaking of their byssus threads making them vulnerable to displacement (Denny, 1987) where they are unlikely to survive (Dare, 1976). Sub-surface disturbance may also remove mussels by breaking up and removing the substratum. Where mussels are removed attached species including macroalgae and barnacles will also be removed. In addition, abrasion and sub-surface damage attracts mobile scavengers and predators including fish, crabs, and starfish to feed on exposed, dead and damaged individuals and discards (Kaiser & Spencer, 1994; Ramsay *et al*., 1998; Groenewold & Fonds, 2000; Bergmann *et al*., 2002). This effect could increase predation pressure on surviving damaged and intact *Mytilus edulis*.

A significant impact resulting from this pressure may be removal and damage of the clay resulting in the clay being more vulnerable to erosion. Natural erosion processes are, however, likely to be on-going within this habitat type. Where abundant the boring activities of piddocks contribute significantly to bioerosion, which can make the substratum habitat more unstable and can result in increased rates of coastal erosion (Evans 1968, Trudgill 1983, Trudgill & Crabtree, 1987). Pinn et al. (2005) estimated that over the lifespan of a piddock (12 years), up to 41% of the shore could be eroded to a depth of 8.5 mm.

Sensitivity assessment. Sub-surface penetration and disturbance could result in damage and removal of the surface infauna including clumps of *Mytilus edulis* and result in the damage, exposure and loss of piddocks and damage to the habitat. Resistance is therefore assessed as 'Low' for piddocks and substratum and 'None' for *Mytilus edulis*. The associated surface dwelling fauana are predicted to recover relatively rapidly via larval recolonisation and migration of adults in mobile species. Recovery of the key characterizing species, piddocks and *Mytilus edulis* is pedicted to require 2-10 years so that resilience is considered to 'Medium' and sensitivity is 'Medium'. As the substratum cannot recover, resilience is assessed as 'Very Low' and sensitivity of the overall biotope, based on the sedimentary habitat, is considered to be 'High'.

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

In general, increased suspended particles may enhance food supply (where these are organic in origin) or decrease feeding efficiency (where the particles are inorganic and require greater filtration efforts). Very high levels of silt may clog respiratory and feeding organs of the suspension feeding piddocks and *Mytilus edulis*. In addition, increased turbidity will decrease light penetration reducing photosynthesis by macroalgae within this biotope. Increased levels of particles may increase scour and deposition in the biotope depending on local hydrodynamic conditions, although changes in substratum are assessed through the physical change (to another seabed type) pressure.

A significant decrease in suspended organic particles may reduce food input to the biotope resulting in reduced growth and fecundity of suspension feeding animals, e.g. piddocks. However, local primary productivity may be enhanced where suspended sediments decrease, increasing food supply. Decreased suspended sediment may increase macroalgal competition enhancing diversity but is considered unlikely to significantly change the character of the biotope as colonisation by larger brown macroalgae is limited by the friability of the surface which is unsuitable for attachment.

The piddocks are protected from scour within burrows and increased organic particles would provide a food subsidy. *Pholas dactylus* occurs in habitats such as soft chalks where turbidity may be high and is therefore unlikely to be affected by an increase in suspended sediments at the pressure benchmark. Piddocks, in common with other suspension feeding bivalves, have efficient mechanisms to remove inorganic particles via pseudofaeces. Experimental work on *Pholas dactylus* showed that large particles can either be rejected immediately in the pseudofaeces or passed very quickly through the gut (Knight, 1984). *Petricola pholadiformis* is able to cope in water laden with much suspended material by binding the material in mucus and using the palps to reject it (Purchon, 1955). Increased suspended sediments may impose sub-lethal energetic costs on piddocks by reducing feeding efficiency and requiring the production of pseudofaeces with impacts on growth and reproduction.

Macroalgae within the biotope may be sensitive to decreased light penetration, however Hily et al. (1992) found that, in conditions of high turbidity, the characterizing species *Ceramium virgatum* (as *Ceramium rubrum*) and *Ulva* sp dominated sediments in the Bay of Brest, France. It is most likely that *Ceramium virgatum* thrived because other species of algae could not. Whilst the field observations in the Bay of Brest suggested that an increase in abundance of *Ceramium virgatum* might be expected in conditions of increased turbidity, populations where light becomes limiting will be adversely affected. However, in shallow depths and the intertidal, photosynthesis can occur during low tides (as long as sediments are not deposited) and *Ceramium virgatum* may benefit from increased turbidity through decreased competition. The other green and red algae species found within this biotope are considered to have similar tolerances based on tolerance of shade and/or eutrophic conditions.

Mytilus edulis are often found in areas with high levels of turbidity. For example, the average suspended particulate matter (SPM) concentration at Hastings Shingle Bank was 15 -20 mg/l in June 2005, reaching 50 mg/l in windier (force 4) conditions, although a concentration of 200 mg/l was recorded at this site during gales (Last et al., 2011). It may be possible for *Mytilus edulis* to adapt to a permanent increase in SPM by decreasing their gill size and increasing their palp size in areas of high turbidity (Theisen, 1982; Essink, 1999). In areas of variable SPM it is likely that the gill size would remain the same but the palp would adapt (Essink, 1999). Whilst the ability to adapt may prevent immediate declines in health, the energetic costs of these adaptations may result in reduced fitness; the extent of which is still to be established. Concentrations above 250 mg/l have been shown to impair the growth of filter-feeding organisms (Essink, 1999). But Purchon (1937) found that concentrations of particulates as high a 440 mg/l did not affect *Mytilus edulis* and that mortality was only occurred when mud was added to the experiment bringing the concentrations up to 1220 mg/l. The reason for some of the discrepancy between studies may be due to the volume of water used in the experiment. Loosanoff (1962) found that in small quantities of turbid water (due to particulates) the mussel can filter out all of the particulates within a few minutes whereas in volumes >50 gallons per individual the mussel becomes exhausted before the turbidity has been significantly lowered, causing it to close its shell and die.

Based on a comprehensive literature review, Moore (1977) concluded that *Mytilus edulis* displayed a higher tolerance to high SPM concentrations than many other bivalves although the upper limit of this tolerance was not certain. He also hypothesised that the ability of the mussel to clean its shell in such conditions played a vital role in its success along with its pseudofaecal expulsion.

Mytilus edulis may be more sensitive to decreased turbidity where this reflects a decrease in the availability of organic matter and seston. Winter (1972) (cited by Moore, 1977) recorded 75% mortality of *Mytilus edulis* in concentrations of 1.84-7.36 mg/l when food was also available. However, a relatively small increase in SPM concentration e.g. from 10 mg/l to 90 mg/l was found to increase growth rates (Hawkins et al., 1996).

Sensitivity assessment. No direct evidence was found to assess sensitivity to this pressure however, based on the occurrence of *Pholas dactylus* in turbid areas and evidence for the production of pseudofaeces by piddocks, resistance is assessed as ‘High’ and resilience as High (no impact to recover from). Evidence indicates that *Mytilus edulis* can tolerate a broad range of suspended solids. The benchmark for this pressure refers to a change in turbidity of one rank on the Water Framework Directive (WFD) scale. Mussel beds form in relatively clear waters of open coasts and wave exposed shores and on sediments in sheltered coast (where turbulent water flow over the mussel beds could resuspend sediments locally) and in turbid bays and estuaries. Therefore, is unlikely that a change in turbidity by of one rank (e.g. from 300 to 100 mg/l or <10 to 100 mg/l) will significantly affect the *Mytilus edulis* or piddocks. Resistance to this pressure is therefore assessed as ‘High. Recovery is assessed ‘High’ (no impact to recover from), and sensitivity is therefore 'Not sensitive'. The biotope is therefore considered to be ‘Not sensitive’. An indirect effect of increased turbidity and reduced light penetration may be reduced phytoplankton productivity which could reduce the food availability for suspension feeders. However, as piddocks and *Mytilus edulis* use a variety of food sources and food is brought in from other areas with currents and tides, the effect is likely to be minimal. This species and the biotopes it forms are therefore not sensitive to changes in water clarity.

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

No empirical evidence for mortality rates in response to siltation was found for piddocks. The burrowing mechanisms of the piddocks *Pholas dactylus*, *Barnea candida* and other Pholads, mean that the burrows have a narrow entrance excavated by the juvenile. As the individual grows and excavates deeper the burrow widens resulting in a conical burrow from which the adult cannot emerge. Piddocks cannot therefore emerge from layers of deposited silt as other more mobile bivalves can. *Petricolaria* *pholadiformis* excavates a cylindrical burrow (Ansell, 1970) and hence may be able to relocate in sandy sediments, however no evidence was found to suggest this species can re-emerge through sediments and re-bury.

Sometimes the substratum in which piddocks reside is covered by a thin layer of loose sandy material, through which the piddocks maintain contact with the surface via their siphons. It is likely that the piddocks would be able to extend their siphons through loose material, particularly where tidal movements shift the sand around. *Pholas dactylu*s have been found living under layers of sand in Aberystwyth, Wales, (Knight, 1984) and in Eastbourne, with their siphons protruding at the surface (Pinn et al., 2008). *Barnea candida* has also been found to survive being covered by shallow layers of sand in Merseyside (Wallace & Wallace, 1983). Wallace & Wallace (1983) were unsure as to how long *Barnea candida* could survive smothering but noted that, on the coast of the Wirral, the piddocks have survived smothering after periods of rough weather. Where smothering is constant, survival can be more difficult. The redistribution of loose material following storms off Whitstable Street, in the Thames Estuary, is thought to be responsible for the suffocation of many *Petricolaria pholadiformi*s and it is possible that this species may be the most intolerant of the three piddock species associated with this biotope. However, it was not known how deep the layer of 'loose material' was, nor how long it lasted for or what type of material it was made up of.

Indirect indications for the impacts of siltation are provided by studies of Witt *et al*., (2004) on the impacts of harbour dredge disposal. *Petricolaria pholadiformis* was absent from the disposal area, and Witt *et al*., (2004) cites reports by Essink (1996, not seen) that smothering of *Petricolaria pholadiformis* from siltation could lead to mortality within a few hours. Hebda (2011) also identified that sedimentation may be one of the key threats to populations of another piddock, *Barnea truncata*. At Agigea (Micu, 2007) reported that smothering of clay beds by sand and finer sediments had removed populations of *Pholas dactylus*. In this area sand banks up to 1m thick frequently shift position driven by storm events and currents (Micu, 2007). Similar smothering was described in the case of *Barnea candida* populations boring into clay beds (Gomoiu & Muller 1962, cited from Micu, 2007).

Mytilus edulis occurs in areas of high suspended particulate matter (SPM) and therefore a level of siltation is expected from the settling of SPM. In addition, the high rate of faecal and pseudofaecal matter production by the mussels naturally results in siltation of the seabed, often resulting in the formation of large mounds beneath the mussel bed. For example, at Morecambe Bay an accumulation of mussel-mud (faeces, pseudofaeces and washed sand) of 0.4-0.5m between May 1968 and September 1971 resulted in the mortality of young mussels (Daly & Mathieson, 1977). In order to survive the mussels needed to keep moving upwards to stay on the surface. Many individuals did not make it to the surface and were smothered by the accumulation of mussel-mud (Daly & Mathieson, 1977), so that whilst *Mytilus edulis* does have the capacity to vertically migrate through sediment some individuals will not survive.

Sand burial has been shown to determine the lower limit of *Mytilus edulis* beds (Daly & Mathieson, 1977). Burial of *Mytilus edulis* beds by large scale movements of sand, and resultant mortalities have been reported from Morecambe Bay, the Cumbrian coast and Solway Firth (Holt *et al*., 1998). Essink (1999) recorded fatal burial depths of 1-2 cm for *Mytilus edulis* and suggested that they had a low tolerance of sedimentation based on investigations by R.Bijkerk (cited by Essink, 1999). Essink (1999) suggested that deposition of sediment (mud or sand) on shallow mussel beds should be avoided. However, Widdows *et al*. (2002) noted that mussels buried by 6 cm of sandy sediment (caused by resuspension of sediment due to turbulent flow across the bed) were able to move to the surface within one day. Conversely, Condie (2009) (cited by Last *et al*., 2011) reported that *Mytilus edulis* was tolerant of repeated burial events.

Last *et al*., (2011) carried out burial experiments on *Mytilus edulis* in pVORTs. They used a range of burial depths and sediment fractions and temperatures. It was found that individual mussels were able to survive burial in depths of 2, 5 and 7cm for over 32 days although the deeper and longer the mussels were buried the higher the mortality. Only 16% of buried mussels died after 16 days compared to almost 50% mortality at 32 days. Mortality also increased sharply with a decrease in particle size and with increases in temperature from 8.0 and 14.5 to 20°C. The ability of a proportion of individuals to emerge from burial was again demonstrated with approximately one quarter of the individuals buried at 2cm resurfacing. However, at depths of 5 cm and 7cm no emergence was recorded (Last et al., 2011). The lower mortality when buried in coarse sands may be related to the greater number of individuals who were able to emerge in these conditions and emergence was to be significant for survival.

It is unclear whether the same results would be recorded when mussels are joined by byssal threads or whether this would have an impact on survival (Last *et al*., 2011), although Daly & Mathieson (1977) recorded loose attachments between juvenile mussels during a burial event and some of these were able to surface. It was not clear whether the same ability would be shown by adult mussels in a more densely packed bed.

Sensitivity assessment. Overburden by 5 cm of fine material (see benchmark) in a single incident is unlikely to result in significant mortality in *Mytilus edulis* clumps before sediments are removed by current and wave action. However, the inability of *Mytilus edulis* to emerge from sediment deeper than 2 cm (Last et al., 2011, Essink, 1999, Daly & Matthieson, 1977) and the increased mortality with depth and reduced particle size observed by Last *et al*. (2011) suggest that some mussels may die and resistance is assessed as 'Medium'. As piddocks are essentially sedentary with relatively short siphons, siltation from fine sediments rather than sands, even at low levels for short periods could be lethal. Resistance to siltation is assessed as ‘Low’ for piddocks although effects would be mitigated where water currents and wave exposure rapidly removed the overburden and this will depend on shore height and local hydrodynamic conditions. Resilience is assessed as ‘Medium’ (2-10 years) for piddocks and *Mytilus edulis* and sensitivity is therefore assessed as ‘Medium’. Survival will be higher in winter months when temperatures are lower and physiological demands are decreased. However, mortality will depend on the duration of smothering. Mortality is likely to be more significant in wave sheltered areas, the smothering sediment remains for prolonged periods and more limited, and possibly avoided, where the smothering sediment is removed due to wave action or tidal streams, depending on how long the sediment remains.

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

A deposit of 30 cm of fine material would lead to smothering of the key characterizing species and the associated biological assemblage.

No examples of direct empirical evidence for response to siltation have been found for piddocks although smothering has been cited as a key threat to piddocks. Piddocks cannot emerge from layers of deposited silt, as other more mobile bivalves can, due to the narrow burrow entrance. *Petricolaria pholadiformis* excavates a cylindrical burrow (Ansell, 1970) and hence may be able to relocate in sandy sediments, however no evidence was found to suggest this species can re-emerge through sediments and re-bury.

Barnea candida has been found to survive being covered by shallow layers of sand in Merseyside (Wallace & Wallace, 1983). Wallace & Wallace (1983) were unsure as to how long *Barnea candida* could survive smothering but noted that, on the coast of the Wirral, the piddocks have survived smothering after periods of rough weather. The redistribution of loose material following storms off Whitstable Street, in the Thames Estuary, is thought to be responsible for the suffocation of many *Petricolaria pholadiformis* and it is possible that this species may be the most intolerant of the three piddock species associated with this biotope. However, it was not known how deep the layer of 'loose material' was, nor how long it lasted for or what type of material it was made up of.

Indirect indications for the impacts of siltation are provided by studies on the impacts of harbour dredge disposal (Witt *et al*., 2004). *Petricolaria pholadiformis* was absent from the disposal area, and Witt *et al*., (2004) cites reports by Essink (1996, not seen) that smothering of *Petricolaria pholadiformis* from siltation could lead to mortality within a few hours. Hebda (2011) also identified that sedimentation may be one of the key threats to populations of another piddock, *Barnea truncata*. At Agigea (Micu, 2007) reported that smothering of clay beds by sand and finer sediments had removed populations of *Pholas dactylus*. In this area sand banks up to 1m thick frequently shift position driven by storm events and currents (Micu, 2007). Similar smothering was described in the case of *Barnea candida* populations boring into clay beds (Gomoiu & Muller 1962, cited from Micu, 2007).

Sand burial has been shown to determine the lower limit of *Mytilus edulis* beds (Daly & Mathieson, 1977a). Burial of *Mytilus edulis* beds by large scale movements of sand, and resultant mortalities have been reported from Morecambe Bay, the Cumbrian coast and Solway Firth (Holt et al., 1998). Essink (1999) recorded fatal burial depths of 1-2 cm for *Mytilus edulis* and suggested that *Mytilus edulis* a low tolerance of sedimentation based on investigations by R.Bijkerk (cited by Essink, 1999). However, Widdows et al. (2002) noted that mussels buried by 6 cm of sandy sediment (caused by resuspension of sediment due to turbulent flow across the bed) were able to move to the surface within one day.

Last *et al.*, (2011) carried out a series of burial experiments on *Mytilus edulis* in pVORTs using a range of burial depths, sediment fractions and temperatures. It was found that individual mussels were able to survive burial in depths of 2, 5 and 7cm for over 32 days although the deeper and longer the mussels were buried the higher the mortality. Only 16% of buried mussels died after 16 days compared to almost 50% mortality at 32 days. Mortality also increased sharply with a decrease in particle size and with increases in temperature from 8.0 and 14.5 to 20°C. The ability of a proportion of individuals to emerge from burial was again demonstrated, with approximately one quarter of the individuals buried at 2cm resurfacing. However, at depths of 5 cm and 7cm no emergence was recorded (Last et al., 2011). The lower mortality when buried in coarse sands may be related to the greater number of individuals who were able to emerge in these conditions.

It is unclear whether the same results would be recorded when mussels are joined by byssal threads or whether this would have an impact on survival (Last *et al.*, 2011), although Daly & Mathieson (1977) recorded loose attachments between juvenile mussels during a burial event and some of these were able to surface. It was not clear whether the same ability would be shown by adult mussels in a more densely packed bed.

Sensitivity assessment. Sensitivity to this pressure will be mediated by site-specific hydrodynamic conditions and the footprint of the impact. Where a large area is covered sediments may be shifted by wave and tides rather than removed. The inability of *Mytilus edulis* to emerge from sediment deeper than 2 cm (Last et al., 2011, Essink, 1999, Daly & Matthieson, 1977) and the increased mortality with depth and reduced particle size observed by Last *et al*. (2011) indicates that there may be significant mortality of mussels. As piddocks are essentially sedentary with relatively short siphons, siltation from fine sediments rather than sands, even at low levels for short periods could be lethal. Resistance to siltation is therefore assessed as 'Low' for piddocks and *Mytilus edulis* and resilience is assessed as 'Medium' (2-10 years). Survival will be higher in winter months when temperatures are lower and physiological demands are decreased. However, mortality will depend on the duration of smothering. Mortality is likely to be more significant in wave sheltered areas where the smothering sediment remains for prolonged periods and reduced where the smothering sediment is rapidly removed by wave action or currents.

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

Mytilus edulis ingest microplastics. A laboratory experiment using microbeads of polystyrene demonstrated uptake of particles by *Mytilus edulis* within 12 hours (Browne *et al*., 2008). After three days some of the the beads were translocated to the circulatory system. Microplastics were excreted in fecal pellets but were still present in hemolymph 48 days later. No toxicological effects were observed and there were no changes in filter feeding activity (Browne *et al*., 2008). As exposure was short-term it is not clear whether lethal or sub-lethal effects would occur in wild populations over extended periods. There is currently no evidence to assess the level of impact and this pressure is 'Not assessed'.

Electromagnetic changes	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

No evidence.

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

Not relevant.

Introduction of light or shading	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

The piddock *Pholas dactylus* can perceive and react to light (Hecht, 1928) however, there is no evidence that this pressure would impact the biotope at the pressure benchmark.

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.

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

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

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

Pholas dactylus reacts quickly to changes in light intensity, after a couple of seconds, by withdrawing its siphon (Knight, 1984). This reaction is ultimately an adaptation to reduce the risk of predation by, for example, approaching birds (Knight, 1984). However, its visual acuity is probably very limited and it is unlikely to be sensitive to visual disturbance. Birds are highly intolerant of visual presence and are likely to be scared away by increased human activity, therefore reducing the predation pressure on piddocks. Therefore, visual disturbance may be of indirect benefit to piddock populations and the biotope is considered to be 'Not sensitive'.

Biological Pressures

	Resistance	Resilience	Sensitivity
Genetic modification & translocation of indigenous species	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

This pressure is only relevant to *Mytilus edulis* as other species within the biotope are not subject to translocation or cultivation. Commercial cultivation of *Mytilus edulis* involves the collection of juvenile mussel 'seed' or spat (newly settled juveniles ca 1-2cm in length) from wild populations, with subsequent transportation around the UK for re-laying in suitable habitats. As the seed is harvested from wild populations from various locations the gene pool will not necessarily be decreased by translocations. Movement of mussel seed has the potential to transport pathogens and non-native species (see relevant pressure sections). This pressure assessment is based on Mainwaring *et al.* (2014) and considers the potential impacts on natural mussel beds of genetic flow between translocated stocks and wild mussel beds.

Two species of *Mytilus* occur in the UK, *Mytilus edulis* and *Mytilus galloprovincialis*. *Mytilus edulis* appears to maintain genetic homogeneity throughout its range whereas *Mytilus galloprovincialis* can be genetically subdivided into a Mediterranean group and an Atlantic group (Beaumont et al. 2007). *Mytilus edulis* and *Mytilus galloprovincialis* have the ability to hybridise in areas where their distribution overlaps e.g. around the Atlantic and European coast (Gardner, 1996; Daguin *et al.*, 2001; Bierne *et al.*, 2002; Beaumont *et al.*, 2004). In the UK overlaps occur on the North East coast, North East Scotland, South West England and in the North, West and South of Ireland (Beaumont *et al.*, 2007). It is difficult to identify *Mytilus edulis*, *Mytilus galloprovincialis* or hybrids based on shell shape because of the extreme plasticity of shape exhibited by mussels under environmental variation, and a genetic test is required (Beaumont et al., 2007). There is some discussion questioning the distinction between the two species as the hybrids are fertile (Beaumont *et al.*, 2007). Hybrids reproduce and spawn at a similar time to both *Mytilus edulis* and *Mytilus galloprovincialis* which supports genetic flow between the taxa (Doherty *et al.*, 2009).

There is some evidence that hybrid larvae have a faster growth rate to metamorphosis than pure individuals which may leave pure individuals more vulnerable to predation (Beaumont *et al.*, 1993). As the physiology of both the hybrid and pure *Mytilus edulis* is so similar there is likely to be very little impact on the tolerance of the bed to pressures nor a change in the associated fauna.

A review by Svåsand *et al*. (2007) concluded that there was a lack of evidence distinguishing between different populations to accurately assess the impacts of hybridisation and in particular how the gene flow may be affected by aquaculture. Therefore, it cannot be confirmed whether farming will have an impact on the genetics of this species beyond a potential for increased hybridisation.

Sensitivity assessment. No direct evidence was found regarding the potential for negative impacts of translocated mussel seed on adjacent natural beds. While it is possible that translocation of mussel seed could lead to genetic flow between cultivated beds and local wild populations, there is currently no evidence to assess the impact (Svåsand *et al*., 2007). Hybrid beds perform the same ecological functions as *Mytilus edulis* so that any impact relates to genetic integrity of a bed alone. This impact is considered to apply to all mussel biotopes equally, as the main habitat forming species *Mytilus edulis* is translocated. Also, given the uncertainty in identification of the species, habitats or biotopes that are considered to be characterized by *Mytilus edulis* may in fact contain *Mytilus galloprovincialis*, their hybrids or a mosaic of the three. Presently, there is no evidence of impact resulting from genetic modification and translocation on *Mytilus edulis* beds in general or the clumps that characterize this biotope.

Introduction or spread of invasive non-indigenous species	None Q: Low A: NR C: NR	Very Low Q: Low A: NR C: NR	High Q: Low A: Low C: Low

The American piddock, *Petricolaria pholadiformis* is a non-native, boring piddock that was unintentionally introduced from America with the American oyster, *Crassostrea virginica*, not later than 1890 (Naylor, 1957). Rosenthal (1980) suggested that from the British Isles, the species has colonized several northern European countries by means of its pelagic larva and may also spread via driftwood, although it usually bores into clay, peat or soft rock shores. In Belgium and The Netherlands *Petricolaria pholadiformis* almost completely displaced the native piddock, *Barnea candida* (ICES, 1972). However, this has not been observed elsewhere, and later studies have found that *Barnea candida* is now more common than *Petricolaria pholadiformis* in Belgium (Wouters, 1993) and there is no documentary evidence to suggest that *Barnea candida* has been displaced in the British Isles (J. Light & I. Kileen pers. comm. to Eno *et al*., 1997). The two species co-occur in this biotope and the biotope is therefore considered to be ‘Not sensitive’ to the presence of *Petricolaria pholadiformis*. No evidence was found for impacts of other invasive non-indigenous species on piddocks although presumably species that extensively cover the surface such as the Pacific oyster, *Magallana gigas* would prevent adults from extending siphons and reduce or prevent juvenile recruitment.

Recent evidence reviews have indicated that *Magallana gigas* is likely to be the most significant invasive non-indigenous species threatening littoral mussel aggregations (Sewell *et al*. 2008; Mainwaring *et al*. 2014) *Magallana gigas* is reported to out-compete and replace mussel beds in the intertidal and was predicted to do so, on both soft sediment and rocky habitats of low or high energy (Padilla, 2010). As oyster reefs form on former mussel beds, the available habitat for *Mytilus edulis* could be restricted (Diederich, 2006). It has been observed that mussel beds in the Wadden Sea that are adjacent to oyster farms were quickly converted to oyster beds (Kochmann *et al.*, 2008).

Although not currently established in UK waters, the whelk *Rapana venosa*, has been recorded offshore and is known to have a fast rate of migration so could be affecting the UK coastal habitats in the near future (Sewell *et al.*, 2008). This species has been observed predating on *Pholas dactylus* in the Romaniam Black Sea by Micu (2007) and has caused a decline in the abundance of *Mytilus galloprovincialis* in Bulgaria (Mann & Harding, 2000). .

Sensitivity assessment. In the upper subtidal, the Pacific oyster, *Magallana gigas* may develop reefs on mussel habitat. Where a reef developed over this biotope the character of the habitat would be significantly altered. The presence of dense *Magallana gigas* would prevent or significantly reduce the access of piddocks to the water column and would prevent settlement of juveniles. Similarly the presence of *Magallana gigas* would prevent the development of clumps of *Mytilus edulis*. Therefore, a precautionary resistance of 'None' is suggested due to the potential significant change in habitat character. Resilience is likely to be 'Very low' as the *Magallana gigas* population would need to be removed for recovery to occur. Therefore, sensitivity is assessed as 'High'.

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

No evidence was found for microbial pathogen impacts on piddocks. As a species with commercial significance more research effort has been expended on *Mytilus edulis* and this assesment is based on a recent evidence review by Mainwaring *et al.*, (2014) of the impacts of *Marteilia refringens* on *Mytilus edulis* populations. It should be noted that *Mytilus edulis* beds are host to a diverse array of disease organisms, parasites and commensals from many animal and plant groups including bacteria, blue green algae, green algae, protozoa, boring sponges, boring polychaetes, boring lichen, the intermediary life stages of several trematodes, copepods and decapods (Bower, 1992; Gray et al., 1999; Bower, 2010). However, at usual levels of infestation these are not considered to lead to high levels of mortality and these are not considered by the sensitivity assessment. Outbreaks of *Bonamia* may cause significant mortalities in some shellfish populations but this protozoan has been shown not to infect *Mytilus edulis* (Culloty et al., 1999).

Marteilia refringens can infect and have significant impacts on the health of *Mytilus edulis*. There is some debate as to whether there are two species of Marteilia, one which infects oysters (*Marteilia refringens*) and another that infects blue mussels (*Marteilia maurini*) (Le Roux et al., 2001) or whether they are just two strains of the same species (Lopez-Flores *et al.*,2004; Balseiro *et* *al*., 2007). Both species are present in southern parts of the United Kingdom. The infection of *Marteilia* results in Marteiliosis which disrupts the digestive glands of *Mytilus edulis* especially at times of spore release. Heavy infection can result in a reduced uptake of food, reduced absorption efficiency, lower carbohydrate levels in the haemolymph and inhibited gonad development particularly after the spring spawning resulting in an overall reduced condition of the individual (Robledo *et al*., 1995).

Recent evidence suggests that *Marteilia* is transferred to and from *Mytilus edulis* via the copepod *Paracartia grani*. This copepod is not currently prevalent in the UK waters, with only a few records in the English Channel and along the South coast. However, it is thought to be transferred by ballast water and so localised introductions of this vector may be possible in areas of mussel seed transfer. The mussel populations here are considered to be naive (i.e. not previously exposed) and therefore could be heavily affected, although the likelihood is slim due to the dependence on the introduction of a vector that is carrying Marteilia and then it being transferred to the mussels.

Berthe *et al*. (2004) concluded that *Mytilus edulis* is rarely significantly affected by *Marteilia* sp. However, occasions have been recorded of nearly 100% mortality when British spat have been transferred from a ‘disease free area’ to areas in France were *Marteilia* sp. are present. This suggests that there is a severe potential risk if naive spat are moved around the UK from northern waters into southern waters where the disease is resident (enzootic) or if increased temperatures allow the spread of *Marteilia* sp. northwards towards the naive northern populations. In addition, rising temperatures could allow increased densities of the *Marteilia* sp. resulting in heavier infections which can lead to mortality.

Sensitivity assessment. There is no evidence for impacts of microbial pathogens on piddocks or other characterizing species and this assessment solely consideres the sensitivity of *Mytilus edulis*. Bower (2010) noted that although *Marteilia* was a potentially lethal pathogen of mussels, most populations were not adversely affected by marteilioisis but that in some areas mortality can be significant in mariculture (Berthe *et al*., 2004). The resultant population would be more sensitive to other pressures, even where the disease only resulted in reduced condition. The removal of clumps of *Mytilus edulis* would alter the character of the biotope and therefore, a precautionary resistance of ‘Medium’ to this pressure is suggested (<25% mortality), with a resilience of ‘Medium’ (2-10 years) resulting in a sensitivity of ‘Medium’.

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

Within this biotope both *Mytilus edulis* and piddocks may be targeted as bait or food by fishers (Holt *et al*., 1998). Commercial harvesting of piddocks has been banned across Europe due to the high levels of habitat damage associated with the removal of boring molluscs (Fanelli *et al*., 1994). The physical damage to the characterizing species and substratum that may arise through harvesting of *Mytilus edulis* and piddocks and associated trampling within the biotope is assessed through the physical damage pressures (abrasion and penetration and sub-surface damage).

This assessment is based on the ecological effects of removal. As *Mytilus edulis* and piddocks are key characterizing species for this biotope their removal will significantly alter the character of the biotope. Even hand-picking for mussels as bait is likely to significantly deplete the biomass of mussels within this biotope, where they occur as clumps on the substratum (Smith & Murray 2005).

Recreational fishermen will often collect moulting *Carcinus maenas* or whelks by hand from intertidal mussel beds for bait. The removal of predators may benefit *Mytilus edulis* although this effect is not considered in the sensitivity assessment.

Sensitivity assessment. *Mytilus edulis* and piddocks have no avoidance mechanisms to escape targeted harvesting. Removal of piddocks and *Mytilus edulis* will result in loss of targeted individuals and damage to the habitat. Resistance is assessed as 'Low' for the piddocks and *Mytilus edulis* as these sessile species are easily detected and removed. Piddocks and clumps of *Mytilus edulis* are predicted to recover within 2-10 years so that resilience is considered to 'Medium' and sensitivity is 'Medium'.

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

This assessment is based on the ecological effects of removal, direct, physical impacts are assessed through the abrasion and penetration of the seabed pressures. As *Mytilus edulis* and piddocks are key characterizing species for this biotope their removal as by-catch would significantly alter the character of the biotope. *Mytilus edulis* clumps may be removed or damaged by activities targeting other species, this would alter the physical structure of the biotope, reducing habitat for attached and mobile species associated with the mussel clumps. It is unlikely that targeted harvesting of other species would unintentionally remove piddocks.

Sensitivity assessment. Removal of *Mytilus edulis* will result in loss of individuals and consequently habitat structure. Resistance is assessed as 'Low' for *Mytilus* and resilience as 'Medium' (within 2-10 years) and biotope sensitivity is therefore considered to be 'Medium'.

Bibliography

Ansell, A.D., 1970. Boring and burrowing mechanisms in *Petricola pholadiformis* Lamarck. *Journal of Experimental Marine Biology and Ecology*, **4** (3), 211-220.

Akaishi, F.M., St-Jean, S.D., Bishay, F., Clarke, J., Rabitto, I.d.S. & Ribeiro, C.A., 2007. Immunological responses, histopathological finding and disease resistance of blue mussel (*Mytilus edulis*) exposed to treated and untreated municipal wastewater. *Aquatic Toxicology*, **82** (1), 1-14.

Alfaro, A.C., 2005. Effect of water flow and oxygen concentration on early settlement of the New Zealand green-lipped mussel, *Perna canaliculus*. *Aquaculture*, **246**, 285-94.

Alfaro, A.C., 2006. Byssal attachment of juvenile mussels,*Perna canaliculus*, affected by water motion and air bubbles. *Aquaculture*, **255**, 357-61

Almada-Villela P.C., 1984. The effects of reduced salinity on the shell growth of small *Mytilus edulis* L. *Journal of the Marine Biological Association of the United Kingdom*, **64**, 171-182.

Almada-Villela, P.C., Davenport, J. & Gruffydd, L.L.D., 1982. The effects of temperature on the shell growth of young *Mytilus edulis* L. *Journal of Experimental Marine Biology and Ecology*, **59**, 275-288.

Arntz, W.E. & Rumohr, H., 1973. Boring clams (*Barnea candida* (L.) and *Zirfaea crispata* (L.)) in Kiel Bay. *Kiel Meeresforsch*, **29**, 141-143.

Bahmet, I., Berger, V. & Halaman, V., 2005. Heart rate in the blue mussel *Mytilus edulis* (Bivalvia) under salinity change. *Russian Journal of Marine Biology* 31: 314-7

Baird, R.H., 1966. Factors affecting the growth and condition of mussels (*Mytilus edulis*). *Fishery Investigations. Ministry of Agriculture, Fisheries and Food, Series II*, no. 25, 1-33.

Balseiro P., Montes A., Ceschia G., Gestal C., Novoa B. & Figueras A., 2007. Molecular epizootiology of the European Marteilia spp., infecting mussels (*Mytilus galloprovincialis* and *M. edulis*) and oysters (*Ostrea edulis*): an update. *Bulletin of the European Association of Fish Pathologists*, **27**(4), 148-156.

Bamber, R.N., 1985. Coarse substrate benthos of Kingsnorth outfall lagoon, with observations on *Petricola pholadiformis* Lamarck. Central Electricity Research Laboratories Report TPRD/L2759/N84., Central Electricity Research Laboratories Report TPRD/L2759/N84.

Barnes, R.D., 1980. *Invertebrate Zoology*, 4th ed. Philadelphia: Holt-Saunders International Editions.

Bayne, B., Iglesias, J., Hawkins, A., Navarro, E., Heral, M., Deslous-Paoli, J-M., 1993. Feeding behaviour of the mussel, *Mytilus edulis*: responses to variations in quantity and organic content of the seston. *Journal of the Marine Biological Association of the United Kingdom*, **73**, 813-29

Bayne, B.L., Widdows, J. & Thompson, R.J., 1976. Physiological integrations. In *Marine mussels: their ecology and physiology* (ed. B.L. Bayne), pp. 261-299. Cambridge: Cambridge University Press. [International Biological Programme 10.]

Beauchamp, K.A., Gowing, M.M., 1982. A quantitative assessment of human trampling effects on a rocky intertidal community. *Marine Environmental Research*, **7**, 279-94

Beaumont A., Abdul-Matin A. & Seed R., 1993. Early development, survival and growth in pure and hybrid larvae of *Mytilus edulis* and *M. galloprovincialis*. *Journal of Molluscan Studies*, 59(1), 120-123.

Beaumont, A.R., Gjedrem, T. & Moran, P., 2007. Blue mussel *Mytilus edulis* and Mediterranean mussel *M. galloprovincialis*. In T., S., et al. (eds.). Genetic impact of aquaculture activities on native populations. *GENIMPACT final scientific report (EU contract n. RICA-CT-2005-022802)*, pp. 62-69.

Beaumont, A.R., Turner, G., Wood, A.R. & Skibinski, D.O.F., 2004. Hybridisations between *Mytilus edulis* and *Mytilus galloprovincialis* and performance of pure species and hybrid veliger larvae at different temperatures. *Journal of Experimental Marine Biology and Ecology*, **302** (2), 177-188.

Bergmann, M., Wieczorek, S.K., Moore, P.G., 2002. Utilisation of invertebrates discarded from the *Nephrops* fishery by variously selective benthic scavengers in the west of Scotland. *Marine Ecology Progress Series*, **233**,185-98

Berthe, F.C.J., Le Roux, F., Adlard, R.D. & Figueras, A., 2004. Marteiliosis in molluscs: a review. *Aquatic Living Resources*, **17** (4), 433-448.

Bierne, N., David, P., Boudry, P. & Bonhomme, F., 2002. Assortative fertilization and selection at larval stage in the mussels *Mytilus edulis* and *M. galloprovincialis*. *Evolution*, **56**, 292-298.

Bower S.M., 2010. Synopsis of Infectious Diseases and Parasites of Commercially Exploited Shellfish [online]. Ontario, Fisheries and Oceans, Canada. Available from: http://dev-public.rhq.pac.dfo-mpo.gc.ca/science/species-especes/shellfish-coquillages/diseases-maladies/index-eng.htm [Accessed: 14/02/2014]

Bower, S.M. & McGladdery, S.E., 1996. Synopsis of Infectious Diseases and Parasites of Commercially Exploited Shellfish. SeaLane Diseases of Shellfish. [on-line].

http://www-sci.pac.dfo-mpo.gc.ca/sealane/aquac/pages/toc.htm, 2000-11-27

Bower, S.M., 1992. Diseases and parasites of mussels. In *The mussel* Mytilus: *ecology, physiology, genetics and culture* (ed. E.M. Gosling), pp. 543-563. Amsterdam: Elsevier Science Publ. [Developments in Aquaculture and Fisheries Science, no. 25.]

Brosnan, D.M., 1993. The effect of human trampling on biodiversity of rocky shores: monitoring and management strategies. *Recent Advances in Marine Science and Technology*, **1992**, 333-341.

Brosnan, D.M. & Crumrine, L.L., 1994. Effects of human trampling on marine rocky shore communities. *Journal of Experimental Marine Biology and Ecology*, **177**, 79-97.

Browne, M.A., Dissanayake, A., Galloway, T.S., Lowe, D.M. & Thompson, R.C., 2008. Ingested microscopic plastic translocates to the circulatory system of the mussel, *Mytilus edulis* (L.). *Environmental Science & Technology*, **42** (13), 5026-5031.

Buschbaum, C. & Saier, B., 2001. Growth of the mussel *Mytilus edulis* L. in the Wadden Sea affected by tidal emergence and barnacle epibionts. *Journal of Sea Research*, **45**, 27-36

Bussell, J. A., Gidman, E. A., Causton, D. R., Gwynn-Jones, D., Malham, S. K., Jones, M. L. M., Reynolds, B. & Seed. R., 2008. Changes in the immune response and metabolic fingerprint of the mussel, *Mytilus edulis* (Linnaeus) in response to lowered salinity and physical stress. *Journal of Experimental Marine Biology and Ecology*, **358**, 78-85.

Castagna, M., & Chanley, P., 1973. Salinity tolerance of some marine bivalves from inshore and estuarine environments in Virginia waters on the western mid- Atlantic coast. *Malacologia* **12**, 47-96

Cole, S., Codling, I.D., Parr, W. & Zabel, T., 1999. Guidelines for managing water quality impacts within UK European Marine sites. *Natura 2000 report prepared for the UK Marine SACs Project.* 441 pp., Swindon: Water Research Council on behalf of EN, SNH, CCW, JNCC, SAMS and EHS. [UK Marine SACs Project.], http://www.ukmarinesac.org.uk/

Connor, D.W., Allen, J.H., Golding, N., Howell, K.L., Lieberknecht, L.M., Northen, K.O. & Reker, J.B., 2004. The Marine Habitat Classification for Britain and Ireland. Version 04.05. ISBN 1 861 07561 8. In JNCC (2015), *The Marine Habitat Classification for Britain and Ireland Version 15.03.* [2019-07-24]. Joint Nature Conservation Committee, Peterborough. Available from https://mhc.jncc.gov.uk/

Culloty, S.C., Novoa, B., Pernas, M., Longshaw, M., Mulcahy, M.F., Feist, S.W. & Figueras, A., 1999. Susceptibility of a number of bivalve species to the protozoan parasite *Bonamia ostreae* and their ability to act as vectors for this parasite. *Diseases of Aquatic Organisms*, **37** (1), 73-80.

Daguin, C., Bonhomme, F. & Borsa, P., 2001. The zone of sympatry and hybridization of *Mytilus edulis* and *M. galloprovincialis*, as described by intron length polymorphism at locus mac-1. *Heredity*, **86,** 342-354.

Daly, M.A. & Mathieson, A.C., 1977. The effects of sand movement on intertidal seaweeds and selected invertebrates at Bound Rock, New Hampshire, USA. *Marine Biology*, **43**, 45-55.

Dare, P.J., 1976. Settlement, growth and production of the mussel, *Mytilus edulis* L., in Morecambe Bay, England. *Fishery Investigations, Ministry of Agriculture, Fisheries and Food, Series II*, **28** , 25pp.

Davenport, J., 1979. The isolation response of mussels (*Mytilus edulis*) exposed to falling sea water concentrations. *Journal of the Marine Biological Association of the United Kingdom*, **59**, 124-132.

Denny, M.W., 1987. Lift as a mechanism of patch initiation in mussel beds. *Journal of Experimental Marine Biology and Ecology*, **113**, 231-45

Diaz, R.J. & Rosenberg, R., 1995. Marine benthic hypoxia: a review of its ecological effects and the behavioural responses of benthic macrofauna. *Oceanography and Marine Biology: an Annual Review*, **33**, 245-303.

Diederich, S., 2006. High survival and growth rates of introduced Pacific oysters may cause restrictions on habitat use by native mussels in the Wadden Sea. *Journal of Experimental Marine Biology and Ecology*, **328** (2), 211-227.

Dinesen, G.E., Timmermann K., Roth E., Markager S., Ravn-Jonsen, L., Hjorth, M., Holmer M. & Støttrup J.G., 2011. Mussel Production and Water Framework Directive Targets in the Limfjord, Denmark: an Integrated Assessment for Use in System-Based Management. *Ecology & Society*, **16**(4). 26

Dobretsov, S. & Wahl, M., 2008. Larval recruitment of the blue mussel *Mytilus edulis*: the effect of flow and algae. *Journal of Experimental Marine Biology and Ecology*, **355**, 137-44

Doherty, S.D., Brophy, D. & Gosling, E., 2009. Synchronous reproduction may facilitate introgression in a hybrid mussel (*Mytilus*) population. *Journal of Experimental Marine Biology and Ecology*, **378**, 1-7.

Dolmer, P. & Svane, I. 1994. Attachment and orientation of *Mytilus edulis* L. in flowing water. *Ophelia*, **40**, 63-74

Duval, D.M., 1962. Observations on the annual cycles of *Barnea candida*: (Class Lamellibranchiata, Family Pholadidae). *Journal of Molluscan Studies*, **35** (2-3), 101-102.

Duval, D.M., 1963a. The biology of *Petricola pholadiformis* Lamarck (Lammellibranchiata: Petricolidae). *Proceedings of the Malacological Society*, **35**, 89-100.

Duval, D.M., 1963b. Observations on the annual cycle of *Barnea candida* (Class Lamellibranchiata, Family Pholadidae). *Proceedings of the Malacological Society*, **35**, 101-102.

Duval, M., 1977. A historical note - *Barnea candida* at Whitstable Street. *The Conchologists Newsletter*, **62**, pp. 28.

El-Maghraby, A., 1955. *The inshore plankton of the Thames Estuary*. , PhD thesis, University of London.

Eno, N.C., Clark, R.A. & Sanderson, W.G. (ed.) 1997. *Non-native marine species in British waters: a review and directory*. Peterborough: Joint Nature Conservation Committee.

Essink, K., 1996. Die Auswirkungen von Baggergutablagerungen auf das Makrozoobenthos—Eine Übersicht der niederländischen Untersuchungen. In: BFG (ed) Baggern und Verklappen im Küstenbereich. BFG Mitt 11:12–17

Essink, K., 1999. Ecological effects of dumping of dredged sediments; options for management. *Journal of Coastal Conservation*, **5**, 69-80.

Evans, J.W., 1968. The role of *Penitella penita* (Conrad 1837)(Family Pholadidae) as eroders along the Pacific coast of North America. *Ecology*, **49**,156-159.

Fanelli, G., Piraino, S., Belmonte, G., Geraci, S. & Boero, F., 1994. Human predation along Apulian rocky coasts (SE Italy): desertification caused by *Lithophaga lithophaga* (Mollusca) fisheries. *Marine Ecology Progress Series*. Oldendorf, **110** (1), 1-8.

Fish, J.D. & Fish, S., 1996. *A student's guide to the seashore.* Cambridge: Cambridge University Press.

Frechette, M., Butman, C.A., Geyer, W.R., 1989. The importance of boundary-layer flow in supplying phytoplankton to the benthic suspension feeder, *Mytilus edulis* L. *Limnology and Oceanography*, **34**, 19-36.

Gardner, J.P.A., 1996. The *Mytilus edulis* species complex in southwest England: effects of hybridization and introgression upon interlocus associations and morphometric variation. *Marine Biology*, **125**(2), 385-399.

Giltrap, M., Ronan, J., Hardenberg, S., Parkes, G., McHugh, B., McGovern, E. & Wilson, J., 2013. Assessment of biomarkers in *Mytilus edulis* to determine good environmental status for implementation of MSFD in Ireland. *Marine Pollution Bulletin*, **71** (1), 240-249.

Gofas, S., 2015. *Barnea candida* (Linnaeus, 1758). Accessed through: World Register of Marine Species at http://www.marinespecies.org/

Gollasch, S. &, Mecke, R., 1996. Eingeschleppte Organismen. In: Lozan JL, Lampe R, Matthaus W, Rachor E, Rumohr H, v. Westernhagen H (eds), *Warnsignale aus der Ostsee*. Parey Buchverlag, Berlin, pp 146-150

Gomoiu M.T. & Müller, G.J., 1962. Studies concerning the benthic association dominated by *Barnea candida* in the Black Sea. *Revue Roumaine de Biologie*, 7 (2): 255-271.

Gosling, E.M. (ed.), 1992a. *The mussel* Mytilus: *ecology, physiology, genetics and culture.* Amsterdam: Elsevier Science Publ. [Developments in Aquaculture and Fisheries Science, no. 25]

Gray, A.R., Lucas, I.A.N, Seed, R. & Richardson, C.A., 1999. *Mytilus edulis chilensis* infested with *Coccomyxa parasitica* (Chlorococcales, Coccomyxaceae). *Journal of Molluscan Studies*, **65**, 289-294.

Gray, J.S., Wu R.S.-S. & Or Y.Y., 2002. Effects of hypoxia and organic enrichment on the coastal marine environment. *Marine Ecology Progress Series*, **238**, 249-279.

Groenewold, S. & Fonds, M., 2000. Effects on benthic scavengers of discards and damaged benthos produced by the beam-trawl fishery in the southern North Sea. *ICES Journal of Marine Science*, **57** (5), 1395-1406.

Gruffydd, L.D., Huxley, R. & Crisp, D., 1984. The reduction in growth of *Mytilus edulis* in fluctuating salinity regimes measured using laser diffraction patterns and the exaggeration of this effect by using tap water as the diluting medium. *Journal of the Marine Biological Association of the United Kingdom* 64: 401-9

Hawkins, A., Smith, R., Bayne, B. & Heral, M., 1996. Novel observations underlying the fast growth of suspension-feeding shellfish in turbid environments: *Mytilus edulis*. *Marine Ecology Progress Series*, **131**, 179-90

Hebda, A., 2011. Information in Support of a Recovery Potential Assessment for Atlantic Mud-piddock (*Barnea Truncata*) in Canada: *Canadian Science Advisory Secretariat*.

Hecht, S.,1928. The relation of time, intensity and wave-length in the photosensory system of *Pholas*. *The Journal of General Physiology*, **11**(5), 657-672.

Hily, C., Potin, P. & Floch, J.Y. 1992. Structure of subtidal algal assemblages on soft-bottom sediments - fauna flora interactions and role of disturbances in the Bay of Brest, France. *Marine*

Ecology Progress Series, **85**, 115-130.

Holt, T.J., Hartnoll, R.G. & Hawkins, S.J., 1997. The sensitivity and vulnerability to man-induced change of selected communities: intertidal brown algal shrubs, *Zostera* beds and *Sabellaria spinulosa* reefs. *English Nature, Peterborough, English Nature Research Report* No. 234.

Holt, T.J., Jones, D.R., Hawkins, S.J. & Hartnoll, R.G., 1995. The sensitivity of marine communities to man induced change - a scoping report. *Countryside Council for Wales, Bangor, Contract Science Report*, no. 65.

Holt, T.J., Rees, E.I., Hawkins, S.J. & Seed, R., 1998. Biogenic reefs (Volume IX). An overview of dynamic and sensitivity characteristics for conservation management of marine SACs. *Scottish Association for Marine Science (UK Marine SACs Project)*, 174 pp.

Huber, M. & Gofas, S., 2015. *Petricolaria pholadiformis* (Lamarck, 1818). Accessed through: World Register of Marine Species [On-line] at http://www.marinespecies.org/aphia.php?p=taxdetails&id=156961 on 2015-05-01

ICES (International Council for the Exploration of the Sea), 1972. *Report of the working group on the introduction of non-indigenous marine organisms*. ICES: International Council for the Exploration of the Sea., ICES: International Council for the Exploration of the Sea.

Jeffries, J.G., 1865. An account of the Mollusca which now inhabit the British Isles and the surrounding seas. Volume 3: Marine shells, Conchifera, the Solenoconcia and \gastropoda as far as Littorina. *British Conchology*, **3**, 93-122

Jensen, K.R., 2010: NOBANIS – Invasive Alien Species Fact Sheet – Petricola pholadiformis – From: Identification key to marine invasive species in Nordic waters – NOBANIS www.nobanis.org, Date of access 23/03/2015.

JNCC, 2015. The Marine Habitat Classification for Britain and Ireland Version 15.03. (20/05/2015). Available from https://mhc.jncc.gov.uk/

Jones, S.J., Lima, F.P. & Wethey, D.S., 2010. Rising environmental temperatures and biogeography: poleward range contraction of the blue mussel, *Mytilus edulis* L., in the western Atlantic. *Journal of Biogeography* 37: 2243-59

Jorgensen, B.B., 1980. Seasonal oxygen depletion in the bottom waters of a Danish fjord and its effect on the benthic community. *Oikos*, **32**, 68-76.

Kaiser, M.J. & Spencer, B.E., 1994. Fish scavenging behaviour in recently trawled areas. *Marine Ecology Progress Series*, **112** (1-2), 41-49.

Kittner, C. & Riisgaard, H.U., 2005. Effect of temperature on filtration rate in the mussel *Mytilus edulis*: no evidence for temperature compensation. *Marine Ecology Progress Series* 305: 147-52

Knight, J.H., 1984. *Studies on the biology and biochemistry of* Pholas dactylus *L..*, PhD thesis. London, University of London.

Kochmann, J., Buschbaum, C., Volkenborn, N. & Reise, K., 2008. Shift from native mussels to alien oysters: differential effects of ecosystem engineers. *Journal of Experimental Marine Biology and Ecology*, **364** (1), 1-10.

Lander, T.R., Robinson, S.M., MacDonald, B.A. & Martin, J.D., 2012. Enhanced growth rates and condition index of blue mussels (*Mytilus edulis*) held at integrated multitrophic aquaculture sites in the Bay of Fundy. *Journal of Shellfish Research*, **31** (4), 997-1007.

Lane, D.J.W., Beaumont, A.R. & Hunter, J.R., 1985. Byssus drifting and the drifting threads of young postlarval mussel *Mytilus edulis*. *Marine Biology*, **84**, 301-308.

Last, K.S., Hendrick V. J, Beveridge C. M & Davies A. J, 2011. Measuring the effects of suspended particulate matter and smothering on the behaviour, growth and survival of key species found in areas associated with aggregate dredging. *Report for the Marine Aggregate Levy Sustainability Fund*,

Le Roux, F., Lorenzo, G., Peyret, P., Audemard, C., Figueras, A., Vivares, C., Gouy, M. & Berthe, F., 2001. Molecular evidence for the existence of two species of *Marteilia* in Europe. *Journal of Eukaryotic Microbiology*, **48** (4), 449-454.

Lindahl, O. & Kollberg, S., 2008. How mussels can improve coastal water quality. *Bioscience Explained*, **5** (1), 1-14.

Loo, L-O., 1992. Filtration, assimilation, respiration and growth of *Mytilus edulis* L. at low temperatures. *Ophelia* 35: 123-31

Loosanoff, V.L., 1962. Effects of turbidity on some larval and adult bivalves. *Proceedings of the Gulf and Caribbean Fisheries Institute*, **14,** 80-95.

Lopez-Flores I., De la Herran, R., Garrido-Ramos, M.A., Navas, J.I., Ruiz-Rejon, C. & Ruiz-Rejon, M., 2004. The molecular diagnosis of *Marteilia refringens* and differentiation between *Marteilia* strains infecting oysters and mussels based on the rDNA IGS sequence. *Parasitology*, **19** (4), 411-419.

Lutz, R.A. & Kennish, M.J., 1992. Ecology and morphology of larval and early larval postlarval mussels. In *The mussel Mytilus: ecology, physiology, genetics and culture*, (ed. E.M. Gosling), pp. 53-85. Amsterdam: Elsevier Science Publ. [Developments in Aquaculture and Fisheries Science, no. 25]

Maddock, A., 2008. UK Biodiversity Action Plan; Priority Habitat Descriptions. *UK Biodiversity Action Plan*, 94pp

Mainwaring, K., Tillin, H. & Tyler-Walters, H., 2014. Assessing the sensitivity of blue mussel beds to pressures associated with human activities. *Joint Nature Conservation Committee, JNCC Report No. 506.*, Peterborough, 96 pp.

Mann, R. & Harding, J.M., 2000. Invasion of the North American Atlantic coast by a large predatory Asian mollusc. *Biological Invasions*, **2** (1), 7-22.

McGrorty, S., Clarke, R.T., Reading, C.J. & Goss, C.J.D., 1990. Population dynamics of the mussel *Mytilus edulis*: density changes and regulation of the population in the Exe Estuary, Devon. *Marine Ecology Progress Series*, **67**, 157-169.

Micu, D., 2007. Recent records of *Pholas dactylus* (Bivalvia: Myoida: Pholadidae) from the Romanian Black Sea, with considerations on its habitat and proposed IUCN regional status. *Acta Zoologica Bulgarica*, **59**, 267-273.

Moore, J., Taylor, P. & Hiscock, K., 1995. Rocky shore monitoring programme. *Proceedings of the Royal Society of Edinburgh*, **103B**, 181-200.

Myrand, B., Guderley, H. & Himmelman, J.H., 2000. Reproduction and summer mortality of blue mussels *Mytilus edulis* in the Magdalen Islands, southern Gulf of St. Lawrence. *Marine Ecology Progress Series* 197: 193-207

Naylor, E., 1957. Immigrant marine animals in Great Britain. *New Scientist*, **2**, 21-53.

Nenonen, N.P., Hannoun, C., Horal, P., Hernroth, B. & Bergström, T., 2008. Tracing of norovirus outbreak strains in mussels collected near sewage effluents. *Applied and Environmental Microbiology*, **74** (8), 2544-2549.

Newell, R.C., 1979. *Biology of intertidal animals*. Faversham: Marine Ecological Surveys Ltd.

Padilla, D.K., 2010. Context-dependent impacts of a non-native ecosystem engineer, the Pacific Oyster *Crassostrea gigas*. *Integrative and Comparative Biology*, **50** (2), 213-225.

Paine, R.T. & Levin, S.A., 1981. Intertidal landscapes: disturbance and the dynamics of pattern. *Ecological Monographs*, **51**, 145-178.

Parry, H., & Pipe, R., 2004. Interactive effects of temperature and copper on immunocompetence and disease susceptibility in mussels (*Mytilus edulis*). *Aquatic Toxicology* 69: 311-25

Pelseneer, P., 1924. La proportion relative des sexes chez les animaux et particulièrement chez les mollusques: *Academie Royale de Belgique. Classe des Sciences Mem Deuxieme Series*, **8**, 1-258.

Pernet, F., Tremblay, R. & Bourget E., 2003. Settlement success, spatial pattern and behavior of mussel larvae Mytilus spp. in experimentaldownwelling'systems of varying velocity and turbulence. *Marine Ecology Progress Series*, **260**, 125-140.

Pinn, E.H., Richardson, C.A., Thompson, R.C. & Hawkins, S.J., 2005. Burrow morphology, biometry, age and growth of piddocks (Mollusca: Bivalvia: Pholadidae) on the south coast of England. *Marine Biology*, **147**(4), 943-953.

Pinn, E.H., Thompson, R. & Hawkins, S., 2008. Piddocks (Mollusca: Bivalvia: Pholadidae) increase topographical complexity and species diversity in the intertidal. *Marine Ecology Progress Series*, **355**, 173-182.

Price, H., 1982. An analysis of factors determining seasonal variation in the byssal attachment strength of *Mytilus edulis*. *Journal of the Marine Biological Association of the United Kingdom*, **62** (01), 147-155

Purchon, R.D., 1937. Studies on the biology of the Bristol Channel. *Proceedings of the Bristol Naturalists' Society*, **8**, 311-329.

Purchon, R.D., 1955. The functional morphology of the rock-boring Lamellibranch *Petricola pholadiformis* Lamarck. *Journal of the Marine Biological Association of the United Kingdom*, **34**, 257-278.

Ramsay, K., Kaiser, M.J. & Hughes, R.N. 1998. The responses of benthic scavengers to fishing disturbance by towed gears in different habitats. *Journal of Experimental Marine Biology and Ecology*, **224**, 73-89.

Rankin, C.J. & Davenport, J.A., 1981. *Animal Osmoregulation*. Glasgow & London: Blackie. [Tertiary Level Biology].

Read, K.R.H. & Cumming, K.B., 1967. Thermal tolerance of the bivalve molluscs *Modiolus modiolus* (L.), *Mytilus edulis* (L.) and *Brachidontes demissus* (Dillwyn). *Comparative Biochemistry and Physiology*, **22**, 149-155.

Reid, G., Liutkus, M., Bennett, A., Robinson, S., MacDonald, B. & Page, F., 2010. Absorption efficiency of blue mussels (*Mytilus edulis* and *M. trossulus*) feeding on Atlantic salmon (*Salmo salar)* feed and fecal particulates: implications for integrated multi-trophic aquaculture. *Aquaculture*, **299** (1), 165-169.

Richter, W. & Sarnthein, M., 1976. Molluscan colonization of different sediments on submerged platforms in the Western Baltic Sea. In *Biology of benthic organsisms* (ed. B.F. Keegan, P.Ó. Céidigh & P.J.S. Boaden), pp. 531-539. Oxford: Pergamon Press.

Riisgård, H.U., Lüskow, F., Pleissner, D., Lundgreen, K. & López, M., 2013. Effect of salinity on filtration rates of mussels *Mytilus edulis* with special emphasis on dwarfed mussels from the low-saline Central Baltic Sea. *Helgoland Marine Research*, **67**, 591-8

Robledo, J.A.F., Santarem, M.M., Gonzalez, P. & Figueras, A., 1995. Seasonal variations in the biochemical composition of the serum of *Mytilus galloprovincialis* Lmk. and its relationship to the reproductive cycle and parasitic load. *Aquaculture*, **133** (3-4), 311-322.

Rosenthal, H., 1980. Implications of transplantations to aquaculture and ecosystems. *Marine Fisheries Review*, **42**, 1-14.

Saier, B., 2002. Subtidal and intertidal mussel beds (*Mytilus edulis* L.) in the Wadden Sea: diversity differences of associated epifauna. *Helgoland Marine Research*, **56**, 44-50

Seed R., 1969. The ecology of *Mytilus edulis* L.(Lamellibranchiata) on exposed rocky shores. Oecologia, **3**, 277-316.

Seed, R. & Suchanek, T.H., 1992. Population and community ecology of *Mytilus*. In *The mussel* Mytilus*: ecology, physiology, genetics and culture*, (ed. E.M. Gosling), pp. 87-169. Amsterdam: Elsevier Science Publ. [Developments in Aquaculture and Fisheries Science, no. 25.]

Sewell, J., Pearce, S., Bishop, J. & Evans, J.L., 2008. Investigations to determine the potential risk for certain non-native species to be introduced to North Wales with mussel seed dredged from wild seed beds. *CCW Policy Research Report*, **835**, 82 pp., Countryside Council for Wales

Shumway, S.E., 1990. A review of the effects of algal blooms on shellfish and aquaculture. *Journal of the World Aquaculture Society*, **21**, 65-104.

Smaal, A.C. & Twisk, F., 1997. Filtration and absorption of *Phaeocysti*s cf. *globosa* by the mussel *Mytilus edulis* L. *Journal of Experimental Marine Biology and Ecology*, **209**, 33-46

Smith, J.R. & Murray, S.N., 2005. The effects of experimental bait collection and trampling on a *Mytilus californianus* mussel bed in southern California. *Marine Biology*, **147**, 699-706

Suchanek, T.H., 1978. The ecology of *Mytilus edulis* L. in exposed rocky intertidal communities. *Journal of Experimental Marine Biology and Ecology*, **31**, 105-120.

Suchanek, T.H., 1985. Mussels and their role in structuring rocky shore communities. In *The Ecology of Rocky Coasts: essays presented to J.R. Lewis, D.Sc.*, (ed. P.G. Moore & R. Seed), pp. 70-96.

Svåsand, T., Crosetti, D., García-Vázquez, E. & Verspoor, E., 2007. Genetic impact of aquaculture activities on native populations. *Genimpact final scientific report (EU contract n. RICA-CT-2005-022802).*

Tangen K., 1977. Blooms of *Gyrodinium aureolum* (Dinophygeae) in North European waters, accompanied by mortality in marine organisms. *Sarsia*, **6** , 123-33.

Theede, H., Ponat, A., Hiroki, K. & Schlieper, C., 1969. Studies on the resistance of marine bottom invertebrates to oxygen-deficiency and hydrogen sulphide. *Marine Biology*, **2**, 325-337.

Theisen, B.F., 1982. Variation in size of gills, labial palps, and adductor muscle in *Mytilus edulis* L.(Bivalvia) from Danish waters. *Ophelia*, **21**, 49-63.

Thompson, I.S., Richardson, C.A., Seed, R. & Walker, G., 2000. Quantification of mussel (*Mytilus edulis*) growth from power station cooling waters in response to chlorination procedures. *Biofouling*, **16**, 1-15.

Tracey, G.A., 1988. Effects of inorganic and organic nutrient enrichment on growth and bioenergetics of the blue mussel, *Mytilus edulis*. *Journal of Shelfish Research*, **7**, 562.

Trudgill, S. T. 1983. *Weathering and erosion*. London: Butterworths.

Trudgill, S.T. & Crabtree, R.W., 1987. Bioerosion of intertidal limestone, Co. Clare, Eire - 2: *Hiatella arctica*. *Marine Geology*, **74** (1-2), 99-109.

Tsuchiya, M., 1983. Mass mortality in a population of the mussel *Mytilus edulis* L. Caused by high temperature on rocky shores. *Journal of Experimental Marine Biology and Ecology* 66: 101-11

Turner, R.D., 1954. The family Pholadidae in the western Atlantic and the eastern Pacific Part 1 - Pholadinae. *Johnsonia*, **3**, 1-64.

UKTAG, 2014. UK Technical Advisory Group on the Water Framework Directive [online]. Available from: http://www.wfduk.org

Wallace, B. & Wallace, I.D., 1983. The white piddock *Barnea candida* (L.) found alive on Merseyside. *The Conchologists Newsletter*, **84**, 71-72.

Wang, W. & Widdows, J., 1991. Physiological responses of mussel larvae *Mytilus edulis* to environmental hypoxia and anoxia. *Marine Ecology Progress Series*, **70**, 223-36

Whitehouse, J., Coughlan, J., Lewis, B., Travade, F. & Britain, G., 1985. The control of biofouling in marine and estuarine power stations: a collaborative research working group report for use by station designers and station managers. *Central Electricity Generating Board*

Widdows J., Lucas J.S., Brinsley M.D., Salkeld P.N. & Staff F.J., 2002. Investigation of the effects of current velocity on mussel feeding and mussel bed stability using an annular flume. *Helgoland Marine Research*, **56**(1), 3-12.

Widdows, J. & Donkin, P., 1992. Mussels and environmental contaminants: bioaccumulation and physiological aspects. In *The mussel* Mytilus: *ecology, physiology, genetics and culture*, (ed. E.M. Gosling), pp. 383-424. Amsterdam: Elsevier Science Publ. [Developments in Aquaculture and Fisheries Science, no. 25]

Widdows, J., 1991. Physiological ecology of mussel larvae. *Aquaculture*, **94**, 147-163.

Widdows, J., Bayne, B.L., Livingstone, D.R., Newell, R.I.E. & Donkin, P., 1979. Physiological and biochemical responses of bivalve molluscs to exposure to air. *Comparative Biochemistry and Physiology*, **62A**, 301-308.

Widdows, J., Brinsley, M.D., Salkeld, P.N. & Elliott, M., 1998. Use of annular flumes to determine the influence of current velocity and bivalves on material flux at the sediment-water interface. *Estuaries*, **21**, 552-559.

Widdows, J., Donkin, P., Brinsley, M.D., Evans, S.V., Salkeld, P.N., Franklin, A., Law, R.J. & Waldock, M.J., 1995. Scope for growth and contaminant levels in North Sea mussels *Mytilus edulis*. *Marine Ecology Progress Series*, **127**, 131-148.

Widdows, J., Livingstone, D.R., Lowe, D., Moore, M.N., Moore, S., Pipe, R. & Salkeld, P.N., 1981. Biological effects monitoring in the region of Sullom Voe, Shetland, September 1981. *Shetland Oil Terminal Environmental Advisory Group (SOTEAG), University of Aberdeen, 1982*.

Winter, J., 1972. Long-term laboratory experiments on the influence of ferric hydroxide flakes on the filter-feeding behaviour, growth, iron content and mortality in *Mytilus edulis* L. *Marine pollution and sea life*. (ed. Ruvio, M.) London, England, pp. 392-396.

Witman, J.D. & Suchanek, T.H., 1984. Mussels in flow: drag and dislodgement by epizoans. *Marine Ecology Progress Series*, **16** (3), 259-268.

Witt, J., Schroeder, A., Knust, R. & Arntz, W.E., 2004. The impact of harbour sludge disposal on benthic macrofauna communities in the Weser estuary. *Helgoland Marine Research*, **58** (2), 117-128.

Wouters, D., 1993. 100 jaar na de invasie van de Amerikaanse boormossel: de relatie *Petricola pholadiformis* Lamarck, 1818, *Barnea candida*, Linnaeus, 1758. *De Strandvlo*, **13**, 3-39.

Young, G.A., 1985. Byssus thread formation by the mussel *Mytilus edulis*: effects of environmental factors. *Marine Ecology Progress Series*, **24**, 261-271.

Zandee, D.I., Holwerda, D.A., Kluytmans, J.H. & De Zwaan, A., 1986. Metabolic adaptations to environmental anoxia in the intertidal bivalve mollusc *Mytilus edulis* L. Netherlands Journal of Zoology, **36**(3), 322-343.

Zenetos, A., Ovalis, P. & Vardala-Theodorou, E., 2009. The American piddock *Petricola pholadiformis* Lamarck, 1818 spreading in the Mediterranean Sea. *Aquatic Invasions*, **4** (2), 385-387.

Zwaan de, A. & Mathieu, M., 1992. Cellular biochemistry and endocrinology. In *The mussel* Mytilus*: ecology, physiology, genetics and culture*, (ed. E.M. Gosling), pp. 223-307. Amsterdam: Elsevier Science Publ. [Developments in Aquaculture and Fisheries Science, no. 25]