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

Phymatolithon calcareum maerl beds with *Neopentadactyla mixta* and other echinoderms in deeper infralittoral clean gravel or coarse sand

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

Angus Jackson

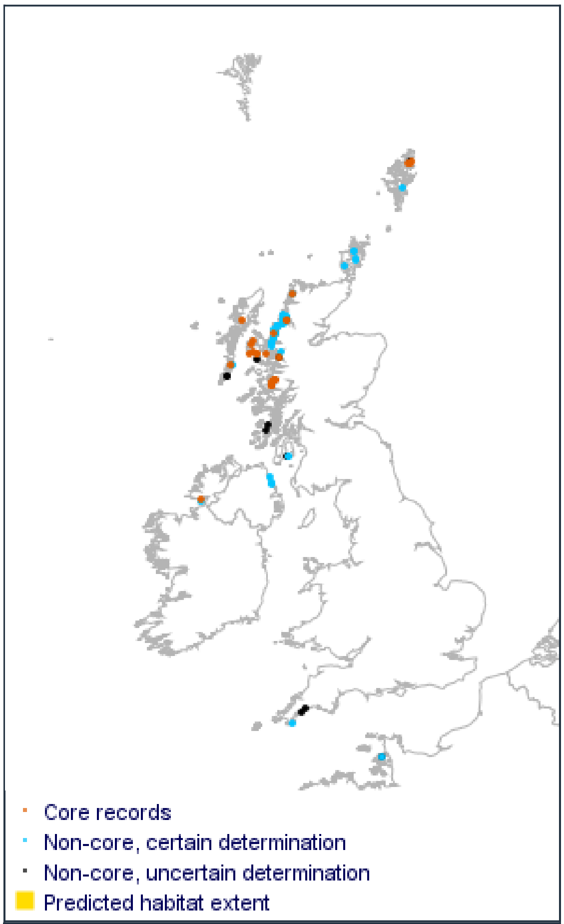
2018-03-28

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

This review can be cited as:
Jackson, A. 2018. [Phymatolithon calcareum] maerl beds with [Neopentadactyla mixta] and other echinoderms in deeper infralittoral clean gravel or coarse sand. 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.64.1

(page left blank)

Phymatolithon calcareum **maerl beds with hydroids and echinoderms in deeper infralittoral clean gravel or coarse sand.**
Photographer: Sarah Fowler
Copyright: Joint Nature Conservation Committee (JNCC)



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

Researched by Angus Jackson **Refereed by** Prof. Jason Hall-Spencer

Summary

UK and Ireland classification

EUNIS 2008	A5.5112	*Phymatolithon calcareum* maerl beds with *Neopentadactyla mixta* and other echinoderms in deeper infralittoral clean gravel or coarse sand
JNCC 2015	SS.SMp.Mrl.Pcal.Nmix	*Phymatolithon calcareum* maerl beds with *Neopentadactyla mixta* and other echinoderms in deeper infralittoral clean gravel or coarse sand
JNCC 2004	SS.SMp.Mrl.Pcal.Nmix	*Phymatolithon calcareum* maerl beds with *Neopentadactyla mixta* and other echinoderms in deeper infralittoral clean gravel or coarse sand
1997 Biotope	SS.IGS.Mrl.Phy.HEc	*Phymatolithon calcareum* maerl beds with hydroids and echinoderms in deeper infralittoral clean gravel or coarse sand

Description

Lower infralittoral maerl beds characterized by *Phymatolithon calcareum* in gravels and sand with a variety of associated echinoderms. The echinoderm *Neopentadactyla mixta* is frequently observed in this biotope. Other echinoderms such as *Echinus esculentus*, *Ophiura albida* and rarely *Luidia ciliaris* may also be present. Red seaweed such as *Plocamium cartilagineum* may be present but at a much lower abundance than in SMp.Mrl.Pcal.R and with fewer species present. Other, more ubiquitous echinoderms such as *Asterias rubens* may also be found in low numbers throughout SMp.Mrl.Pcal biotopes. (Information from Connor *et al*., 2004; JNCC, 2015).

Depth range

5-10 m, 10-20 m, 20-30 m

Additional information

-

Listed By

- none -

Further information sources

Search on:

Habitat review

Ecology

Ecological and functional relationships

The ecological relationships of maerl beds can be very complex. The maerl thalli provide a considerable surface area to which both flora and fauna can attach. The maerl nodules themselves may be directly grazed by species like *Tectura virginea*. The surface film of microalgae and detritus can also be grazed. The loose structure permits water circulation and oxygenation to a considerable depth. As a consequence of this loose structure, maerl provides shelter for an astonishing variety of fauna e.g. molluscs (Hall-Spencer, 1998) and amphipods (De Grave, 1999). The loose structure also permits animals to burrow to considerable depths (at least 60 cm) within the gravel.

Seasonal and longer term change

Cabioch (1969) suggested *Phymatolithon calcareum* may have phasic reproduction with peaks every six years. This may account for observed changes in the relative proportions of live *Lithothamnion corallioides* and *Phymatolithon calcareum* nodules in some maerl beds. Dominance cycles with periods of about thirty years have been recorded on some of the maerl beds of northern Brittany.

Habitat structure and complexity

The habitat of this biotope is extremely complex. The maerl nodules are frequently loose and mobile preventing colonization by many species. However, deep burrowing fauna (to 68 cm) are a notable feature of this biotope (Hall-Spencer & Atkinson, 1999). Some surveys record as few as 10 species in the biotope, primarily because the vast majority of species live below the maerl surface. Maerl, in general, is known as a particularly diverse habitat with over 150 macroalgal species and 500 benthic faunal species recorded (Birkett *et al*., 1998a). Peña *et al.* (2014) recorded 349 macroalgal species on maerl beds in the North East Atlantic.

Productivity

Maerl beds may contain dead as well as live nodules. Productivity will depend on the relative proportions of dead and alive nodules. Primary productivity may be less than in maerl biotopes found in shallower waters (e.g. IGS.Phy.R) where there are more epiphytic algae. Secondary production may be very high in situations where there are dense aggregations of consumers. The sea cucumber *Neopentadactyla mixta* can reach densities of up to 400 per square metre in loose gravels such as maerl (Smith and Keegan, 1984).

Recruitment processes

Recruitment of *Phymatolithon calcareum* is mainly through vegetative propagation. Although spore bearing individuals of *Phymatolithon calcareum* thalli have been found in the British Isles, the crustose individuals that would result from sexual reproduction have yet to be recorded in the British Isles. Recruitment may occur from distant populations that exhibit sexual reproduction and have crustose individuals (e.g. Brittany). Hall-Spencer (pers. comm.) has observed that colonization of new locations by maerl can be mediated by a 'rafting' process where maerl thalli are bound up with other sessile organisms that are displaced and carried by currents (e.g. *Saccharina latissima* holdfasts after storms).

Time for community to reach maturity

Phymatolithon calcareum is extremely slow growing (c. 1mm per year) (Potin *et al*., 1990 and Birkett *et al*., 1998a). Development of a new maerl bed would take a long time. Maerl beds are also extremely long lived with lifespan of the habitat being 6000 years or more (Birkett *et al*., 1998a) Within the biotope, the community is dependent on the growth of a surface veneer of photosynthetically active maerl thalli.

Additional information

Although *Phymatolithon calcareum* has a patchy distribution around the British Isles, it is the most widespread maerl-forming species in European waters (BIOMAERL team, 1999). "Maerl is a 'living sediment'; it is slow to recover from disturbance due to infrequent recruitment and extremely slow growth rates (Hall-Spencer & Moore, 2000a)". Although from outward appearances suspension feeders may appear to be dominant, Grall & Glemarec (1997) found that dominant trophic groups varied according to the assessment criteria used. In terms of species richness carnivores were most dominant, for abundance it was detritivores and for biomass, it was surface deposit feeders. Detrital input is important in enclosed areas such as the Firth of Clyde and the Fal estuary.

Preferences & Distribution

Habitat preferences

Depth Range	5-10 m, 10-20 m, 20-30 m
Water clarity preferences	High clarity / Low turbidity
Limiting Nutrients	Calcium
Salinity preferences	Full (30-40 psu)
Physiographic preferences	Open coast, Strait / sound
Biological zone preferences	Lower infralittoral, Upper circalittoral
Substratum/habitat preferences	Coarse clean sand, Maerl
Tidal strength preferences	Moderately Strong 1 to 3 knots (0.5-1.5 m/sec.), Very Weak (negligible), Weak < 1 knot (<0.5 m/sec.)
Wave exposure preferences	Exposed, Moderately exposed, Sheltered
Other preferences	See additional information.

Additional Information

In laboratory conditions, *Phymatolithon calcareum* survived down to 2°C, died at 0.4°C, and had a recorded optimum temperature for growth of 12-13°C (Adey & McKibbin 1970 cited in Wilson *et al*., 2004). *Phymatolithon calcareum* showed no significant difference on photosynthetic activity at 9°C (the control), 17°C or 25°C for 4-5 weeks but were judged to be dead after 90 minutes at 40°C (Wilson *et al*., 2004).

The growth of *Phymatolithon calcareum* is impaired at salinities below 24 psu (King & Schramm,

1976) so the species is absent from areas with variable or reduced salinity. Distribution of maerl is dependent on several factors. Living maerl has poor tolerance of desiccation and so is typically found subtidally (Hall-Spencer, 1998). As a photosynthesising organism, there is a requirement for light which restricts the species to depths shallower than 32m in the relatively turbid waters of northern Europe (Hall-Spencer, 1998). Some shelter from wave action is required to prevent physical damage, dispersal or burial although some degree of water movement is important to ensure that silt does not smother the maerl bed. King & Schramm (1982) report that ionic calcium concentration is the main factor affecting the growth of maerl in culture experiments rather than salinity *per se* (although this has not been shown in the field). Uptake of calcium carbonate occurs optimally at 30 psu.

Species composition

Species found especially in this biotope

- *Cruoria cruoriiformis*
- *Gelidiella calcicola*
- *Gelidium maggsiae*
- *Halymenia latifolia*
- *Scinaia turgida*
- *Tectura virginea*

Rare or scarce species associated with this biotope

-

Additional information

- Maerl biotopes are well recognised as having particularly rich and diverse communities. The MNCR survey recorded a maximum of 88 species but the BIOMAERL team (1999) recorded a maximum species richness of 490 at one Scottish site. From maerl biotopes in general, over 150 macroalgal species and 500 benthic faunal species have been recorded (Birkett *et al*., 1998a).
- Species richness can vary considerably in maerl beds, even within the same geographical area. There are also seasonal changes in species richness although this applies particularly to epiphytic algae.
- Maerl beds that are or have been dredged for scallops have modified species compositions, reduced species richness and abundance (Hall-Spencer & Moore, 2000).
- There are several species of algae that are apparently restricted to calcareous habitats and may be characteristically found in maerl beds (e.g. *Halymenia latifolia*, *Scinaia turgida*, *Gelidiella calcicola*, *Gelidium maggsiae* & *Cruoria cruoriiformis*)(Birkett *et al*., 1998(a)). Since the biotope occurs in deeper waters, then the number of algal species present will be reduced in comparison to other biotopes such as IGS.Phy.R.
- *Tectura virginea* can be considered to be associated with maerl although is most common on encrusting coralline algal species. There are several species of mollusc that are common in maerl beds (e.g. *Steromphala cineraria*, *Rissoa interrupta*, *Modiolarca tumida*, *Hinia incrassata*, *Tricolia pullus* & *Hiatella arctica*) but these are also common in other habitats and probably either reflect the nature of the substratum or are widespread in

lower shore and sublittoral environments
- Neither the MNCR surveys (JNCC, 1999) nor Birkett et al., 1998(a) specifically record any species recorded from maerl beds as being rare or scarce. However, this is likely to be caused by non-recognition or under-recording of rare or scarce species.

Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

Maerls beds are formed by calcareous red algae that grow as unattached nodules (occasionally crusts) forming dense but relatively open beds of coralline algal gravel. Beds of maerl form on a variety of sediments and occur on the open coast and in tide-swept channels of marine inlets (the latter are often stony). In fully marine conditions, the dominant maerl is typically *Phymatolithon calcareum* or *Lithothamnion coralloides* in England. Maerl beds support diverse communities of burrowing infauna, especially bivalves, and interstitial invertebrates; including suspension feeding polychaetes and echinoderms.

Long-lived maerl thalli and their dead remains build upon underlying sediments to produce deposits with a three-dimensional structure that is intermediate in character between hard and soft grounds (Jacquotte, 1962; Cabioch, 1969; Keegan, 1974; Hall-Spencer, 1998; Barbera *et al.*, 2003). Thicker maerl beds occur in areas of water movement (wave or current based) while sheltered beds tend to be thinner with more epiphytes. The associated community varies with underlying and surrounding sediment type, water movement, depth of bed and salinity (Tyler-Walters, 2013).

Maerl beds are highly variable and range from a thin layer of living maerl on top of a thick deposit of dead maerl to a layer of live maerl on silty or variable substrata to a deposit of completely dead maerl or maerl debris of variable thickness. Live maerl beds vary in the depth and proportion of 'live maerl' present (Birkett *et al.*, 1998a). In areas subject to wave action, they may form wave ripples or mega ripples e.g. in Galway Bay (Keegan, 1974) and in Stravanan Bay (Hall-Spencer & Atkinson, 1999). Maerl beds also show considerable variation in water depth, the depth of the bed, and biodiversity (see Birkett *et al.*, 1998a). They also vary in the dominant maerl forming species, with *Phymatolithon calcareum* dominating northern beds while both *Phymatolithon calcareum* and *Lithothamnion coralloides* occur in the south west of England and Ireland. *Lithothamnion glaciale* and *Lithothamnion erinaceum* also occur in northern waters and replaces *Lithothamnion coralloides* in Scotland (Birkett *et al.*, 1998a; Melbourne *et al.*, 2017). Birkett *et al.* (1998a) list other minor maerl forming species in the UK, however, their taxonomic status remains unresolved (Pena *et al.*, 2013).

Maerl has a complex three dimensional structure with interlocking thalli providing a wide range of niches for infaunal and epifaunal invertebrates (Birkett *et al.*, 1998a). Un-impacted maerl grounds are more structurally complex than those which have been affected by dredging (Kamenos *et al.*, 2003). The interstitial space provided by maerl beds allow water to flow through the bed, and oxygenated water to penetrate at depth so that other species can colonize the bed to greater depths than most other sediments. Maerl forming species are the pivotal, ecosystem engineer and biogenic reef species in maerl beds (including this biotope and its sub-biotopes). The integrity and survival of maerl beds are dependent on the thin surface layer of living maerl (Birkett *et al.*, 1998a; Hall-Spencer & Moore, 2000a&b). Therefore, maerl species are the single most important functional group with respect to the sensitivity of this habitat.

The other members of the community occur in other coarse substrata, although the maerl habitat supports a diverse community. This biotope (SMp.Mrl.Pcal.Nmix) is a deeper sub-biotope of SMp.Mrl.Pcal distinguished by a lower abundance of red seaweeds than SMp.Mrl.Pcal.R, and the presence of *Neopentadactyla mixta* (Connor *et al.*, 2004). Where appropriate, the sensitivity of other members of the community is mentioned. However, most pressures that would adversely affect the echinoderm component of the community would also adversely affect the maerl forming species. Hence, the sensitivity of the maerl forming species represents the sensitivity of the biotope for the majority of pressures but any differences in sensitivity are highlighted in the text. The biotopes assessed under this review are live maerl beds. The sensitivity of 'dead' maerl beds was reviewed by Tyler-Walters (2013).

Resilience and recovery rates of habitat

Maerl beds occur from the tropics to the poles (Foster, 2001; Hinojosa-Arango & Riosmena-Rodriquez, 2004). Both dead and live maerl contribute to subtidal biotopes. Maerl thalli grow very slowly (Adey & McKibbin, 1970; Potin *et al.*, 1990; Littler *et al.*, 1991; Hall-Spencer, 1994; Birkett *et al.*, 1998a Hall-Spencer & Moore, 2000a,b) so that maerl deposits may take hundreds of years to develop, especially in high latitudes (BIOMAERL, 1998). Species of maerl are extremely slow growing. Growth rates of European maerl species range between tenths of a millimetre to 1 millimetre per annum (Bosence & Wilson, 2003). The growth rates of the three most abundant species of maerl in Europe (*Phymatolithon calcareum*, *Lithothamnion glaciale* and *Lithothamnion coralloides*) ranged between 0.5 to 1.5 mm per tip per year under a wide range of field and laboratory conditions (Blake & Maggs, 2003).

Individual maerl thalli may live for >100 years (Foster, 2001). Maerl beds off Brittany are over 5500 years old (Grall & Hall-Spencer, 2003) and the maerl bed at St Mawes Bank, Falmouth was estimated to have a maximum age of 4000 years (Bosence & Wilson, 2003) while carbon dating suggested that some established beds may be 4000 to 6000 years old (Birkett et al. (1998a). A maerl bed in the Sound of Iona is up to 4000 years old (Hall-Spencer *et al.*, 2003). Maerl is highly sensitive to damage from any source due to this very slow rate of growth (Hall-Spencer, 1998). Maerl is also very slow to recruit as it rarely produces reproductive spores. Maerl is considered to be a non-renewable resource due to its very slow growth rate and its inability to sustain direct exploitation (Barbera *et al.*, 2003; Wilson *et al.*, 2004).

Maerl species in the UK propagate mainly by fragmentation (Wilson *et al.*, 2004). Recruitment of *Phymatolithon calcareum* is mainly through vegetative propagation. Although spore bearing individuals of *Phymatolithon calcareum* thalli have been found in the British Isles, the crustose individuals that would result from sexual reproduction have yet to be recorded in the British Isles (Irvine & Chmberlain, 1994). Recruitment may occur from distant populations that exhibit sexual reproduction and have crustose individuals (e.g. Brittany). Hall-Spencer (pers. comm.) observed that colonization of new locations by maerl can be mediated by a 'rafting' process where maerl thalli are bound up with other sessile organisms that are displaced and carried by currents (e.g. *Saccharina latissima* holdfasts after storms). Cabioch (1969) suggested that *Phymatolithon calcareum* may have phasic reproduction with peaks every six years. This may account for observed changes in the relative proportions of live *Lithothamnion coralloides* and *Phymatolithon calcareum* in maerl beds. Dominance cycles with periods of about thirty years have been recorded on some of the maerl beds of northern Brittany. Adey & McKibbin (1970) undertook growth studies of *Phymatolithon calcareum* in the field and under laboratory conditions. Field studies in the Ria de Vigo, show that growth occurs predominantly in the summer and suggests an annual growth of about 0.55 mm/year for branch tips of *Phymatolithon calcareum* (Adey & McKibbin, 1970). Newly settled maerl thalli have never been found in the British Isles (Irvine and Chamberlain, 1994). Hall-Spencer (2009) wrote a maerl recovery report for the Port of Falmouth development initiative. Hall-spencer (2009) suggested that a live maerl bed would take 1000's of years to return to the site of navigation channel after planned capital dredging in the Fal estuary. He also suggested that it would take 100's of years for live maerl to grow on a translocated bed, based on the growth and accumulation rates of maerl given by Blake *et al.* (2007) (Hall-Spencer, 2009).

The BIOMAERL project confirmed the high levels of biodiversity associated with maerl beds that had been recorded from numerous other projects (Barbera *et al*., 2003; BIOMAERL, 1998, 1999). The maerl thalli are frequently loose and mobile preventing colonization by many species. However, deep burrowing fauna (to 68 cm) are a notable feature of this biotope (Hall-Spencer & Atkinson, 1999). Maerl is known as a particularly diverse habitat with over 150 macroalgal species and 500 benthic faunal species recorded (Birkett *et al*., 1998a). To date, 349 macroalgal species have been recorded on maerl beds in the North East Atlantic (Peña *et al*., 2014). Around the UK there are several maerl specialists, e.g. *Cruoria cruoriiformis*, *Cladophora rhodolithocola* and *Gelidiella calcicola* (Peña *et al*., 2014).

Little is known about the population dynamics or life history of *Neopentadactyla mixta*. Their abundance in coarse sediments might suggest either good local recruitment and or sporadic but high-level recruitment. For example, Keeghan et al. (1985) recorded adult densities of ca 420 /m^2 together with juvenile densities of ca 15,000 /m^2 (at different locations) on the west coast of Ireland. Breeding is presumed to occur between April and September when the population is at the substratum surface. Neopentadactyla mixta is dioecious, with large eggs (ca 300 µm in size) (Smith & Keegan, 1985). As a result, Southward & Campbell (2006) suggested that larval development is lecithotrophic. As a group, echinoderms are highly fecund; producing long-lived planktonic larvae with high dispersal potential. However, recruitment in echinoderms is poorly understood, often sporadic and variable between locations and dependent on environmental conditions such as temperature, water quality, and food availability. For example, in the heart urchin, *Echinocardium cordatum* recruitment was recorded as sporadic, only occurring in 3 years out of a 10 year period (Buchanan, 1967). Millport populations of Echinus esculentus showed annual recruitment, whereas few recruits were found in Plymouth populations during Nichols studies between 1980 and 1981 (Nichols, 1984). Similarly, Bishop & Earll (1984) suggested that the population of *Echinus esculentus* at St Abbs had a high density and recruited regularly whereas the Skomer population was sparse, ageing and had probably not successfully recruited larvae in the previous six years.

In an analysis of re-colonization processes following cessation of maerl dredging in Ireland, De Grave & Whitaker (1999a) found clear differences in the benthos between dredged and fallow sites but they were unable to determine whether there had been a return to pre-dredging conditions as there were no pre-dredge data (Hall-Spencer, 2009). The diverse nature of communities within maerl beds results in a high level of ecological function. Hall-Spencer (2009) stated that within a translocated maerl bed, from which the long-lived species such as *Dosinia exoleta* and *Mya truncata* had been killed, could take 20 – 50 years to recover, assuming dead or live maerl remained. De Grave & Whitaker (1999) compared a dredged (extracted) maerl bed with one that been left 'fallow' for six months in Bantry Bay, Ireland. They noted that the dredged bed had significantly fewer molluscs than the fallow bed, but significantly more crustaceans and oligochaetes. Hall-Spencer & Moore (2000a,b) examined the recovery of maerl community after scallop dredging in previously un-dredged and dredged sites in Scotland. In comparison with control plots, mobile epibenthos returned within one month; fleshy macroalgae within six months; the abundance of *Cerianthus lloydii* was not significantly different after 14 months; other epifauna (e.g. *Lanice conchilega* and *Ascidiella aspersa*) returned after 1-2 years; but some of the larger sessile surface species (e.g. sponges, *Metridium senile*, *Modiolus modiolus* and *Limaria hians*) exhibited lower abundances on dredged plots after four years. Deep burrowing species (mud shrimp, large bivalves e.g. *Mya truncata* and the gravel sea cucumber *Neopentadactyla mixta*) were not impacted and their abundance changed little over the four year period. Hall-Spencer *et al*. (2003) noted that long-lived (>10 years) species (e.g. *Dosinia exoleta*) can occur at high abundances in maerl beds but that the sustainability of stocks is unknown at present. Hall-Spencer (2000a) noted that there was no significant difference between controls and experimentally dredged sites after 1-2 years at the sites previously subject to dredging. A review of historical data and the current situation at a maerl bed on the west coast of Scotland (Firth of Clyde) revealed extensive damage over the last 100 years (Hall-Spencer *et al.*, 2010). A living maerl bed with abundant large thalli and nests of the gaping file shell *Limaria hians* had become a bed of predominately dead maerl with few, small, live maerl thalli and no *Limaria hians* (Hall-Spencer & Moore, 2003).

Resilience assessment. The current evidence regarding the recovery of maerl suggests that if maerl is removed, fragmented or killed then it has almost no ability to recover. Therefore, resilience is assessed as **'Very low'** and probably far exceeds the minimum of 25 years for this category on the scale in cases where the resistance is Medium, Low or None. If the maerl is killed but dead maerl remains then the resident community may recover within 2-10 years (Tyler-Walters, 2013), but where the maerl is fragmented, species richness will probably decrease. However, Hall-spencer (2009) suggested that large long-lived species such as *Dosinia exoleta* and *Mya truncata* may take 20-50 years to recover ('Low' to 'Very low' resilience). Also, there is no direct evidence of larval development, recruitment and/or population dynamics in *Neopentadactyla mixta*. As many echinoderms show sporadic and variable recruitment, any population could take anywhere from one year to perhaps ten years to recruit and recolonize a habitat from which they were reduced in abundance and or removed. Therefore (based on expert judgement), a population of *Neopentadactyla mixta* may take 2-10 years ('Medium' resilience) to recover.

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

Hydrological Pressures

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

Maerl beds occur from the tropics to polar waters (Foster, 2001; Hinojosa-Arango & Riosmena-Rodriquez, 2004). Maerl beds in the North East Atlantic range from Norway to the African coast, although the component maerl species vary in temperature tolerance (Birkett *et al.*, 1998a; Wilson *et al.*, 2004). There are four species of biotope creating maerl beds in the UK. These species vary in their distribution within the UK, a phenomenon which is thought to be due to their temperature tolerances. Similarly, the associated communities within the maerl habitat differ and represent a diverse sample of species within the local area. *Lithothamnion coralloides* is absent from Scottish waters. This is due, either to winter temperatures dropping below the minimum survival temperature (between 2 and 5°C) or because the temperatures don't allow a suitable growing season (Adey & McKibbin, 1970; cited in Wilson *et al.*, 2004). *Lithothamnion corallioides* had a higher minimum survival temperature; dying at 2°C and surviving without growth at 5°C (Adey & McKibbin, 1970). In laboratory conditions, *Phymatolithon calcareum* survived down to 2°C, died at

0.4°C, and had a recorded optimum temperature for growth of 12-13°C (Adey & McKibbin 1970 cited in Wilson *et al*., 2004). *Phymatolithon calcareum* showed no significant difference on photosynthetic activity at 9°C (the control), 17°C or 25°C for 4-5 weeks but were judged to be dead after 90 minutes at 40°C (Wilson *et al*., 2004). Temperature appears to confine *Lithothamnion glaciale* to northern parts of the British Isles, possibly because reproductive conceptacles are only produced in winter when temperature fall below 9°C (Hall-Spencer, 1994 cited in Wilson *et al*., 2004). In addition, Adey (1970) found optimal growth rates of *Lithothamnion glaciale* between 10-12°C and that development of reproductive conceptacles in *Lithothamnion glaciale* requires winter temperatures of between 1-5°C (Adey, 1970). Blake & Maggs (2003) reported that the growth rate of *Phymatolithon calcareum* in the laboratory was only slightly affected by temperature treatments (10, 14 and 18°C), with an optimum at 10°C while the growth rate of *Lithothamnion corallioides* was significantly affected by temperature with an optimum at 14°C, at which temperature it grew faster than *Phymatolithon calcareum.* Martin *et al.* (2006) reported that primary productivity in *Lithothamnion corallioides* was twice as high in August as in January to February in the Bay of Brest. They found that primary productivity, calcification and respiration rates *of Lithothamnion corallioides* increased as temperature rose from 10 to 16°C (Martin *et al*., 2006).

The main maerl forming species have wide geographic ranges and their range indicates the limits of their temperature tolerance. *Phymatolithon calcareum* is a cold temperate species that ranges from Norway to the Mediterranean (Wilson *et al*., 2004; Martin *et al*., 2006) and tolerates high temperatures better than many subtidal temperate red algae (Wilson *et al*., 2004). *Lithothamnion corallioides* is a warm temperate species ranging from Ireland and the south of Britain to the Mediterranean, while *Lithothamnion glaciale* and *Lithothamnion erinaceum* are cold temperate species that replace *Lithothamnion corallioides* in northern waters of the UK and the North East Atlantic (Melbourne *et al*., 2017). Martin & Hall-Spencer (2017) noted that a 3°C increase in temperature above that normally experienced by tropical or warm-temperate coralline algae caused bleaching and adversely affected heath, rates of calcification and photosynthesis and survival. Current trends in climate change driven temperature increases have already caused shifts in seaweed biogeography, as the tropical regions widen polewards, to the detriment of the warm-temperate region, and the cold-temperate region shrinks (Martin & Hall-spencer, 2017).

Neopentadactyla mixta is not reported from shallow water, and it is only likely to be exposed to acute temperature changes due to thermal effluents. It is likely to withdraw into the sediment, away from the thermal plume, and be protected by the temperature of the interstitial waters. Only long-term acute change (greater than the benchmark) is likely to adversely affect the population. In winter months, it is probably too deep to be affected by significant decreases in temperature as it burrows to a depth of 30-60 cm into the substratum (Smith & Keegan, 1985). Smith & Keegan (1985) suggested that light or winter temperature might be one cue for seasonal torpor but noted that winter turbulence and increased turbidity, due to water movement, may also induce *Neopentadactyla mixta* to overwinter at depth.

Sensitivity assessment. An increase in temperature at the benchmark level is unlikely to affect *Phymatolithon calcareum* (Wilson *et al*., 2004) and given the slow growth rates exhibited by maerls, no effect is likely to be perceived within the duration of the benchmark. Therefore, the SS.SMp.Mrl.Pcal biotope and its sub-biotopes probably have a **'High'** resistance to an increase in temperature at the benchmark level. Resilience is, therefore, **'High'**, and sensitivity assessed as **'Not sensitive'** at the benchmark level.

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

Maerl beds occur from the tropics to polar waters (Foster, 2001; Hinojosa-Arango & Riosmena-Rodriquez, 2004). Maerl beds in the North East Atlantic range from Norway to the African coast, although the component maerl species vary in temperature tolerance (Birkett *et al.*, 1998a; Wilson *et al.*, 2004). There are four species of biotope creating maerl beds in the UK. These species vary in their distribution within the UK, a phenomenon which is thought to be due to their temperature tolerances. Similarly, the associated communities within the maerl habitat differ and represent a diverse sample of species within the local area. *Lithothamnion coralloides* is absent from Scottish waters. This is due, either to winter temperatures dropping below the minimum survival temperature (between 2 and 5°C) or because the temperatures don't allow a suitable growing season (Adey & McKibbin, 1970; cited in Wilson *et al.*, 2004). *Lithothamnion corallioides* had a higher minimum survival temperature; dying at 2°C and surviving without growth at 5°C (Adey & McKibbin, 1970). In laboratory conditions, *Phymatolithon calcareum* survived down to 2°C, died at 0.4°C, and had a recorded optimum temperature for growth of 12-13°C (Adey & McKibbin 1970 cited in Wilson *et al.*, 2004). *Phymatolithon calcareum* showed no significant difference on photosynthetic activity at 9°C (the control), 17°C or 25°C for 4-5 weeks but were judged to be dead after 90 minutes at 40°C (Wilson *et al.*, 2004). Temperature appears to confine *Lithothamnion glaciale* to northern parts of the British Isles, possibly because reproductive conceptacles are only produced in winter when temperature fall below 9°C (Hall-Spencer, 1994 cited in Wilson *et al.*, 2004). In addition, Adey (1970) found optimal growth rates of *Lithothamnion glaciale* between 10-12°C and that development of reproductive conceptacles in *Lithothamnion glaciale* requires winter temperatures of between 1-5°C (Adey, 1970). Blake & Maggs (2003) reported that the growth rate of *Phymatolithon calcareum* in the laboratory was only slightly affected by temperature treatments (10, 14 and 18°C), with an optimum at 10°C while the growth rate of *Lithothamnion corallioides* was significantly affected by temperature with an optimum at 14°C, at which temperature it grew faster than *Phymatolithon calcareum.* Martin *et al.* (2006) reported that primary productivity in *Lithothamnion corallioides* was twice as high in August as in January to February in the Bay of Brest. They found that primary productivity, calcification and respiration rates *of Lithothamnion corallioides* increased as temperature rose from 10 to 16°C (Martin *et al.*, 2006).

The main maerl forming species have wide geographic ranges and their range indicates the limits of their temperature tolerance. *Phymatolithon calcareum* is a cold temperate species that ranges from Norway to the Mediterranean (Wilson *et al.*, 2004; Martin *et al.*, 2006) and tolerates high temperatures better than many subtidal temperate red algae (Wilson *et al.*, 2004). *Lithothamnion corallioides* is a warm temperate species ranging from Ireland and the south of Britain to the Mediterranean, while *Lithothamnion glaciale* and *Lithothamnion erinaceum* are cold temperate species that replace *Lithothamnion corallioides* in northern waters of the UK and the North East Atlantic (Melbourne *et al.*, 2017).

Neopentadactyla mixta is not reported from shallow water, and it is only likely to be exposed to acute temperature changes due to thermal effluents. It is likely to withdraw into the sediment, away from the thermal plume, and be protected by the temperature of the interstitial waters. Only long-term acute change (greater than the benchmark) is likely to adversely affect the population. In winter months, it is probably too deep to be affected by significant decreases in temperature as it burrows to a depth of 30-60 cm into the substratum (Smith & Keegan, 1985). Smith & Keegan (1985) suggested that light or winter temperature might be one cue for seasonal torpor but noted that winter turbulence and increased turbidity, due to water movement, may also induce

Neopentadactyla mixta to overwinter at depth.

Sensitivity assessment. A decrease in temperature at the benchmark level is unlikely to affect *Phymatolithon calcareum* (Wilson *et al*., 2004). *Lithothamnion glaciale* has a more northern distribution in the UK and may benefit from a localised temperature decrease in the long-term, so that the relative abundance of *Lithothamnion glaciale* and *Phymatolithon calcareum* may change in the long-term. However, given the slow growth rates exhibited by maerls, no effect is likely to be perceived within the duration of the benchmark, but long-term climate change effects may be noticed in future. Therefore, the biotope SS.SMp.Mrl.Pcal and its sub-biotopes probably have a '**High'** resistance to a decrease in temperature at the benchmark level. Resilience is, therefore **'High'**, and sensitivity is assessed as **'Not sensitive'** at the benchmark level.

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

The majority of maerl beds occur in full salinity. Joubin, (1910 cited in Wilson *et al*., 2004) thought that maerl beds were only present in areas with lowered salinity. Bosence (1976) found that, although surface salinities could be low, the benthic water was mostly fully saline. The only maerl species currently thought to create beds in biotopes with salinities below fully marine is *Lithothamnion glaciale* (Connor *et al*., 2004), although the recently described *Lithothamnion erinaceum* might also. Wilson *et al.* (2004) noted that *Phymatolithon calcareum* and *Lithothamnion coralloides* were tolerant up to 40 psu while most subtidal seaweeds can survive up to 50 psu. The growth of *Phymatolithon calcareum* is impaired at salinities <24% (Adey & McKibbin, 1970; King & Schramm, 1982).

Echinoderms are restricted to the marine environment and one of the only stenohaline phyla in the animal kingdom (Russell, 2013). Although some species can acclimatise to hypo/hypersaline conditions, Russell (2013) did not mention *Neopentadactyla mixta* amongst them. Smith (1983) noted that hypo or hypersaline water caused the animal to withdraw its tentacles. *Neopentadactyla mixta* is not reported from shallow water, and it is only likely to be exposed due to hypo/hypersaline effluents. Roberts *et al.* (2010b) reported that hypersaline effluents from desalination plants disperse with tens of metres of the discharge point but reported widespread alteration in seagrass and soft sediment communities in poorly flushed environment. Echinoderms and ascidians were amongst the most sensitive to hypersaline brine in the studies examined (Roberts *et al*., 2010b). While hypersaline effluents are likely to sink to the seabed, and potentially penetrate into the sediment, the water movement characteristic of this biotope is likely to disperse the effluent and limit the effect to the immediate vicinity of any discharge point.

Sensitivity assessment. An increase in salinity above full is unlikely, except via the discharge of hypersaline effluents from desalination plants, none of which occur in the UK at present. An increase in salinity above 40 psu is likely to be detrimental to *Neopentadactyla mixta* and interrupt feeding but if prolonged for a year (see benchmark) may result in the death of individuals in the vicinity of the discharge. Others echinoderms are mobile are may avoid the impact. Maerl does not naturally occur within hypersaline areas, and although it may be able to tolerate a short-term increase in salinity, an increase to hypersaline conditions for a year would probably cause significant negative impacts. However, no evidence was found on which to base an assessment of maerl forming species. Therefore, a precautionary resistance assessment of **'Medium'** for SMp.Mrl.Pcal.Nmix, and therefore SMp.Mrl.Pcal is suggested to represent the potential loss in abundance of the characterizing *Neopentadactyla mixta* population, but with Low confidence.

Resilience is probably **Medium** so that sensitivity is assessed as **Medium**.

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

The majority of maerl beds occur in full salinity. Although Joubin, (1910, cited in Wilson *et al.*, 2004) thought that maerl beds were only present in areas with lowered salinity, Bosence (1976) found that although surface salinities could be low, the benthic water was mostly fully saline. The only maerl species currently thought to survive in biotopes with salinities below fully marine is *Lithothamnion glaciale* (Connor *et al.*, 2004). The growth of *Phymatolithon calcareum* is impaired at salinities <24 ppt (Adey & McKibbin, 1970; King & Schramm, 1982). However, Wilson *et al.* (2004) noted that *Phymatolithon calcareum* was more tolerant of low salinity than *Lithothamnion glaciale* in their experiments. Both species survived at 3 psu for five weeks but showed significantly reduced photosynthetic activity. However, at 15 psu, *Phymatolithon calcareum* recovered from the initial drop in photosynthetic activity, while *Lithothamnion glaciale* did not.

Echinoderms are restricted to the marine environment and one of the only stenohaline phyla in the animal kingdom (Russell, 2013). Although some species can acclimatise to hypo/hypersaline conditions, Russell (2013) did not mention *Neopentadactyla mixta* amongst them. Smith (1983) noted that hypo or hypersaline water caused the animal to withdraw its tentacles. A reduction is salinity to reduced (18 to <30 psu) for a year is likely to reduce feeding or drive *Neopentadactyla mixta* into the sediment where it cannot feed. Its seasonal torpor lasts from September to March each year, during which it loses condition significantly so it is unlikely to survive for a year without feeding.

Sensitivity assessment. SS.SMp.Mrl.Pcal, SS.SMp.Mrl.Pcal.R, SS.SMp.Mrl.Pcal.Nmix are characterized by *Phymatolithon calcareum* and are all only found in fully saline conditions. However, a reduced salinity for an extended period of time would stress *Phymatolithon calcareum* and could lead to mortality. No long-term salinity experiments have been carried out on *Phymatolithon calcareum*. However, reduced salinity may also result in a reduction in the abundance of echinoderms within the biotope, in particular, *Neopentadactyla mixta*. Therefore, precautionary resistance assessment of **'Medium'** has been given, the resilience is, therefore, '**Very low**' and sensitivity is assessed as **'Medium'.**

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

Maerl requires enough water movement to prevent smothering with silt (Hall-Spencer, 1998). Therefore, maerl beds are restricted to areas of strong tidal currents or wave oscillation (Birkett *et al.* 1998a). For example, Birkett *et al.* (1998a) quote a flow rate of 0.1 m/s across the maerl bed at spring tides in Greatman's Bay, Galway, while the UK biotope classification (Connor *et al.*, 2004) reports maerl beds occurring at sites with between moderately strong to very weak tidal streams. As Birkett *et al.* (1998a) note, local topography and wave generated oscillation probably result in stronger local currents at the position of the bed. Hall-Spencer *et al.* (2006) reported that maerls beds in the vicinity of fish farms became silted with particulates from fish farms even in areas of strong flow. Hall-Spencer et al. (2006) reported peak flow rates of 0.5 to 0.7 m/s at the sites studied, and one site experienced mean flows of 0.11 to 0.12 m/s and maxima of 0.21 to 0.47 m/s depending on depth above the seabed.

Neopentadactyla mixta occurs in maerl beds and coarse gravel sediments, both of which are associated with water flow either due to tidal streams (moderately strong to weak) or wave mediated water movement (exposed to moderately wave exposed) (Connor *et al.* 2004). For example, the beds of *Neopentadactyla mixta* in coarse sediments examined by Konnecker & Keegan (1973) were found in tidal currents of up to 2.5 knots (ca 1.28 m/s). Nevertheless, artificially increased current beyond the calm weather, spring tide, maximum of ca 1.5 m/s caused *Neopentadactyla mixta* to stop feeding a withdraw into its burrow, as did bombardment with dislodged sediment (Smith & Keegan 1985). Similarly, a heavy gale in August caused *Neopentadactyla mixta* to withdraw deep into the sediment for six to ten days (Smith & Keegan, 1985). The species regularly undertakes a ca six month long torpor period, during which it loses condition and lipid energy stores. Smith & Keegan (1985) suggested that the overwinter torpor may be a response to poor food availability coupled with increased turbulence experienced in winter at their study site.

Sensitivity assessment. An increase in water flow to strong or very strong may winnow away the surface of the bed and result in loss of the biotope. A decrease in water flow may result in increased siltation, smothering maerl, and causing the death of maerl and significant change in the associated community (see smothering/siltation below). The effect will depend on local hydrography and the wave climate. A change of 0.1-0.2 m/s may have a limited effect in areas of moderately strong flow but may be significant in areas of weak or negligible flow. Hall-spencer (pers. comm.) noted that any change in water flow is likely to affect maerl beds. Therefore, a resistance of **'Low'** is suggested but with 'Low' confidence. Hence, as resilience is likely to be **'Very low'**, sensitivity is assessed as **'High'.**

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

In the UK, maerl beds do not occur in the intertidal, as maerl is highly sensitive to desiccation (Wilson *et al.*, 2004). Also, it is very unlikely that a maerl bed would be exposed at low water as a result of human activities or natural events (Tyler-Walters, 2013). Therefore, this pressure is probably 'Not relevant'.

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

Maerl requires enough water movement to prevent smothering with silt (Hall-Spencer, 1998). Therefore, maerl beds develop in strong currents but are restricted to areas of low wave action. For example, in Mannin Bay dense maerl beds were restricted to less wave exposed parts of the bay (Birkett *et al.*, 1998a). In Galway Bay, Keegan (1974) noted the formation of ripples due to wave action and storms, where the ripples were flattened over time by tidal currents. However, he reported that the rippled area (average crest height 20 cm) had a poor faunal diversity with heavy macroalgal settlement on any firm substratum, including the tubes of *Chaetopterus* sp. However, the infauna was a typical '*Venus*' community, the majority of which was found at depths of more than 20 cm. Hall-Spencer & Atkinson (1999) noted that mega-ripples at their wave exposed site were relatively stable but underwent large shifts due to storms. However, the mixed sediments of the subsurface of the bed (>12 cm) were unaffected so that the burrows of the mud shrimp remained in place. Similarly, Birkett *et al.* (1998a) noted that in areas where storms affected the maerl at a depth of 10 m, only the coarse upper layer of maerl was moved while the underlying layers were stable. Following storms, infaunal species renewed burrow linings within a week.

However, the epiflora of maerl beds was severely disturbed by storms in Galway Bay with a marked drop in abundance in winter months. Deep beds are less likely to be affected by an increase in wave exposure.

Neopentadactyla mixta occurs in maerl beds and coarse gravel sediments, both of which are associated with water flow either due to tidal streams (moderately strong to weak) or wave mediated water movement (exposed to moderately exposed) (Connor *et al.*, 2004). Smith & Keegan (1985) noted that a heavy gale at their study site in August caused *Neopentadactyla mixta* to withdraw deep into the sediment for six to ten days. The species regularly undertakes a ca six month long torpor period, during which it loses condition and lipid energy stores. Smith & Keegan (1985) suggested that the overwinter torpor may be a response to poor food availability coupled with increased turbulence experienced in winter at their study site.

Sensitivity assessment. Maerl beds occur in a range of wave exposures and can survive in areas subject to wave action and storms. Therefore, an increase in wave exposure is probably detrimental to shallow maerl beds. Similarly, a decrease in wave action may be detrimental where wave action is the main contribution to water movement through the bed, due to the potential increase of siltation and reduction in infaunal diversity. However, a 3-5% change in significant wave height is unlikely to damage the maerl bed. Both resistance and resilience are assessed as **'High'**, and the biotope is assessed as **'Not sensitive'** to this pressure at the benchmark.

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	Not relevant (NR) 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	Low Q: High A: High C: Medium	Very Low Q: High A: Medium C: High	High Q: High A: Medium C: Medium

Deoxygenation at the benchmark level is likely to be detrimental to the maerl beds and their infaunal community but mitigated. Water flow experienced by these biotopes suggests that deoxygenating conditions may be short-lived. However, Hall-Spencer *et al.* (2006) examined maerl beds in the vicinity of fish farms in strongly tidal areas. They noted a build-up of waste organic materials up to 100 m from the farms examined and a 10-100 fold increase in scavenging fauna (e.g. crabs). In the vicinity of the farm cages, the biodiversity was reduced, particularly of small crustaceans, with significant increases in species tolerant of organic enrichment (e.g. *Capitella*). In addition, they reported less live maerl around all three of the fish farm sites studied than the 50-60% found at reference sites. Most of the maerl around fish farms in Orkney and South Uist was dead and clogged with black sulphurous anoxic silt. The Shetland farm had the most live maerl but this was formed into mega-ripples, indicating that the maerl had been transported to the site by rough weather (Hall-Spencer *et al.*, 2006). Eutrophication resulting from aquaculture is cited as one reason for the decline of maerl beds in the North East Atlantic (Hall-Spencer *et al.*, 2010). In the laboratory, Wilson *et al.* (2004) noted that burial in black muddy sand, smelling of hydrogen sulphide, was fatal to live maerl. Even thalli placed on the surface of the black muddy sand died within two weeks, together with thalli buried by 0.25 cm and 2 cm of the sediment (Wilson *et al.*, 2004). A study of a phytoplankton bloom that killed herring eggs on a maerl bed in the Firth of Clyde found that the resultant anoxia caused mass mortalities of the burrowing infauna (Napier, in press, cited by Hall-Spencer pers comm.).

Neopentadactyla mixta probably needs coarse sediments to survive, as the open matrix provided by coarse sediments or maerls at depth, together with water flow, ensures that the water is oxygenated at depth in the sediment. *Neopentadactyla mixta* reduces its metabolism and oxygen consumption from 0.11 ml O_2/ gm dry wt. to 0.03 ml O_2/ gm dry wt. during its overwinter torpor (Smith & Keegan, 1985). Therefore, it might be able to survive lower oxygen levels overwinter than in spring, summer and autumn. Vaquer-Sunyer & Duarte (2008) suggested a median sublethal oxygen concentration of 1.22 mg O_2/l (± 0.25) for a number of echinoderms reviewed in their study. Echinoderms were neither the most or the least sensitive of the taxonomic groups examined.

Sensitivity assessment. The available evidence suggests that maerl and its associated community is sensitive to the effects of deoxygenation and anoxia, even in areas of strong water movement. Therefore, resistance has been assessed as **'Low'**, resilience as **'Very low'**, and sensitivity is assessed as **'High'**.

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

This pressure relates to increased levels of nitrogen, phosphorus and silicon in the marine environment compared to background concentrations. The nutrient enrichment of a marine environment leads to organisms no longer being limited by the availability of certain nutrients. The consequent changes in ecosystem functions can lead to the progression of eutrophic symptoms (Bricker *et al.*, 2008), changes in species diversity and evenness (Johnston & Roberts, 2009) decreases in dissolved oxygen and uncharacteristic microalgal blooms (Bricker *et al.*, 1999, 2008).

Johnston & Roberts (2009) undertook a review and meta-analysis of the effect of contaminants on species richness and evenness in the marine environment. Of the 47 papers reviewed relating to nutrients as a contaminant, over 75% found that it had a negative impact on species diversity, <5% found increased diversity, and the remaining papers finding no detectable effect. None of the 47 papers considered the impact of nutrients on this biotope. Yet this finding is still relevant as the meta-analysis revealed that the effect of marine pollutants on species diversity was 'remarkably consistent' between habitats (Johnston & Roberts, 2009). It was found that any single pollutant reduced species richness by 30-50% within any of the marine habitats considered (Johnston & Roberts, 2009). Throughout their investigation, there were only a few examples where species richness was increased due to the anthropogenic introduction of a contaminant. These examples were almost entirely from the introduction of nutrients, either from aquaculture or sewage outfalls. However research into the impacts of nutrient enrichment from these sources on intertidal rocky shores often lead to shores lacking species diversity and the domination by algae with fast growth rates (Abou-Aisha *et al*., 1995, Archambault *et al*., 2001, Arévalo *et al*., 2007, Diez *et al*., 2003, Littler & Murray, 1975).

Grall & Glemarec (1997) noted that increased turbidity and eutrophication due to agricultural runoff in Brittany prevented the establishment of many algal species resulting in domination of ubiquitous species (e.g. *Ceramium* sp. and *Ulva* sp.), while localised eutrophication due to fish and mussel farming (aquaculture) in a sheltered area resulted in bacterial mats of *Beggiatoa*. Hall-Spencer *et al*. (2006) examined maerl beds in the vicinity of fish farms in strongly tidal areas. They noted a build-up of waste organic materials up to 100 m from the farms examined and a 10-100 fold increase in scavenging fauna (e.g. crabs). In the vicinity of the farm cages, the biodiversity was reduced, particularly of small crustaceans, with significant increases in species tolerant of organic enrichment (e.g. *Capitella*). In addition, they reported less live maerl around all three of the fish farm sites studied than the 50-60% found at reference sites. Most of the maerl around fish farms in Orkney and South Uist was dead and clogged with black sulphurous anoxic silt (Hall-Spencer *et al*., 2006). Eutrophication resulting from aquaculture is cited as one reason for the decline of some beds in the North East Atlantic (Hall-Spencer *et al*., 2010).

In Brittany, numerous maerl beds were affected by sewage outfalls and urban effluents, resulting in increases in contaminants, suspended solids, microbes and organic matter with resultant deoxygenation (Grall & Hall-Spencer, 2003). This resulted in increased siltation, higher abundance and biomass of opportunistic species, loss of sensitive species and reduction in biodiversity. Grall & Hall-Spencer (2003) note that two maerl beds directly under sewage outfalls were converted from dense deposits of live maerl in the 1950s to heterogeneous mud with maerl fragments buried under several centimetres of fine sediment with species poor communities. These maerl beds were effectively lost.

Sensitivity assessment. The effect of eutrophication on maerl beds is difficult to disentangle from the effects of organic enrichment, and sedimentation. It is likely that nutrient enrichment could adversely affect the infauna and epiflora communities but the direct effect on maerl is unclear. Nevertheless the biotope is **'Not sensitive'** at the pressure benchmark of compliance with good status as defined by the WFD.

Organic enrichment	None Q: High A: High C: High	Very Low Q: High A: Medium C: High	High Q: High A: Medium C: High

The organic enrichment of a marine environment at this pressure benchmark leads to organisms no longer being limited by the availability of organic carbon. The consequent changes in ecosystem functions can lead to the progression of eutrophic symptoms (Bricker *et al*., 2008), changes in species diversity and evenness (Johnston & Roberts, 2009) and decreases in dissolved oxygen and uncharacteristic microalgae blooms (Bricker *et al*., 1999, 2008). Grall & Hall-Spencer (2003) considered the impacts of eutrophication as a major threat to maerl beds.

Hall-Spencer *et al.* (2006) compared maerl beds under salmon farms with reference maerl beds. It was found that maerl beds underneath salmon farms had visible signs of organic enrichment (feed pellets, fish faeces and/or *Beggiatoa* mats), and significantly lower biodiversity. At the sites underneath the salmon nets, there were 10 – 100 times the number of scavenging species present compared to the reference sites. Grall & Glémarec (1997) noted similar decreases in maerl bed biodiversity due to anthropogenic eutrophication in the Bay of Brest. In Brittany, numerous maerl beds were affected by sewage outfalls and urban effluents, resulting in increases in contaminants, suspended solids, microbes and organic matter with resultant deoxygenation (Grall & Hall-Spencer, 2003). This resulted in increased siltation, higher abundance and biomass of opportunistic species, loss of sensitive species and reduction in biodiversity. Grall & Hall-Spencer (2003) note that two maerl beds directly under sewage outfalls were converted from dense deposits of live maerl in the 1950s to heterogeneous mud with maerl fragments buried under several centimetres of fine sediment with species poor communities. These maerl beds were effectively lost.

Grall & Hall-Spencer (2003) note that two maerl beds directly under sewage outfalls were converted from dense deposits of live maerl in the 1950s to heterogeneous mud with maerl fragments buried under several centimetres of fine sediment with species poor communities. These maerl beds were effectively lost.

Sensitivity assessment. Little empirical evidence was found to directly compare the benchmark organic enrichment of maerl biotopes. However, the evidence strongly suggests that organic enrichment and resultant increased in organic content, hydrogen sulphide levels and sedimentation may result in loss of maerl beds. Resistance has been assessed as **'None'** and resilience has been assessed as **'Very low'**. This gives an overall sensitivity score of **'High'**.

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

Maerl biotopes can contain a variety of sediment types including gravels, sand and mud. However, maerl biotopes never contain bedrock. Therefore, if rock or an artificial substrate was to replace the normal substratum within this biotope the physical conditions required for this biotope would be lost along with the biotope itself. Therefore, resistance is likely to be **'None'**, resilience **'Very Low'** (permanent change) and sensitivity is assessed as **'High'.**

Physical change (to another sediment type)	High Q: High A: High C: High	High Q: High A: High C: High	Not sensitive Q: High A: High C: High

The sediment associated with maerl biotopes varies from shell and maerl gravel through to sand and mud. The characterizing maerl species is also not attached to the substratum, and instead, lies over the top of it. Therefore, if the substratum were to change this wouldn't have a negative effect on the characterizing species. The other species within the associated community depend on different aspects of the sediment. Those species which are found infaunally may be negatively affected.

Sensitivity assessment. A change in this pressure at the benchmark will not affect the characterizing species yet may affect other species found infaunally within the biotope. The loss of an infaunal species will create a niche for another species to become established, therefore continuing the biological function and ensuring the character of the biotope remains. Resistance and resilience are assessed as **'High'**, resulting in a **'Not Sensitive'** assessment.

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

As maerl need to photosynthesise only the top layer of the deposit which has access to light will be alive. Live maerl also requires good water flow around it, a factor which is likely to be limited 30 cm into the bed. Maerls requirement for both light and water flow suggest that the majority if not all of the live maerl will be found in the top 30 cm of a maerl bed. This is also where many of the associated species will be found. Although long-lived elements of maerl bed fauna are known to burrow up to 72 cm into the substrate (Hall-Spencer & Atkinson, 1999). The extraction of the substratum to 30 cm within this biotope would remove the vast majority of the biological component of the biotope.

Hauton *et al.* (2003) undertook experimental suction (hydraulic dredging) in Stravanan Bay, Scotland, a site subject to scallop dredging and recorded as impacted dead maerl by Kamenos *et al.* (2003). The suction dredge removed epiflora (burrowing algae and macroalgae), maerl, slow moving epifauna (e.g. starfish, gastropods and clingfish) and mainly infauna. Large or fragile polychaetes (e.g. *Chaetopterus*) and *Cerianthus lloydii* were removed and damaged, while polychaetes with tough bodies or strong tubes survived. Large infaunal bivalves dominated the catch, including *Dosinia exoleta*, *Tapes rhomboides*, *Abra alba*, and *Ensis arcuatus* but, while *Mya truncata and Lutraria angustior* were not caught because of their depth, the catch did include torn siphons from these species; an injury they are unlikely to survive. The dredge resulted in a visible track that left numerous damaged megafauna, which in turn attracted scavengers. In addition, the dredging fragmented maerl and resulted in a large plume of fine sediment that settled over the surrounding area. However, recovery was not examined. Hall-Spencer *et al.* (2003) drew attention to the dangers of suction dredging for bivalves in maerl beds, especially as many of the larger infaunal bivalves are long-lived (e.g. *Dosinia exoleta*), suggesting that the population would take a long time to recover.

Neopentadactyla mixta lives in the sediment is a ‘U-shaped’ posture with its oral tentacles raised above the surface and its anus just below the surface of the sediment (Smith & Keegan, 1985). It is usually found in this position in its burrow 15-25 cm deep in the sediment (Könnecker & Keegan, 1973). However, in the winter months (ca September to March) its burrows into the sediment to a depth of 30-60 cm. It maintains this depth, even if the surface of the sediment is eroded or accreted (Smith & Keegan, 1985). In spring to autumn, extraction of the sediment to 30 cm is likely to remove the majority of the resident population but in winter, the majority of the population would survive as long as suitable substratum remained after extraction.

Sensitivity assessment. The resistance of the biotope to this pressure at the benchmark is **‘None’** and the resilience is assessed as **‘Very low’,** giving the biotope a **‘High’** sensitivity to this pressure.

Abrasion/disturbance of the surface of the substratum or seabed	None Q: High A: High C: High	Very Low Q: High A: Medium C: High	High Q: High A: Medium C: High

Physical disturbance can result from; channelization (capital dredging), suction dredging for bivalves, extraction of maerl, scallop dredging or demersal trawling. The effects of physical disturbance were summarised by Birkett *et al.* (1998a) and Hall-Spencer *et al.* (2010), and documented by Hall-Spencer and co-authors (Hall-Spencer, 1998; Hall-Spencer *et al.*, 2003; Hall-Spencer & Moore, 2000a,b; Hauton *et al.*, 2003; and others). For example, in experimental studies, Hall-Spencer & Moore (2000a, c) reported that the passage of a single scallop dredge through a maerl bed could bury and kill 70% of living maerl in its path. The passing dredge also re-suspended sand and silt that settled over a wide area (up to 15 m from the dredged track) and smothered the living maerl. The dredge left a 2.5 m track and damaged or removed most megafauna within the top 10 cm of maerl (Hall-Spencer & Moore, 2000a). For example; crabs, *Ensis* species, the bivalve *Laevicardium crassum*, and sea urchins. Deep burrowing species such as the tube anemone *Cerianthus lloydii* and the crustacean *Upogebia deltaura* were protected by depth, although torn tubes of *Cerianthus lloydii* were present in the scallop dredge tracks (Hall-Spencer & Moore, 2000a). *Neopentadactyla mixta* may also escape damage due to the depth of its burrow, especially during winter torpor. Hall-Spencer & Moore (2000a) reported that sessile epifauna or shallow infauna such as *Modiolus modiolus* or *Limaria hians*, sponges and the anemone *Metridium senile* where present, were significantly reduced in abundance in dredged areas for 4 years post-dredging. Other epifaunal species, such as hydroids (e.g. *Nemertesia* species) and red seaweeds are likely to be removed by a passing dredge. The tracks remained visible for up to 2.5 years. In pristine live beds, experimental scallop dredging reduced the population densities of epibenthic species for over 4 years. However, in previously dredged maerl beds, the benthic communities recovered in 1-2 years.

Abrasion may break up maerl thalli into smaller pieces, reduce structural heterogeneity and lower the diversity of species (Kamenos *et al.*, 2003). Hall-Spencer *et al.* (2003) noted that certain maerl beds in the Bay of Brest have been dredged for scallops and *Venus verrucosa* for over 40 years, yet remain productive with high levels of live maerl. Although they suggest that this is due to local restrictions that limit the activity to one scallop dredge per boat. Nevertheless, scallop dredging, demersal trawling and extraction have been reported to contribute to declines in the condition of maerl beds in the North East Atlantic and the UK (Barbera *et al.*, 2003, Hall-Spencer *et al.*, 2010, Hall-Spencer *et al.*, 2003). Irish maerl are considered to be in generally good condition but some are deteriorating due to commercial extraction, mariculture, demersal fishing and the localized effects of boat mooring chains (Vize, 2005).

Sensitivity assessment. Physical disturbance is likely to result is drastic changes in and loss of components of the community within the maerl bed. Fragmentation of the maerl will not kill the maerl directly but subsequent death is likely due to a reduction in water flow caused by compaction and sedimentation (Hall-spencer & Moore, 2000a; 2000c). Dredging can create plumes of sediment that can settle on top of the maerl, and overturn and bury maerl, causing it to be smothered, a pressure to which maerl is highly intolerant (see smothering and siltation (light) pressure). The evidence from Hall-Spencer & Moore (2000a; 2000c) alone strongly suggests that resistance to physical disturbance and abrasion is **'None'**. Therefore, resilience is probably **'Very low'**, resulting in a sensitivity assessment of **'High'**.

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

As maerl need to photosynthesise only the top layer of the deposit which has access to light will be alive. Live maerl also requires water flow around it. Maerl beds become less structurally complex if they have been affected by dredging (Kamenos *et al.*, 2003). A lack of structural complexity will restrict the niches for other species, reducing biodiversity and will also restrict water flow through the bed. Penetration and disturbance both have the capacity to break up maerl into smaller fragments. The evidence provided within the abrasion and disturbance pressure shows that maerl is intolerant of the abrasion of any form. Penetration of the maerl bed will exacerbate the negative effect by damaging more of the underlying maerl.

Sensitivity assessment. Based on the evidence provided within the 'abrasion and disturbance' assessment the resistance of the biotope to this pressure at the benchmark is considered **'None'** and the resilience is assessed as **'Very low'** so that sensitivity is assessed as **'High'**.

Changes in suspended solids (water clarity)	Medium Q: Medium A: Medium C: Medium	Very Low Q: High A: Medium C: High	Medium Q: Medium A: Medium C: Medium

Maerl's requirement for light restricts live maerl to depths shallower than 32 m in the relatively turbid waters of northern Europe (Hall-Spencer, 1998). An increase in suspended sediments in the water column will increase light attenuation and decrease the availability of light to the biotope. A decrease in light availability will alter the ability of the maerl to photosynthesise. This could be detrimental to maerl beds found towards their bottom depth limit (i.e. 32 m). An increase in suspended solids within this biotope is likely to also increase scour, as there are characteristically high levels of water movement through maerl beds. Scour is known to induce high mortality in early post-settlement algal stages and prevents the settlement of propagules owing to the accumulation of silt on the substratum (Vadas *et al.*, 1992). Increased particulates may provide additional food for filter feeders. However, an increase in suspended sediment may increase the fines within the bed, decreasing water flow and oxygenation through the bed, and hence the depth of the surface epifauna. It may result in an increase in burrowing species compared to filter feeding species. However, De Grave (1999) noted that sedimentary heterogeneity within maerl beds (including maerl debris with mud, sand or gravel) resulted in only minor changes in the community of amphipods and crustaceans present.

A decrease in suspended solids will increase light levels, which could benefit maerl. However, a decrease in the suspended matter is likely to reduce the quantity of food available for filter feeders. This could change the species present within the community.

Sensitivity assessment. Any factor which decreases the ability for the characterizing maerl species to photosynthesise will have a negative impact. Examples of the biotope found at the very bottom depth limit may experience high levels of mortality of the characterizing species. The resistance of this biotope is assessed as **'Medium'** and the resilience is **'Very low'.** Hence, the sensitivity is assessed as **'Medium'** to the pressure at the benchmark level.

Smothering and siltation rate changes (light)	None Q: High A: High C: High	Very Low Q: High A: Medium C: High	High Q: High A: Medium C: High

Smothering results from the rapid deposition of sediment or spoil, which may occur after dredging (suction or scallop), capital dredging (channelization), extreme runoff, spoil dumping etc. The effects depend on the nature of the smothering sediment. For example, live maerl was found to survive burial in coarse sediment (Wilson *et al*., 2004) but to die in fine sediments. *Phymatolithon calcareum* survived for 4 weeks under 4 and 8 cm of sand or gravel but died within 2 weeks under 2 cm of muddy sand. Wilson et al. (2004) suggested that the hydrogen sulphide content of the muddy sand was the most detrimental aspect of burial since even those maerl nodules on the surface of the muddy sand died within two weeks. They also suggested that the high death rate of maerl observed after burial due to scallop dredging (Hall-Spencer & Moore, 2000a,c) was probably due to physical and chemical effects of burial rather than a lack of light (Wilson *et al*., 2004).

In addition, detrimental effects on *Fucus* embryos were reported in fine sediments, presumably as fine sediment restricts water flow. Similarly, fine sediment is likely to prevent settlement of algal propagules, so that the effects are potentially greater during their settlement period. Kranz (1972; cited in Maurer *et al*. (1986) reported that shallow burying siphonate suspension feeders are typically able to escape smothering with 10-50 cm of their native sediment and relocate to their preferred depth by burrowing. Dow & Wallace (1961) noted that large mortalities in clam beds resulted from smothering by blankets of algae (Ulva sp.) or mussels (*Mytilus edulis*). In addition, clam beds have been lost due to smothering by 6 cm of sawdust, thin layers of eroded clay material, and shifting sand (moved by water flow or storms) in the intertidal.

Smothering by 5 cm of sediment (the benchmark) is likely to clog or reduce water flow through the surface of the bed, and directly smother small non-mobile members of the epifauna and epiflora, while larger species e.g. sea squirts, anemones, some sponges and macroalgae would protrude above the smothering sediment. Mobile small burrowing species (e.g. amphipods and polychaetes) would probably burrow to safety. However, non-motile epifauna (e.g. encrusting bryozoans and small hydroids) and small or prostrate algal will probably be reduced in abundance. Deep burrowing bivalves may experience some mortality due to loss of water flow through the bed, deoxygenating and lack of food depending on their depth. But large burrowing anemones and mud shrimp would probably just burrow through the smothering material. In Galicia, France, ongoing deterioration of maerl has been linked to mussel farming which increases sedimentation, reducing habitat complexity, lowering biodiversity, and killing maerl (Pena & Barbara, 2007a, b; cited in Hall-Spencer *et al*., 2010). Wilson *et al*. (2004) also point out that the toxic effect of fine organic sediment and associated hydrogen sulphide explain the detrimental effect on maerl beds of *Crepidula fornicata* in Brittany, sewage outfalls, and aquaculture (Grall & Hall-spencer, 2003).

Neopentadactyla mixta lives in the sediment is a 'U-shaped' posture with its oral tentacles raised above the surface and its anus just below the surface of the sediment (Smith & Keegan, 1985). It is usually found in this position in its burrow 15-25 cm deep in the sediment (Könnecker & Keegan, 1973). However, in the winter months (ca September to March) its burrows into the sediment to a depth of 30-60 cm. It maintains this depth, even if the surface of the sediment is eroded or accreted (Smith & Keegan, 1985).The tentacular crown can expand to 140 cm^2 (Smith & Keegan, 1985) and probably extends to ca 4-5 cm above the substratum (expert opinion). However, the deposit of 5 cm of fine sediment would probably discourage *Neopentadactyla mixta* from feeding and it would probably withdraw into its burrow.

Sensitivity assessment. Even though these biotopes occur in areas of tidal or wave mediated water flow, the fine smothering material would penetrate the open matrix of the maerl bed rather than sit on top of the bed. At the pressure benchmark this biotopes resistance is assessed as **'None'**, and the resilience is **'Very low'**, resulting in an overall sensitivity of **'High'.**

Smothering and siltation rate changes (heavy)	None Q: High A: High C: High	Very Low Q: High A: Medium C: High	High Q: High A: Medium C: High

A deposit at the pressure benchmark would cover all species with a thick layer of fine materials. The pressure is significantly higher than light smothering discussed above. Therefore, resistance is assessed as **'None',** and the resilience is **'Very low',** resulting in an overall sensitivity of **'High'.**

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

Not assessed.

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

No evidence.

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

Species characterizing this habitat do not have hearing perception but vibrations may cause an effect, however, no studies exist to support an assessment.

Introduction of light or shading	No evidence (NEv) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

Maerl forming species require light, which restricts them to depths shallower than 32 m in the relatively turbid waters of northern Europe (Hall-Spencer, 1998). This suggests that maerl is intolerant of long-term reductions in light availability. However, in the short-term maerl exhibits little stress after being kept in the dark for 4 weeks (Wilson *et al*., 2004). In addition, Fazakerley & Guiry (1998; cited in Blake & Maggs, 2003) noted that the growth rate of *Phymatolithon calcareum* approximately doubled at very shallow depth due to a 10% reduction in ambient light. This observation indicated that the growth of *Phymatolithon calcareum* was photo-inhibited at shallow depth, and explained its faster growth at 10 m than 5 m (Blake & Maggs, 2003).

Sensitivity assessment. Artificial light is unlikely to affect any but the shallowest biotopes. There is a possibility that shading by artificial structures could result in the loss of live maerl in deep examples of the biotope, but only where shading was long-term or permanent. There is insufficient information regarding to assess the effect of this pressure at the benchmark on this biotope. The sensitivity of this biotope is given as 'No evidence'.

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

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

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

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

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

Not relevant.

Biological Pressures

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

This pressure is not relevant to the characterizing species within this biotope.

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

No evidence of the effects of non-native species in the UK was found. However, Grall & Hall-spencer (2003) note that beds of invasive slipper limpet *Crepidula fornicata* grew across maerl beds in Brittany. As a result, the maerl thalli were killed, and the bed clogged with silt and pseudo-faeces so that the associated community was drastically changed. Bivalve fishing was also rendered impossible. Peña *et al.* (2014) identified eleven invasive algal species found on maerl beds in the North East Atlantic. The invasive species included *Sargassum muticum*, which causes habitat shading (Hall-Spencer pers. comm.).

Sensitivity assessment. Removal of the surface layer of *Crepidula fornicata* is possible but only with the removal of the surface layer of maerl itself, which would be extremely destructive on live beds. A resistance of **'None'** and a resilience of **'Very low'** has been given, resulting in an overall sensitivity assessment of **'High'**.

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

Coralline lethal orange disease found in the Pacific and could have devastating consequences for maerl beds in Europe. However, this disease was not known to be in Europe (Birkett *et al.*, 1998a). Many of the species that make up the biological community within this biotope will be susceptible to disease in the form of viruses or parasites. However, 'No evidence' of the effects of diseases and pathogens on maerl beds was found.

Removal of target species	None Q: High A: High C: Medium	Very Low Q: High A: Medium C: High	High Q: High A: Medium C: Medium

Maerl is mainly sold dried as a soil additive but is also used in animal feed, water filtration systems, pharmaceuticals, cosmetics and bone surgery. Maerl beds are dredged for scallops (found in high densities compared with other scallop habitats) where extraction efficiency is very high. This harvesting has serious detrimental effects on the diversity, species richness and abundance of maerl beds (Hall-Spencer & Moore, 2000c).

Within Europe, there is a history of the commercial collection and sale of maerl. Two notable sites from western Europe which from which Maerl has been collected are off the coast of Brittany, where 300,000 – 500,000 t / annum are dredged (Blunden, 1991), and off Falmouth Harbour in Cornwall where extraction is around 20,000 t / annum (Martin, 1994; Hall-Spencer, 1998).

Kamenos *et al.* (2003) reported that maerl grounds impacted by towed demersal fishing gears are structurally less heterogeneous than pristine, un-impacted maerl grounds, diminishing the biodiversity potential of these habitats. Birkett *et al.* (1998a) noted that although maerl beds subject to extraction in the Fal estuary exhibit a diverse flora and fauna, they were less species-rich than those in Galway Bay, although direct correlation with dredging was unclear. Grall & Glemarec (1997; cited in Birkett *et al.*, 1998a) reported few differences in biological composition between exploited and control beds in Brittany. Dyer & Worsfold (1998) showed differences in the communities present in exploited, previously exploited and unexploited areas of maerl bed in the Fal Estuary but it was unclear if the differences were due to extraction or the hydrography and depth of the maerl beds sampled. In Brittany, many of the maerl beds are subject to extraction (Grall & Hall-Spencer, 2003). For example, the clean maerl gravel of the Glenan maerl bank described in 1969, was degraded to muddy sand dominated by deposit feeders and omnivores within 30 years. Grall & Hall-Spencer (2003) noted that the bed would be completed removed within 50-100 years at the rates reported in their study. Hall-Spencer *et al.* (2010) note that maerl extraction was banned in the Fal in 2005.

The other species of commercial interest found within maerl beds are scallops, for which there are two methods of capture for these organisms. Firstly the use of a scallop dredge the effect of which is assessed under the abrasion and disturbance pressure. The second method of removal is diver collection. There is no evidence to suggest that there is a symbiotic relationship between maerl and scallops. Consequently, the removal of this species is unlikely to have a significant effect on the health of the biotope.

Sensitivity assessment. Maerl itself has historically been targeted for commercial collection. The removal of this characterizing species is highly destructive for this biotope and the resistance is assessed as **'None',** and the resilience is assessed as **'Very low'**, giving a sensitivity assessment of **'High'.** However, the practice of removing maerl for industry is now banned in places such as the Fal.

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

Direct, physical impacts from harvesting are assessed through the 'abrasion' and 'penetration of the seabed' pressures above. The extraction of maerl itself, scallop dredging for scallops and/or suction dredging for other commercially exploited shellfish would also damage other members of the community. For example, the red seaweed community is likely to be damaged or removed at the surface, and interstitial bivalves damaged within or removed from the bed. The loss of these species and other associated species would decrease species richness and negatively impact on the ecosystem function. In long-term studies of scallop dredging and subsequent recovery (Hall-Spencer & Moore 2000a, 2000b) deep burrowing species including *Neopentadactyla mixta* were not impacted and their abundance changed little over the four year period. However, experimental hydraulic blade dredging removed and damaged deep-burrowing species, including small numbers of *Neopentadactyla mixta* (Hauton *et al.* 2003) and affected the maerl bed to a depth of 9 cm. Hydraulic dredging in coarse sand and gravel may have similar effects.

Sensitivity assessment. Removal of a large percentage of the characterizing species would alter the character of the biotope. The resistance to removal is **'Low'** due to the easy accessibility of the biotopes location and the inability of these species to evade collection. The resilience is '**Very low'**, with recovery only being able to begin when the harvesting pressure is removed altogether. This gives an overall sensitivity score of **'High'**.

Bibliography

Abou-Aisha, K.M., Kobbia, I., El Abyad, M., Shabana, E.F. & Schanz, F., 1995. Impact of phosphorus loadings on macro-algal communities in the Red Sea coast of Egypt. *Water, Air, and Soil Pollution*, **83** (3-4), 285-297.

Adey, W.H. & McKibbin, D.L., 1970. Studies on the maerl species *Phymatolithon calcareum* (Pallas) nov. comb. and *Lithothamnion corallioides* (Crouan) in the Ria de Vigo. *Botanica Marina*, **13**, 100-106.

Anonymous, 1999q. Maerl beds. Habitat Action Plan. In *UK Biodiversity Group. Tranche 2 Action Plans. English Nature for the UK Biodiversity Group, Peterborough.*, *English Nature for the UK Biodiversity Group, Peterborough.*

Arévalo, R., Pinedo, S. & Ballesteros, E., 2007. Changes in the composition and structure of Mediterranean rocky-shore communities following a gradient of nutrient enrichment: descriptive study and test of proposed methods to assess water quality regarding macroalgae. *Marine Pollution Bulletin*, **55** (1), 104-113.

Archambault, P., Banwell, K. & Underwood, A., 2001. Temporal variation in the structure of intertidal assemblages following the removal of sewage. *Marine Ecology Progress Series*, **222**, 51-62.

Barbera C., Bordehore C., Borg J.A., Glemarec M., Grall J., Hall-Spencer J.M., De la Huz C., Lanfranco E., Lastra M., Moore P.G., Mora J., Pita M.E., Ramos-Espla A.A., Rizzo M., Sanchez-Mata A., Seva A., Schembri P.J. and Valle C. 2003. Conservation and managment of northeast Atlantic and Mediterranean maerl beds. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **13**, S65-S76.

BIOMAERL team, 1998. Maerl grounds: Habitats of high biodiversity in European seas. *In Proceedings of the Third European Marine Science and Technology Conference, Lisbon 23-27 May 1998, Project Synopses*, pp. 170-178.

BIOMAERL team, 1999. Biomaerl: maerl biodiversity; functional structure and anthropogenic impacts. *EC Contract* no. MAS3-CT95-0020, 973 pp.

Birkett, D.A., Maggs, C.A. & Dring, M.J., 1998a. Maerl. an overview of dynamic and sensitivity characteristics for conservation management of marine SACs. *Natura 2000 report prepared by Scottish Association of Marine Science (SAMS) for the UK Marine SACs Project.*, Scottish Association for Marine Science. (UK Marine SACs Project, vol V.). Available from: http://www.ukmarinesac.org.uk/publications.htm

Blake, C., Maggs, C. & Reimer, P., 2007. Use of radiocarbon dating to interpret past environments of maerl beds. *Ciencias Marinas*, **33** (4), 385-397.

Blunden, G. & Wildgoose, P.B., 1977. The effects of aqueous seaweed extract and kinetin on potato yields. *Journal of the Science of Food and Agriculture*, **28** (2), 121-125.

Blunden G., 1991. Agricultural uses of seaweeds and seaweed extracts. In Guiry M. D. & Blunden, G. *Seaweed Resources in Europe: Uses and Potential.* John Wiley & Sons, Chichester, pp. 65-81

Bosence D. and Wilson J. 2003. Maerl growth, carbonate production rates and accumulation rates in the northeast Atlantic. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **13**, S21-S31.

Bosence, D.W., 1976. Ecological studies on two unattached coralline algae from western Ireland. *Palaeontology*, **19** (2), 365-395.

Bosence, D.W.J., 1979. Live and dead faunas from coralline algal gravels, Co. Galway. *Palaeontology*, **22**, 449-478.

Bricker, S.B., Clement, C.G., Pirhalla, D.E., Orlando, S.P. & Farrow, D.R., 1999. National estuarine eutrophication assessment: effects of nutrient enrichment in the nation's estuaries. NOAA, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Science, Silver Spring, MD, 71 pp.

Bricker, S.B., Longstaff, B., Dennison, W., Jones, A., Boicourt, K., Wicks, C. & Woerner, J., 2008. Effects of nutrient enrichment in the nation's estuaries: a decade of change. *Harmful Algae*, **8** (1), 21-32.

Cabioch, J., 1969. Les fonds de maerl de la baie de Morlaix et leur peuplement vegetale. *Cahiers de Biologie Marine*, **10**, 139-161.

Camplin, M., 2007. Monitoring the impact of civil engineering works on maerl in Milford Haven. Abstracts, Countryside Council for Wales Marine and Freshwater Workshop 2007.

Canals, M. & Ballesteros, E., 1997. Production of carbonate particles by phytobenthic communities on the Mallorca-Menorca shelf, northwestern Mediterranean Sea. *Deep Sea Research Part II: Topical Studies in Oceanography*, **44** (3), 611-629.

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/

De Grave S. and Whitaker A. 1999. Benthic community re-adjustment following dredging of a muddy-maerl matrix. *Marine Pollution Bulletin*, **38**(2), 102-108.

De Grave S., 1999. The influence of sedimentary heterogeneity on within maerl bed differences in infaunal crustacean community *Estuarine, Coastal and Shelf Science*, **49**(1), 153-163.

Dıez, I., Santolaria, A. & Gorostiaga, J., 2003. The relationship of environmental factors to the structure and distribution of subtidal seaweed vegetation of the western Basque coast (N Spain). *Estuarine, Coastal and Shelf Science*, **56** (5), 1041-1054.

Donnan, D.W. & Davies, J., 1996. *Assessing the Natural Heritage Importance of Scotland's Maerl Resource.* In *Partnership in Coastal Zone Management*, (ed. J. Taussik & J. Mitchel), 533-540.

Dow, R.L. & Wallace, D.E., 1961. The soft-shell clam industry of Maine. *U.S. Fish and Wildlife Service, Department of the Interior, Circular* no. 110., U.S.A: Washington D.C.

Dyer M. and Worsfold T. 1998. Comparative maerl surveys in Falmouth Bay. Report to English Nature from Unicomarine Ltd., Letchworth: Unicomarine Ltd

Foster, M.S., 2001. Rhodoliths: between rocks and soft places. *Journal of Phycology*, **37** (5), 659-667.

Gili, J-M. & Hughes, R.G., 1995. The ecology of marine benthic hydroids. *Oceanography and Marine Biology: an Annual Review*, **33**, 351-426.

Grall J. & Hall-Spencer J.M. 2003. Problems facing maerl conservation in Brittany. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **13**, S55-S64.

Grall, J. & Glemarec, J., 1997. Biodiversity des fonds de maerl en Bretagne: approche fonctionelle et impacts anthropiques. *Vie et Milieu*, **47**, 339-349.

Grall J., Glémarec, M., 1997. Using biotic indices to estimate macrobenthic community perturbations in the Bay of Brest. *Estuarine, Coastal and Shelf Science*, **44**, 43–53

Grave De, S. & Whitaker, A., 1999a. Benthic community re-adjustment following dredging of a muddy-maerl matrix. *Marine Pollution Bulletin*, **38**, 102-8

Grave De, S., 1999. The influence of sediment heterogeneity on within maerl bed differences in infaunal crustacean community. *Estuarine, Coastal and Shelf Science*, **49**, 153-163.

Grave De, S., & Whitaker, A., 1999b. A census of maerl beds in Irish waters. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **9**, 303-311.

Hall-Spencer J., Kelly J. and Maggs C. 2010. Background document for Maerl Beds. OSPAR Commission, The Department of the Environment, Heritage and Local Government (DEHLG), Ireland

Hall-Spencer J., White N., Gillespie E., Gillham K. and Foggo A. 2006. Impact of fish farms on maerl beds in strongly tidal areas. *Marine Ecology Progress Series*, **326**, 1-9

Hall-Spencer, J., 2005. Ban on maerl extraction. *Marine Pollution Bulletin*, **50**.

Hall-Spencer, J. & Bamber, R., 2007. Effects of salmon farming on benthic Crustacea. *Ciencias Marinas*, **33** (4), 353-366.

Hall-Spencer, J.M., 1994. *Biological studies on nongeniculate Corallinaceae.* Ph.D. thesis, University of London.

Hall-Spencer, J.M. & Atkinson, R.J.A., 1999. *Upogebia deltaura* (Crustacea: Thalassinidea) in Clyde Sea maerl beds, Scotland. *Journal of the Marine Biological Association of the United Kingdom*, **79**, 871-880.

Hall-Spencer, J.M. & Moore, P.G., 2000a. Impact of scallop dredging on maerl grounds. In *Effects of fishing on non-target species and habitats.* (ed. M.J. Kaiser & S.J., de Groot) 105-117. Oxford: Blackwell Science.

Hall-Spencer, J.M. & Moore, P.G., 2000b. *Limaria hians* (Mollusca: Limacea): A neglected reef-forming keystone species. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **10**, 267-278.

Hall-Spencer, J.M. & Moore, P.G., 2000c. Scallop dredging has profound, long-term impacts on maerl habitats. *ICES Journal of Marine Science*, **57**, 1407-1415.

Hall-Spencer, J.M., 1995. *Lithothamnion corallioides* (P. & H. Crouan) P. & H. Crouan may not extend into Scottish waters. http://www.botany.uwc.ac.za/clines/clnews/cnews20.htm, 2000-10-15

Hall-Spencer, J.M., 1998. Conservation issues relating to maerl beds as habitats for molluscs. *Journal of Conchology Special Publication*, **2**, 271-286.

Hall-Spencer, J.M., Grall, J., Moore, P.G. & Atkinson, R.J.A., 2003. Bivalve fishing and maerl-bed conservation in France and the UK - retrospect and prospect. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **13**, Suppl. 1 S33-S41.

Hall-Spencer, J.M., Tasker, M., Soffker, M., Christiansen, S., Rogers, S.I., Campbell, M. & Hoydal, K., 2009. Design of Marine Protected Areas on high seas and territorial waters of Rockall Bank. *Marine Ecology Progress Series*, **397**, 305-308.

Hauton, C., Hall-Spencer, J.M. & Moore, P.G., 2003. An experimental study of the ecological impacts of hydraulic bivalve dredging on maerl. *ICES Journal of Marine Science*, **60**, 381-392.

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.

Hinojosa-Arango, G. & Riosmena-Rodríguez, R., 2004. Influence of Rhodolith-Forming Species and Growth-Form on Associated Fauna of Rhodolith Beds in the Central-West Gulf of California, México. *Marine Ecology*, **25** (2), 109-127.

Hughes, R.G., 1977. Aspects of the biology and life-history of *Nemertesia antennina* (L.) (Hydrozoa: Plumulariidae). *Journal of the Marine Biological Association of the United Kingdom*, **57**, 641-657.

Irvine, L. M. & Chamberlain, Y. M., 1994. *Seaweeds of the British Isles*, vol. 1. *Rhodophyta*, Part 2B *Corallinales, Hildenbrandiales.* London: Her Majesty's Stationery Office.

Jacquotte, R., 1962. Etude des fonds de maërl de Méditerranée. *Recueil des Travaux de la Stations Marine d'Endoume*, **26**, 141-235.

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

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

JNCC (Joint Nature Conservation Committee), 1999. *Marine Environment Resource Mapping And Information Database (MERMAID): Marine Nature Conservation Review Survey Database.* [on-line] http://www.jncc.gov.uk/mermaid

Johnston, E.L. & Roberts, D.A., 2009. Contaminants reduce the richness and evenness of marine communities: a review and meta-analysis. *Environmental Pollution*, **157** (6), 1745-1752.

Jones, L.A., Hiscock, K. & Connor, D.W., 2000. Marine habitat reviews. A summary of ecological requirements and sensitivity characteristics for the conservation and management of marine SACs. *Joint Nature Conservation Committee, Peterborough. (UK Marine SACs Project report.)*. Available from: http://www.ukmarinesac.org.uk/pdfs/marine-habitats-review.pdf

Joubin, L., 1910. Nemertea, National Antarctic Expedition, 1901-1904, 5: 1-15. SÁIZ-SALINAS, J.I.; RAMOS, A.; GARCÍA, F.J.; TRONCOSO, J.S.; SAN

Kamenos N.A., Moore P.G. & Hall-Spencer J.M. 2003. Substratum heterogeneity of dredged vs un-dredged maerl grounds. *Journal of the Marine Biological Association of the UK*, **83**(02), 411-413.

Keegan, B.F., 1974. The macro fauna of maerl substrates on the west coast of Ireland. *Cahiers de Biologie Marine*, **XV**, 513-530.

King, R.J., & Schramm, W., 1976. Photosynthetic rates of benthic marine algae in relation to light intensity and seasonal variations. *Marine Biology*, **37**, 215-212.

King, R.J., & Schramm, W., 1982. Calcification in the maerl coralline alga *Phymatolithon calcareum* : Effects of salinity and temperature. *Marine Biology*, **70**, 197-204.

Konnecker, G. & Keegan, B.F., 1973. In situ behavioural studies on echinoderm aggregations. *Helgolander Wissenschaftliche Meeresuntersuchungen*, **24**, 157-162.

Kranz, P.M., 1974. The anastrophic burial of bivalves and its paleoecological significance. *The Journal of Geology*, 237-265.

Littler, M. & Murray, S., 1975. Impact of sewage on the distribution, abundance and community structure of rocky intertidal macro-organisms. *Marine Biology*, **30** (4), 277-291.

Littler, M.M., Littler, D.S. & Hanisak, M.D., 1991. Deep-water rhodolith distribution, productivity, and growth history at sites of formation and subsequent degradation. *Journal of Experimental Marine Biology and Ecology*, **150** (2), 163-182.

Martin, C.J., 1994. *A marine survey and environmental assessment of the proposed dredging of dead maerl within Falmouth Bay by the Cornish Calcified Seaweed Company Ltd*. Contractor: Environemtal Tracing Systems Ltd. pp 59.

Martin, S., Clavier, J., Chauvaud, L. & Thouzeau, G., 2007b. Community metabolism in temperate maerl beds. II. Nutrient fluxes. *Marine Ecology progress Series*, **335**, 31-41.

Maurer, D., Keck, R.T., Tinsman, J.C., Leatham, W.A., Wethe, C., Lord, C. & Church, T.M., 1986. Vertical migration and mortality of marine benthos in dredged material: a synthesis. *Internationale Revue der Gesamten Hydrobiologie*, **71**, 49-63.

OSPAR, 2008. OSPAR List of Threatened and/or Declining Species and Habitats (Reference Number: 2008-6), OSPAR Convention For The Protection Of The Marine Environment Of The North-East Atlantic

Peña, V. & Barbera, I., 2007b. Los fondos de maërl en Galicia. *Bulletin of the Spanish Society of Phycology*, *ALGAS*, **37**: 11-18. [cited 15/02/16]. Available from .

Peña, V., Bárbara, I., Grall, J., Maggs, C.A. & Hall-Spencer, J.M., 2014. The diversity of seaweeds on maerl in the NE Atlantic. *Marine Biodiversity*, **44** (4), 533-551. DOI: 10.1007/s12526-014-0214-7

Peña. V. & Bárbara. I., 2007a. Maërl community in the northwestern Iberian Peninsula: a review of floristic studies and long-term changes. Aquatic Conservation: *Marine and Freshwater Ecosystems*, **17**, 1-28.

Potin, P., Floc'h, J.Y., Augris, C., & Cabioch, J., 1990. Annual growth rate of the calcareous red alga *Lithothamnion corallioides* (Corallinales, Rhodophyta) in the bay of Brest, France. *Hydrobiologia*, **204/205**, 263-277

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

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

Russell, M., 2013. Echinoderm Responses to Variation in Salinity. *Advances in Marine Biology*, **66**, 171-212.

Smith T.B. & Keegan, B.F., 1985. Seasonal torpor in *Neopentadactyla mixta* (Ostergren) (Holothuroidea: Dendrochirotida). In *Echinodermata. Proceedings of the Fifth International Echinoderm Conference. Galway, 24-29 September 1984.* (B.F. Keegan & B.D.S O'Connor, pp. 459-464. Rotterdam: A.A. Balkema.

Smith, T.B., 1983. Tentacular ultrastructure and feeding behaviour of *Neopentadactyla mixta* (Holothuroidea: Dendrochirota). *Journal of the Marine Biological Association of the United Kingdom*, **63**, 301-311.

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

Vadas, R.L., Johnson, S. & Norton, T.A., 1992. Recruitment and mortality of early post-settlement stages of benthic algae. *British Phycological Journal*, **27**, 331-351.

Vaquer-Sunyer, R. & Duarte, C.M., 2008. Thresholds of hypoxia for marine biodiversity. *Proceedings of the National Academy of Sciences*, **105** (40), 15452-15457.

Vize, S.J., 2005. *The distribution and biodiversity of maerl beds in Northern Ireland*. Ph.D. thesis, Queen's University of Belfast.

Wilson S., Blake C., Berges J.A. and Maggs C.A. 2004. Environmental tolerances of free-living coralline algae (maerl): implications for European marine conservation. *Biological Conservation*, **120**(2), 279-289.