



# MarLIN

## Marine Information Network

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

# *Palmaria palmata* on very exposed to moderately exposed lower eulittoral rock

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

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**Please note.** This MarESA report is a dated version of the online review. Please refer to the website for the most up-to-date version [<https://www.marlin.ac.uk/habitats/detail/126>]. All terms and the MarESA methodology are outlined on the website (<https://www.marlin.ac.uk>)

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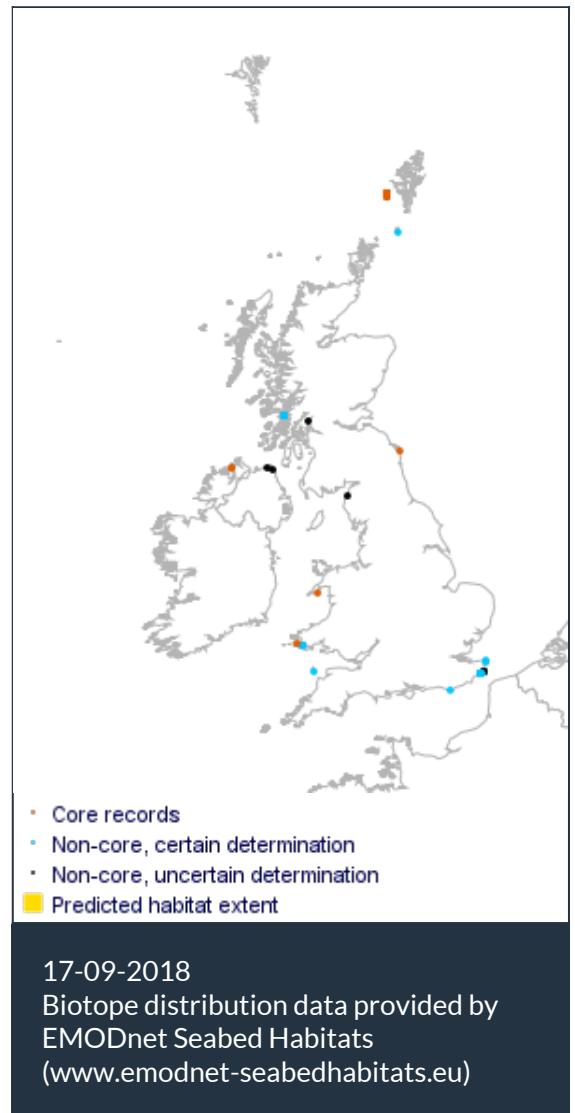
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*Palmaria palmata* on very exposed to moderately exposed lower eu littoral rock

Photographer: Keith Hiscock

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Researched by Dr Heidi Tillin & Jacqueline Hill      Referred by Admin

## Summary

### ☰ UK and Ireland classification

EUNIS 2008	A1.124	<i>Palmaria palmata</i> on very exposed to moderately exposed lower eu littoral rock
JNCC 2015	LR.HLR.FR.Pal	<i>Palmaria palmata</i> on very exposed to moderately exposed lower eu littoral rock
JNCC 2004	LR.HLR.FR.Pal	<i>Palmaria palmata</i> on very exposed to moderately exposed lower eu littoral rock
1997 Biotope	LR.MLR.R.Pal	<i>Palmaria palmata</i> on very to moderately exposed lower eu littoral rock

### 🔍 Description

Very exposed to moderately exposed lower eu littoral rock which supports a pure stand of dulse *Palmaria palmata* as a dense band or in large patches above the main kelp zone. *Palmaria palmata*

favours shaded or overhanging rock and often forms a band at the top of overhanging rock. Relatively low abundance of other seaweeds, such as the red seaweed *Porphyra umbilicalis* or the green seaweeds *Ulva intestinalis*, *Ulva lactuca* and *Cladophora rupestris* may also occur in this biotope although *Palmaria palmata* always dominates. On the rock underneath the seaweed turf are the barnacle *Semibalanus balanoides* and the limpet *Patella vulgata* and the olive-green lichen *Verrucaria mucosa*. Sites should only be recorded as Pal where *Palmaria palmata* forms a distinct band or occurs in large patches on the shore (Connor *et al.*, 2004).

### ↓ Depth range

-

### 🏛️ Additional information

-

### ✓ Listed By

- none -

### 🔗 Further information sources

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## Sensitivity review

### Sensitivity characteristics of the habitat and relevant characteristic species

The biotope description and characterizing species is taken from Connor *et al.* (2004). This biotope is characterized by a pure stand of dulse, *Palmaria palmata* which occurs as a dense band or in large patches above the main kelp zone. Other seaweeds, such as the red seaweed *Porphyra umbilicalis* or the green seaweeds *Ulva intestinalis*, *Ulva lactuca* and *Cladophora rupestris* may be present in this biotope at low abundances. Other species typically associated with rocky intertidal habitats are found within this biotope including the barnacle *Semibalanus balanoides* and the limpet *Patella vulgata* and the lichen *Verrucaria mucosa*.

As the key species that defines this biotope is *Palmaria palmata*, the sensitivity assessments for the biotope are based on this species. The sensitivity of associated green and red species and barnacles are described generally. More information on these species can be found in the assessments for other biotopes on this website. Grazers can directly or indirectly structure algal biotopes by grazing on key species or their competitors and the sensitivity of the limpet, *Patella vulgata*, which occurs in this biotope is described generally.

### Resilience and recovery rates of habitat

The key, characterizing species, *Palmaria palmata*, exhibits a range of life stages with different morphologies. The male plant is foliose in form while female plants are small crusts which are overgrown by the tetrasporophyte (asexual, foliose, spore producing stage). The plants are perennial and the foliose blades of male plants and tetrasporophytes can regrow from the small discoid holdfast. Where this biotope is impacted by pressures, recovery of *Palmaria palmata*, will occur through regrowth of damaged fronds, regrowth from surviving perennial holdfast or recolonization by propagules. Where fronds are damaged, regrowth will be rapid during the spring summer growth season and older parts of individuals typically have small 'leaflets' along the margin especially where damaged. On the northern coast of Spain, populations of epiphytic *Palmaria palmata* showed a seasonal growth cycle with net growth from March-August and breakage from August to March (Faes & Viejo, 2003).

The spores of red algae are non-motile (Norton, 1992) and therefore entirely reliant on the hydrographic regime for dispersal. Norton (1992) reviewed dispersal by macroalgae and concluded that dispersal potential is highly variable, recruitment usually occurs on a much more local scale, typically within 10 m of the parent plant. It is likely that *Palmaria palmata* could recolonize an area from adjacent populations within a short period of time in ideal conditions. However, as the female does not release carpospores and needs to be close to the adult male population for fertilization to occur, recolonization from distant populations would probably take much longer where this species was eradicated from broad areas. Recovery rates will therefore be highly dependent on the severity of the impact and its spatial footprint.

Connor *et al.*, (2004) suggest that the *Palmaria palmata* biotope represents an opportunistic assemblage of fast-growing species which occupy gaps within or between the canopies of long lived perennials such as the wrack *Fucus serratus*. Rapid recovery and recolonization rates have been observed. Following kelp and furoid canopy removal experiments in the Isle of Man in 2m x 2m plots, Hawkins & Harkin (1985) observed a rapid increase in the number of *Palmaria palmata* sporelings and the species came to dominate cleared plots within five months. *Palmaria palmata* present epiphytically on adjacent kelp plants may have supplied recruits (Hawkins & Harkin,

1985). The experimental results suggest that small gaps can be filled rapidly where adults remain, however these results should not be generalised to impacts where removal occurs over a wide area.

Biotopes dominated by red algal turfs and furoid dominated biotopes may represent alternate stable states that continue while the dominant turf or furoids occupy space. Removal of the turf may therefore allow re-establishment of a furoid or kelp dominated biotope that will remain until environmental or other factors again alter the state. Lubchenco (1980) for example, found that the removal of *Chondrus crispus* turf on shores in New England, allowed the establishment of *Fucus* spp.; highlighting the significance of grazers and disturbance in structuring algal biotopes. On moderately exposed shores this biotope may be replaced by furoids following disturbance or as natural temporal variation. Where this biotope occurs on very exposed and exposed shores, the degree of wave action reduces the suitability of the habitat for kelps and furoids, however, competition between other red algae may prevent recovery following disturbance. MacFarlane (1952), recorded a shift to a *Corallina officinalis* and encrusting coralline biotope following over raking (for harvesting) of *Chondrus crispus* turf, as gastropods had increased in abundance and prevented the recovery of *Chondrus crispus* by grazing. It should, therefore, be noted that where a large proportion of the algal turf is removed, recovery may be prolonged and may be influenced by a number of variables, including the presence or absence of grazers and competition between macroalgae.

**Resilience assessment** Recovery by regrowth will be rapid where only a small proportion of the *Palmaria palmata* population are removed and the holdfasts remain. Resilience is therefore assessed as 'High' (within 2 years) where resistance is 'High' or 'Medium' or 'Low' and the holdfasts remain. Where resistance is assessed as 'Low' (holdfasts and fronds removed) or 'None' then recovery is assessed as 'Medium' as recruitment may require longer to allow for poor dispersal and the potential for biotope replacement by other algal species. The resilience of 'Medium' also considers the recovery time for *Patella vulgata* and *Semibalanus balanoides* which may recruit episodically. The green ephemeral algae that occur in this biotope are considered to have 'High' recovery to any level of resistance and these may dominate the biotope before reestablishment of the red algal turf occurs as observed in clearance experiments (Hawkins & Harkin, 1985). As recovery, where turfs are removed over large areas, will depend on the supply of propagules from neighbouring populations, and as dispersal is limited, the recovery will depend on the supply of propagules which will be influenced site-specific factors, particularly local water transport. Caveats regarding possible state shifts where beds are extensively removed should also be considered when applying sensitivity assessments. Identifying tipping points for shifts to alternate stable states is problematic, therefore although the recovery rates based on examples and life history traits are used in the assessments, these may underestimate recovery time which will be influenced by pressure and site-specific factors.

(Where resilience is assessed as high, confidence in the quality of evidence is assessed as 'High' (based on Hawkins & Harkin, 1985 and Connor *et al.*, 2004), applicability is assessed as 'Low' concordance as High. Where resilience is Medium, it is based on expert judgement (Quality, 'Low', applicability and concordance are therefore NR (not relevant)

**NB:** 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 recognizable 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)	<b>Low</b> Q: High A: Medium C: High	<b>Medium</b> Q: Low A: NR C: NR	<b>Medium</b> Q: Low A: Low C: Low

Intertidal species are exposed to extremes of high and low air temperatures during periods of emersion. They must also be able to cope with sharp temperature fluctuations over a short period of time during the tidal cycle. In winter air temperatures are colder than the sea, conversely in summer air temperatures are much warmer than the sea. Species that occur in this intertidal biotope are therefore generally adapted to tolerate a range of temperatures.

*Palmaria palmata* does well in low temperatures, with an optimum between 6 and 15°C (Bak, 2014), consistent with a distribution in northern temperate and arctic waters. The species is also found in warmer temperate waters as far south as Portugal in Europe and with localized large populations in northern Spain (Garbary *et al.*, 2012 and references therein). In the laboratory, plants only became fertile if left at temperatures between 5-7 °C with a short light period (Van der Meer, 1979). Temperatures at or above 15 °C may induce physiological stress (Werner & Dring, 2011; Morgan *et al.*, 1980). In tank cultures of *Palmaria palmata* maintained at 20°C and above, all plants were dead within a week (Morgan *et al.*, 1980). Kain & Norton (1990) suggest, however, that a widely distributed species like *Palmaria palmata* reacts less strongly to temperature differences than some other red algae.

The associated *Ulva* spp. are distributed globally and occur in warmer waters than those surrounding the UK suggesting that they can withstand increases in temperature at the pressure benchmark. *Ulva* spp. are characteristic of upper shore rock pools, where water and air temperatures are greatly elevated on hot days. Empirical evidence for thermal tolerance to anthropogenic increases in temperature is provided by the effects of heated effluents on rocky shore communities in Maine, USA. *Ascophyllum* and *Fucus* were eliminated from a rocky shore heated to 27-30 °C by a power station whilst *Ulva intestinalis* (as *Enteromorpha intestinalis*) increased significantly near the outfall (Vadas *et al.*, 1976).

Barnacles (*Semibalanus balanoides*) and *Patella vulgata* occur in this biotope. Laboratory studies suggest that adults of these species can tolerate temperature increases. The median upper lethal temperature limit in laboratory tests on *Semibalanus balanoides* was approximately 35 °C (Davenport & Davenport, 2005). *Patella vulgata* can also tolerate high temperatures. The body temperature of *Patella vulgata* can exceed 36 °C in the field, (Davies, 1970); adults become non-responsive at 37-38 °C and die at temperatures of 42 °C (Evans, 1948). Although adults may be able to withstand acute and chronic increases in temperature at the pressure benchmark, increased temperatures may have sub-lethal effects on the population by impacting the success of reproduction phases. *Semibalanus balanoides* and *Patella vulgata* are 'northern' with their range extending from Portugal or Northern Spain to the Arctic circle. Populations in the southern part of England are therefore relatively close to the southern edge of their geographic range.



Reproductive and recruitment success in both species is linked to temperature and long-term changes in temperature (exceeding the duration of the pressure benchmark) may lead to replacement by the warm water species *Chthamalus montagui* and *Chthamalus stellatus* (Southward *et al.*, 1995). In Northern Portugal warming seas appear to be linked to a shortening of the reproductive period and the lack of multiple spawning events in *Patella vulgata* and other northern species (Ribeiro *et al.*, 2009).

**Sensitivity assessment.** As maximum sea surface temperatures around the British Isles exceed 20 °C (Hiscock, 1998) and that *Palmaria palmata* occurs in warmer waters in Spain and Portugal, it is considered unlikely that *Palmaria palmata* would suffer mortality due to the chronic benchmark increase in temperature of seawater. An acute increase at the pressure benchmark may, however, lead to mortalities or inhibit reproduction (depending on timing). Adults of the associated species, *Patella vulgata* and *Semibalanus balanoides* are considered likely to be able to tolerate an acute or chronic increase in temperature at the pressure benchmark, although the timing of acute and chronic increases would alter the degree of impact and hence sensitivity. An acute change occurring during warm, summer periods that exceeds thermal tolerances could lead to mortality. Sensitivity of *Patella vulgata* and *Semibalanus balanoides* to longer-term, broad-scale perturbations would potentially be greater due to effects on reproduction. *Ulva* spp., are considered to tolerate increases in temperature at the pressure benchmark. This biotope is considered to be 'Not sensitive' to chronic increases but to have 'Low' resistance to an acute increase in temperature. Biotope resilience is assessed as 'Medium' (as no evidence was found to suggest that holdfasts have great resistance) and biotope sensitivity is assessed as 'Medium'. Where resilience is Medium, it is based on expert judgement (Quality Low, applicability and concordance = NR (not relevant)).

#### Temperature decrease (local)

High

Q: High A: Medium C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: High

Many intertidal species are tolerant of freezing conditions as they are exposed to extremes of low air temperatures during periods of emersion. They must also be able to cope with sharp temperature fluctuations over a short period of time during the tidal cycle. In winter air temperatures are colder than the sea, conversely in summer air temperatures are much warmer than the sea. Species that occur in the intertidal are therefore generally adapted to tolerate a range of temperatures, with the width of the thermal niche positively correlated with the height of the shore (Davenport & Davenport, 2005).

*Palmaria palmata* does well in low temperatures, with an optimum between 6 and 15°C, consistent with a distribution in northern temperate and arctic waters. This species is also found in warmer temperate waters as far south as Portugal in Europe and with localized large populations in northern Spain (Garbary *et al.*, 2012 and references therein). In the laboratory, plants only became fertile if left at temperatures between 5-7°C with a short light period (Meer van der, 1979). Acute or chronic changes in temperature below 5 °C may therefore reduce reproductive success although reproduction and vegetative growth in warmer months should compensate for any reduction in output. Temperatures at or above 15°C may induce physiological stress (Werner &



Dring, 2011; Morgan *et al.*, 1980) In tank cultures of the species at 20°C and above, all plants were dead within a week (Morgan *et al.*, 1980). Such high temperatures, however, are unlikely in most parts of Britain and Ireland. The growth of *Palmaria palmata* is reduced below 6°C but the plant can survive lower temperatures as long as the tissue does not freeze (Werner & Dring, 2011).

The associated red algae *Porphyra umbilicalis* occurs in both temperate and arctic regions and freezing has been demonstrated to have little physiological effect (Green & Neefus, 2014). Other species associated with the biotope are able to tolerate decreases in temperature. Lüning (1990) reported that *Corallina officinalis* from Helgoland survived 0 °C when exposed for one week. New Zealand specimens were found to tolerate -4 °C (Frazer *et al.*, 1988). *Ulva* spp. are eurytopic, found in a wide temperature range and in areas which frequently experience freezing conditions and are vulnerable to ice scour (Seed & Suchanek 1992).

The limpet *Patella vulgata* and the barnacle *Semibalanus balanoides* are both northern species and relatively close to their southern range limit in the UK, suggesting these are tolerant of colder temperatures than those typically experienced in UK habitats. The tolerance of *Semibalanus balanoides*, collected in the winter (and thus acclimated to lower temperatures), to low temperatures was tested in the laboratory. The median lower lethal temperature tolerance was -14.6 °C (Davenport & Davenport, 2005). A decrease in temperature at the pressure benchmark is therefore unlikely to negatively affect this species. Adults of *Patella vulgata* are also largely unaffected by short periods of extreme cold. Ekaratne & Crisp (1984) found adult limpets continuing to grow over winter when temperatures fell to -6 °C, and stopped only by still more severe weather. Loss of adhesion after exposure to -13 °C has been observed with limpets falling off rocks and therefore becoming easy prey to crabs or birds (Fretter & Graham, 1994). However, in the very cold winter of 1962-3 when temperatures repeatedly fell below 0 °C over a period of 2 months large numbers of *Patella vulgata* were found dead (Crisp, 1964a). Periods of frost may also kill juvenile *Patella vulgata*, resulting in recruitment failures in some years (Bowman & Lewis, 1977).

In colder conditions an active migration by mobile species found within the turf may occur down the shore to a zone where exposure time to the air (and hence time in freezing temperatures) is less.

**Sensitivity assessment.** The key characterizing species, *Palmaria palmata* occurs over a wide geographical range and as an intertidal species is predicted to have high tolerances for decreased temperature at the acute and chronic pressure benchmarks. Biotope resistance is assessed as 'High' as these effects do not result in mortality and resilience is assessed as 'High', so that the biotope is not considered to be sensitive to this pressure. The timing of acute changes and seasonal weather could result in greater impacts on species. An acute decrease in temperature coinciding with unusually low winter temperatures may exceed thermal tolerances and lead to mortalities of the associated species although this would not alter the character of the biotope.

(Where resilience is assessed as high, confidence in the quality of evidence is assessed as 'High' (based on Hawkins & Harkin, 1985 and Connor *et al.*, 2004), applicability is assessed as 'Low', concordance as High.)

#### Salinity increase (local)

**Low**

Q: High A: Low C: NR

**Medium**

Q: Low A: NR C: NR

**Medium**

Q: Low A: Low C: Low

Biotores found in the intertidal will naturally experience fluctuations in salinity where evaporation increases salinity and inputs of rainwater expose individuals to freshwater. Species found in the

intertidal are therefore likely to have some form of behavioural or physiological adaptations to changes in salinity.

Laboratory experiments have defined the upper and lethal lower limits for *Palmaria palmata* as 15 psu and 50 psu (Karsten *et al.*, 2003), with optimal salinity defined as 23-34 psu (Robbins, 1978). It is not clear whether a sustained increase in salinity would be tolerated, or whether different life stages have different tolerances as this species is under studied, in comparison to some other species of commercial importance (Bak, 2014).

The associated *Ulva* species can survive hypersaline conditions in supralittoral rockpools subjected to evaporation and are considered to be a very euryhaline, tolerant of extreme salinities ranging from 0 psu to 136 psu (Reed & Russell, 1979). Some variations in salinity tolerance between populations of *Ulva intestinalis* have been found, however, suggesting that plants have some adaptation to the local salinity regime (Alström-Rapaport *et al.*, 2010; Reed & Russell (1979). Increased salinity is most likely to occur in the region of the littoral fringe and supralittoral zone and specimens from these areas were able to tolerate very high salinities, a significant decrease in regeneration only being recorded after exposure to concentrated seawater (102 psu and 136 psu) for > 7 days (Reed & Russell, 1979). In laboratory experiments, *Semibalanus balanoides* was found to tolerate salinities between 12 and 50 psu (Foster, 1970).

**Sensitivity assessment.** Based on the laboratory studies by Karsten *et al.*, (2003) *Palmaria palmata* is considered likely to tolerate some increases in salinity although the level will be sub-optimal for growth, so that over a year the biomass of *Palmaria palmata* is likely to decrease and mortalities are likely. An increase at the pressure benchmark may also lead to an increase in abundance of the very euryhaline *Ulva* spp. As an increase in salinity at the pressure benchmark may lead to changes in the composition of the algal turf, altering it from the biotope description and biotope resistance is assessed as 'Low'. Biotope resilience (following a return to normal habitat conditions) is assessed as 'Medium' as it is unclear whether holdfasts would survive. Biotope sensitivity is therefore assessed as 'Medium'.

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

Biotores found in the intertidal will naturally experience fluctuations in salinity where evaporation increases salinity and inputs of rainwater expose individuals to freshwater. Species found in the intertidal are therefore likely to have some form of behavioural or physiological adaptations to changes in salinity. As this biotope is present in full salinity, the assessed change at the pressure benchmark is a reduction in salinity to a variable regime (18-35 ppt) or reduced regime (18-30 ppt).

Laboratory experiments have defined the upper and lethal lower limits for *Palmaria palmata* as 15 psu and 50 psu, (Karsten *et al.*, 2003) with optimal salinity defined as 23-34 psu (Robbins, 1978). High growth rates of *Palmaria palmata* were observed in cultivation experiments at 21 psu in the *In-situ Palmaria palmata* from the Arctic Kongsfjord (Spitsbergen) exposed for four days to salinities of 15 psu, following freshwater run-off suffered high levels of mortality (Karsten *et al.*, 2003).

In Danish waters where salinities are lowered by freshwater inputs, cultivation experiments found that *Palmaria palmata* growth over a seven month period was greatest at a site where mean salinity was 21±3 psu, while no growth occurred at a site where mean salinity was 17±5 psu (Bak, 2014).

**Sensitivity assessment.** The sensitivity of *Palmaria palmata* appears to be greater than some other turf-forming species such as *Chondrus crispus*. A change in salinity at the pressure benchmark is considered to lead to some mortality of *Palmaria palmata*, although the tolerance threshold reported in laboratory studies and the cultivation experiments found mortality and growth cessation occurred at slightly lower salinities than the assessed benchmark. Long-term changes may lead to replacement by more resistant species such as *Chondrus crispus* may occur altering the character of the biotope. Biotope resistance is assessed as 'Low' and resilience as 'Medium' following a return to full salinity conditions. Biotope sensitivity is therefore assessed as 'Medium'.

**NB.** Where resilience is Medium, it is based on expert judgement (Quality Low, applicability and concordance = NR (not relevant)).

#### Water flow (tidal current) changes (local)

**High**

Q: High A: Low C: Medium

**High**

Q: High A: High C: High

**Not sensitive**

Q: High A: Low C: Medium

*Palmaria palmata* is found in a range of water flow regimes from moderately strong to weak. In increasing water flow rate the downstream deflection of the thallus caused by flowing water increases the plants rate of growth by presenting the thallus perpendicular to the incident light. As a result *Palmaria palmata* can achieve high growth rates in steady tidal streams, growing up to a meter long (Jorde, 1966). However, an increase to very strong flows may inhibit settlement of spores and may remove adults or germlings although flow rates experienced within dense populations will be reduced through friction. Experiments have shown that the flexibility of the very morphologically similar *Grateloupia turuturu* allows the species to show high reconfiguration rates (reduction in size when aligned with flow) to reduce drag and hence the risk of damage and dislodgement (Boller & Carrington, 2007).

**Sensitivity assessment.** As the key characterizing species *Palmaria palmata* can occur in a range of flow speeds and flex to reduce drag, resistance of the biotope was assessed as 'High', resilience was assessed as 'High' (by default), so that the biotope is classed as 'Not sensitive'.

(Where resilience is assessed as 'High', confidence in the quality of evidence is assessed as 'High' (based on Hawkins & Harkin, 1985 and Connor *et al.*, 2004), applicability is assessed as 'Low' and concordance as 'High')

#### Emergence regime changes

**Low**

Q: High A: Low C: Medium

**Medium**

Q: Low A: NR C: NR

**Medium**

Q: Low A: Low C: Low

The emergence regime is a key factor structuring this (and other) intertidal biotopes. This biotope generally occurs in the lower eulittoral above the main kelp zone, stands of *Alaria esculenta* or the mussel, *Mytilus edulis* and below biotopes dominated by *Patella vulgata*, *Semibalanus balanoides* and the wrack *Fucus distichus* (Connor *et al.*, 2004).

Environmental factors partly set upper and lower limits of algal distribution on shores. Spores and developing germlings are particularly susceptible to desiccation as they have very large surface-to-volume ratios, although they benefit from the film of water that persists in concavities on the substratum (Kain & Norton, 1990). An increase in desiccation resulting from increased emergence is likely to result in the death of the upper portion of the *Palmaria palmata* population depressing the upper limit of the species. At higher shore levels red algae tend to occur only under canopy forming species, as these limit exposure to desiccation (Hawkins and Hartnoll, 1983).

Experimental grazer removal allowed algae including *Palmaria palmata*, *Ceramium* spp. and *Osmundea* (as *Laurencia*) *pinnatifida* to grow higher on the shore (during winter and damp summers) than usual (Hawkins & Hartnoll, 1985). *Palmaria palmata* also grew more abundantly higher up the shore following the massive mortality of molluscan grazers after the Torrey Canyon oil spill (Hawkins & Hartnoll, 1983). These observations and further grazer removal experiments by Boaventura *et al.* (2003), indicate that grazing, in combination with physiological tolerances, limits the upper shore extent of biotopes characterized by red algal turfs on moderately and more exposed shores, where grazing is greater than on sheltered shores (Hawkins & Hartnoll, 1983; Boaventura *et al.*, 2003). These results concord with other studies that show grazing and emersion stress limit the height to which red algal turfs can extend (Underwood, 1980; Boaventura, 2000).

The associated ephemeral green algae, *Patella vulgata*, *Semibalanus balanoides* and littorinids are found at a range of shore levels and are found in abundance at higher shore levels than this biotope typically occurs at. These species are therefore considered unaffected by increased emergence experienced by this low-shore biotope.

Decreased emergence may increase predation on grazers by crabs, starfish and other predators, reducing grazing pressure and allowing the growth of algae more suited to the emergence regime (typically fucoids kelps and *Alaria esculenta*, depending on the shore height in relation to tidal changes). Competition may, however, be reduced by the level of wave exposure experienced by this biotope which will reduce habitat suitability for canopy forming macroalgae (Hawkins & Hartnoll, 1985).

**Sensitivity assessment.** Significant long-term increases or decreases in emergence are likely to alter environmental factors and grazing pressures which may result in increased competition or grazing from species better adapted to the changed conditions. Biotope resistance to this pressure is assessed as 'Low' based on *Palmaria palmata*. Resilience is assessed as 'Medium' (based on the loss of a large proportion of the population and the loss of holdfasts) and biotope sensitivity to this pressure is assessed as 'Medium'.

(Where resilience is Medium, it is based on expert judgement (Quality Low, applicability and concordance = NR (not relevant))

**Wave exposure changes (local)**

**High**

Q: High A: High C: High

**High**

Q: High A: High C: High

**Not sensitive**

Q: High A: High C: High

This biotope is recorded from locations that are judged to range from very exposed, moderately exposed or exposed (Connor *et al.*, 2004). The degree of wave exposure influences wave height, as in more exposed areas with a longer fetch waves would be predicted to be higher. As this biotope occurs across a range of exposures, this was therefore considered to indicate, by proxy, that biotopes in the middle of the wave exposure range would tolerate either an increase or decrease in significant wave height at the pressure benchmark.

**Sensitivity assessment.** The biotope is found across a range of wave exposures, mid-range populations are considered to have 'High' resistance to a change in significant wave height at the pressure benchmark. Resilience is assessed as 'High', by default, and the biotope is considered 'Not sensitive'.

## Chemical Pressures

	Resistance	Resilience	Sensitivity
<b>Transition elements &amp; organo-metal contamination</b>	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.

However, exposure to contaminants at levels greater than the benchmark may lead to impacts. Bryan (1984) suggested that the general order for heavy metal toxicity in seaweeds is: Organic Hg > inorganic Hg > Cu > Ag > Zn > Cd > Pb. Cole *et al.* (1999) reported that Hg was very toxic to macrophytes. The sub-lethal effects of Hg (organic and inorganic) on the sporelings of another intertidal red algae, *Plumaria elegans*, were reported by Boney (1971), where 100% growth inhibition was caused by 1 ppm Hg in his study. However, no information concerning the effects of heavy metals on *Palmaria palmata* was found. Heavy metals have the potential to accumulate in plant tissue, therefore it may take some time for tissue levels to fall before recovery can begin.

<b>Hydrocarbon &amp; PAH contamination</b>	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
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This pressure is **Not assessed** but evidence is presented where available.

However, exposure to contaminanats at levels greater than the benchmark may lead to impacts. O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination, possibly due to the susceptibility of phycoerythrins to destruction, but that the filamentous forms were the most sensitive. Laboratory studies of the effects of oil and dispersants on several red algae species, including *Palmaria palmata* (Grandy, 1984 cited in Holt *et al.* 1995) concluded that they were all sensitive to oil/ dispersant mixtures, with little differences between adults, sporelings, diploid or haploid life stages.

<b>Synthetic compound contamination</b>	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
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This pressure is **Not assessed** but evidence is presented where available.

However, exposure to synthetic chemical at levels greater than the benchmark may lead to impacts. O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil contamination, although the filamentous forms were the most sensitive. Laboratory studies of the effects of oil and dispersants on several red algae species, including *Palmaria palmata* (Grandy, 1984 cited in Holt *et al.*, 1995) concluded that they were all intolerant of oil/ dispersant mixtures, with little differences between adults, sporelings, diploid or haploid life stages. Cole *et al.* (1999) suggested that herbicides, such as simazina and atrazine were very toxic to macrophytes. Hoare & Hiscock (1974) noted that all red algae was excluded from Amlwch Bay, Anglesey by acidified halogenated effluent discharge. Such evidence suggests *Palmaria palmata* has high intolerance to synthetic chemicals at levels greater than the benchmark.

<b>Radionuclide contamination</b>	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
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No evidence was found to assess this pressure at the benchmark. Algae bioaccumulate radionuclides (with extent depending on the radionuclide and the algae species). Adverse effects have not been reported at low levels.

### 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**. However, exposure to contaminants at levels greater than the benchmark may lead to impacts.

### De-oxygenation

High

Q: High A: Low C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: Low C: High

This biotope would only be exposed to low oxygen in the water column intermittently during periods of tidal immersion. In addition, in areas of wave exposure and moderately strong current flow, low oxygen levels in the water are unlikely to persist for very long as oxygen levels will be recharged by the incorporation of oxygen in the air into the water column or flushing with oxygenated waters.

Little information on the effects of oxygen depletion on macroalgae was found although Kinne (1972) reports that reduced oxygen concentrations inhibit both photosynthesis and respiration which may affect growth and reproduction. The effects of decreased oxygen concentration equivalent of the benchmark would be greatest during the dark when the macroalgae are dependent on respiration. However, this biotope occurs in the intertidal and *Palmaria palmata* will be able to respire during periods of emersion.

The associated species are unlikely to be impacted by this pressure, at the benchmark. Experiments have shown that thallus discs of *Ulva lactuca* plants can survive prolonged exposure to anoxia and hypoxia (Vermaat & Sand-Jensen, 1987; Corradi *et al.*, 2006). Following resumption of normal oxygen conditions gametes were produced. The associated invertebrate species also show high tolerances for reduced oxygen at levels that exceed the pressure benchmark. *Semibalanus balanoides* can respire anaerobically, so they can tolerate some reduction in oxygen concentration (Newell, 1979). When placed in wet nitrogen, where oxygen stress is maximal and desiccation stress is low, *Semibalanus balanoides* have a mean survival time of 5 days (Barnes *et al.*, 1963). Limpets can also survive for a short time in anoxic seawater; Grenon & Walker, (1981) found that in oxygen free water limpets could survive up to 36 hours, although Marshall & McQuaid (1989) found a lower tolerance for *Patella granularis*, which survived up to 11 hours in anoxic water. *Patella vulgata* are able to respire in air, mitigating the effects of this pressure during the tidal cycle.

**Sensitivity assessment.** As the biotope will only be exposed to this pressure when emersed and respiration of characterizing and associated will occur in air, biotope resistance was assessed as 'High' and resilience as 'High' (no effect to recover from), resulting in a sensitivity of 'Not sensitive'.

### Nutrient enrichment

High

Q: High A: Medium C: Medium

High

Q: High A: Low C: High

Not sensitive

Q: High A: Low C: Medium

This pressure relates to increased levels of nitrogen, phosphorus and silicon in the marine environment compared to background concentrations. The pressure benchmark is set at

compliance with Water Framework Directive (WFD) criteria for good status, based on nitrogen concentration (UKTAG, 2014).

Marine algae are often nutrient limited, by nitrogen in particular, so an increase in nutrient levels usually results in increase growth and fecundity. In the Bay of Fundy, for example, where there is a tidal flux of nutrients from the marshes there is luxurious growth of *Palmaria palmata*. However, very high levels of nutrients can be toxic to macroalgae. Plants placed in tanks with continuous immersion in high nutrients over several weeks stopped growing (Morgan *et al.*, 1980). In general, the great majority of reports refer to an increase in the number of green algae associated with eutrophicated waters, usually at the expense of red and brown algae. In *Palmaria palmata* nitrogen accumulates in the blades when growth does not keep up with uptake (Morgan *et al.*, 1980). Such storage can be particularly important at high latitudes where nutrient availability and light are limited at certain times of the year.

Atalah & Crowe (2010) added nutrients to rockpools. The experimental treatments do not directly relate to the pressure benchmark but indicate some general trends in sensitivity. The rockpools were occupied by a range of algae including encrusting corallines, turfs of *Mastocarpus stellatus*, *Chondrus crispus* and *Corallina officinalis* and green and red filamentous algae. Nitrogen and phosphorous enhancement was via the addition of fertilisers, as either 40 g/litre or 20 g/litre. The treatments were applied for seven months and experimental conditions were maintained every two weeks. Nutrients had no significant effect on the cover of crustose coralline algae or the cover of red turfing algae (Atalah & Crowe, 2010). However, the cover of green filamentous algae increased where grazers were removed (Atalah & Crowe, 2010). The study suggests that, although red algal turfs may be tolerant of eutrophication and may even benefit, biotope composition may alter due to the proliferation of fast growing ephemeral algae.

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

## Organic enrichment

High

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

As this biotopes occurs in wave exposed areas it is considered unlikely to be exposed to the build-up of organic matter (at the pressure benchmark), as wave action will remove organic deposits. The effects of sedimentation of organic matter are therefore not considered relevant to this biotope. Organic enrichment and nutrient enrichment commonly co-occur, for example sewage deposits or outputs from fish farms may enhance nitrogen and phosphorous and organic matter. The effect of inorganic nutrients has more effects on algal communities than inorganic matter which is not assimilated. Deposit and filter feeders within the biotope may benefit from increased organic matter where this can be used as food.

Cabral-Oliveira *et al.*, (2014), found higher abundances of juvenile *Patella* sp. and lower abundances of adults closer to sewage inputs, Cabral-Oliveira *et al.*, (2014) suggested the structure of these populations was due to increased competition closer to the sewage outfalls.

**Sensitivity assessment.** Based on resistance to sedimentation, it is judged that this biotope has 'High' resistance to increased organic matter at the pressure benchmark (which represents enrichment rather than gross pollution). Resilience is therefore assessed as 'High' (no



effect to recover from) and the biotope is considered to be 'Not sensitive'.

(Where resilience is assessed as 'High', confidence in the quality of evidence is assessed as 'High' (based on Hawkins & Harkin, 1985 and Connor *et al.*, 2004), applicability is assessed as 'Low' and concordance as 'High')

## A Physical Pressures

	Resistance	Resilience	Sensitivity
Physical loss (to land or freshwater habitat)	<b>None</b> Q: High A: High C: High	<b>Very Low</b> Q: High A: High C: High	<b>High</b> 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.

	Resistance	Resilience	Sensitivity
Physical change (to another seabed type)	<b>None</b> Q: Low A: NR C: NR	<b>Very Low</b> Q: Low A: NR C: NR	<b>High</b> Q: Low A: Low C: Low

The loss of hard substratum would remove the rock habitat; sediments would be unsuitable for *Palmaria palmata* and other attached algae that characterize this biotope. Other associated species such as barnacles and limpets would also be lost as these are associated with rock habitats.

Artificial hard substratum may also differ in character from natural hard substratum, so that replacement of natural surfaces with artificial may lead to changes in the biotope through changes in species composition, richness and diversity (Green *et al.*, 2012; Firth *et al.*, 2013) or the presence of non-native species (Bulleri & Airoidi, 2005). Rock types may also have indirect effects on distribution. On the Isle of Cumbrae, porous sandstone retains water and probably allows some red algae to grow further up the shore than is typical (Hawkins & Hartnoll, 1985).

**Sensitivity assessment.** Based on the loss of suitable habitat, biotope resistance is assessed as 'None', resilience is assessed as 'Very Low', as the change at the pressure benchmark is permanent. Biotope sensitivity is therefore 'High'.

	Resistance	Resilience	Sensitivity
Physical change (to another sediment type)	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 biotopes occurring on bedrock.

	Resistance	Resilience	Sensitivity
Habitat structure changes - removal of substratum (extraction)	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

The species characterizing this biotope are epiflora and epifauna occurring on rock and would be sensitive to the removal of the habitat. However, extraction of rock substratum is considered

unlikely and this pressure is considered to be 'Not relevant' to hard substratum habitats.

#### Abrasion/disturbance of the surface of the substratum or seabed

**Medium**

Q: Low A: NR C: NR

**High**

Q: High A: Low C: High

**Low**

Q: Low A: Low C: Low

Little information is available on the effects of abrasion on intertidal red algae. Although no reports of the effects of trampling (a source of abrasion) were found for *Palmaria palmata*, Brosnan & Crumrine (1994) found that the foliose red algae *Mastocarpus papillatus* was intolerant of moderate levels of trampling.

**Sensitivity assessment.** The impact of surface abrasion will depend on the footprint, duration and magnitude of the pressure. Biotope resistance, to a single abrasion event is assessed as 'Medium' (<25% of population damaged or removed), as some damage may occur and some fronds may be removed although the bases may remain. Resilience is assessed as 'High', (through regrowth of fronds), so that biotope sensitivity is assessed as 'Low'. Resistance and resilience will be lower (and hence sensitivity greater) to abrasion events that exert a greater crushing force and remove the bases, or that occur at greater intensities and duration.

(Where resilience is assessed as high, confidence in the quality of evidence is assessed as 'High' (based on Hawkins & Harkin, 1985 and Connor *et al.*, 2004), applicability is assessed as 'Low' concordance as High. Where resilience is Medium, it is based on expert judgement (Quality L, applicability and concordance = NR (not relevant))

#### Penetration or disturbance of the substratum subsurface

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

The species characterizing this biotope group are epiflora and epifauna occurring on rock which is resistant to subsurface penetration. The assessment for abrasion at the surface only is therefore considered to equally represent sensitivity to this pressure

#### Changes in suspended solids (water clarity)

**Medium**

Q: High A: Medium C: Medium

**High**

Q: Low A: NR C: NR

**Low**

Q: Low A: Low C: Low

Intertidal biotopes will only be exposed to this pressure when submerged during the tidal cycle and thus have limited exposure. Siltation, which may be associated with increased suspended solids and the subsequent deposition of these is assessed separately (see siltation pressures). In general, increased suspended particles reduce light penetration and increase scour and deposition. They may enhance food supply to filter or deposit feeders (where the particles are organic in origin) or decrease feeding efficiency (where the particles are inorganic and require greater filtration efforts).

Increases in the cover of robust, sediment trapping, turf forming algae at the expense of canopy forming species has been observed worldwide in temperate systems and has been linked to increased suspended solids linked to human activities worldwide (Airoidi, 2003). Increased suspended sediment may also result in increased scour, which may adversely affect foliose red algae, and interfere with settling spores and recruitment if the factor is coincident with their major

reproductive period. However, coralline algae, especially the crustose forms and most likely the crustose holdfasts of other algal turf forming species, including *Palmaria palmata* are considered likely to be resistant of sediment scour (Littler & Kauker, 1984) and regeneration will not be dependent on settlement.

This community is unlikely to be dependent on suspended sediment. Although accumulated sediment within turf habitats is likely to increase the species diversity of the epiphytic fauna, in wave exposed locations, accumulated sediment in the habitat is likely to be minimal. A reduction in suspended sediment will probably reduce the risk of scour, and reduce food availability for the few suspension feeding species in the biotope (e.g. barnacles and spirorbids present), although effects are not likely to be lethal.

Red algae in general are shade tolerant and are common components of the understory on seaweed dominated shores. *Palmaria palmata* is often found under partially shaded conditions as an epiphyte on the stems of *Laminaria* spp. (Morgan *et al.* 1980) in the sublittoral zone (Lüning 1990). Research on light tolerance of *Palmaria palmata* is limited (Bak, 2014), however, red algae are well adapted to low light conditions and so may be tolerant of increased turbidity. In the Bay of Fundy where the tidal flux of nutrients from the marshes includes a high level of suspended sediment, *Palmaria palmata* grows well despite high turbidity. Irvine (1983), observed morphological adaptation of the plant in fairly sheltered, silty conditions; sometimes the blade divisions are wedge-shaped and finely dissected above or the blade has numerous linear divisions throughout. It is likely that this form reduces possible smothering that may result from increased siltation resulting from increased levels of suspended sediments. In the absence of nutrients short-term increase in turbidity may affect growth and reproduction, however, as a perennial, the adults will probably survive.

Although not sensitive to light attenuation, *Palmaria palmata* has relatively thin fronds and may be damaged through scour where levels of suspended sediments are high. On sites affected by high levels of resuspended colliery waste particles, Hyslop *et al.* (1997) found that *Palmaria palmata* and *Ulva* spp. were reduced or absent, although the more tough fucoids were less affected. It is not clear how the levels of suspended solids experienced by these sites relate to the pressure benchmark.

Experiments have shown that the associated green algae, *Ulva* spp. is a shade tolerant genus and can compensate for reduced irradiance by increasing chlorophyll concentration and light absorption at low light levels. *Ulva* spp. was able to survive over two months in darkness and to begin photosynthesising immediately when returned to the light (Vermaat & Sand-Jensen, 1987). Limited shading from suspended sediments is therefore not considered to negatively affect this genus. Therefore, a decrease in light intensity is unlikely to adversely affect the biotope. An increase in light intensity is unlikely to adversely affect the biotope as plants can acclimate to different light levels.

**Sensitivity assessment.** The exposure of biotope to suspended sediments in the water column will be limited to immersion periods, and wave action will reduce accumulation. The biotope is considered to be 'Not sensitive' to a reduction in suspended solids, although this may reduce food supply to the barnacles and other filter and deposit feeders that occur in this biotope. An increase in suspended solids may lead to some abrasion of fronds of *Palmaria palmata* and *Ulva* spp., and biotope resistance is therefore assessed as 'Medium', resilience is assessed as 'High', based on survival of holdfasts. Evidence globally indicates that increases in suspended solids favour robust turf-forming algae such as *Corallina officinalis* (Airoldi, 2003). An increase in suspended solids for

longer periods than a year, may result in a change in species composition with an increase in species seen in very turbid, silty environments e.g. *Ahnfeltia plicata*, *Rhodothamniella floridula*, *Polyides rotunda* and *Furcellaria lumbricalis*.

### Smothering and siltation rate changes (light)

Medium

Q: Low A: NR C: NR

High

Q: High A: Low C: High

Low

Q: Low A: Low C: Low

Sedimentation can directly affect assemblages inhabiting rocky shores through burial/smothering and scour/abrasion of organisms. This biotope occurs low on the shore, in very exposed to moderately exposed conditions. In areas experiencing wave action, excess sediments are likely to be removed from the rock surface within a few tidal cycles, reducing the time of exposure to this pressure.

The state of the tide may mediate the degree of impact on macroalgae. If smothering occurs at low tide when the algae is lying flat on the substratum, then most of the organism as well as the associated community will be covered by the deposition of fine material at the level of the benchmark. Smothering will prevent photosynthesis resulting in reduced growth and eventually death. If however smothering occurs whilst the alga is submerged standing upright some of the fronds may be left uncovered. The resistance of this biotope to the given pressure could therefore vary with time of day.

No empirical evidence was found to assess the sensitivity of the key characterizing species, *Palmaria palmata*, to this pressure. Irvine (1983), observed morphological adaptation of the plant in fairly sheltered, silty conditions; sometimes the blade divisions are wedge-shaped and finely dissected above, or the blade has numerous linear divisions throughout. It is likely that this form reduces possible smothering that may result from increased siltation. However, this adaptation occurs in areas with chronic, relatively low levels of siltation and the blade form is unlikely to confer different levels of resistance to a single deposition event at the pressure benchmark. The perennial holdfasts may survive short periods of siltation, even though fronds may be damaged or removed aiding recovery.

In general, propagules, early post-settlement stages and juveniles suffer severe stress and mortality from sediments (Devlin & Vorse, 1978; Eriksson & Johansson, 2003; Berger *et al.* 2003; Vadas *et al.*, 1992; Airoidi, 2003). Moss *et al.*, (1973), for example, found that growth of zygotes of *Himanthalia elongata* was inhibited by a layer of silt 1-2 mm thick and that attachment on silt was insecure.

Other species within the biotope, particularly limpets are sensitive to sedimentation. Field observations and laboratory experiments have highlighted the sensitivity of limpets to sediment deposition. Airoidi & Hawkins (2007) tested the effects of different grain sizes and deposit thickness in laboratory experiments using *Patella vulgata*. At 1 and 2 mm thicknesses, fine sediments decreased grazing by 40 and 77 % respectively. The addition of approximately 4 mm of fine sediment completely inhibited grazing. Limpets tried to escape the sediment but lost attachment and died after a few days (Airoidi & Hawkins, 2007) Observations on exposed and sheltered shores with patches of sediment around Plymouth in the south west of England confirmed that *Patella vulgata* abundances were higher where deposits were absent. The limpets were locally absent in plots with 50-65 % sediment cover (Airoidi & Hawkins, 2007).

**Sensitivity assessment.** Deposition of 5 cm of fine material (see benchmark) in a single incident will lower survival and germination rates of spores and cause some mortality in early life stages

of *Palmaria palmata* and other algae within the biotope. Adults are more resistant but will experience a decrease in growth and photosynthetic rates. Mortality will be more limited, and possibly avoided, where the smothering sediment is removed due to wave action or tidal streams, depending on how long the sediment remains. Biotope resistance is assessed as 'Medium' and resilience is assessed as 'High' (based on regrowth from holdfasts). So that biotope sensitivity is judged to be 'Low'. It should be noted that the associated.

(Where resilience is assessed as high, confidence in the quality of evidence is assessed as 'High' (based on Hawkins & Harkin, 1985 and Connor *et al.*, 2004), applicability is assessed as 'Low' and concordance as 'High'. Where resilience is 'Medium', it is based on expert judgement (Quality 'Low', applicability and concordance is 'NR' (not relevant))

### Smothering and siltation rate changes (heavy)

**Low**

Q: Low A: NR C: NR

**High**

Q: High A: Low C: High

**Low**

Q: Low A: Low C: Low

No evidence was found to assess this pressure at the benchmark. Sensitivity to this pressure will be mediated by site-specific hydrodynamic conditions and the footprint of the impact. A deposit at the pressure benchmark would cover species with a thick layer of fine materials, however, as this biotope occurs in the lower intertidal on wave exposed shores it is subject to prolonged immersion and silts may be relatively rapidly re-suspended and removed. Where a large area is covered sediments may be shifted by wave and tides rather than removed.

Mortality of red algae is likely to depend on the duration of smothering, where wave action rapidly mobilises and removes fine sediments, survival may be much greater.

Species associated with this biotope such as limpets would not be able to escape from deposits and would likely suffer mortality (see evidence for light siltation). Even the most tolerant of organisms would eventually suffer from inhibition and mortality following smothering although the thresholds for these effects have not been identified (Airoldi, 2003).

The evidence for siltation effects on the associated species, *Patella vulgata*, are outlined above for 'light' deposition. In summary, experiments by Airoldi & Hawkins (2007), supported by field observations, indicate that this species would be unable to escape from sediment deposits of 30cm thickness and would rapidly die.

**Sensitivity assessment.** At the level of the benchmark (30 cm of fine material added to the seabed in a single event), smothering is likely to result in death and removal of red algal fronds, germlings and invertebrate grazers and biotope resistance is assessed as 'Low'. Resilience is assessed as 'High' (based on survival of holdfasts). Overall the biotope has a 'Low' sensitivity to siltation at the pressure benchmark, based on recovery of *Palmaria palmata* via re-growth from holdfasts.

### 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

No evidence (NEv)

Q: NR A: NR C: NR

No evidence (NEv)

Q: NR A: NR C: NR

No evidence.

### Underwater noise changes

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant

### Introduction of light or shading

High

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

The key structuring and characterizing species, *Palmaria palmata*, can colonize a broad range of light environments from intertidal to subtidal and shaded understorey habitats. *Palmaria palmata* appears to be light saturated between 75 and 210  $\mu\text{mol photons m}^2/\text{s}^1$  (Bak, 2014 and references therein) and photoinhibition has been observed at 290  $\mu\text{mol photons m}^2/\text{s}^1$  (Pang & Lüning, 2004).

**Sensitivity assessment.** Based on occurrence beneath canopies, *Palmaria palmata* and other associated species are considered to have 'High' resistance and, by default, 'High' resilience to some shading. The biotope is, therefore, assessed as 'Not sensitive' to this pressure. A change in shading, which severely reduced light penetration would negatively impact *Palmaria palmata* and other algae within the biotope. Very high light levels can also negatively impact algae through photoinhibition.

(Where resilience is assessed as 'High', confidence in the quality of evidence is assessed as 'High' (based on Hawkins & Harkin, 1985 and Connor *et al.*, 2004), applicability is assessed as 'Low' and concordance as 'High').

### Barrier to species movement

High

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

Barriers that reduce the degree of tidal excursion may alter larval supply to suitable habitats from source populations. Conversely the presence of barriers may enhance local population supply by preventing the loss of larvae from enclosed habitats. Barriers and changes in tidal excursion are not considered relevant to the characterizing red algal species, as dispersal is limited by the rapid rate of settlement and vegetative growth from bases rather than reliance on recruitment from outside of populations. Other species associated with the biotope are widely distributed and produce large numbers of larvae capable of long distance transport and survival, resistance to this pressure is assessed as 'High' and resilience as 'High' by default. This biotope is, therefore, considered to be 'Not sensitive'.

### 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
<b>Genetic modification &amp; translocation of indigenous species</b>	<b>High</b> Q: High A: Low C: NR	<b>High</b> Q: High A: High C: High	<b>Not sensitive</b> Q: High A: Low C: Low

The key characterizing species *Palmaria palmata* may be cultivated for use as biofilters and/or food. No information was found on current production in the UK and no evidence was found for the effects of gene flow between cultivated species and wild populations. Experiments by Van der Meer (1987) found that the hybrids of *Palmaria palmata* crosses from Canada and Ireland had vigorous growth and normal morphology, however the tetraspores had lower viability and those that germinated produced abnormal sporelings. It was concluded that populations from Ireland and Canada represent the same species that is in the process of splitting into sibling species. Populations around the UK express different haplotypes (Provan *et al.*, 2005) indicating some genetic variation between populations. Although cultivation of different genotypes may lead to gene flow between wild and cultivated populations the limited dispersal may reduce exposure. Some negative effects may arise from hybridisation between very geographically separated populations but there is no evidence to suggest that gene flow between different UK haplotypes would lead to negative effects.

**Sensitivity assessment.** No direct evidence for genetic effects arising from cultivation and/or translocation of *Palmaria palmata* was found. Translocation of individuals between widely separated areas may lead to hybridisation and changes in genetic structure. Cultivation of *Palmaria palmata* is understood to currently involve collecting spores from locally collected plants in hatcheries or from on-growing locally collected fronds. Where locally collected material is used, as seems usual, resistance is assessed as 'High' and resilience as 'High' so that the biotope is 'Not sensitive'. This assessment may require updating if cultivation methods change and translocate material from geographically separate locations.

(Where resilience is assessed as 'High', confidence in the quality of evidence is assessed as 'High' (based on Hawkins & Harkin, 1985 and Connor *et al.*, 2004), applicability is assessed as 'Low' and concordance as 'High')

	Low	Very Low	High
<b>Introduction or spread of invasive non-indigenous species</b>	Q: Low A: NR C: NR	Q: Low A: NR C: NR	Q: Low A: Low C: Low

Invasive non-indigenous species (INIS) that can alter habitats (ecological engineers), or out-compete native macroalgae for space and other resources such as light and nutrients, are the most likely species to negatively affect this biotope. Space pre-emption by holdfasts may prevent settlement of INIS until disturbance events create gaps for invasion. However, in the Mediterranean crustose corallines and algal turfs facilitate attachment of *Caulerpa racemosa* by providing a more complex substratum than bare rock (Bulleri & Benedetti-Cecchi, 2008).

Algal species which may have overlapping habitat requirements include the green seaweed *Codium fragile* subsp *tormentosoides* (now renamed as *Codium fragile fragile*) and the red



seaweed *Heterosiphonia japonica*, neither of these have so far been recorded in nuisance densities (Sweet, 2011j). Wireweed, *Sargassum muticum* and *Grateloupia turuturu* grows best on sheltered shores and in rockpools (Sewell, 2011c, 2011g) and the wave exposed habitats where this biotope occurs may not be suitable for establishment. The red seaweeds *Heterosiphonia japonica* and *Neosiphonia harveyi* may also occur in this biotope but, again, no impacts have been reported.

The tunicates *Didemnum vexillum* and *Asterocarpa humilis*, the hydroid *Schizoporella japonica* and the bryozoan *Watersipora subatra* (Bishop, 2012c; Bishop, 2015a and b; Wood, 2015) are currently only recorded from artificial hard substratum in the UK and it is not clear what their established range and impacts in the UK would be.

A significant potential INIS is the Pacific oyster *Magallana gigas*, as its distribution and environmental tolerances are considered to overlap with this biotope on moderately exposed shores where this reef forming species can alter habitat structure. This species may also affect the grazers present in the biotope. In the Wadden Sea and North Sea, *Magallana gigas* overgrows mussel beds in the intertidal zone (Diederich, 2005, 2006; Kochmann *et al.*, 2008).

The non-native crab *Hemigrapsus sanguineus* has recently been recorded in the UK (Sweet & Sewell, 2014) and has the potential to be a significant predator of intertidal invertebrates. Significant reductions in common shore crab abundance and mussel density have been reported where the Asian shore crab has achieved high densities in mainland Europe (Sweet & Sewell, 2014). In Rye, New York, declines of approximately 80 % of *Littorina littorea* in the intertidal were reported to coincide with an expansion of the *Hemigrapsus sanguineus* population (Kraemer *et al.*, 2007). This crab occurs on exposed shores and may therefore occur in this biotope when established.

**Sensitivity assessment.** Little evidence was found to assess the impact of INIS on this biotope and much of the evidence comes from intertidal habitats in other countries. The conversion of this biotope to a *Magallana gigas* reef on moderately exposed shores would present a significantly negative impact. Colonization of red algal turfs by other similar species may lead to some subtle effects on local ecology but at low abundances the biotope would still be recognisable from the description. Based on *Magallana gigas*, biotope resistance to this pressure is assessed as 'Low'. The biotope will only recover if these species are removed, either through active management or natural processes. To recognise that recovery may be prolonged, resilience is assessed as 'Very Low' and sensitivity is therefore assessed as 'High'. Where this biotope occurs on exposed or very exposed shores, the level of wave action may prevent colonization by *Magallana gigas*.

#### Introduction of microbial pathogens

High

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

No evidence was found to assess this pressure. The fungal pathogen, *Petersenia palmaria* n. sp (Oomycetes) which infects *Palmaria mollis*, does not affect *Palmaria palmata* (Meer & Poeschel, 1985). Other species associated with this biotope such as, patellid limpets and other algae also experience low levels of infestation by pathogens but mass-mortalities have not been recorded.

**Sensitivity assessment.** Based on the lack of evidence for major pathogens or significant mortalities of the key characterizing species *Palmaria palmata*, this biotope is considered to have 'High' resistance and hence 'High' resilience and is classed as 'Not sensitive' at the pressure benchmark.

**Removal of target species****Low**

Q: High A: High C: Low

**High**

Q: High A: Low C: High

**Low**

Q: High A: Low C: Low

Direct, physical impacts from harvesting are assessed through the abrasion and penetration of the seabed pressures. The sensitivity assessment for this pressure considers any biological/ecological effects resulting from the removal of target species on this biotope. *Palmaria palmata* (known as dulse) is harvested from the wild for human consumption both commercially and recreationally. As the key characterizing and structuring species, extensive removal of *Palmaria palmata* would alter the character of the biotope. Garbary *et al.*, (2012) studied harvested and non-harvested shores in Nova Scotia, Canada containing stands of *Palmaria palmata*. They also conducted experimental removal of *Palmaria palmata* and assessed simulated removal of *Palmaria palmata* by an experienced commercial harvester. Simulated commercial harvesting reduced cover of *Palmaria palmata* from 70% to 40%, although experimental removal on shores not usually harvested reduced cover to 20% (Garbary *et al.*, 2012).

**Sensitivity assessment.** Based on evidence from Garbary *et al.*, (2012), biotope resistance, based on the commercial removal of *Palmaria palmata*, is assessed as 'Low' (removal of 25-75% of cover). Resilience is assessed as 'High' (based on removal by cutting, leaving the holdfast to regenerate) and biotope sensitivity is assessed as 'Low'.

(Where resilience is assessed as 'High', confidence in the quality of evidence is assessed as 'High' (based on Hawkins & Harkin, 1985 and Connor *et al.*, 2004), applicability is assessed as 'Low' and concordance as 'High')

**Removal of non-target species****Low**

Q: Low A: NR C: NR

**Medium**

Q: Low A: NR C: NR

**Medium**

Q: Low A: Low C: Low

Direct, physical impacts from harvesting are assessed through the abrasion and penetration of the seabed pressures. The sensitivity assessment for this pressure considers any biological/ecological effects resulting from the removal of non-target species on this biotope. The biotope is characterized by dense stands of *Palmaria palmata*. The loss of this species due to incidental removal as by-catch would alter the character of the habitat from the biotope description. The ecological services such as primary production and the habitat provided by this species would also be lost.

**Sensitivity assessment.** Removal of a large percentage of the characterizing species, resulting in bare rock would alter the character of the biotope, species richness and ecosystem function. Resistance is, therefore, assessed as 'Low' and resilience as 'Medium', (based on the loss of fronds and holdfasts, but see resilience section for caveats) so that sensitivity is assessed as 'Medium'. If a high proportion of holdfasts remained, recovery would be assessed as 'High' and sensitivity would be assessed as 'Low'. Where resilience is 'Medium', it is based on expert judgement (Quality 'Low', applicability and concordance is 'NR' (not relevant))

## Bibliography

- Airoidi, L., 2003. The effects of sedimentation on rocky coast assemblages. *Oceanography and Marine Biology: An Annual Review*, **41**,161-236
- Airoidi, L. & Hawkins, S.J., 2007. Negative effects of sediment deposition on grazing activity and survival of the limpet *Patella vulgata*. *Marine Ecology Progress Series*, **332**, 235-240.
- Alström-Rapaport, C., Leskinen, E. & Pamilo, P., 2010. Seasonal variation in the mode of reproduction of *Ulva intestinalis* in a brackish water environment. *Aquatic Botany*, **93** (4), 244-249.
- Atalah, J. & Crowe, T.P., 2010. Combined effects of nutrient enrichment, sedimentation and grazer loss on rock pool assemblages. *Journal of Experimental Marine Biology and Ecology*, **388** (1), 51-57.
- Bak, U.G. 2014. Suitable cultivation areas for *Palmaria palmata* (Rhodophyta) and *Saccharina latissima* (Phaeophyceae) in the inner Danish waters in relation to variations in light, temperature and salinity. Roskilde University. MSc thesis
- Bamber, R.N. & Irving, P.W., 1997. The differential growth of *Sabellaria alveolata* (L.) reefs at a power station outfall. *Polychaete Research*, **17**, 9-14.
- Barnes, H., Finlayson, D.M. & Piatigorsky, J., 1963. The effect of desiccation and anaerobic conditions on the behaviour, survival and general metabolism of three common cirripedes. *Journal of Animal Ecology*, **32**, 233-252.
- Beauchamp, E., 2012. Effects of UV radiation and salinity on the intertidal macroalgae *Palmaria palmata* and *Ulva lactuca*; effects on photosynthetic performance, growth and pigments. *The Plymouth Student Scientist*, **5** (1), 3-22.
- Berger, R., Henriksson, E., Kautsky, L. & Malm, T., 2003. Effects of filamentous algae and deposited matter on the survival of *Fucus vesiculosus* L. germings in the Baltic Sea. *Aquatic Ecology*, **37** (1), 1-11.
- Bishop J. 2011b. Orange-tipped sea squirt, *Corella eumyota*. Great Britain Non-native Species Secretariat. [cited 16/06/2015]. Available from: <http://www.nonnativespecies.org>
- Bishop, J. 2012c. Carpet Sea-squirt, *Didemnum vexillum*. Great Britain Non-native Species Secretariat [On-line]. [cited 30/10/2018]. Available from: <http://www.nonnativespecies.org/factsheet/factsheet.cfm?speciesId=1209>
- Bishop, J. 2012b. *Botrylloides violaceus*. Great Britain Non-native Species Secretariat. [On-line] [cited 16/06/2015]. Available from: Bishop, J. 2015a. Compass sea squirt, *Asterocarpa humilis*. Great Britain Non-native Species Secretariat. [On-line] [cited 16/06/2015]. Available from: <<http://www.nonnativespecies.org>
- Bishop, J. 2015b. *Watersipora subatra*. Great Britain Non-native Species Secretariat. [On-line][cited 16/06/2015]. Available from: <<http://www.nonnativespecies.org>
- Boaventura, D., 2000. Patterns of distribution in intertidal rocky shores: the role of grazing and competition in structuring communities. Tese de Doutoramento, Universidade do Algarve.
- Boaventura, D., Da Fonseca, L.C. & Hawkins, S.J., 2003. Size matters: competition within populations of the limpet *Patella depressa*. *Journal of Animal Ecology*, **72** (3), 435-446.
- Boller, M.L. & Carrington, E., 2007. Interspecific comparison of hydrodynamic performance and structural properties among intertidal macroalgae. *Journal of Experimental Biology*, **210** (11), 1874-1884.
- Boney, A.D., 1971. Sub-lethal effects of mercury on marine algae. *Marine Pollution Bulletin*, **2**, 69-71.
- Bowman, R.S. & Lewis, J.R., 1977. Annual fluctuations in the recruitment of *Patella vulgata* L. *Journal of the Marine Biological Association of the United Kingdom*, **57**, 793-815.
- Brosnan, D.M. & Crumrine, L.L., 1994. Effects of human trampling on marine rocky shore communities. *Journal of Experimental Marine Biology and Ecology*, **177**, 79-97.
- Bulleri, F. & Airoidi, L., 2005. Artificial marine structures facilitate the spread of a non-indigenous green alga, *Codium fragile* ssp. *tomentosoides*, in the north Adriatic Sea. *Journal of Applied Ecology*, **42** (6), 1063-1072.
- Bulleri, F. & Benedetti-Cecchi, L., 2008. Facilitation of the introduced green alga *Caulerpa racemosa* by resident algal turfs: experimental evaluation of underlying mechanisms. *Marine Ecology Progress Series*, **364**, 77-86.
- Cabral-Oliveira, J., Mendes, S., Maranhão, P. & Pardal, M., 2014. Effects of sewage pollution on the structure of rocky shore macroinvertebrate assemblages. *Hydrobiologia*, **726** (1), 271-283.
- Chandrasekara, W.U. & Frid, C.L.J., 1998. A laboratory assessment of the survival and vertical movement of two epibenthic gastropod species, *Hydrobia ulvae*, (Pennant) and *Littorina littorea* (Linnaeus), after burial in sediment. *Journal of Experimental Marine Biology and Ecology*, **221**, 191-207.
- Cole, S., Codling, I.D., Parr, W. & Zabel, T., 1999. Guidelines for managing water quality impacts within UK European Marine sites. *Natura 2000 report prepared for the UK Marine SACs Project*. 441 pp., Swindon: Water Research Council on behalf of EN, SNH, CCW, JNCC, SAMS and EHS. [UK Marine SACs Project.], <http://www.ukmarinesac.org.uk/>
- Connor, D.W., Allen, J.H., Golding, N., Howell, K.L., Lieberknecht, L.M., Northen, K.O. & Reker, J.B., 2004. The Marine Habitat Classification for Britain and Ireland. Version 04.05. ISBN 1 861 07561 8. In JNCC (2015), *The Marine Habitat Classification for Britain and Ireland Version 15.03*. [2019-07-24]. Joint Nature Conservation Committee, Peterborough. Available from <https://mhc.jncc.gov.uk/>

- Corradi, M.G., Gorbi, G. & Zanni, C., 2006. Hypoxia and sulphide influence gamete production in *Ulva* sp. *Aquatic Botany*, **84** (2), 144-150.
- Crisp, D.J. (ed.), 1964. The effects of the severe winter of 1962-63 on marine life in Britain. *Journal of Animal Ecology*, **33**, 165-210.
- Davenport, J. & Davenport, J.L., 2005. Effects of shore height, wave exposure and geographical distance on thermal niche width of intertidal fauna. *Marine Ecology Progress Series*, **292**, 41-50.
- Davies, S.P., 1970. Physiological ecology of *Patella* IV. Environmental and limpet body temperatures. *Journal of the Marine Biological Association of the United Kingdom*, **50** (04), 1069-1077.
- Devinny, J. & Volse, L., 1978. Effects of sediments on the development of *Macrocystis pyrifera* gametophytes. *Marine Biology*, **48** (4), 343-348.
- Diederich, S., 2005. Differential recruitment of introduced Pacific oysters and native mussels at the North Sea coast: coexistence possible? *Journal of Sea Research*, **53** (4), 269-281.
- Diederich, S., 2006. High survival and growth rates of introduced Pacific oysters may cause restrictions on habitat use by native mussels in the Wadden Sea. *Journal of Experimental Marine Biology and Ecology*, **328** (2), 211-227.
- Ekaratne, S.U.K. & Crisp, D.J., 1984. Seasonal growth studies of intertidal gastropods from shell micro-growth band measurements, including a comparison with alternative methods. *Journal of the Marine Biological Association of the United Kingdom*, **64**, 183-210.
- Eriksson, B.K. & Johansson, G., 2003. Sedimentation reduces recruitment success of *Fucus vesiculosus* (Phaeophyceae) in the Baltic Sea. *European Journal of Phycology*, **38** (3), 217-222.
- Evans, R.G., 1948. The lethal temperatures of some common British littoral molluscs. *The Journal of Animal Ecology*, **17**, 165-173.
- Faes, V.A. & Viejo, R.M., 2003. Structure and dynamics of a population of *Palmaria palmata* (Rhodophyta) in Northern Spain. *Journal of Phycology*, **39** (6), 1038-1049.
- Firth, L., Thompson, R., Bohn, K., Abbiati, M., Airoidi, L., Bouma, T., Bozzeda, F., Ceccherelli, V., Colangelo, M. & Evans, A., 2014. Between a rock and a hard place: Environmental and engineering considerations when designing coastal defence structures. *Coastal Engineering*, **87**, 122-135.
- Foster, B.A., 1970. Responses and acclimation to salinity in the adults of some balanomorph barnacles. *Philosophical Transactions of the Royal Society of London, Series B*, **256**, 377-400.
- Frazer, A.W.J., Brown, M.T. & Bannister, P., 1988. The frost resistance of some littoral and sub-littoral algae from southern New Zealand. *Botanica Marina*, **31**, 461-464.
- Fretter, V. & Graham, A., 1994. *British prosobranch molluscs: their functional anatomy and ecology*, revised and updated edition. London: The Ray Society.
- Garbary, D.J., Beveridge, L.F., Flynn, A.D. & White, K.L., 2012. Population ecology of *Palmaria palmata* (Palmariales, Rhodophyta) from harvested and non-harvested shores on Digby Neck, Nova Scotia, Canada. *Algae*, **27** (1), 33-42.
- Grandy, N., 1984. *The effects of oil and dispersants on subtidal red algae*. Ph.D. Thesis. University of Liverpool.
- Green, D., Chapman, M. & Blockley, D., 2012. Ecological consequences of the type of rock used in the construction of artificial boulder-fields. *Ecological Engineering*, **46**, 1-10.
- Green, L.A. & Neefus, C.D., 2014. The effects of short- and long-term freezing on *Porphyra umbilicalis* Kutzing (Bangiales, Rhodophyta) blade viability. *Journal of Experimental Marine Biology and Ecology*, **461**, 499-503.
- Grenon, J.F. & Walker, G., 1981. The tenacity of the limpet, *Patella vulgata* L.: an experimental approach. *Journal of Experimental Marine Biology and Ecology*, **54**, 277-308.
- Hawkins, S.J. & Harkin, E., 1985. Preliminary canopy removal experiments in algal dominated communities low on the shore and in the shallow subtidal on the Isle of Man. *Botanica Marina*, **28**, 223-30.
- Hawkins, S.J. & Hartnoll, R.G., 1983. Grazing of intertidal algae by marine invertebrates. *Oceanography and Marine Biology: an Annual Review*, **21**, 195-282.
- Hawkins, S.J. & Hartnoll, R.G., 1985. Factors determining the upper limits of intertidal canopy-forming algae. *Marine Ecology Progress Series*, **20**, 265-271.
- Herbert, R.J.H., Roberts, C., Humphreys, J., & Fletcher, S. 2012. The Pacific oyster (*Crassostrea gigas*) in the UK: economic, legal and environmental issues associated with its cultivation, wild establishment and exploitation. Available from: <http://www.dardni.gov.uk/pacific-oysters-issue-paper.pdf>
- Hiscock, K., ed. 1998. *Marine Nature Conservation Review. Benthic marine ecosystems of Great Britain and the north-east Atlantic*. Peterborough, Joint Nature Conservation Committee.
- Hoare, R. & Hiscock, K., 1974. An ecological survey of the rocky coast adjacent to the effluent of a bromine extraction plant. *Estuarine and Coastal Marine Science*, **2** (4), 329-348.
- Holt, T.J., Jones, D.R., Hawkins, S.J. & Hartnoll, R.G., 1995. The sensitivity of marine communities to man induced change - a scoping report. *Countryside Council for Wales, Bangor, Contract Science Report*, no. 65.
- Hyslop, B.T., Davies, M.S., Arthur, W., Gazey, N.J. & Holroyd, S., 1997. Effects of colliery waste on littoral communities in north-east England. *Environmental Pollution*, **96** (3), 383-400.
- Irvine, L.M., 1983. *Seaweeds of the British Isles* vol. 1. Rhodophyta Part 2A. Cryptonemiales (sensu stricto), Palmariales, Rhodymeniales.

London: British Museum (Natural History).

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

Jorde, I., 1966. Algal associations of a coastal area south of Bergen, Norway. *Sarsia*, **23**, 1-52.

Kain, J.M., & Norton, T.A., 1990. Marine Ecology. In *Biology of the Red Algae*, (ed. K.M. Cole & Sheath, R.G.). Cambridge: Cambridge University Press.

Karsten, U., Dummermuth, A., Hoyer, K. & Wiencke, C., 2003. Interactive effects of ultraviolet radiation and salinity on the ecophysiology of two Arctic red algae from shallow waters. *Polar Biology*, **26** (4), 249-258.

Kinne, O. (ed.), 1972. *Marine Ecology: A Comprehensive, Integrated Treatise on Life in Oceans and Coastal Waters*, Vol.1, *Environmental Factors*, part 3. New York: John Wiley & Sons.

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

Kraemer, G.P., Sellberg, M., Gordon, A. & Main, J., 2007. Eight-year record of *Hemigrapsus sanguineus* (Asian shore crab) invasion in western Long Island sound estuary. *Northeastern Naturalist*, **14** (2), 207-224.

Littler, M.M., & Kauker, B.J., 1984. Heterotrichy and survival strategies in the red alga *Corallina officinalis* L. *Botanica Marina*, **27**, 37-44.

Lubchenco, J., 1980. Algal zonation in the New England rocky intertidal community: an experimental analysis. *Ecology*, **61**, 333-344.

Lüning, K., 1990. *Seaweeds: their environment, biogeography, and ecophysiology*: John Wiley & Sons.

MacFarlane, C.I., 1952. A survey of certain seaweeds of commercial importance in southwest Nova Scotia. *Canadian Journal of Botany*, **30**, 78-97.

Marshall, D.J. & McQuaid, C.D., 1989. The influence of respiratory responses on the tolerance to sand inundation of the limpets *Patella granularis* L.(Prosobranchia) and *Siphonaria capensis* Q. et G.(Pulmonata). *Journal of Experimental Marine Biology and Ecology*, **128** (3), 191-201.

Van der Meer, J., 1987. Experimental hybridization of *Palmaria palmata* (Rhodophyta) from the northeast and northwest Atlantic Ocean. *Canadian Journal of Botany*, **65** (7), 1451-1458.

Morgan, K.C., Shacklock, P.F. & Simpson, F.J., 1980. Some aspects of the culture of *Palmaria palmata* in greenhouse tanks. *Botanica Marina*, **23**, 765-770.

Moss, B., Mercer, S., & Shearer, A., 1973. Factors Affecting the Distribution of *Himantalia elongata* (L.) S.F. Gray on the North-east Coast of England. *Estuarine and Coastal Marine Science*, **1**, 233-243.

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

Norton, T.A., 1992. Dispersal by macroalgae. *British Phycological Journal*, **27**, 293-301.

O'Brien, P.J. & Dixon, P.S., 1976. Effects of oils and oil components on algae: a review. *British Phycological Journal*, **11**, 115-142.

Pang, S. & Lüning, K., 2004. Tank cultivation of the red alga *Palmaria palmata*: Effects of intermittent light on growth rate, yield and growth kinetics. *Journal of Applied Phycology*, **16** (2), 93-99.

Provan, J., Murphy, S. & Maggs, C.A., 2005. Tracking the invasive history of the green alga *Codium fragile* ssp. *tomentosoides*. *Molecular Ecology*, **14**, 189-194.

Reed, R.H. & Russell, G., 1979. Adaptation to salinity stress in populations of *Enteromorpha intestinalis* (L.) Link. *Estuarine and Coastal Marine Science*, **8**, 251-258.

Ribeiro, P.A., Xavier, R., Santos, A.M. & Hawkins, S.J., 2009. Reproductive cycles of four species of *Patella* (Mollusca: Gastropoda) on the northern and central Portuguese coast. *Journal of the Marine Biological Association of the United Kingdom*, **89** (06), 1215-1221.

Robbins, J.V., 1978. Effects of physical and chemical factors on photosynthetic and respiratory rates of *Palmaria palmata* (Florideophyceae), In *Proceedings of the ninth International Seaweed Symposium, Santa Barbara, California, USA, 20-27 August 1977*, (ed. Jensen, A. & Stein, J.R.), 273-283. Science Press, Princeton, NJ, USA.

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

Sewell, J. 2011c. Wireweed, *Sargassum muticum*. *Great Britain Non-native Species Secretariat*. [cited 16/06/2015]. Available from: <<http://www.nonnativespecies.org>

Southward, A.J., Hawkins, S.J. & Burrows, M.T., 1995. Seventy years observations of changes in distribution and abundance of zooplankton and intertidal organisms in the western English Channel in relation to rising sea temperature. *Journal of Thermal Biology*, **20**, 127-155.

Sweet, N.S. 2011j. Green sea-fingers (tomentosoides), *Codium fragile* subsp. *tomentosoides*. *Great Britain Non-native Species Secretariat*. [cited 16/06/2015]. Available from: <<http://www.nonnativespecies.org>

Sweet, N.S. 2011g. Devil's Tongue Weed, *Grateloupia turuturu*. *Great Britain Non-native Species Secretariat*. [cited 16/06/2015]. Available from: