Maerl (*Phymatolithon calcareum*)

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

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The Marine Life Information Network, Marine Biological Association of the United Kingdom.

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Phymatolithon calcareum **forming a maerl bed. Loch Carron, West Scotland.**
Photographer: Keith Hiscock
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See online review for distribution map

Distribution data supplied by the Ocean Biogeographic Information System (OBIS). To interrogate UK data visit the NBN Atlas.

Researched by	Frances Perry & Angus Jackson	**Refereed by**	Dr Christine Maggs
Authority	(Pallas) W.H.Adey & D.L.McKibbin, 1970		
Other common names	-	**Synonyms**	-

Summary

Description

A fragile, coralline alga often confused with *Lithothamnion corallioides*. Its form is very variable but commonly resembles stag's horns of irregular diameter. Older specimens become somewhat erect with nodular branches and are reminiscent of red 'coral'. Unattached plants may reach about 7 cm in diameter with branches up to 6 mm in diameter and mauvish brown in colour. The surface can be smooth or flaky.

Recorded distribution in Britain and Ireland

Recorded around the Shetland Isles and Orkney, along the east coast of Scotland, and the south coast of England with isolated records at Bideford Bay, Pembrokeshire and Caernarfon Bay. Abundant around the west coasts of Ireland and Scotland.

Global distribution

Recorded from Norway down to northern Spain, including the western Baltic and the Mediterranean.

Habitat

Typically found in less than 20 m depth on sand, mud or gravel substrata in areas that are protected from strong wave action but have moderate to high water flow. The crustose form is very rare in the British Isles. Usually found as unattached plants forming beds of coralline algal gravel (maerl) in the sublittoral and occasionally lower littoral. Typically found together with *Lithothamnion corallioides* in the southern British Isles or *Lithothamnion glaciale* in the northern British Isles.

Depth range

1-30

Identifying features

- Thallus comprising either attached crustose plant or unattached branching systems.
- Unattached plants varying from single branches to subglobular or flattened branching systems, sparsely to densely branched.
- Branches sometimes confluent, slender to robust, terete to flattened, to 6 mm diameter with apices rounded to flattened.
- Surface mainly rather smooth or with white flaky areas.

Additional information

Maerl is a generic name for certain coralline algae that grow unattached on the sea bed. No crustose plants of *Phymatolithon calcareum* have been recorded from the British Isles.

Listed by

UKBAP SPI[e] SPI[w] FOCI

Further information sources

Search on:

NBN WoRMS

Biology review

Taxonomy

Phylum	Rhodophyta	Red seaweeds
Class	Florideophyceae	
Order	Corallinales	
Family	Hapalidiaceae	
Genus	Phymatolithon	
Authority	(Pallas) W.H.Adey & D.L.McKibbin, 1970	
Recent Synonyms	-	

Biology

Typical abundance	High density
Male size range	Not relevant
Male size at maturity	Not relevant
Female size range	3-10 cm
Female size at maturity	3-10 cm
Growth form	Algal gravel
Growth rate	1-2 mm/year
Body flexibility	None (less than 10 degrees)
Mobility	Sessile
Characteristic feeding method	Autotroph
Diet/food source	Autotroph
Typically feeds on	Not relevant
Sociability	Not relevant
Environmental position	Epilithic
Dependency	Independent.
Supports	None
Is the species harmful?	No

Biology information

Phymatolithon calcareum grows as maerl nodules or medallions forming dense but relatively open beds of algal gravel. Beds of these maerl form in coarse clean sediments of gravels and clean sands, and occur either on the open coast or in tide-swept channels of marine inlets (the latter are often stony). In fully marine conditions, *Phymatolithon calcareum* is one of two dominant maerl species in England (Tyler-Walters, 2013).

Phymatolithon calcareum does have a crustose permanently attached form but this has not been recorded in the British Isles. It is typically found as an unattached plant. Coralline algal thalli that form maerl beds have been found in densities of up to 22,000 thalli per square metre. The proportion of live to dead nodules varies considerably. As far as is known maerl continues to grow throughout its life but fragmentation limits the size of the nodules. There are no sexes and individual plants may reach up to 5 cm across.

Growth rates of European maerl species range between tenths of a millimetre to one millimetre per annum (Bosence & Wilson, 2003). Recent studies suggested that 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 nodules may live for >100 years (Foster, 2001).

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 the 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 substratum, 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). *Lithothamnion coralloides* occurs in the south-west of England and Ireland mixed in with *Phymatolithon calcareum*.

Maerl exhibits a complex three-dimensional structure with interlocking lattices providing a wide range of niches for infaunal and epifaunal invertebrates (Birkett *et al.*, 1998a). Pristine, un-impacted maerl grounds are more structurally complex than those which have been affected by dredging (Kamenos *et al.*, 2003). The interstitial space and open structure of provided by maerl beds allows 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 other coarse substrata. Maerls are the pivotal, ecosystem engineer and biogenic reef species. 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).

Maerl beds are highly species rich with 150 macroalgal species and over five hundred faunal species (of which 120 are molluscs) recorded as living on or in maerl beds (Birkett *et al.*, 1998a); see the maerl biotope SS.SMp.Mrl for further information. As far as is known, the maerl does not host any commensal or parasitic species. However, a few algae are almost entirely restricted to maerl communities e.g. the red algae *Gelidiella calcicola*, *Gelidium maggsiae* and the crustose *Cruoria cruoriiformis* (Birkett *et al.*, 1998a).

Habitat preferences

Physiographic preferences	Estuary, Open coast, Ria / Voe, Sea loch / Sea lough, Strait / sound
Biological zone preferences	Lower infralittoral, Sublittoral fringe, Upper infralittoral
Substratum / habitat preferences	Coarse clean sand, Fine clean sand, Gravel / shingle, Maerl, Mixed, Mud, Muddy gravel, Muddy sand, Pebbles, Sandy mud

Tidal strength preferences	Moderately Strong 1 to 3 knots (0.5-1.5 m/sec.), Strong 3 to 6 knots (1.5-3 m/sec.)
Wave exposure preferences	Exposed, Moderately exposed, Sheltered
Salinity preferences	Full (30-40 psu)
Depth range	1-30
Other preferences	No text entered
Migration Pattern	Non-migratory / resident

Habitat Information

Most frequent at depths between 1-10 m. May be found deeper in clear waters, e.g. found at depths of up to 30 m in outer Galway Bay.
Phymatolithon calcareum has been reported recently from 13-20m off Swange to Old Harry and off Bembridge, the Isle of Wight (Collins pers. comm.; Collins *et al.*, 1990).

Life history

Adult characteristics

Reproductive type	Vegetative
Reproductive frequency	Data deficient
Fecundity (number of eggs)	No information
Generation time	Insufficient information
Age at maturity	Not relevant
Season	Insufficient information
Life span	20-100 years

Larval characteristics

Larval/propagule type	Not relevant
Larval/juvenile development	Not relevant
Duration of larval stage	No information
Larval dispersal potential	<10 m
Larval settlement period	Insufficient information

Life history information

Recruitment in France is believed to be primarily through fragmentation from crustose forms. No crustose forms are known from the British Isles so propagation must be virtually entirely vegetative. Maerl beds in the Sound of Iona are recorded as containing dead nodules up to 4,000 years old (Farrow, 1983, cited in Maggs *et al.*, 1998). Insufficient information is available on reproductive frequency, fecundity and developmental mechanism. In the British Isles there are a few records of fertile plants but no records of the crustose forms that this reproduction would produce. Plants may be fertile and develop conceptacles throughout the year. Plants from Brittany are mostly fertile in winter. 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 corallioides* and *Phymatolithon calcareum* nodules in maerl beds. Dominance cycles with periods of about thirty years have been recorded on some of the maerl beds of northern Brittany. Adey & McKibbon (1970) undertook growth studies of *Phymatolithon calcareum* in the field and under laboratory conditions. Their results for field studies in the Ria de Vigo, expressed as μ/day, 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* according to Maggs *et al.* (1998).

Sensitivity review

Resilience and recovery rates

All species of maerl, including *Phymatolithon calcareum*, 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 maerl deposits may take hundreds of years to develop, especially in high latitudes (BIOMAERL, 1998). The growth rates of European maerl species range between tenths of a millimetre to 1 millimetre per annum (Bosence & Wilson, 2003). Adey & McKibbin (1970) undertook growth studies of *Phymatolithon calcareum* in the field and under laboratory conditions. Field studies in the Ria de Vigo, Spain, 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). More recent studies suggested that the growth rate of *Phymatolithon calcareum* tips are 0.9 mm/per year under a wide range of field and laboratory conditions (Blake & Maggs, 2003).

Individual maerl nodules 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). The 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).

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 & Chamberlain, 1994). Newly settled maerl thalli have never been found in the British Isles (Irvine and Chamberlain, 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 go through phases of reproduction with peaks every six years. This may account for observed changes in the relative proportions of live *Lithothamnion coralloides* and *Phymatolithon calcareum* nodules in maerl beds. Dominance cycles with periods of about thirty years have been recorded on some of the maerl beds of northern Brittany. 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).

Resilience assessment. The current evidence regarding the recovery of maerl, including *Phymatolithon calcareum*, 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'.

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 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). *Phymatolithon calcareum* dominates maerl beds in the north of the UK. In the south-west of England and Ireland, *Phymatolithon calcareum* is often found interspersed with *Lithothamnion coralloides.* During laboratory experiments aquaria temperatures on Spanish specimens of *Phymatolithon calcareum* were increased from 15.1°C to and 17°C and then 19°C at one month intervals (Adey & McKibbin, 1970). A steady decrease in growth rate was recorded from *Phymatolithon calcareum* in these tanks. However, Adey & McKibbin (1970) suggested that 12-13°C was the optimum temperature for growth in *Phymatolithon calcareum.*

Specimens *of Phymatolithon calcareum* from Strangford Lough, Northern Ireland, 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 temperatures used in their study were typical of winter (9°C) and summer conditions (17°C) in the lough. *Phymatolithon calcareum* appear to have a wide geographic range (from Norway to the Mediterranean) and are likely to be tolerant of higher temperatures than those experienced in the British Isles. The geographic range of *Phymatolithon calcareum* may not accurately describe its ability to withstand localized changes in temperature, as it may be acclimatized to local conditions. However, the range of *Phymatolithon calcareum* may to some extent display the limits of the species genetic ability to acclimatize to temperatures. *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). 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 health, 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).

Sensitivity assessment. An increase in temperature at the benchmark level is unlikely to affect *Phymatolithon calcareum*. However, given the slow growth rates of *Phymatolithon calcareum*, no effect is likely to be perceived within the duration of the benchmark, although long-term climate change effects may be noticed in future. Therefore, *Phymatolithon calcareum* probably has a **'High'** resistance to an increase in temperature at the benchmark level. Resilience is, therefore, **'High'**, and a sensitivity assessment of **'Not sensitive'** is recorded.

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 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). During laboratory experiments on Spanish *Phymatolithon calcareum*, aquaria temperatures were reduced from 10°C to 0.4°C or 0.2°C (depending on light intensity and light: dark cycle) over a period of two to eight weeks (Adey & McKibbin, 1970). After the period of temperature reduction, all samples of *Phymatolithon calcareum* were dead or showed a reduction in pigmentation. When temperatures were returned to 10°C over three weeks, six out of fifteen *Phymatolithon calcareum* specimens showed signs of recovery. Specimens in aquaria where temperatures had only been reduced to 2.1°C or 5°C survived. In the same study 13°C was recorded as the optimum temperature for *Phymatolithon calcareum* (Adey & McKibbin 1970).

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). Hence, *Phymatolithon calcareum* is likely to be tolerant of lower temperatures than those experienced in the British Isles. Species ranges may not accurately describe their ability to withstand localized changes in temperature, as species will be acclimatized to local conditions. However, the range of *Phymatolithon calcareum* may to some extent display the limits of the species genetic ability to acclimatize to temperatures.

Sensitivity assessment. A decrease in temperature at the benchmark level is unlikely to affect *Phymatolithon calcareum* in UK waters. 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, *Phymatolithon calcareum* probably have a **'High'** resistance to an increase in temperature at the benchmark level. Resilience is, therefore **'High'**, and a sensitivity assessment of '**Not sensitive'** is recorded.

Salinity increase (local)	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

Phymatolithon calcareum occurs 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. Wilson *et al*. (2004) noted that Phymatolithon calcareum tolerated up to 40 psu. The growth of *Phymatolithon calcareum* is impaired at salinities <24 ppt (Adey & McKibbin, 1970; King & Schramm, 1982).

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. Where *Phymatolithon calcareum* is found in areas of reduced or variable salinity, an increase in salinity is very unlikely to have an effect. 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.

Salinity decrease (local)

Resistance	Resilience	Sensitivity
Medium	Very Low	Medium
Q: Medium A: Medium C: Medium	Q: High A: Medium C: High	Q: Medium A: Medium C: Medium

Phymatolithon calcareum occurs 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 growth of *Phymatolithon calcareum* is impaired at salinities <24 ppt (Adey & McKibbin, 1970; King & Schramm, 1982). Wilson *et al.* (2004) noted that *Phymatolithon calcareum* survived at 3 psu for five weeks, but showed significantly reduced photosynthetic activity. At 15 psu, *Phymatolithon calcareum* was able to recover from the initial drop in photosynthetic activity.

Sensitivity assessment. A reduction from a fully marine regime to one that is reduced for a short period of time is unlikely to have a significant negative impact on *Phymatolithon calcareum*. However, a reduced salinity regime for an extended period of time would remove *Phymatolithon calcareum* from its optimum conditions and will cause a reduction in the growth rate, and may lead to mortality. No long-term salinity experiments have been carried out on *Phymatolithon calcareum*. Therefore, a precautionary resistance assessment of **'Medium'** is suggested. , Therefore, he resilience is **'Very low'** and sensitivity is assessed as **'Medium'**.

Water flow (tidal current) changes (local)

Resistance	Resilience	Sensitivity
Low	Very Low	High
Q: Low A: NR C: NR	Q: High A: Medium C: High	Q: Low A: Low C: Low

Maerl species, including *Phymatolithon calcareum*, require a degree of shelter from wave action, to prevent burial and dispersal into deep water. However, they also need enough water movement to prevent smothering with silt (Hall-Spencer, 1998). Therefore, maerl is 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 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. However, 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.

Sensitivity assessment. An increase in water flow to strong or very strong may result winnow away the surface of the bed and result in loss of the live layer of *Phymatolithon calcareum*. However, beds in moderately strong water flow probably occur at greater depths than those in weaker flow. Similarly, as a decrease in water flow may result in an increase in siltation, smothering maerl and filling the bed with silt, causing the death of maerl (see smothering/siltation below). However, maerl beds in very weak tidal streams probably receive wave mediated flow. So 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. However, 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

Resistance	Resilience	Sensitivity
Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Phymatolithon calcareum does not occur in the intertidal, as it is highly sensitive to desiccation (Wilson *et al*., 2004). Also, it is very unlikely that *Phymatolithon calcareum* 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: Medium C: High	Not sensitive Q: High A: Medium C: Medium

Phymatolithon calcareum requires a degree of shelter from wave action, to prevent burial and dispersal into deep water. However, enough water movement needed to prevent smothering with silt (Hall-Spencer, 1998). Therefore, *Phymatolithon calcareum* 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). Areas of maerl subject to wave action often show mobile areas in the form of ripples or mega-ripples (Hall-Spencer & Atkinson, 1999, Keegan, 1974). 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. Hall-Spencer & Atkinson (1999) noted that mega-ripples at their wave exposed site were relatively stable but underwent large shifts due to storms. 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. Deep beds are less likely to be affected by an increase in wave exposure.

Sensitivity assessment. *Phymatolithon calcareum* occurs in a range of wave exposures and can survive in areas subject to wave action and even storms, if deep enough. Therefore, an increase in wave exposure is probably detrimental to *Phymatolithon calcareum* in shallow waters. 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. However, a 3-5% change in significant wave height is unlikely to be significant. Both resistance and resilience are assessed as **'High'**, and *Phymatolithon calcareum* 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**.

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**.

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**.

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.).

Sensitivity assessment. The available evidence suggests that maerl and its associated community are 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 bloom (Bricker *et al.*, 1999, 2008).

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, and loss of sensitive species. 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 is difficult to disentangle from the effects of organic enrichment, and sedimentation. However, the nutrient load from sewage outfalls and urban runoff is likely to be higher than the benchmark level. Hence, *Phymatolithon calcareum* is considered to be **'Not sensitive'** at the pressure benchmark of compliance with WFD criteria for good status.

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 microalgal 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.

Sensitivity assessment. Little empirical evidence was found to directly compare the benchmark organic enrichment to *Phymatolithon calcareum*. However, the evidence suggests that organic enrichment and resultant increased in organic content, hydrogen sulphide levels and sedimentation may result in loss of maerl. 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 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

Phymatolithon calcareum can be found on top of a variety of sediment types including gravels, sand and mud, but never bedrock. Therefore, if rock or an artificial substrate were to replace the normal substratum that this species is found on then the species would not be able to survive. 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 often found underneath *Phymatolithon calcareum* can vary from shell and maerl gravel through to sand and mud. *Phymatolithon calcareum* is also not attached to the substratum, and instead lies over the top of it. Therefore, if the substratum were to change this would not have a negative effect on the species.

Sensitivity assessment. A change in this pressure at the benchmark will not affect *Phymatolithon calcareum*. 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

The extraction of the substratum to 30 cm would remove almost all of the *Phymatolithon calcareum* (live and dead), within the footprint of the activity.

Sensitivity assessment. The resistance of *Phymatolithon calcareum* to this pressure at the benchmark is **'None'** and resilience is assessed as '**Very low'** so that sensitivity is assessed as **'High'**.

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). 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.

Abrasion may break up *Phymatolithon calcareum* nodules into smaller pieces resulting in easier displacement by wave action, a reduced structural heterogeneity and reduced biodiversity of the bed (Kamenos *et al.*, 2003).

Sensitivity assessment. Physical disturbance can result in the fragmentation of *Phymatolithon calcareum* but will not kill it directly. However, 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 not resistant (see 'smothering' and 'siltation' pressures). The evidence from Hall-Spencer & Moore (2000a; 2000 c) alone strongly suggests that resistance to physical disturbance and abrasion is **'Low'**. Therefore, resilience is probably **'Very low'**, and sensitivity is assessed as **'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

The fragmentation of *Phymatolithon calcareum* will not directly cause mortality of the organism. However, the smaller pieces will be lighter and therefore more likely to be entrained and exported in the strong tidal flows characteristic of where this species is found. Nevertheless, the evidence provided under the 'abrasion and disturbance' pressure suggests that maerl is not resistant of physical disturbance. Penetration of the maerl bed will only exacerbate the negative effect by damaging more of the underlying maerl.

Sensitivity assessment. Based on the evidence provided by the 'abrasion and disturbance' assessment the resistance of *Phymatolithon calcareum* to this pressure at the benchmark is assessed as **'None',** the resilience as **'Very low'**, and sensitivity 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

Phymatolithon calcareum requires light and is, therefore, restricted 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. A decrease in light availability will alter the ability of the maerl to photosynthesise. This could be detrimental to maerl found towards the bottom of its depth limit in Europe (i.e. 32 m). An increase in suspended solids is also likely to increase scour, as there are characteristically high levels of water movement in maerl habitat. 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). A decrease in suspended solids may increase light levels, which could benefit maerl.

Sensitivity assessment. Any factor that could decrease the ability for *Phymatolithon calcareum* to photosynthesise will have a negative impact. Where this species is found at the bottom depth limit of itsange, it may experience high levels of mortality. The resistance of this species is considered to be **'Medium'** and the resilience is **'Very low'**. This gives the species an overall sensitivity of

'Medium' to the pressure at the benchmark.

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 four weeks buried 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 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).

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

Smothering and siltation rate changes (heavy)	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

A deposit at the pressure benchmark would cover *Phymatolithon calcareum* 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	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

‘Not relevant’.

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

Phymatolithon calcareum has a requirement for light which restricts it to depths shallower than 32 m in the relatively turbid waters of northern Europe (Hall-Spencer, 1998), which suggests that maerl is not resistant 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).

Sensitivity assessment. Artificial light is unlikely to affect any but *Phymatolithon calcareum* in the shallowest conditions. There is a possibility that shading by artificial structures could result in the loss if *Phymatolithon calcareum* is found at its most extreme depths, but only where shading was long-term or permanent. There is insufficient information to assess the effect of this pressure at the benchmark on this species. Therefore, **‘No evidence’** is recorded.

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 immobile benthic species. 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 immobile benthic species. 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	No evidence (NEv) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

‘No evidence’ of genetic modification and/or translocation was found.

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- indigenous invasive species in the UK was found. However, Grall & Hall-spencer (2003) note that beds of invasive slipper limpet *Crepidula fornicata* grew across maerl in Brittany. As a result, the maerl thalli were killed, and the bed clogged with silt and pseudofaeces 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 *Phymatolithon calcareum* itself, which in itself would be extremely destructive. A resistance of **'None'** and a resilience of **'Very low'** have been recorded, 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 is found in the Pacific and could have devastating consequences for *Phymatolithon calcareum*. However, this disease was not known to be in Europe (Birkett *et al.*, 1998a) and **'No evidence'** of the effects of diseases and pathogens on *Phymatolithon calcareum* could be 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

Phymatolithon calcareum can be sold dried as a soil additive but is also used in animal feed, water filtration systems, pharmaceuticals, cosmetics and bone surgery. Maerl beds containing *Phymatolithon calcareum* 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, from which maerl was collected, were off the coast of Brittany, where 300,000 – 500,000 t / annum were dredged (Blunden, 1991), and off Falmouth harbour in Cornwall where extraction was around 20,000 t / annum (Martin, 1994; Hall-Spencer, 1998). However, maerl extraction was banned in the Fal in 2005 Hall-Spencer *et al.* (2010).

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.

Sensitivity assessment. Maerl, including *Phymatolithon calcareum*, has historically been targeted for commercial collection. *Phymatolithon calcareum* has no ability to avoid removal, and therefore, resistance is assessed as **'None**', and the resilience is assessed as **'Very low'**, giving a sensitivity assessment of **'High'**.

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

Direct, physical impacts from harvesting are assessed through the abrasion and penetration of the seabed pressures. *Phymatolithon calcareum* could easily be incidentally removed as by-catch when other species are being targeted (e.g. via scallop dredging), see 'removal of target species' and 'abrasion' pressures above.

Sensitivity assessment. The resistance to removal is **'Low'** due to the inability of *Phymatolithon calcareum* 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'**.

Importance review

Policy/legislation

UK Biodiversity Action Plan Priority	☑
Species of principal importance (England)	☑
Species of principal importance (Wales)	☑
Features of Conservation Importance (England & Wales)	☑

Status

National (GB) importance	Not rare/scarce	**Global red list (IUCN) category**	-

Non-native

Native	-		
Origin	-	**Date Arrived**	Not relevant

Importance information

Maerl forms a very complex structure and provides a substratum for other species as well as crevices and shelter. Maerl beds are highly species rich with 150 macroalgal species and over five hundred faunal species (of which 120 are molluscs) recorded as living on or in maerl beds (Birkett *et al.*, 1998a; Hall-spencer, 1998). Hall-Spencer *et al.* (2003) note that maerl beds are feeding areas for juvenile Atlantic cod, and host reserves of brood stock for razor shells *Ensis* spp., the great scallop *Pecten maximus* and the warty venus *Venus verrucosa.* and it may provide nursery areas for commercially important species of bivalves e.g. scallops (see the maerl biotope SS.SMp.Mrl for further information).

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). The maerl bed in the Sound of Iona recorded to be □4000 years old (Hall-Spencer *et al.*, 2003). 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).

Over 500,000 tonnes per annum of maerl are dredged up from the coast of Brittany. This is primarily sold dried as a soil additive. Maerl is frequently washed up in some locations in Scotland and Ireland in sufficient quantities to form white 'coral' beaches.

Bibliography

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.

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.A., 2003. Comparative growth rates and internal banding periodicity of maerl species (Corallinales, Rhodophyta) from northern Europe. *Phycologia*, **42** (6), 606-612.

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

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.

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.

Campbell, A., 1994. *Seashores and shallow seas of Britain and Europe.* London: Hamlyn.

Collins, K.J., Herbert, R.J.H. & Mallinson, J.J., 1990. Marine flora and fauna of Bembridge and St. Helen's Isle of Wight. *Proceedings of the Isle of Wight Natural History and Archaeological Society*, **9**, 41-85.

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. Joint Nature Conservation Committee, Peterborough. www.jncc.gov.uk/MarineHabitatClassification.

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.

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.

Frantz, B. R., Kashgarian, M., Coale, K. H. & Foster, M.S. 2000. Growth rate and potential climate record from a rhodolith using 14C accelerator mass spectrometry. *Limnology and Oceanography*, **45**, 1773-1777.

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

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.

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

Guiry, M.D., 1998. *Phymatolithon calcareum*, (Pallas) Adey and McKibbin. http://seaweed.ucg.ie/descriptions/Phycal.html, 1999-08-31

Halfar, J., Zack, T., Kronz, A. & Zachos, J.C. 2000. Growth and high-resolution paleoenvironmental signals of rhodoliths (coralline red algae): a new biogenic archive. *Journal of Geophysical Research*, **105**, 107-116.

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.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., 1994. *Biological studies on nongeniculate Corallinaceae.* Ph.D. thesis, University of London.

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.

Hardy, F.G. & Guiry, M.D., 2003. *A check-list and atlas of the seaweeds of Britain and Ireland.* London: British Phycological Society

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.

Howson, C.M. & Picton, B.E., 1997. *The species directory of the marine fauna and flora of the British Isles and surrounding seas.* Belfast: Ulster Museum. [Ulster Museum publication, no. 276.]

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.

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.

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

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, S. & Hall-Spencer, J.M., 2017. Effects of Ocean Warming and Acidification on Rhodolith / Maerl Beds. In Riosmena-Rodriguez, R., Nelson, W., Aguirre, J. (ed.) *Rhodolith / Maerl Beds: A Global Perspective*, Switzerland: Springer Nature, pp. 55-85. [Coastal Research Library, 15].

Martin, S., Castets, M.-D. & Clavier, J., 2006. Primary production, respiration and calcification of the temperate free-living coralline alga *Lithothamnion corallioides*. *Aquatic Botany*, **85** (2), 121-128. DOI https://doi.org/10.1016/j.aquabot.2006.02.005

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

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

Tyler-Walters, H., 2013. Beds of dead maerl. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line], Plymouth: Marine Biological Association of the United Kingdom. [cited 12/02/16]. Available from:http://www.marlin.ac.uk/habitats/detail/999

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.

Veale, L.O., Thompson, R.C. & Bates, M., 1999. Isle of Man Sublittoral Survey: 1994 - 1997. In *Monitoring the marine and coastal environment* (ed. H. Davies) Isle of Man: Irish Sea Forum.

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.

Datasets

Centre for Environmental Data and Recording, 2018. Ulster Museum Marine Surveys of Northern Ireland Coastal Waters. Occurrence dataset https://www.nmni.com/CEDaR/CEDaR-Centre-for-Environmental-Data-and-Recording.aspx accessed via NBNAtlas.org on 2018-09-25.

Manx Biological Recording Partnership, 2017. Isle of Man wildlife records from 01/01/2000 to 13/02/2017. Occurrence dataset: https://doi.org/10.15468/mopwow accessed via GBIF.org on 2018-10-01.

NBN (National Biodiversity Network) Atlas. Available from: https://www.nbnatlas.org.

OBIS (Ocean Biogeographic Information System), 2019. Global map of species distribution using gridded data. Available from: Ocean Biogeographic Information System. www.iobis.org. Accessed: 2019-03-21

Outer Hebrides Biological Recording, 2018. Non-vascular Plants, Outer Hebrides. Occurrence dataset: https://doi.org/10.15468/goidos accessed via GBIF.org on 2018-10-01.

Royal Botanic Garden Edinburgh, 2018. Royal Botanic Garden Edinburgh Herbarium (E). Occurrence dataset: https://doi.org/10.15468/ypoair accessed via GBIF.org on 2018-10-02.