



# MarLIN

## Marine Information Network

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

# *Ascophyllum nodosum*, sponges and ascidians on tide-swept mid 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/100>]. All terms and the MarESA methodology are outlined on the website (<https://www.marlin.ac.uk>)

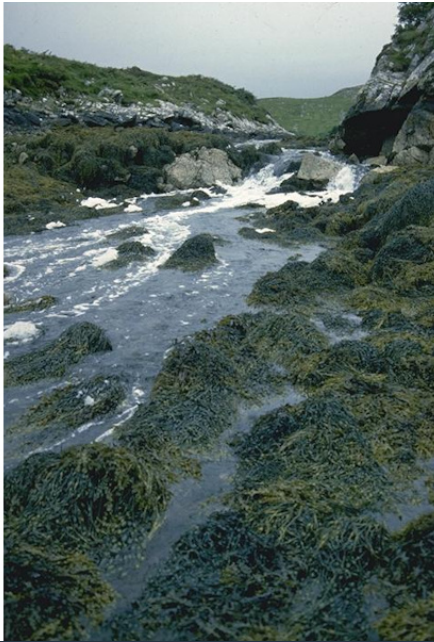
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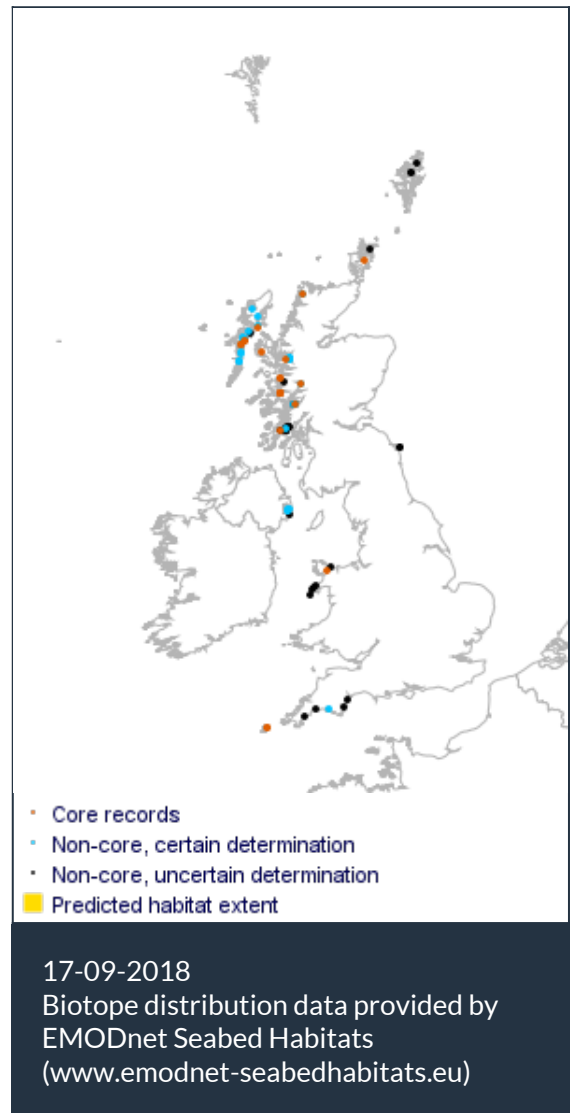


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*Ascophyllum nodosum*, sponges and ascidians on tide-swept mid eulittoral rock  
 Photographer: Rohan Holt  
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Researched by Frances Perry & Charlotte Marshall

Refereed by This information is not refereed.

## Summary

### ☰ UK and Ireland classification

EUNIS 2008	A1.151	<i>Ascophyllum nodosum</i> , sponges and ascidians on tide-swept mid eulittoral rock
JNCC 2015	LR.HLR.FT.AscT	<i>Ascophyllum nodosum</i> , sponges and ascidians on tide-swept mid eulittoral rock
JNCC 2004	LR.HLR.FT.AscT	<i>Ascophyllum nodosum</i> , sponges and ascidians on tide-swept mid eulittoral rock
1997 Biotope	LR.SLR.F.Asc.T	<i>Ascophyllum nodosum</i> , sponges and ascidians on tide-swept mid eulittoral rock

### 🔍 Description

Very sheltered to extremely sheltered areas of mid eulittoral rock that are subject to strong to moderate tidal streams, such as the narrows in sea lochs, and characterized by the wrack

*Ascophyllum nodosum*. The wracks *Fucus vesiculosus* and *Fucus serratus* are occasionally present. The increased water movement encourages a rich associated fauna including several filter-feeding groups. These include the sponges *Leucosolenia* spp., *Grantia compressa*, *Halichondria panicea* and *Hymeniacidon perleve* which frequently occur on steep and overhanging faces of boulders and bedrock. It also includes the sea squirts *Dendrodoa grossularia* and *Asciidiella scabra*, which occur on steep surfaces and beneath boulders. Hydroids such as the pink *Clava multicornis* can form colonies on *Ascophyllum nodosum* while *Dynamena pumila* is more often found on *Fucus vesiculosus* or *Fucus serratus*. Underneath the canopy formed by the brown seaweeds is a diverse community of the red seaweeds *Gelidium pusillum*, *Chondrus crispus*, *Lomentaria articulata*, *Membranoptera alata* and coralline crusts, but the green seaweeds *Ulva* (syn. *Enteromorpha*) *intestinalis*, *Ulva lactuca* and *Cladophora rupestris* can be present. The filamentous red seaweed *Polysiphonia lanosa* can usually be found growing on *Ascophyllum nodosum*. On the rock beneath are the limpet *Patella vulgata* and the barnacle *Semibalanus balanoides*, while the crab *Carcinus maenas* and a variety of winkles including *Littorina littorea*, *Littorina mariae* and *Littorina obtusata* can be found on or among the boulders. The whelk *Nucella lapillus* can either be found in cracks and crevices or preying on the barnacles. (Information taken from the revised Marine Biotope Classification, Version 04.06, Connor *et al.*, 2004).

## ↓ Depth range

Mid shore

## 🏛️ Additional information

-

## ✓ Listed By

- none -

## 🔗 Further information sources

Search on:



## Habitat review

### 🔄 Ecology

#### Ecological and functional relationships

The moderately strong to very strong tidal streams associated with this biotope support a rich and varied marine life, of which the suspension feeders and autotrophs are the dominant trophic groups. *Ascophyllum nodosum*, the knotted wrack, forms a canopy in this biotope. The serrated wrack *Fucus serratus* and bladder wrack *Fucus vesiculosus* may also form part of this canopy but the long lived *Ascophyllum nodosum* tends to dominate in terms of abundance and standing biomass. The canopy layer limits light penetration and the understory is dominated by shade tolerant foliose and red seaweeds including *Chondrus crispus*, *Corallina officinalis*, *Mastocarpus stellatus* and encrusting calcareous algae. The filamentous red seaweed *Polysiphonia lanosa* is possibly the most commonly occurring red algal species in this biotope. It has root like fibres which penetrate the tissue of *Ascophyllum nodosum* and, less frequently, *Fucus* sp. (Fish & Fish, 1996). Green algae, especially *Ulva* sp. and *Cladophora rupestris* may also be found.

Suspension feeders representing several phyla are commonly associated with this biotope. Representatives of the sponge and ascidian communities, that give the biotope its name, are varied and diverse. Both encrusting sponges, including the breadcrumb sponge *Halichondria panicea* and *Hymeniacidon perleve*, and solitary forms such as the purse sponge *Grantia compressa* are found. Similarly, both colonial and solitary ascidians are found although the baked bean ascidian *Dendrodoa grossularia*, for example, is far more abundant and frequently associated with this biotope than the colonial star ascidian *Botrylloides leachi*. Large stands of hydroids may be found on the fucoids including *Dynamena pumila* and the pink hydroid *Clava multicornis*. In general, *Ascophyllum nodosum* is remarkably free of epiphytes even when adjacent plants of other species of fucoid algae are heavily infested (Filion-Myalebust & Norton, 1981). This is due to the fact that *Ascophyllum nodosum* repeatedly sloughs its entire outer epidermis, and potential epiphytes, including spores and germlings of other algae that had settled on the surface are, therefore, discarded with it (Filion-Myalebust & Norton, 1981).

A variety of winkles, most commonly the common periwinkle *Littorina littorea* and flat periwinkle *Littorina obtusata* graze on microorganisms, detritus and algae in this biotope. Whilst the common periwinkle grazes on rock in the biotope, *Ascophyllum nodosum* is the preferred food for the flat periwinkle (Fish & Fish, 1996). The flat periwinkle lays its eggs on *Ascophyllum nodosum*, *Fucus vesiculosus* and *Fucus serratus* and, occasionally, on the rock surface (Fish & Fish, 1996). The common limpet *Patella vulgata* can be abundant and grazes on tough plants including *Fucus* sp. and encrusting red algae. Grazing by *Patella vulgata* can be an important structuring feature on rocky shores and is often considered to be a keystone species on north-east Atlantic rocky shores. Reductions in limpet density have been observed to have a significant impact on rocky shore community composition, particularly of fucoid algae and barnacles (Hawkins & Hartnoll, 1985; Raffaelli & Hawkins, 1999).

The common shore crab *Carcinus maenas* is the largest mobile predator frequently associated with this biotope and is likely to move between the boulders and pebbles feeding primarily on small molluscs, especially *Littorina* sp. and the common mussel *Mytilus edulis*, annelids and other crustacea. It is an omnivore and will also consume algal material. The predatory mollusc *Nucella lapillus* also feeds primarily on the common mussel, in addition to acorn barnacles (Fish & Fish, 1996) such as *Semibalanus balanoides* which can also be abundant in the biotope.

## Seasonal and longer term change

*Ascophyllum nodosum* can reach an age of 25 years and the community associated with this biotope is usually very stable (Connor *et al.*, 2004). There are unlikely to be large visible changes in the biotope throughout the year, especially since the biotope occurs in very sheltered / extremely sheltered habitats where winter storms are unlikely to have as significant an effect on the algal standing biomass as wave exposed shores. However, an increase in ephemeral algae such as *Cladophora rupestris* may be observed over the summer months.

## Habitat structure and complexity

Owing to the tidally swept habitat with which this biotope is associated, a diverse marine life is supported. The fast currents provide a continual supply of food for both active and passive suspension feeders that dominate the attached fauna. Fine sediment is removed by the current and the settlement of material, that could otherwise be detrimental to the suspension feeders, is prevented. Almost every possible substratum, including the bedrock, boulders, cobbles and overhanging faces, is covered with various flora and fauna. In addition to the luxuriant conditions for suspension feeders, Hiscock (1983) lists some the benefits of strong water movement to include the potential for a greater photosynthetic efficiency, thereby possibly increasing the depth penetration of the algae. Increased water movement has been associated with an increase in photosynthesis in several algal species including *Fucus serratus* and *Ascophyllum nodosum* (Robins, 1968, cited in Hiscock, 1983).

The algae themselves provide a substratum for epiphytic species including hydroid, sponge and ascidian communities. *Leucosolenia* sp., for example, are often found on red seaweeds. The hydroid *Dynamena pumila* may grow on several *Fucus* species whereas the spirorbid worm *Spirorbis spirorbis* grows preferentially on *Fucus serratus*. The fronds of *Ascophyllum nodosum*, however, are narrow, flexible and slimy, offering a poor support for most encrusting animals. The species is unattractive to most intertidal species with the exception of the pink hydroid *Clava multicornis*, the bryozoan *Bowerbankia imbricata* and, on sheltered shores, the tube worm *Spirorbis spirorbis*. *Ascophyllum nodosum* also supports the red algae *Polysiphonia lanosa*, which penetrates its fronds with root-like fibres.

Rock surfaces may, depending on their geology, be broken and include shaded overhangs and damp crevices which, together with the shelter of the algal canopy, allow many animal species to thrive in the damp conditions.

## Productivity

Rocky shore communities are highly productive and are an important source of food and nutrients for members of neighbouring terrestrial and marine ecosystems (Hill *et al.*, 1998). Rocky shores make a contribution to the food of many marine species through the production of planktonic larvae and propagules which contribute to pelagic food chains. Production rates of *Ascophyllum nodosum* in Nova Scotia were estimated to be between 0.61 and 2.82 kg/m (Cousens, 1984). Raffaelli & Hawkins (1999) reported an estimate of the productivity of intertidal fucoids as 160 gC/m/year, although this figure was an estimate for moderately wave exposed habitats. The fucoids and other macroalgae associated with this biotope can exude dissolved organic carbon, which is taken-up readily by bacteria and may even be taken-up directly by some larger invertebrates. Dissolved organic carbon, algal fragments and microbial film organisms are continually removed by the sea. This may enter the food chain of local subtidal ecosystems, or be

exported further offshore. Many of the species associated with this biotope make a contribution to the food of many marine species through the production of planktonic larvae and propagules, which contribute to pelagic food chains.

### Recruitment processes

- *Ascophyllum nodosum* is dioecious and, like all other fucoids, has only a sexual generation. Receptacles are initiated in April, are present on the plant for 12-14 months and ripen in April to June of the following year. Gametes are released from April onwards. In the laboratory, the release of gametes can be triggered by exposing ripe receptacles to air overnight. Fertilization takes place externally and zygotes settle and form a rhizoid within ten days. Recruitment in *Ascophyllum nodosum* is very poor with few germlings found on the shore. The reason for this poor recruitment is unclear, because the species invests the same high level of energy in reproduction as other fucoids and is extremely fertile every year (Printz, 1959). However, the reproductive period lasts about two months, much shorter than for other fucoids. Printz (1959) suggests that it must be assumed that some special combination of climatic or environmental conditions is needed for effective colonization by *Ascophyllum nodosum*. The slow growth rate of germlings, which increases the chance of their being covered by diatoms or grazed by gastropods, may also help to explain the scarcity of germlings (Baardseth, 1970).
- Reproduction in *Fucus serratus* commences in late spring and continues until November, with a peak in August and October. Eggs and sperm are produced separately and fertilized externally to form a planktonic zygote. Recruitment is therefore possible from sources outside the biotope. *Fucus vesiculosus* is highly fecund often bearing more than 1000 receptacles on each plant, which may produce in excess of one million eggs. In England, the species has a protracted reproduction period of about six months. Gametes may be produced from mid winter until late summer with a peak of fertility in May and June. Like *Fucus serratus*, the eggs are fertilized externally to produce a zygote. Zygotes start to develop whenever they settle, even if the substratum is entirely unsuitable. Mortality is extremely high in the early stages of germination up to a time when plants are 3 cm in length and this is due mostly to mollusc predation (Knight & Parke, 1950).
- *Chondrus crispus* has an extended reproductive period (e.g. Pybus, 1977; Fernandez & Menendez, 1991; Scrosati *et al.*, 1994) and produces large numbers of spores (Fernandez & Menendez, 1991). The spores of red algae are non-motile (Norton, 1992) and therefore entirely reliant on the hydrographic regime for dispersal. Hence, it is expected that *Chondrus crispus* would normally only recruit from local populations and that recovery of remote populations would be much more protracted.
- The breadcrumb sponge *Halichondria panicea* is likely to have a short, annual season of sexual reproduction (see MarLIN review).
- *Patella vulgata* become sexually mature as males aged about nine months. Reproduction is an annual process with peaks within a defined spawning season (October - January) depending on location. Planktonic trophic larvae are produced although the larvae are only planktonic for a few days.
- *Asciella scabra* has a high fecundity and settles readily, probably for an extended period from spring to autumn. Eggs and larvae are free-living for only a few hours and so recolonization would have to be from existing individuals no more than a few km away. It is also likely that *Asciella scabra* larvae are attracted by existing populations and settle near to adults (Svane *et al.*, 1987).
- The flat periwinkle *Littorina obtusata* are capable of reproducing through out the year (Graham, 1988). Eggs are laid in a jelly mass, usually on the fronds of *Fucus* species and

hatch three or four weeks later (Goodwin, 1978, cited in Graham, 1988). Recruitment from external sources would therefore rely on the movement of adults into the area.

### Time for community to reach maturity

*Ascophyllum nodosum* is a long lived, slow growing algae with poor recruitment rates that limit recovery (Holt *et al.*, 1997). The lack of recovery of *Ascophyllum nodosum* from harvesting is well documented. For example, in their work on furoid recolonization of cleared areas at Port Erin, Knight and Parke (1950) observed that even eight years after the original clearance there was still no sign of the establishment of an *Ascophyllum nodosum* population. In terms of community maturation however, recoverability is likely to take significantly longer. Jenkins *et al.* (2004) studied the long-term effects of *Ascophyllum nodosum* canopy removal on the whole understory community structure on a sheltered rocky shore on the Isle of Man. They reported that, even after twelve years, major effects of the canopy removal were still apparent. At the culmination of the study, the emerging canopy was a mixture of *Ascophyllum* and *Fucus serratus* with occasional patches of *Fucus vesiculosus*. Despite some recovery, mean cover of *Ascophyllum nodosum* was still only about 50% of its original level compared with control plots. However, the most alarming changes were evident in the understory community. Previously, this community was characterized by a balance between patches of red algal turf and patches grazed by *Patella vulgata*. Removal of the canopy layer broke down the balance between these two 'functional units' to the extent that the community showed no signs of reverting to its pre-disturbance state. In a cascade of events, the red algal turf deteriorated from the lack of canopy protection which in turn increased the available area for limpet grazing, thereby increasing the limpet population.

The time for this biotope to reach maturity is therefore likely to depend on the circumstance under which the community changed in the first place. For example, it would depend on what species had been lost or reduced in abundance. Starting from bare substratum, the time taken for this biotope to reach maturity is likely to be at least fifteen years and under certain circumstances may take significantly longer.

### Additional information

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## Preferences & Distribution

### Habitat preferences

<b>Depth Range</b>	Mid shore
<b><a href="#">Water clarity preferences</a></b>	
<b>Limiting Nutrients</b>	Data deficient
<b>Salinity preferences</b>	Full (30-40 psu), Variable (18-40 psu)
<b>Physiographic preferences</b>	Strait / sound
<b>Biological zone preferences</b>	Eulittoral
<b>Substratum/habitat preferences</b>	Bedrock, Cobbles, Large to very large boulders, Small boulders
<b>Tidal strength preferences</b>	Moderately Strong 1 to 3 knots (0.5-1.5 m/sec.), Strong 3 to 6 knots (1.5-3 m/sec.), Very Strong > 6 knots (>3 m/sec.)
<b>Wave exposure preferences</b>	Extremely sheltered, Sheltered, Very sheltered



**Other preferences**

Moderately strong to very strong tidal streams.

**Additional Information**

This biotope is found exclusively in tide-swept areas with a moderately strong to strong water flow. In the Menai Strait, for instance, water flow rates can reach 8 knots (Brazier *et al.*, 1999).

** Species composition****Species found especially in this biotope****Rare or scarce species associated with this biotope**

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**Additional information**

## Sensitivity review

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

The community within this biotope is dominated by a canopy by the characterizing species *Ascophyllum nodosum*. The furoids *Fucus vesiculosus* and *Fucus serratus* can occasionally contribute to the canopy. Sheltered by the canopy a number of red algae can be common; *Gellidium pusillum*, *Chondrus crispus*, *Lomentaria articulata*, *Membranoptera alata* as well as species of coralline crusts. The red seaweed *Polysiphonia lanosa* is a common epiphyte on *Ascophyllum nodosum*. The green seaweeds *Ulva* (syn. *Enteromorpha*) *intestinalis*, *Ulva lactuca* and *Cladophora rupestris* can be found within this biotope. The high levels of water movement within this biotope caused by tidal streams create conditions for a rich associated community. The sponges *Leucosolenia* spp., *Grantia compressa*, *Halichondria panacea* and *Hymeniacidon perleve*, as well as the ascidians *Dendrodoa grossularia* and *Asciella scabra* frequently occur on steep and overhanging faces of boulders and bedrock. Colonies of the hydroid *Clava multicornis* can be found on *Ascophyllum nodosum* whereas *Dynamena pumila* is more often found on *Fucus vesiculosus* or *Fucus serratus*. The limpet *Patella vulgata* the barnacle *Semibalanus balanoides* and the littorinids *Littorina littorea*, *Littorina mariae* and *Littorina obtusata* are occasionally found attached to the rock. The crab *Carcinus maenas* and the whelk *Nucella lapillus* are the mobile predators within this biotope (Connor *et al.*, 2004).

*Ascophyllum nodosum* is the key structuring species of this biotope. This species acts as an ecosystem engineer and the canopy that its fronds create modify habitat conditions. Although *Fucus vesiculosus* and *Fucus serratus* are important to the biotope, if these species were missing from the biotope could still exist. The canopy provided by the furoid protects the various underlying seaweeds from desiccation in addition to providing a substratum for epifauna and being the primary food resource for grazers. This can facilitate the existence and survival of other intertidal species and therefore strongly influencing the structure and functioning of intertidal ecosystems (Jenkins *et al.*, 2008). Therefore, the sensitivity assessment is based on the key structuring species (*Ascophyllum nodosum*), although the sensitivity of other species is addressed where relevant.

### Resilience and recovery rates of habitat

*Ascophyllum nodosum* has been reported to survive for over 100 years in areas free from ice scour (Åberg, 1992). However, individual fronds are more likely to last for 15 -20 years after which they will break off, and new fronds will regenerate from the holdfast. The average age within populations of *Ascophyllum nodosum* is high, and there is little population turn over (Schiel & Foster, 2006). *Ascophyllum nodosum* takes five years to become sexually mature (Sundene 1973). Within a mature stand of *Ascophyllum nodosum*, as many as  $10^9$  eggs  $m^{-2} years^{-1}$  may be produced (Åberg & Pavia 1997). However, Dudgeon & Petraitis (2005) estimate that it will take a minimum of 13 years for an individual to replace itself. This is due to high mortality rates of germlings. Lazo *et al.* (1994) found that predation by grazers can reduce annual recruit survival rates to 0.01%. Other factors which affect the survival rates of recruited *Ascophyllum nodosum* include their susceptibility to sedimentation (Airoldi, 2003), ability to tolerate desiccation at low tide (Brawley & Johnson, 1991) and inter and intraspecific density dependent competition of germlings (Choi & Norton, 2005).

The investigation by Choi & Norton (2005) looks at the competitive interactions between the germlings of *Ascophyllum nodosum* and *Fucus vesiculosus*. Experiments undertaken on the Isle of Man and in a laboratory found that with an increasing density of germlings, growth rates of both

species decreased. Of the two species, *Ascophyllum nodosum* germlings grew slower and were least competitive in mixed cultures. This finding was mirrored in earlier experiments undertaken by Sundene (1973). Sundene (1973) noted that the production of sexual cells in *Ascophyllum nodosum* was as rapid as it was in *Fucus vesiculosus*, but that it was the growth rates of *Ascophyllum nodosum* which led to *Fucus vesiculosus* being more competitive on the shore. Choi & Norton (2005) also found that the presence of *Fucus vesiculosus* increased the survival of *Ascophyllum nodosum* when exposed to desiccation stress. This showed that under different environmental conditions the presence of a mixed culture could either facilitate germling survival or lead to competitive exclusion (Choi & Norton, 2005). Competition is reversed in mature ecosystems where *Ascophyllum nodosum* plants can out-compete Fucoids (Keser *et al.*, 1981).

Lamote & Johnson (2008) studied temporal and spatial variation in recruitment of fucoid algae (including *Ascophyllum nodosum*). They found that recruitment to artificial substrata located in different microhabitats along a semi-exposed shore was noticeably different. Under the fucoid canopy in the study area, recruitment was 10-50 times greater than it was on exposed surfaces and in tide pools. To determine if this difference was due to lower levels of mortality under the canopy or to restricted distribution capacity, newly settled recruits from under the canopy were relocated to alternative microhabitats. Mortality rates of the relocated germlings were higher in the more exposed locations, however, the difference was not great enough to explain the observed difference in the number of germlings within the two different microhabitats. Lamote & Johnson (2008) concluded that the number of recruits was greater from under the fucoid canopy because of restricted distribution abilities.

*Ascophyllum nodosum* has a low dispersal capacity which means re-colonization of a shore after a mass mortality event can be extremely slow. It can also limit the speed at which the species recovers from a partial die back. *Ascophyllum nodosum*'s poor dispersal ability has been widely acknowledged and the reasons behind it have been well studied. Experiments on the effect of wave action on *Ascophyllum nodosum* showed that a low-velocity wave can remove 99% of 15 minute old zygotes from experimental tiles Vadas *et al.* (1990). Further investigation with the use of refuges found that 75-90% of zygotes as old as four hours could be removed by a single wave. Current speeds of over 20 cm/s<sup>-1</sup> make attachment success of *Ascophyllum nodosum* very poor (Vadas *et al.*, 1992). Therefore, calm conditions are required for successful recruitment in *Ascophyllum nodosum*.

The current and historic commercial interest in *Ascophyllum nodosum* has resulted in recovery times for this species being well documented. Keser *et al.*, (1981) recorded the levels of re-growth exhibited by *Ascophyllum nodosum* and *Fucus vesiculosus* after harvesting activity in Maine. Harvesting was simulated by cutting fronds to three different lengths; frond removed to the holdfast, 15 cm from the holdfast and 25 cm from the holdfast. Subsequent harvesting was repeated annually for three years. The experiment was carried out at eight sites, six of which were in sheltered areas. Re-growth of *Ascophyllum nodosum* was found to be dependent on a number of variables. These included; the age structure of the population, the extent and pattern of branching with a clump, the presence or absence of grazers (importantly *Littorina littorea*), and the environmental conditions (recovery was found to be more rapid in estuaries) (Keser *et al.*, 1981). Of the fronds which were cut back to the holdfast, only those within sheltered, estuarine and grazer free conditions showed any re-growth. More mature *Ascophyllum nodosum* fronds cut back to 15 cm and 25 cm within a sheltered site showed some re-growth; however, there were high rates of mortality. The lack of re-growth was suggested to be caused by a lack of functional growing points found towards the bottom of the frond in older individuals. 95% of young *Ascophyllum nodosum* individuals cut back to 15 cm and 25 cm re-grew. The detrimental impact of

annual harvests on *Ascophyllum nodosum* populations was shown through the results of this investigation. In almost all populations measured within the experiment, repeat harvests resulted in lower biomass yields (Keser *et al.*, 1981).

Slow re-growth of *Ascophyllum nodosum* after harvesting from the holdfast has also been reported by Baardseth (1970). The harvest of *Ascophyllum nodosum* from areas of the bed, by scrapping it from the substratum, were found to destroy beds for extended periods of time. On shores where *Ascophyllum nodosum* had been removed, re-colonization was dominated by *Fucus vesiculosus*, with very little recovery of *Ascophyllum nodosum*. When artificial substrata, such as sea walls, are introduced into an intertidal area *Ascophyllum nodosum* can take many years to colonize it. When the colonization and succession of a breakwater built in Norway were recorded the first species to appear were *Fucus vesiculosus* and *Fucus spiralis* (Baardseth, 1970). It took two years for occasional *Ascophyllum nodosum* individuals to appear on the breakwater, and after eight years there was still no distinct *Ascophyllum nodosum* zone. Another breakwater studied had an established *Ascophyllum nodosum* zone after 30 years (Knight & Parke, 1950).

Printz (1956) also carried out harvesting experiments where fronds were cut back to 25 cm, 15 cm and 5 cm. Results showed that those individuals that had been cut back to 25 cm had an 'abundance of new shoots' and had grown to 30-35 cm in length after a year. Those algae which had been trimmed back to 5 cm showed almost no change a year after a harvesting event had been simulated. When the 5 cm individuals were re-visited three years after the harvesting event they were still almost unaltered. The reasons for the lack of re-growth were attributed to the lack of regenerative tissue found in the older flesh found further down the thallus (Printz, 1956).

Mass mortality events caused by changes in the physical environment have been observed in *Ascophyllum nodosum*. A total mortality event of an *Ascophyllum nodosum* population occurred within the Long Island Sound in 1984 (caused by water temperatures from two power plant thermal discharge pipes exceeding 28 °C) (Keser *et al.*, 2005). From 1984 onwards temperatures at the site fluctuated with the opening of a third thermal discharge pipe and the closing and reopening of the pipes all three pipes. However, in the 18 years since the mortality event and the end of Keser *et al.*'s. (2005) study, there has been no recovery of the population. Keser *et al.*, (2005) reported that similar mortality events have been observed near other power plant thermal discharge pipes in Maine (Vadas *et al.*, 1978) and Massachusetts (Wilce *et al.*, 1978).

Printz (1956) indicated that a number of other studies (unreferenced in the paper) reported similar findings. Other studies which have concluded that *Ascophyllum nodosum* takes long periods of time to recover from removal include Bertness *et al.* (2002), Jenkins *et al.* (1999, 2004); Petraitis & Dudgeon, (2005). Ingólfsson & Hawkins (2008) sum up the findings from previous studies on *Ascophyllum nodosum* re-colonization times within their discussion where they state 'the partial recovery of the *Ascophyllum nodosum* canopy after a 12 year period is consistent with some very early studies'. The twenty year study undertaken by Ingólfsson and Hawkins (2008) found that after removing an *Ascophyllum nodosum* community, the canopy could return within the study time period, yet the understory communities had still not recovered after 20 years. There is a considerable amount of evidence that suggests that when *Ascophyllum nodosum* fronds are cut higher up the thallus recovery times are reduced considerably to two to three years (Ang *et al.*, 1996; Fegley, 2001; Keser *et al.*, 1981; Sharp, 1987; Ugarte *et al.*, 2006) (taken from Phillipi *et al.*, 2014). However, the effect of this kind of canopy removal on the understory community is not known and neither is the recovery time.

Svensson *et al.*, (2009) compared the population growth of *Ascophyllum nodosum* from two shores,

one on the Isle of Man and one from Sweden. Although there were significant differences in the demography and appearance of the two populations, the phenotypic plasticity and sensitivities of the two populations were very similar. This is curious as the poor dispersal abilities of *Ascophyllum nodosum* means that minimal recruitment would occur between the two study populations. In addition, the geographical locations of the two shores mean that the environmental factors are significantly different and provide different selective pressures. It was suggested that the combination of different selective pressures and lack of genetic crossover could lead some level of allopatric speciation. However, this was not the case, which suggests that *Ascophyllum nodosum* has significant life history plasticity and can able to withstand 'very large environmental variation' (Svensson *et al.*, 2009). The results from Svensson *et al.*, (2009) also suggest that pressures which affect the survival or growth of large sexually reproductive *Ascophyllum nodosum* could have severe negative effects on regional abundance and biomass of the species.

The high levels of water movement within this biotope make it a suitable habitat for a number of filter feeders. Although their presence is mediated by the presence of *Ascophyllum nodosum* the resistance and resilience of these species is important when considering how long it would take for this biotope to return to full ecosystem function. The average life expectancy of *Halichondria panicea* is three years (Fish & Fish, 1996) with individuals reaching sexual maturity within their first year. Wapstra & van Soest (1987) found that oocytes were present in the hermaphroditic *Halichondria panicea* year round. Maturation of these oocytes and the present of embryos were present from May to August when water temperatures increased. New *Halichondria panicea* recruits can become apparent on the shore a year after they were spawned (Vethaak, 1982). *Ascidiella scabra* the sea squirt is a highly fecund species (Lindsay & Thompson, 1930). Age at maturity is thought to be 6 months with a lifespan of 2-5 years. *Semibalanus balanoides* are often quick to colonize available gaps on intertidal rocky shores. Bennell (1981) observed that barnacles that were removed when the surface rock was scraped off in a barge accident at Amlwch, North Wales returned to pre-accident levels within 3 years. Petraitis & Dudgeon (2005) also found that *Semibalanus balanoides* quickly recruited (present a year after and increasing in density) to experimentally cleared areas within the Gulf of Maine, that had previously been dominated by *Ascophyllum nodosum*. However barnacles are gregarious and larvae settle within areas where adults are present (Knight-Jones & Stevenson, 1950). Re-colonization of *Patella vulgata* on rocky shores is rapid as seen by the appearance of limpet spat 6 months after the *Torrey Canyon* oil spill reaching peak numbers 4-5 years after the spill. However, although re-colonization was rapid, the alteration to the population structure (size and age class) persisted for about 15 years because of the complex cycles of dominance (see below) involving limpets, barnacles and algae (Hawkins & Southward, 1992, Lewis & Bowman, 1975). The ability of these species to recolonize a habitat after the negative effects of a pressure varies. However, *Ascophyllum nodosum* takes the longest to recover and therefore it is this species on which the recovery of this biotope hinges.

**Resilience assessment.** *Ascophyllum nodosum* has low dispersal abilities, high juvenile mortality rates and can take in excess of five years to reach reproductive maturity. If a pressure causes a mass mortality event on a shore an *Ascophyllum nodosum* canopy can take 12 years to recover. This recovery depends on mature populations of the macroalgae in the vicinity from which to recruit. If partial damage occurs to the frond but 15 cm – 25 cm remain, then recovery of an individual can occur within two to three years. Evidence suggests that even after the recovery of an *Ascophyllum nodosum* population after a mass mortality event the understory communities and ecosystem functioning of the area can take in excess of 20 years to return (Jenkins *et al.*, 2004).

Although no experiments have been undertaken within this biotope, the length of time for understory communities to recover within other wave sheltered *Ascophyllum nodosum* habitats is

reported to be in excess of twenty years. This biotope has a diverse associated community, some of the species within which can recover relatively quickly, so recovery times scales may vary. In conclusion, if only partial damage is done to the characterizing macroalgae within his biotope then recovery could be quick between two to ten years, giving a resilience of 'Medium'. However, if a pressure causes a significant mortality of the characterizing species, *Ascophyllum nodosum*, the resilience is categorized as 'Low'.

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)	Medium Q: High A: High C: Medium	Medium Q: High A: Medium C: Medium	Medium Q: High A: Medium C: Medium

Schonbeck & Norton (1979) demonstrated that fucoids can increase tolerance in response to gradual change in temperature through a process known as 'drought hardening'. However acute changes in temperatures may cause damage to macroalgae and other species. Temperature ranges of species may not accurately describe their ability to withstand localized changes in temperature. However they will display the limits of the species genetic ability to acclimatize to temperatures. Juvenile life stages of organisms can be less tolerant to environmental conditions than more mature stages.

*Ascophyllum nodosum* is found in the middle of its range in the British Isles, with populations in the north east Atlantic as far south as Portugal and extending north to the White Sea. *Ascophyllum nodosum* is unlikely to be affected by a short-term change of 5°C, as it was not damaged during the unusually hot summer of 1983 when the average temperature was 8.3°C higher than normal (Hawkins & Hartnoll, 1985). *Ascophyllum nodosum* can tolerate certain levels of exposure as they are regularly exposed to rapid and short-term variations in temperature. Both exposure at low tide or rising tide on a sun-heated shore involves considerable temperature changes, and during winter the air temperature may be far below freezing point. Growth of *Ascophyllum nodosum* has been measured between 2.5 and 35°C with an optimum between 10 and 17°C (Strömberg, 1977). *Ascophyllum nodosum* can be damaged by thermal pollution if the water temperature remains above 24°C for several weeks (Lobban & Harrison, 1997), and temperatures exceeding 27°C cause direct mortality (Keser et al., 2005). Water temperature is an excellent predictor of gamete release in *Ascophyllum* (Bacon & Vadas, 1991). Consequently changes in temperatures could impact on gamete release. Investigations into the tolerance of *Ascophyllum nodosum* germlings from Norway, to temperatures between 7°C -17°C found that there was no difference in survival rates within the given range (Steen & Rueness, 2004). Germination of *Ascophyllum nodosum* has been recorded between the temperatures of 4°C - 23°C.

Other species found within this biotope are probably tolerant of temperature changes at the benchmark level as they are widely distributed in the UK.. The balance of interactions between furoids and barnacles changes with geographical location. Warmer conditions further south than the British Isles favour greater penetration of barnacles into sheltered locations (Ballantine, 1961 cited in Raffaelli & Hawkins, 1996). Warmer conditions are also likely to favour Chthamalus spp. rather than Semibalanus balanoides although a change of species will not alter the function of the biotope. Those species which are mobile, such as the littorinids and Carcinus maenas have the opportunity to move away from areas if physical conditions become too harsh

**Sensitivity assessment.** The characterizing species *Ascophyllum nodosum* is found in the middle of its habitat range in the British Isles. Although the range of these species can extend down to Portugal if the temperature changes are acute and occur over a short period leaving no time for acclimation then there could be some damage caused to the microalgae's. However if the changes are more gradual then the algae may have time to acclimate which would not produce any significant negative impact. The benchmark scenario which is likely to cause the most stress to this biotope is an increase of 5°C for one month. The sensitivity assessment for this scenario gives both resistance and resilience a score of 'Medium'. Meaning that the biotope has a 'Medium' sensitivity to this pressure at the benchmark.

#### Temperature decrease (local)

**Medium**

Q: High A: High C: Medium

**Medium**

Q: High A: Medium C: Medium

**Medium**

Q: Medium A: Medium C: Medium

Schonbeck & Norton (1979) demonstrated that furoids can increase tolerance in response to gradual change in temperature through a process known as 'drought hardening'. However acute changes in temperatures may cause damage to macroalgae and other species. Temperature ranges of species may not accurately describe their ability to withstand localized changes in temperature. However they will display the limits of the species genetic ability to acclimatize to temperatures. Juvenile life stages of organisms can be less tolerant to environmental conditions than more mature stages.

*Ascophyllum nodosum* is found in the middle of its range in the British Isles, with populations in the north east Atlantic as far south as Portugal and extending north to the White Sea. Growth of *Ascophyllum nodosum* has been measured between 2.5 and 35°C with an optimum between 10 and 17°C (Strömngren, 1977). Water temperature is an excellent predictor of gamete release in *Ascophyllum* (Bacon & Vadas, 1991). Consequently changes in temperatures could impact on gamete release. Investigations into the tolerance of *Ascophyllum nodosum* germlings from Norway, to temperatures between 7°C -17°C found that there was no difference in survival rates within the given range (Steen & Rueness, 2004). Germination of *Ascophyllum nodosum* has been recorded between the temperatures of 4°C - 23°C.

A large number of the species found within this biotope, including *Halichondria panicea* and *Ascidia aspersa* are found throughout the British Isles and are not on the edge of their range. Therefore it is unlikely that a decrease in temperature is going to cause significant mortalities. In addition to this those species which are mobile, such as the littorinids, *Nucella lapillus* and *Carcinus maenas* have the opportunity to move away from areas if physical conditions become too harsh. Consequently these species may decrease in abundance.

**Sensitivity assessment.** The characterizing species, *Ascophyllum nodosum*, is found in the middle of its habitat range in the British Isles. Although the range of this species can extend up to the White Sea if the temperature changes are acute and occur over a short period leaving no time for

acclimation then there could be some damage caused to the macroalgae. However if the changes are more gradual then the algae may have time to acclimate which would not produce any significant negative impact. The benchmark scenario which is likely to cause the most stress to this biotope is a decrease of 5 °C for one month. The sensitivity assessment for this scenario gives both resistance and resilience a score of 'Medium'. Meaning that the biotope has a 'Medium' sensitivity to this pressure at the benchmark.

### Salinity increase (local)

**None**

Q: High A: High C: Medium

**Medium**

Q: High A: Medium C: Medium

**Medium**

Q: High A: Medium C: Medium

Intertidal macroalgae often experience large but short-term changes in salinities (Lobban & Harrison, 1997). Salinities within these habitats vary due to weather conditions such as rain fall at low tide and evaporation from rock pools causing hyper saline conditions on hot days. Intertidal shores within estuarine environments can also experience considerable short-term changes in salinities. However intertidal macroalgae tolerances to longer term changes in salinities can be minimal and can quickly reduce photosynthetic abilities and cause mortality.

This biotope is only recorded from fully saline conditions (30 - 40 ppt) (Connor *et al.*, 2004). Consequently an increase in salinity would make the conditions hypersaline. Little empirical evidence was found to assess how an increase in salinity at this benchmark would affect *Ascophyllum nodosum*. Baardseth, 1970 noted that *Ascophyllum nodosum* is euryhaline with a salinity tolerance of about 15 to 37 psu. Studies undertaken by Chock & Mathieson (1979) found *Ascophyllum nodosum* plants in the laboratory photosynthesised at salinities from 0 to 40 psu although the long-term effects within this range were not evaluated. No information could be found on the effects of an increase in salinity on the reproductive cycle of *Ascophyllum nodosum*.

A number of the species associated with this biotope can also be found within rockpools where hypersaline conditions can be found for short periods of time (Newell, 1979). Consequently an increase in salinity within the benchmark of this pressure may not cause negative impacts for a short period of time. *Semibalanus balanoides* can tolerate salinities between 12 and 50 psu; below and above this cirral activity ceases (Foster, 1970). The littorinids, *Nucella lapillus* and *Carcinus maenus* are mobile species and have the ability to move to suitable conditions on the shore.

**Sensitivity assessment.** This biotope is only found in fully saline conditions (Connor *et al.*, 2004). Therefore the pressure at this benchmark would create hyper-saline conditions. Although many species within this biotope would be able to cope with a short-term increase in salinity, long-term hypersaline conditions could cause mass mortalities of the biological community within this biotope. Both the resistance and resilience of this biotope to pressure at the stated benchmark has been assessed as 'Low'. Overall the biotope has a 'High' sensitivity to changes in emergence regime at the pressure benchmark.

### Salinity decrease (local)

**Medium**

Q: High A: High C: Medium

**Medium**

Q: High A: Medium C: Medium

**Medium**

Q: High A: Medium C: Medium

Intertidal macroalgae often experience large but short-term changes in salinities (Lobban & Harrison, 1994). Salinities within these habitats vary due to weather conditions such as rain fall at low tide and evaporation from rock pools causing hyper saline conditions on hot days. Intertidal shores within estuarine environments can also experience considerable short-term changes in salinities. However intertidal macroalgae tolerances to longer term changes in salinities are



minimal and can quickly reduce photosynthetic abilities and cause mortality.

*Ascophyllum nodosum* is euryhaline with a salinity tolerance of about 15 to 37 psu (Baardseth, 1970). The species can also withstand periodic emersion in freshwater (Baardseth, 1970) and frequently inhabits estuaries where salinity is variable. Doty & Newhouse (1954) reported *Ascophyllum nodosum* from estuarine waters with a maximum salinity of 17.3 psu and a minimum of 0 psu. Chock & Mathieson (1979) found *Ascophyllum nodosum* plants in the laboratory photosynthesised at salinities from 0 to 40 psu although the long-term effects within this range were not evaluated. In the Teign Estuary in South Devon *Ascophyllum nodosum* inhabits areas subject to salinities as low as 8psu (Laffoley & Hiscock, 1993). Investigations into the salinity tolerance of *Ascophyllum nodosum* in laboratory controlled conditions found that the photosynthetic capabilities of this species decreased with reduced salinities. *Ascophyllum nodosum* tolerated 7 days at salinities of 5, and all samples died after 15 days at salinities of 5 (Connan & Stengel, 2011). There is some evidence to suggest that reduced salinities can influence the rate of receptacle maturation in fucoids (Munda, 1964). Rate of fructification in *Ascophyllum nodosum* has been measured to increase in diluted seawater (Munda, 1964).

A number of the other species within the biotope can also be found within rockpools where hyposaline conditions can be found for short periods of time (Newell, 1979). Consequently a decrease in salinity within the benchmark of this pressure would not cause any significant mortalities. For example, *Semibalanus balanoides* can tolerate salinities between 12 and 50 psu, below and above this cirral activity ceases (Foster, 1970). Both *Asciella scabra* and *Halichondria panicea* can be found in habitats with variable salinity and would therefore tolerate a decrease in the salinity within this biotope. The littorinids, *Nucella lapillus* and *Carcinus maenas* are mobile species and have the ability to move to suitable conditions on the shore.

Sensitivity assessment. This biotope is only recorded from fully saline conditions (30 -35 ppt) (Connor et al., 2004). A decrease in salinity at the given benchmark would create a variable salinity regime similar to that found in LR.LLR.FVS.AcsVS. The biological community within this reduced salinity biotope is characteristically impoverished. With a change in the salinity at the bench mark the species within this biotope including the characterizing species would be able to withstand these reductions in salinities; however there may be reductions in the reproductive success and growth rates and consequently the abundances. Both the resistance and resilience of this biotope is given as 'Medium'. The sensitivity of this biotope to the pressure at this benchmark is 'Medium'.

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

**High**

Q: High A: Medium C: Medium

**High**

Q: High A: Medium C: Medium

**Not sensitive**

Q: High A: Medium C: Medium

Water motion is a key determinant of marine macroalgal ecology, influencing physiological rates and community structure (Hurd, 2000). Higher water flow rates increase mechanical stress on macroalgae by increasing drag. Fucoids are highly flexible but not physically robust and an increase in water flow could cause mechanical damage, breaking fronds or even dislodging whole algae from the substratum. Fucoids are however highly flexible and are able to re-orientate their position in the water column to become more streamlined. This ability allows fucoids to reduce the relative velocity between algae and the surrounding water, thereby reducing drag and lift (Denny *et al.*, 1998). Fucoids are permanently attached to the substratum and would not be able to re-attach if removed. Organisms living on the fronds and holdfasts will be washed away with the algae whereas free-living community components could find new habitat in surrounding areas. Wave exposure has been shown to limit size of fucoids (Blanchette, 1997) as smaller individuals create

less resistance to water movement, it is likely that water flow exerts a very similar pressure on fucooids.

This biotope can be found in tidal currents ranging from 1 - >6 knots (0.5 - >3.0 m/s) (Connor *et al.*, 2004). The increased water movement makes the habitat suitable for a diverse associated community, including a number of filter feeding organisms (Connor *et al.*, 2004). A decrease in the flow rate may reduce the diversity and abundance of some of these species.

*Fucus vesiculosus* individuals of 10cm or larger have been recorded to be completely removed at 7-8m/s (Jonsson *et al.*, 2006). Flow rates at which adult *Ascophyllum nodosum* are removed are not known. However Thompson & Wernberg (2005) provide strong evidence that with an increase in thallus size there is an increase in the break force required to remove algae. Consequently the force required to remove *Ascophyllum nodosum* from a shore is likely to be comparable to that of *Fucus vesiculosus* due to them both being large macroalgae with similar thallus sizes. The upper limit of the tidal flows within this biotope are >3.0 m/s. An increase in current flow of 0.2 m/s is unlikely to have an impact on many examples of this biotope except for those which are at the upper limit of water flow tolerance.

Propagule dispersal, fertilization, settlement, and recruitment are also influenced by water movement (Pearson & Brawley, 1996). An increase in water flow could have negative impacts on the reproductive success of *Ascophyllum nodosum*. Experiments on the effect of wave action on *Ascophyllum nodosum* showed that a low-velocity wave can remove 99% of 15 minute old zygotes from experimental tiles Vadas *et al.* (1990). Further investigation with the use of refuges found that 75-90% of zygotes as old as four hours could be removed by a single wave. Current speeds of over 20 cm s<sup>-1</sup> make attachment success of *Ascophyllum nodosum* very poor (Vadas *et al.*, 1992). These studies show the need for periods of calm conditions for successful recruitment for *Ascophyllum nodosum*. An increase in the mean water flow will reduce the time during which attachment is possible. In addition, greater water flow can increase scour through increased sediment movement. Small life stages of macroalgae are likely to be affected by removing new recruits from the substratum and hence reducing successful recruitment (Devlinny & Volse, 1978) (see 'siltation' pressures). Changes in water motion can thus strongly influence local distribution patterns of *Fucus* spp. (Ladah *et al.*, 2008).

The high levels of water movement within this biotope makes it suitable for the greater abundance of filter feeding species such *Halichondria panicea* and *Ascidella scabra*. These species are absent from *Ascophyllum nodosum* biotopes that are found in areas with lower levels of water flow such as; LR.LLR.F.Asc and LR.LLR.F.Asc.FS.

**Sensitivity assessment.** This is a tidally swept biotope, where the abundance of filter feeders and epifauna is dependent on the high water flow. Therefore, a decrease in water flow would reduce the biodiversity and species abundance within this biotope, which would come to resemble the LR.LLR.F.Asc biotope. An increase in the level of water flow is unlikely (as is already occurs in very strong tidal conditions). However, a decrease on 0.1-0.2 m/s (the benchmark) is unlikely to have significant effect. Therefore, resistance and resilience have been assessed as 'High'. This gives the biotope an overall sensitivity of 'Not Sensitive' at the benchmark level.

#### Emergence regime changes

**Low**  
Q: High A: High C: High

**Low**  
Q: High A: Medium C: Medium

**High**  
Q: High A: Medium C: Medium

Within the British Isles populations of *Ascophyllum nodosum* can suffer from bleaching and

consequent mortality during exceptionally hot weather (Schonbeck & Norton, 1978, Hawkins & Hartnoll, 1985, Norton, 1985). However, these mortality events do not occur every year and tend to occur when the effects of unusually hot conditions combine with periods of rapid change, which do not allow for macroalgae to acclimate (Raffioli & Hawkins, 1996).

Stengel & Dring (1997) reported that growth rates in *Ascophyllum nodosum* decreased with height on the shore, correlating with an increase in environmental severity. *Ascophyllum nodosum* productivity is affected by desiccation when water loss exceeds 50% (Brinkhuis *et al.*, 1976). Higher temperatures can increase the rate of desiccation and consequently lead to a loss of productivity, and eventually mortality (Keser *et al.*, 1981).

When Stengel & Dring (1997) transplanted *Ascophyllum nodosum* from the lower shore to the upper shore, 80% of the transplants died within 3 months. In contrast, 100% of the individuals from the upper shore transplanted to the lower shore survived, as did all of the controls. The plants which survived transplantation to the upper shore acclimated to the conditions on the upper shore, yet their survival was determined by thallus morphology a predetermined genetic attribute which may be fixed (Stengel & Dring, 1997). Choi & Norton (2005) also carried out transplantation experiments and found that the growth rates of *Ascophyllum nodosum* decreased dramatically from the lower shore to the upper shore.

The southern and northern range limits of a number of intertidal macroalgae fall within Portugal. Lima *et al.* (2007) mapped the re-adjustment of 129 macroalgal ranges in relation to the change in air and sea temperatures observed within the north-eastern Atlantic over the past 50 years. Significant differences in distributions of algae were found, yet there was disparity in the level of change found in the ranges of those of warm and cold adapted species. The species that were at the northern limit of their range in Portugal showed a greater change in distribution than the cold adapted species. Roughly half of the cold adapted species, including *Ascophyllum nodosum*, showed no significant change in their distribution. Lima *et al.*, (2007) suggested that the cold adapted species had greater tolerance to adverse conditions for longer periods of time than the warm adapted species.

Information regarding the effect of changes in the level of exposure on *Ascophyllum nodosum* germlings is not available. Germlings will be protected from desiccation stresses to a certain extent because of the protection provided to them by the furoid canopy. Increases in temperature will be one of the effects changes in exposure will have on germlings. For further information refer to temperature pressure.

Dense aggregations of algae can reduce the effect of more severe physical conditions such as those experienced with greater levels of exposure. Clumping enables organisms to retain moisture and reduce heat stress (Scrosati & DeWreede, 1998, Stafford & Davies, 2005)

**Sensitivity assessment.** Desiccation and the associated osmotic stress, especially when combined with high temperatures can cause mortalities (Pearson *et al.*, 2009). The sensitivity of the characterizing species to emersion pressure will depend on the health and demography of individual populations, with germlings being most vulnerable life stage to this pressure.

*Ascophyllum nodosum* has a level of resistance to an increase in emersion. However at the level of the benchmark there is likely to be a change in biotope, with the top of the biotope being most sensitive to change as it is already at the upper tolerance limits. The change in this pressure at the benchmark is likely to see all of the biotopes on the shore shifting downwards. *Ascophyllum*

*nodosum* can take as many as twelve years to recover, with return of ecosystem functioning taking considerably longer. Resistance of this biotope to pressure at the stated benchmark has been assessed as 'Low' and resilience is assessed as 'Low'. Overall the biotope has a 'High' sensitivity to changes in emergence regime at the pressure benchmark.

### 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

An increase in wave exposure generally leads to a decrease in macroalgae abundance and size (Lewis, 1961, Stephenson & Stephenson, 1972, Hawkins et al., 1992, Jonsson et al., 2006). Fucoids are highly flexible but not physically robust and an increase in wave exposure can cause mechanical damage, breaking fronds or even dislodging whole algae from the substratum. *Ascophyllum nodosum* is permanently attached to the substratum and would not be able to re-attach if removed. Organisms living on the fronds and holdfasts will be washed away with the algae whereas free-living community components could find new habitat in surrounding areas. Wave exposure has been shown to limit size of fucoids (Blanchette, 1997) as smaller individuals create less resistance to waves. As exposure to waves increases the fucoid population will become dominated by small juvenile algae, and dwarf forms of macroalgae which are more resistant to strong wave action. An increase in wave action beyond the tolerance of these fucoid species leads to a further increase in the abundance of robust fucoids, such as *Fucus spiralis* f. *nana* and red seaweeds, such as *Corallina officinalis* (Connor et al., 2004).

*Ascophyllum nodosum* cannot resist very heavy wave action so exposure to wave action is an important factor controlling the distribution of the species, and therefore this biotope. This biotope is found in very sheltered to extremely sheltered conditions. Propagule dispersal, fertilization, settlement, and recruitment are also influenced by water movement (Pearson & Brawley, 1996). An increase in water flow due to wave exposure could have negative impacts on the reproductive success of *Ascophyllum nodosum*. Experiments on the effect of wave action on *Ascophyllum nodosum* showed that a low-velocity wave can remove 99% of 15 minute old zygotes from experimental tiles Vadas et al. (1990). Further investigation with the use of refuges found that 75-90% of zygotes as old as four hours could be removed by a single wave. Current speeds over 20cm s<sup>-1</sup> make attachment success of *Ascophyllum nodosum* very poor (Vadas et al., 1992). These studies show the need for periods of calm conditions for successful recruitment for *Ascophyllum nodosum*. An increase in the mean wave exposure will reduce the time during which attachment is possible. In addition, greater wave action can increase scour through increased sediment movement. Small life stages of macroalgae are likely to be affected by removing new recruits from the substratum and hence reducing successful recruitment (Deviny & Volsøe, 1978) (see 'siltation' pressures).

The other characterizing species are found in a range of wave exposures and unlikely to be directly affected. However, loss of the fucoid cover would result in major changes to the associated community, especially attached epifauna and understory algae.

**Sensitivity assessment.** As this is a very to extremely sheltered biotope a further decrease in wave exposure is unlikely, and not significant given the very strong to strong tidal flow in which the biotope occurs. An increase in wave action, is likely to adversely affect fucoid cover, especially of *Ascophyllum nodosum*. The biotope will probably be lost if wave exposure increase from e.g. sheltered to moderately exposed. It is difficult to qualify a 3-5% change in significant wave height in terms of wave exposure, but the biotope is likely to have at least a 'Medium' resistance to an

increase in wave exposure. Therefore, as the resilience is probably 'Medium', sensitivity is also 'Medium'.

## 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.

<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.

<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.

<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.

<b>Introduction of other substances</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**.

<b>De-oxygenation</b>	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low
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Reduced oxygen concentrations have been shown to inhibit both photosynthesis and respiration in macroalgae (Kinne, 1977). Despite this, macroalgae are thought to buffer the environmental conditions of low oxygen, thereby acting as a refuge for organisms in oxygen depleted regions especially if the oxygen depletion is short-term (Frieder *et al.*, 2012). Reduced oxygen levels are likely to inhibit respiration whilst immersed, but it is unlikely to cause a loss of the macroalgae population directly. This biotope is found in the mid-eulittoral and consequently, a proportion of time will be spent in the air where oxygen is not limited. As long as certain physical conditions are not exceeded, respiration and photosynthesis will be able to continue.

Although the macroalgae species within this biotope may not be negatively affected some of the associated fauna may be lost, causing a reduction in species richness. Josefson & Widbom (1988)

investigated the response of benthic macro and meiofauna to reduced dissolved oxygen levels in the bottom waters of a fjord. At dissolved oxygen concentrations of 0.21 mg/l, the macrofaunal community was eradicated and was not fully re-established 18 months after the hypoxic event. Meiofauna seemed, however, unaffected by de-oxygenation. Mobile species will be able to relocate to more optimal conditions, whereas immobile species such as barnacles are likely to be put under more stress by de-oxygenation. Complete smothering caused by the *Torrey Canyon* oil spill appeared to have little impact on barnacle species; A few *Semibalanus balanoides* died, yet *Chthamalus montagui* seemed unaffected (Smith, 1968). *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).

**Sensitivity assessment.** The characterizing species *Ascophyllum nodosum* may not be negatively affected by a decrease in oxygen within the water column for at the benchmark level of this pressure. However, some of the associated faunal community within this biotope may be negatively affected. Mobile species such as littorinids and the crab *Carcinus maenas* could relocate to conditions that were less physiologically taxing and would be able to return when the pressure abated. Those immobile species such as the barnacle *Semibalanus balanoides* may experience some mortality but barnacles can completely recolonize within three years (Bennell, 1981). A reduction in oxygen levels at the benchmark for this pressure may result in mortalities. The very sheltered to extremely sheltered conditions that are characteristic of this biotope mean that water mixing from wave movement is not very strong. However, the strong water movement in tide-swept tidal currents combined with turbulent flow over rocks would aerate the water column, and emersion at low tide would mean that any oxygen depletion was transient. Therefore, resistance is assessed as 'High'. Hence, resilience is assessed as 'High', and the biotope as 'Not sensitive'.

#### Nutrient enrichment

High

Q: High A: High C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: High

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 microalgae blooms (Bricker *et al.*, 1999, 2008).

Johnston & Roberts (2009) undertook a review and meta-analysis of the effect of contaminants on species richness and evenness in the marine environment. Of the 47 papers reviewed relating to nutrients as a contaminant, over 75% found that it had a negative impact on species diversity, <5% found increased diversity, and the remaining papers finding no detectable effect. Not all of the 47 papers considered the impact of nutrients on intertidal rocky shores. Yet this finding is still relevant as the meta-analysis revealed that the effect of marine pollutants on species diversity was 'remarkably consistent' between habitats (Johnston & Roberts, 2009). It was found that any single pollutant reduced species richness by 30-50% within any of the marine habitats considered (Johnston & Roberts, 2009). Throughout their investigation, there were only a few examples where species richness was increased due to the anthropogenic introduction of a contaminant. These examples were almost entirely from the introduction of nutrients, either from aquaculture or sewage outfalls. However research into the impacts of nutrient enrichment from these sources on intertidal rocky shores often lead to shores lacking species diversity and the domination by algae with fast growth rates (Abou-Aisha *et al.*, 1995, Archambault *et al.*, 2001, Arévalo *et al.*,

2007, Diez et al., 2003, Littler & Murray, 1975).

Nutrient enrichment alters the selective environment by favouring fast growing, ephemeral species such as *Ulva lactuca* and *Ulva intestinalis* (Berger et al., 2004, Kraufvelin, 2007). Rohde et al., (2008) found that both free growing filamentous algae and epiphytic microalgae can increase in abundance with nutrient enrichment. This stimulation of annual ephemerals may accentuate the competition for light and space and hinder perennial species development or harm their recruitment (Berger et al., 2003; Kraufvelin et al., 2007). Nutrient enrichment can also enhance fouling of *Fucus* fronds by biofilms (Olsenz, 2011). Nutrient enriched environments can not only increase algae abundance but the abundance of grazing species (Kraufvelin, 2007).

White et al. (2011) investigated the effects of nutrient effluent from land based finfish farms on the morphologies of *Ascophyllum nodosum* in the vicinity of the outfall pipes. It was estimated that the nitrogen effluent from the farm was 1500kg y<sup>-1</sup>. The background levels of nitrite at the test site were 300 µM. In comparison, the ambient nitrite levels in south-west Nova Scotia are 3 µM (White et al., 2011). *Ascophyllum nodosum* at the test sites were found to be younger than those at the control sites, but significantly larger. This experiment suggested that nutrient effluent could have positive impacts on *Ascophyllum nodosum*. Yet it must be noted that the effect of the effluent on the rest of the biological community was not studied.

Changes in community composition on intertidal rocky shores can happen rapidly, and fast growing ephemeral species can become established quickly in the presence of higher concentrations of nutrients. The establishment and growth of these species are not controlled by wave exposure (Kraufvelin, 2007). However, even though these fast growing ephemeral species can become well established quickly, healthy communities on intertidal rocky shores can survive long periods of time, and maintain ecological function after these species have become established (Bokn et al., 2002, 2003, Karez et al., 2004, Kraufvelin, 2007, Kraufvelin et al., 2006b).

Sensitivity assessment. A slight increase in nutrients may enhance growth rates but high nutrient concentrations could lead to the overgrowth of the algae by ephemeral green algae and an increase in the number of grazers. If the biotope is well established and in a healthy state the biotope could persist. However, the biotope is 'Not Sensitive' at the pressure benchmark that assumes compliance with good status as defined by the WFD.

## Organic enrichment

Medium

Q: High A: Medium C: Medium

Medium

Q: High A: Medium C: Medium

Medium

Q: High A: Medium C: Medium

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

Johnston & Roberts (2009) undertook a review and meta-analysis of the effect of contaminants on species richness and evenness in the marine environment. Of the 49 papers reviewed relating to sewage as a contaminant, over 70% found that it had a negative impact on species diversity, <5% found increased diversity, and the remaining papers finding no detectable effect. Not all of the 49 papers considered the impact of sewage on intertidal rocky shores. Yet this finding is still relevant as the meta-analysis revealed that the effect of marine pollutants on species diversity was 'remarkably consistent' between habitats (Johnston & Roberts, 2009). It was found that any single

pollutant reduced species richness by 30-50% within any of the marine habitats considered (Johnston & Roberts, 2009). Throughout their investigation, there were only a few examples where species richness was increased due to the anthropogenic introduction of a contaminant. These examples were almost entirely from the introduction of nutrients, either from aquaculture or sewage outfalls. However research into the impacts of organic enrichment from these sources on intertidal rocky shores often lead to shores lacking species diversity and the domination by algae with fast growth rates (Abou-Aisha et al., 1995, Archambault et al., 2001, Arévalo et al., 2007, Diez et al., 2003, Littler & Murray, 1975).

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Changes in community composition on intertidal rocky shores can happen rapidly, and fast growing ephemeral species can become established quickly in the presence of higher concentrations of nutrients. The establishment and growth of these species are not controlled by wave exposure (Kraufvelin, 2007). However, even though these fast growing ephemeral species can become well established quickly, healthy communities on intertidal rocky shores can survive long periods of time, and maintain ecological function after these species have become established (Bokn et al., 2002, 2003, Karez et al., 2004, Kraufvelin, 2007, Kraufvelin et al., 2006b).

Sensitivity assessment. Little empirical evidence was found to support an assessment of this biotope at this benchmark. Due to the negative impacts that can be experienced with the introduction of excess organic carbon both resistance and resilience have been assessed as 'Medium'. This gives an overall sensitivity score of 'Medium'.

## A Physical Pressures

	Resistance	Resilience	Sensitivity
<b>Physical loss (to land or freshwater habitat)</b>	<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.

<b>Physical change (to another seabed type)</b>	<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
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This biotope occurs on rock substratum so that a change to sedimentary or soft rock substratum



would lead to the direct loss of suitable attachment area for macroalgae and other epibiota. This change in substratum would result in the loss of the characterizing species *Ascophyllum nodosum* along with other species found within the associated community of this biotope. Resistance is assessed as 'None'. As this pressure represents a permanent change, recovery is impossible as the suitable substratum for the biological community of this biotope is lacking. Consequently, resilience is assessed as 'Very low'. The habitat, therefore, scores a 'High' sensitivity. Although no specific evidence is described confidence in this assessment is 'High', due to the incontrovertible nature of this pressure.

#### Physical change (to another sediment type)

**None**

Q: High A: High C: High

**Very Low**

Q: High A: High C: High

**High**

Q: High A: High C: High

Not relevant to biotopes occurring on bedrock

#### 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 occur 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

**Low**

Q: High A: High C: High

**Low**

Q: High A: Medium C: Medium

**High**

Q: High A: Medium C: Medium

Trampling on the rocky shore has been observed to reduce furoid cover which decreased the microhabitat available for epiphytic species, increased bare space and increased cover of opportunistic species such as *Ulva* (Fletcher & Frid, 1996). This biotope is found in the mid intertidal shore. An area easily accessible by humans especially at low tide. Fucoids are intolerant of abrasion from human trampling, which has been reported to reduce the cover of seaweeds on a shore (Holt et al., 1997; Tyler-Walters & Arnold, 2005).

Brosnan (1993) investigated the effect of trampling on a number of algal species, including *Fucus vesiculosus*, on an intertidal rocky shore in Oregon. The effects of 250 tramples per plot, once a month for a year were recorded. Abundances of algae in each plot were reduced from 80% to 35% within a month of the introduction of the pressure and remained low for the remainder of the experiment. As few as 20 steps/m<sup>2</sup> on stations on an intertidal rocky shore in the north-east of England were sufficient to reduce the abundance of fucoids (Fletcher & Frid, 1996). This reduction in the complexity of the algae community, in turn, reduced the microhabitat available for epiphytic species. Trampling pressure can thus result in an increase in the area of bare rock on the shore (Hill et al., 1998). Chronic trampling can affect community structure with shores becoming dominated by algal turf or crusts (Tyler-Walters, 2005). Pinn & Rodgers (2005) compared the biological communities found on two intertidal rocky shore ledges in Dorset. They found that the ledge which had a higher number of visitors had few branching algal species, including fucoids, but had greater abundances of crustose and ephemeral species (Pinn & Rodgers, 2005). The densities of fucoids were recorded from the intertidal rocky shore at Wembury, Devon in 1930 (Colman, 1933) and 1973 (Boalch et al., 1974). Boalch et al. (1974) found a reduction in fucoids on the shore at

Wembury and that the average frond length of *Ascophyllum nodosum* was smaller.

*Ascophyllum nodosum* seems to be particularly intolerant of damage from trampling (Flavell, 1995; unpublished cited in Holt et al., 1997), as its length means it is more likely that the thallus is 'cut' between a footstep and sharp rock (Boalch et al., 1974, Tyler-Walters & Arnold, 1995). Araujo et al. (2009) found that trampling negatively affected both *Ascophyllum nodosum* abundances and reduced understorey species while promoting the colonization by ephemeral green algae. However, within a year of the disturbance event, *Fucus vesiculosus* had become the dominant canopy forming species, replacing a pre-disturbance *Ascophyllum nodosum* community. The replacement of *Ascophyllum nodosum* with *Fucus vesiculosus* may have been due to the poor recovery rate of *Ascophyllum nodosum*. The increase in abundance suggests the competitive superiority of *Fucus vesiculosus* individuals in occupying newly available space in the disturbed patches. Similar results were found by Cervin et al. (2005) and Araujo et al. (2012) with *Fucus vesiculosus* outcompeting *Ascophyllum nodosum* after small-scale disturbances. Rita et al., (2012) also undertook experiments on the effect of trampling on *Ascophyllum nodosum* and its associated communities. It was concluded that trampling caused significant damage to both the macroalgae and the understory communities, which had not recovered within five years of the initial experiment.

**Sensitivity assessment.** Abrasion of the substratum will cause a reduction in the abundances of *Ascophyllum nodosum*, as well as other species found in the associated community. Therefore the resistance is 'Low'. Experiments undertaken on the trampling effects on *Ascophyllum nodosum* have shown that for the community to return to its pre-experimental state can take in excess of 10 years, consequently, the resilience is assessed as 'Low' giving a sensitivity of 'High'.

**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 epifauna or epiflora occurring on rock, which is resistant to subsurface penetration. Therefore, 'penetration' is '**Not relevant**'. The assessment for abrasion at the surface only is, therefore, considered to equally represent sensitivity to this pressure'. Please refer to 'abrasion' above.

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

Medium

Q: Medium A: Medium C: Medium

Medium

Q: High A: Medium C: Medium

Medium

Q: Medium A: Medium C: Medium

Light is an essential resource for all photoautotrophic organisms and a change in turbidity would affect light availability to photosynthesising organisms during immersion which could result in reduced biomass of plants. Changes in the suspended sediment load can change the levels of scour and alter the abundances of certain species. Greater levels of suspended particulate matter may also increase the amount of material which is falling out of suspension, which could consequently smother organisms (see siltation pressures).

An increase in turbidity would alter the light available for photosynthesis during immersion. The shallow water depth within this biotope means that although light attenuation will be greater, the change in turbidity at this pressure benchmark will still allow light to penetrate to the depth at which the algae are found. *Ascophyllum nodosum* will also be able to continue to photosynthesize at low tide when the plants are emersed, as long as the plant has a sufficiently high water content and

so (Beer & Kautsky, 1992).

Daly & Mathieson (1977) found that *Ascophyllum nodosum* was completely absent from an intertidal rocky shore which was subject to a high level of scour from sand movement. The lack of *Ascophyllum nodosum* from this shore was particularly conspicuous due to the high abundance of the species on a nearby rocky shore with very similar conditions, except for the level of suspended sediment. *Ascophyllum nodosum* is not likely to be directly intolerant of a decrease in suspended sediment because the species is a primary producer.

Scour caused by increased sediment in suspension can cause mortality to many of the other species found within this biotope. For example Daly & Mathieson, (1977) found that *Semibalanus balanoides* could be totally removed from a shore if scour is severe enough. A reduction in light levels due to an increase in the level of suspended sediment will not have a negative impact on the fauna within this biotope, and it is unlikely to have a significant negative impact on the other flora species, due to the intertidal nature of the biotope. An increase in levels of suspended sediment could be beneficial to filter feeding organisms.

**Sensitivity assessment.** This biotope is found on the mid intertidal shore and consequently is subject to long periods of emersion during which time macroalgae can continue to photosynthesize as long as plants have a sufficiently high water content. Therefore, photosynthesis and consequently growth will not be greatly affected. The level of water movement through wave exposure is unlikely to be high enough to cause any significant damage through scour. However the tidal streams can be considerable, and sediment entrained within these currents could cause damage through scour to some species. Consequently, the resistance and resilience of this biotope have been assessed as 'Medium'. The sensitivity of this biotope to this pressure at the benchmark is 'Medium'.

#### Smothering and siltation rate changes (light)

**Medium**

Q: Medium A: Medium C: Medium

**Medium**

Q: High A: Medium C: Medium

**Medium**

Q: Medium A: Medium C: Medium

A discrete event where sediment inundates this biotope to 5 cm will have very different effects on the characterizing species and the associated community depending on the state of the tide. High tide will mean that both of the characterizing species will be vertical in the water column, meaning only a small proportion of the stipe and holdfast will be smothered, leaving the fronds sediment free, and able to continue photosynthesis. In contrast, if the tide is out then fronds of the characterizing furoid canopy will be flat on the substratum and will be smothered by the sediment deposit. The high level of water flow caused by tidal movements within this biotope will mean that the sediment will be removed from the shore quickly. Smothering will prevent photosynthesis resulting in reduced growth and eventually death.

However, germlings are likely to be smothered and killed in both scenarios and are inherently most susceptible to this pressure. Indeed early life stages are smaller in size than adults and are thus most vulnerable to this pressure as even a small load of added sediment will lead to the complete burial. Sediment deposition can reduce macroalgal recruitment by (1) reducing the amount of substratum available for attachment of propagules; (2) scour, removing attached juveniles and (3) burial, altering the light and/or the chemical microenvironment (Deviny & Volse, 1978, Eriksson & Johansson, 2003).

*Ascophyllum nodosum* is intolerant of sediment movement as shown by the shore comparisons undertaken by Daly & Mathieson (1977). Daly & Mathieson (1977) compared two rocky shores

which were similar except for the level of sediment movement experienced on the shore. The shore with more sediment movement was devoid of *Ascophyllum nodosum*.

Smothering will cause direct mortalities in the associated community, notably of the filter feeding sessile organisms unable to clear their feeding appendages or relocate. Airoidi & Hawkins (2007) found that *Patella vulgata* reduces its feeding activity by 35% with just 1 mm of sediment over the substratum (equivalent to 50 mg/cm<sup>2</sup>). At 200 mg/cm<sup>2</sup> mortality occurred. It is possible that 5 cm of sand may create similar mortality events to other grazing organisms, as not only will they be weighted down by sand but food availability will also be restricted.

**Sensitivity assessment.** *Ascophyllum nodosum* adults are sediment intolerant, and germlings of *Ascophyllum nodosum* are intolerant of even small levels of sediment. Many of the smaller species found within the associated community will be totally smothered by 5 cm. However, the fast moving tidal currents will allow deposited sediment to be entrained and removed quickly. Therefore, resistance and resilience have both been assessed as 'High'. Overall the biotope is 'Not Sensitive' at the level of the benchmark.

### Smothering and siltation rate changes (heavy)

**Medium**

Q: Medium A: Medium C: Medium

**Medium**

Q: High A: Medium C: Medium

**Medium**

Q: Medium A: Medium C: Medium

Several studies found that increasing the vertical sediment burden negatively impact fucoid's survival and associated communities. 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 mortalities of understory algae, invertebrate grazers and young (germling) fucoids (see above) and possibly some *Ascophyllum nodosum*. The strong tidal currents will probably remove sediment within a few tidal cycles; however there may be some mortality of the organisms within this biotope. Therefore, resistance and resilience are assessed as 'Medium'. Overall the biotope has a 'Medium' sensitivity to siltation at the pressure benchmark.

### Litter

**Not Assessed (NA)**

Q: NR A: NR C: NR

**Not assessed (NA)**

Q: NR A: NR C: NR

**Not assessed (NA)**

Q: NR A: NR C: NR

Not assessed

### Electromagnetic changes

**No evidence (NEv)**

Q: NR A: NR C: NR

**Not relevant (NR)**

Q: NR A: NR C: NR

**No evidence (NEv)**

Q: NR A: NR C: NR

No evidence.

### Underwater noise changes

**Not relevant (NR)**

Q: NR A: NR C: NR

**Not relevant (NR)**

Q: NR A: NR C: NR

**Not relevant (NR)**

Q: NR A: NR C: NR

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

### Introduction of light or shading

**No evidence (NEv)**

Q: NR A: NR C: NR

**Not relevant (NR)**

Q: NR A: NR C: NR

**No evidence (NEv)**

Q: NR A: NR C: NR

Increased levels of diffuse irradiation correlate with increased growth in macroalgae (Aguilaria *et al.*, 1999). Levels of diffuse irradiation increase in summer, and with a decrease in latitude. As *Ascophyllum nodosum* is found in the middle its natural range in the British Isles an increase in the level of diffuse irradiation will not cause a negative impact on the species or the biotope. However, it is not clear how these findings may reflect changes in light levels from artificial sources, and whether observable changes would occur at the population level as a result. There is, therefore, 'No evidence' on which to base an assessment.

### 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

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

### 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

This pressure is 'Not Relevant' to this biotope.

## Biological Pressures

Resistance

Resilience

Sensitivity

### Genetic modification & translocation of indigenous species

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Key characterizing species within this biotope are not cultivated or relocated. This pressure is therefore considered 'Not relevant' to this biotope.

### Introduction or spread of invasive non-indigenous species

No evidence (NEv)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

No evidence (NEv)

Q: NR A: NR C: NR

Thompson & Schiel (2012) found that native fucoids show high resistance to invasions by the Japanese kelp *Undaria pinnatifida*. However cover of *Fucus vesiculosus* was inversely correlated with the cover of the invasive *Sargassum muticum* indicating competitive interaction between the two species (Stæhr *et al.*, 2000). Stæhr *et al.* (2000) determined that the invasion of *Sargassum muticum* could affect local algal communities through competition mainly for light and space.

*Gracilaria vermiculophylla* is suggested to be one of the most successful marine non-native species (Kim et al., 2010, Sfriso et al., taken from Thomsen *et al.*, 2013). This species invades wave sheltered, shallow water areas, and have been found in biotopes naturally dominated by furoid canopies (Weinberger *et al.*, 2008). To date *Gracilaria vermiculophylla* has only been recorded in Northern Ireland, and not on mainland Britain. The introduction of this species to intertidal rocky shores around the British Isles could have negative impacts on native furoid biotopes, and could become relevant to this specific biotope.

**Sensitivity assessment.** Furoid species have been negatively affected by both the direct and indirect consequences of INNS being present. However, no evidence can be found on the impacts of INNS on *Ascophyllum nodosum* within this biotope. For this reason the effect of this pressure has been given as 'No Evidence'. Literature for this pressure should be revisited.

<b>Introduction of microbial pathogens</b>	No evidence (NEv)	Not relevant (NR)	No evidence (NEv)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR
No evidence.			
<b>Removal of target species</b>	Low	Low	High
	Q: High A: Medium C: Medium	Q: High A: Medium C: Medium	Q: High A: Medium C: Medium

Seaweeds have been collected from the middle of the 16th century for the iodine industry. Modern day industrial uses for seaweed are extensive and include fertilizer, animal feed, alginate extracts (Phillipi *et al.*, 2014), water treatment, and human food and health supplements (Bixler & Porse, 2010). The characteristic furoid algae within this biotope are commercially collected. These commercial harvests remove seaweed canopies which have important effects on the wider ecosystem.

Stagnol *et al.* (2013) investigated the effects of commercial harvesting of intertidal furoids on ecosystem biodiversity and functioning. The study found that the removal of the macroalgae canopy affected the metabolic flux of the area. Flows from primary production and community respiration were lower on the impacted area as the removal of the canopy caused changes in temperature and humidity conditions (Stagnol *et al.*, 2013). Bertness *et al.* (1999) found that the presence of an *Ascophyllum nodosum* canopy reduced maximum daily rock temperatures by 5-10 °C. It was also reported that water loss via evaporation was an order of magnitude less than that in areas where the furoid canopy had been removed (Bertness *et al.*, 1999).

Stagnol *et al.* (2013) found that suspension feeders were the most affected by the canopy removal as canopy-forming algae are crucial habitats for these species. Other studies confirm that loss of canopy had both short and long-term consequences for benthic community diversity resulting in shifts in community composition and a loss of ecosystem functioning such as primary productivity (Lilley & Schiel, 2006; Gollety *et al.*, 2008).

Studies on the effects of commercial harvesting on the faunal communities associated with *Ascophyllum nodosum* have found that removing this key species can reduce abundances of epifauna found on the un-harvested biomass (Jarvis & Seed, 1996, Johnson & Scheibling, 1987; taken from Phillippi *et al.*, 2014). Changes *Ascophyllum nodosum* have also been found to affect the large, mobile fauna such as crabs or grazing gastropods (Bertness *et al.*, 1999; Fegley, 2001; Jenkins *et al.*, 1999, 2004, Phillippi *et al.*, 2014).

However, Phillipi *et al.* (2014) replicated commercial harvesting techniques in Maine, USA where *Ascophyllum nodosum* fronds were removed 40.6 cm from the holdfast and the lowest lateral branch must remain with the holdfast (DMR, 2009). The experiment looked specifically at the effect of canopy reduction on infaunal species living within the soft sediments within intertidal rocky shores where *Ascophyllum nodosum* was present. The experiment found that invertebrate species found living on and within sediments were not negatively affected by the harvesting activity (Phillipi *et al.*, 2014).

Due to the intolerance of macroalgae communities to human exploitation, the European Union put in place a framework to regulate the exploitation of algae establishing an organic label that implies that 'harvest shall not cause any impact on ecosystems' (no. 710/2009 and 834/2007).

**Sensitivity assessment.** The removal of *Ascophyllum nodosum* canopy will significantly change the community composition of the biotope. The quantity of biomass removed from the shore and the regularity of removal will all affect how quickly the biotope will be able to recover. *Ascophyllum nodosum* has a 'Low' resistance to removal as it is easy to locate and have no escape strategy. Resilience is 'Low', however recovery will only be able to start when the pressure is removed from the shore i.e. harvesting is no longer occurring. A sensitivity of 'High' is recorded.

#### Removal of non-target species

**Low**

Q: Medium A: Medium C: Medium

**Low**

Q: High A: Medium C: Medium

**High**

Q: Medium A: Medium C: Medium

Direct, physical impacts from harvesting are assessed through the abrasion and penetration of the seabed pressures. The characterizing species *Ascophyllum nodosum* creates a dominant canopy within this biotope. The dominance of this characterizing species means that it could easily be incidentally removed from this biotope as by-catch when other species are being targeted. The loss of this fucoid species and other associated species would decrease species richness and negatively impact on the ecosystem function.

**Sensitivity assessment.** Removal of a large percentage of the characterizing species would alter the character of the biotope. The resistance to removal is 'Low' due to the easy accessibility of the biotopes location and the inability of these species to evade collection. The resilience is 'Low', giving an overall sensitivity score of 'High'.

## Bibliography

- Åberg, P. & Pavia, H., 1997. Brown Alga *Ascophyllum nodosum*. *Marine Ecological Progress Series*, **158** (11), 1-119.
- Åberg, P., 1992. Size-based demography of the seaweed *Ascophyllum nodosum* in stochastic environments. *Ecology*, **73**: 1488-1501.
- Abou-Aisha, K.M., Kobbia, I., El Abyad, M., Shabana, E.F. & Schanz, F., 1995. Impact of phosphorus loadings on macro-algal communities in the Red Sea coast of Egypt. *Water, Air, and Soil Pollution*, **83** (3-4), 285-297.
- Aguilera, J., Karsten, U., Lippert, H., Voegelé, B., Philipp, E., Hanelt, D. & Wiencke, C., 1999. Effects of solar radiation on growth, photosynthesis and respiration of marine macroalgae from the Arctic. *Marine Ecology Progress Series*, **191**, 109-119.
- 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.
- Ang, P., Sharp, G. & Semple, R., 1996. Comparison of the structure of populations of *Ascophyllum nodosum* (Fucales, Phaeophyta) at sites with different harvesting histories. *Hydrobiologia*, **326** (1), 179-184.
- Arévalo, R., Pinedo, S. & Ballesteros, E., 2007. Changes in the composition and structure of Mediterranean rocky-shore communities following a gradient of nutrient enrichment: descriptive study and test of proposed methods to assess water quality regarding macroalgae. *Marine Pollution Bulletin*, **55** (1), 104-113.
- Araújo, R., Isabel, S.-P., Serrão, E.A. & Per, A., 2012. Recovery after trampling disturbance in a canopy-forming seaweed population. *Marine Biology*, **159** (3), 697-707.
- Araújo, R., Vaselli, S., Almeida, M., Serrão, E. & Sousa-Pinto, I., 2009. Effects of disturbance on marginal populations: human trampling on *Ascophyllum nodosum* assemblages at its southern distribution limit. *Marine Ecology Progress Series*, **378**, 81-92.
- Archambault, P., Banwell, K. & Underwood, A., 2001. Temporal variation in the structure of intertidal assemblages following the removal of sewage. *Marine Ecology Progress Series*, **222**, 51-62.
- Baardseth, E., 1970. Synopsis of the biological data on knotted wrack *Ascophyllum nodosum* (L.) Le Jolis. *FAO Fisheries Synopsis*, no. 38, Rev. 1.
- Bacon, L.M. & Vadas, R.L., 1991. A model for gamete release in *Ascophyllum nodosum* (Phaeophyta). *Journal of Phycology*, **27**, 166-173.
- Ballantine, W., 1961. A biologically-defined exposure scale for the comparative description of rocky shores. *Field Studies*, **1**, 73-84.
- Barthel, D. & Wolfrath, B., 1989. Tissue sloughing in the sponge *Halichondria panicea*: a fouling organism prevents being fouled. *Oecologia*, **78**, 357-360.
- Beer, S. & Kautsky, L., 1992. The recovery of net photosynthesis during rehydration of three *Fucus* species from the Swedish West Coast following exposure to air. *Botanica Marina*, **35** (6), 487-492.
- Bellgrove, A., McKenzie, P.F., McKenzie, J.L. & Sfiligoj, B.J., 2010. Restoration of the habitat-forming furoid alga *Hormosira banksii* at effluent-affected sites: competitive exclusion by coralline turfs. *Marine Ecology Progress Series*, **419**, 47-56.
- Bennell, S.J., 1981. Some observations on the littoral barnacle populations of North Wales. *Marine Environmental Research*, **5**, 227-240.
- Berger, R., Bergström, L., Granéli, E. & Kautsky, L., 2004. How does eutrophication affect different life stages of *Fucus vesiculosus* in the Baltic Sea? - a conceptual model. *Hydrobiologia*, **514** (1-3), 243-248.
- Berger, R., Henriksson, E., Kautsky, L. & Malm, T., 2003. Effects of filamentous algae and deposited matter on the survival of *Fucus vesiculosus* L. germlings in the Baltic Sea. *Aquatic Ecology*, **37** (1), 1-11.
- Bertness, M.D., Ewanchuk, P.J., & Silliman, B.R., 2002. Anthropogenic modification of New England salt marsh landscapes. *Proceedings of the National Academy of Sciences, USA*, **99**, 1395-1398.
- Blanchette, C.A., 1997. Size and survival of intertidal plants in response to wave action: a case study with *Fucus gardneri*. *Ecology*, **78** (5), 1563-1578.
- Boalch, G.T., Holme, N.A., Jephson, N.A. & Sidwell, J.M.C., 1974. A resurvey of Colman's intertidal traverses at Wembury, South Devon. *Journal of the Marine Biological Association of the United Kingdom*, **5**, 551-553.
- Bokn, T., 1987. Effects of diesel oil and subsequent recovery of commercial benthic algae. *Hydrobiologia*, **151/152**, 277-284.
- Bokn, T.L., Duarte, C.M., Pedersen, M.F., Marba, N., Moy, F.E., Barrón, C., Bjerkeng, B., Borum, J., Christie, H. & Engelbert, S., 2003. The response of experimental rocky shore communities to nutrient additions. *Ecosystems*, **6** (6), 577-594.
- Bokn, T.L., Moy, F.E. & Murray, S.N., 1993. Long-term effects of the water-accommodated fraction (WAF) of diesel oil on rocky shore populations maintained in experimental mesocosms. *Botanica Marina*, **36**, 313-319.
- Bokn, T.L., Moy, F.E., Christie, H., Engelbert, S., Karez, R., Kersting, K., Kraufvelin, P., Lindblad, C., Marba, N. & Pedersen, M.F., 2002. Are rocky shore ecosystems affected by nutrient-enriched seawater? Some preliminary results from a mesocosm experiment. *Sustainable Increase of Marine Harvesting: Fundamental Mechanisms and New Concepts*: Springer, pp. 167-175.
- Bradshaw, C., Veale, L.O., Hill, A.S. & Brand, A.R., 2000. The effects of scallop dredging on gravelly seabed communities. In: *Effects*



- of fishing on non-target species and habitats (ed. M.J. Kaiser & de S.J. Groot), pp. 83-104. Oxford: Blackwell Science.
- Bradshaw, C., Veale, L.O., Hill, A.S. & Brand, A.R., 2002. The role of scallop-dredge disturbance in long-term changes in Irish Sea benthic communities: a re-analysis of an historical dataset. *Journal of Sea Research*, **47**, 161-184.
- Brawley, S.H. & Johnson, L.E., 1991. Survival of furoid embryos in the intertidal zone depends upon developmental stages and microhabitat. *Journal of Phycology*, **27** (2), 179-186.
- Brazier, D.P., Holt, R.H.F., Murray, E. & Nichols, D.M., 1999. *Marine Nature Conservation Review Sector 10. Cardigan Bay and North Wales: area summaries*. Peterborough: Joint Nature Conservation Committee. [Coasts and seas of the United Kingdom. MNCR Series.]
- 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.
- Brinkhuis, B.H., Tempel, N.R. & Jones, R.F., 1976. Photosynthesis and respiration of exposed salt-marsh fucoids. *Marine Biology*, **34**, 339-348.
- Brosnan, D.M., 1993. The effect of human trampling on biodiversity of rocky shores: monitoring and management strategies. *Recent Advances in Marine Science and Technology*, **1992**, 333-341.
- Bryan, G.W. & Gibbs, P.E., 1983. *Heavy metals from the Fal estuary, Cornwall: a study of long-term contamination by mining waste and its effects on estuarine organisms*. Plymouth: Marine Biological Association of the United Kingdom. [Occasional Publication, no. 2.]
- Bryan, G.W., 1984. Pollution due to heavy metals and their compounds. In *Marine Ecology: A Comprehensive, Integrated Treatise on Life in the Oceans and Coastal Waters*, vol. 5. *Ocean Management*, part 3, (ed. O. Kinne), pp.1289-1431. New York: John Wiley & Sons.
- Cervin, G., Aberg, P. & Jenkins, S.R., 2005. Small-scale disturbance in a stable canopy dominated community: implications for macroalgal recruitment and growth. *Marine Ecology Progress Series*, **305**, 31-40.
- Chock, J.S. & Mathieson, A.C., 1979. Physiological ecology of *Ascophyllum nodosum* (L.) Le Jolis and its detached ecad *scorpioides* (Hornemann) Hauck (Fucales, Phaeophyta). *Botanica Marina*, **22**, 21-26.
- Choi, H.G. & Norton, T.A., 2005. Competition and facilitation between germlings of *Ascophyllum nodosum* and *Fucus vesiculosus*. *Marine Biology*, **147**(2), 525-532.
- 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/>
- Colman, J., 1933. The nature of the intertidal zonation of plants and animals. *Journal of the Marine Biological Association of the United Kingdom*, **18**, 435-476.
- Connan, S. & Stengel, D.B., 2011. Impacts of ambient salinity and copper on brown algae: 1. Interactive effects on photosynthesis, growth, and copper accumulation. *Aquatic Toxicology*, **104** (1-2), 94-107.
- 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](http://www.jncc.gov.uk/MarineHabitatClassification).
- Cousens, R., 1984. Estimation of annual production by the intertidal brown algae *Ascophyllum nodosum* (L.) Le Jolis. *Botanica Marina*, **27**, 217-227.
- 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.
- Daly, M.A. & Mathieson, A.C., 1977. The effects of sand movement on intertidal seaweeds and selected invertebrates at Bound Rock, New Hampshire, USA. *Marine Biology*, **43**, 45-55.
- Davies, C.E. & Moss, D., 1998. European Union Nature Information System (EUNIS) Habitat Classification. *Report to European Topic Centre on Nature Conservation from the Institute of Terrestrial Ecology, Monks Wood, Cambridgeshire*. [Final draft with further revisions to marine habitats.], Brussels: European Environment Agency.
- Denny, M., Gaylord, B., Helmuth, B. & Daniel, T., 1998. The menace of momentum: dynamic forces on flexible organisms. *Limnology and Oceanography*, **43** (5), 955-968.
- Devlin, J. & Volse, L., 1978. Effects of sediments on the development of *Macrocystis pyrifera* gametophytes. *Marine Biology*, **48** (4), 343-348.
- Diez, I., Santolaria, A. & Gorostiaga, J., 2003. The relationship of environmental factors to the structure and distribution of subtidal seaweed vegetation of the western Basque coast (N Spain). *Estuarine, Coastal and Shelf Science*, **56** (5), 1041-1054.
- Doty, S. & Newhouse, J., 1954. The distribution of marine algae into estuarine waters. *American Journal of Botany*, **41**, 508-515.
- Dudgeon, S. & Petraitis, P.S., 2005. First year demography of the foundation species, *Ascophyllum nodosum*, and its community implications. *Oikos*, **109** (2), 405-415.
- 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.

- Fegley, J., 2001. *Ecological implications of rockweed, Ascophyllum nodosum (L.) Le Jolis, harvesting*. University of Maine, Orono, ME.
- Fernandez, C. & Menendez, M.P., 1991. Ecology of *Chondrus crispus* on the northern coast of Spain. 2. Reproduction. *Botanica Marina*, **34**, 303-310.
- Filion-Myclebust, C. & Norton, T.A., 1981. Epidermis shedding in the brown seaweed *Ascophyllum nodosum* (L.) Le Jolis, and its ecological significance. *Marine Biology Letters*, **2**, 45-51.
- Fish, J.D. & Fish, S., 1996. *A student's guide to the seashore*. Cambridge: Cambridge University Press.
- Fletcher, H. & Frid, C.L.J., 1996a. Impact and management of visitor pressure on rocky intertidal algal communities. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **6**, 287-297.
- Fletcher, R.L., 1996. The occurrence of 'green tides' - a review. In *Marine Benthic Vegetation. Recent changes and the Effects of Eutrophication* (ed. W. Schramm & P.H. Nienhuis). Berlin Heidelberg: Springer-Verlag. [Ecological Studies, vol. 123].
- Floc'h, J. H. & Diouris, M., 1980. Initial effects of Amoco Cadiz oil on intertidal algae. *Ambio*, **9**, 284-286.
- 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.
- Frieder, C., Nam, S., Martz, T. & Levin, L., 2012. High temporal and spatial variability of dissolved oxygen and pH in a nearshore California kelp forest. *Biogeosciences*, **9** (10), 3917-3930.
- Glegg, G. A., Hickman, L. & Rowland, S. J., 1999. Contamination of limpets (*Patella vulgata*) following the Sea Empress oil spill. *Marine Pollution Bulletin*, **38**, 119-125.
- Graham, A., 1988. *Molluscs: prosobranchs and pyramellid gastropods (2nd ed.)*. Leiden: E.J. Brill/Dr W. Backhuys. [Synopses of the British Fauna No. 2]
- Guiry, M.D. & Blunden, G., 1991. *Seaweed Resources in Europe: Uses and Potential*. Chichester: John Wiley & Sons.
- Hawkins, S.J. & Hartnoll, R.G., 1985. Factors determining the upper limits of intertidal canopy-forming algae. *Marine Ecology Progress Series*, **20**, 265-271.
- Hawkins, S.J. & Southward, A.J., 1992. The Torrey Canyon oil spill: recovery of rocky shore communities. In *Restoring the Nations Marine Environment*, (ed. G.W. Thorpe), Chapter 13, pp. 583-631. Maryland, USA: Maryland Sea Grant College.
- Hawkins, S.J., Hartnoll, R.G., Kain, J.M. & Norton, T.A., 1992. Plant-animal interactions on hard substrata in the north-east Atlantic. In *Plant-animal interactions in the marine benthos* (ed. D.M. John, S.J. Hawkins & J.H. Price), pp. 1-32. Oxford: Clarendon Press. [Systematics Association Special Volume, no. 46.]
- Hill, S., Burrows, S.J. & Hawkins, S.J., 1998. *Intertidal Reef Biotopes (Volume VI). An overview of dynamics and sensitivity characteristics for conservation management of marine Special Areas of Conservation*. Oban: Scottish Association for Marine Science (UK Marine SACs Project), Scottish Association for Marine Science (UK Marine SACs Project).
- Hiscock, K., 1983. Water movement. In *Sublittoral ecology. The ecology of shallow sublittoral benthos* (ed. R. Earll & D.G. Erwin), pp. 58-96. Oxford: Clarendon Press.
- 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., Hartnoll, R.G. & Hawkins, S.J., 1997. The sensitivity and vulnerability to man-induced change of selected communities: intertidal brown algal shrubs, *Zostera* beds and *Sabellaria spinulosa* reefs. *English Nature, Peterborough, English Nature Research Report No. 234*.
- Holt, T.J., Jones, D.R., Hawkins, S.J. & Hartnoll, R.G., 1995. The sensitivity of marine communities to man induced change - a scoping report. *Countryside Council for Wales, Bangor, Contract Science Report*, no. 65.
- Hurd, C.L., 2000. Water motion, marine macroalgal physiology, and production. *Journal of Phycology*, **36** (3), 453-472.
- Ingólfsson, A. & Hawkins, S., 2008. Slow recovery from disturbance: a 20 year study of *Ascophyllum* canopy clearances. *Journal of the Marine Biological Association of the United Kingdom*, **88** (4), 689-691.
- Jenkins, S.R., Hawkins, S.J. & Norton, T.A., 1999. Direct and indirect effects of a macroalgal canopy and limpet grazing in structuring a sheltered inter-tidal community. *Marine Ecology Progress Series*, **188**, 81-92.
- Jenkins, S.R., Moore, P., Burrows, M.T., Garbary, D.J., Hawkins, S.J., Ingólfsson, A., Sebens, K.P., Snelgrove, P.V., Wethey, D.S. & Woodin, S.A., 2008. Comparative ecology of North Atlantic shores: do differences in players matter for process? *Ecology*, **89** (11), 3-523.
- Jenkins, S.R., Norton, T.A. & Hawkins, S.J., 2004. Long term effects of *Ascophyllum nodosum* canopy removal on mid shore community structure. *Journal of the Marine Biological Association of the United Kingdom*, **84**, 327-329.
- Jennings, S. & Kaiser, M.J., 1998. The effects of fishing on marine ecosystems. *Advances in Marine Biology*, **34**, 201-352.
- Johnston, C.S., 1977. The sub-lethal effects of water-soluble extracts of oil on the fertilisation and development of *Fucus serratus* L. (Serrated wrack). *Rapports et Proces Verbaux des Reunions. Conseil International pour l'Exploration de la Mer*, **171**, 184-185.
- 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.
- Jonsson, P.R., Granhag, L., Moschella, P.S., Åberg, P., Hawkins, S.J. & Thompson, R.C., 2006. Interactions between wave action and grazing control the distribution of intertidal macroalgae. *Ecology*, **87** (5), 1169-1178.
- Josefson, A. & Widbom, B., 1988. Differential response of benthic macrofauna and meiofauna to hypoxia in the Gullmar Fjord

basin. *Marine Biology*, **100** (1), 31-40.

Karez, R., Engelbert, S., Kraufvelin, P., Pedersen, M.F. & Sommer, U., 2004. Biomass response and changes in composition of ephemeral macroalgal assemblages along an experimental gradient of nutrient enrichment. *Aquatic Botany*, **78** (2), 103-117.

Kautsky, H., 1992. The impact of pulp-mill effluents on phytobenthic communities in the Baltic Sea. *Ambio*, **21**, 308-313.

Keser, M., Swenarton, J.T. & Foertch, J.F., 2005. Effects of thermal input and climate change on growth of *Ascophyllum nodosum* (Fucales, Phaeophyceae) in eastern Long Island Sound (USA). *Journal of Sea Research*, **54** (3), 211-220.

Keser, M., Vadas, R. & Larson, B., 1981. Regrowth of *Ascophyllum nodosum* and *Fucus vesiculosus* under various harvesting regimes in Maine, USA. *Botanica Marina*, **24** (1), 29-38.

Kim, S.Y., Weinberger, F. & Boo, S.M., 2010. Genetic data hint at a common donor region for invasive Atlantic and Pacific population of *Gracilaria vermiculophylla* (Gracilariales, Rhodophyta) 1. *Journal of Phycology*, **46** (6), 1346-1349.

Kinne, O., 1977. International Helgoland Symposium "Ecosystem research": summary, conclusions and closing. *Helgoländer Wissenschaftliche Meeresuntersuchungen*, **30**(1-4), 709-727.

Knight, M. & Parke, M., 1950. A biological study of *Fucus vesiculosus* L. and *Fucus serratus* L. *Journal of the Marine Biological Association of the United Kingdom*, **29**, 439-514.

Knight-Jones, E. & Stevenson, J., 1950. Gregariousness during settlement in the barnacle *Elminius modestus* Darwin. *Journal of the Marine Biological Association of the United Kingdom*, **29** (02), 281-297.

Kraufvelin, P., Moy, F.E., Christie, H. & Bokn, T.L., 2006. Nutrient addition to experimental rocky shore communities revisited: delayed responses, rapid recovery. *Ecosystems*, **9** (7), 1076-1093.

Ladah, L., Feddersen, F., Pearson, G. & Serrão, E., 2008. Egg release and settlement patterns of dioecious and hermaphroditic fucoid algae during the tidal cycle. *Marine Biology*, **155** (6), 583-591.

Laffoley, D. & Hiscock, K., 1993. The classification of benthic estuarine communities for nature conservation assessments in Great Britain. *Netherlands Journal of Aquatic Ecology*, **27**, 181-187.

Lamote, M. & Johnson, L.E., 2008. Temporal and spatial variation in the early recruitment of fucoid algae: the role of microhabitats and temporal scales. *Marine Ecological Progress Series*. **368**, 93-102.

Lazo, L., Markham, J.H. & Chapman, A., 1994. Herbivory and harvesting: effects on sexual recruitment and vegetative modules of *Ascophyllum nodosum*. *Ophelia*, **40** (2), 95-113.

Levin, P.S. & Mathieson, A.C., 1991. Variation in host-epiphyte relationship along a wave exposure gradient. *Marine Ecology Progress Series*, **77**, 271-278.

Lewis, J., 1961. The Littoral Zone on Rocky Shores: A Biological or Physical Entity? *Oikos*, **12** (2), 280-301.

Lewis, J. & Bowman, R.S., 1975. Local habitat-induced variations in the population dynamics of *Patella vulgata* L. *Journal of Experimental Marine Biology and Ecology*, **17** (2), 165-203.

Lima, F.P., Ribeiro, P.A., Queiroz, N., Hawkins, S.J. & Santos, A.M., 2007. Do distributional shifts of northern and southern species of algae match the warming pattern? *Global Change Biology*, **13** (12), 2592-2604.

Lindsay, S.J. & Thompson, H. 1930. The determination of specific characters for the identification of certain ascidians. *Journal of the Marine Biological Association of the United Kingdom*, **17**, 1-35.

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

Lobban, C.S. & Harrison, P.J., 1997. *Seaweed ecology and physiology*. Cambridge: Cambridge University Press.

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

Marchan, S., Davies, M.S., Fleming, S. & Jones, H.D., 1999. Effects of copper and zinc on the heart rate of the limpet *Patella vulgata* (L.) *Comparative Biochemistry and Physiology*, **123A**, 89-93.

Mathieson, A.C. & Burns, R.L., 1971. Ecological studies of economic red algae. 1. Photosynthesis and respiration of *Chondrus crispus* (Stackhouse) and *Gigartina stellata* (Stackhouse) Batters. *Journal of Experimental Marine Biology and Ecology*, **7**, 197-206.

Moore, J., 1997. *Rocky shore transect monitoring in Milford Haven, October 1996. Impacts of the Sea Empress oil spill*. Countryside Council for Wales Sea Empress Contract Report, **241**, 90pp.

Morrissey, J., Kraan, S. & Guiry, M.D., 2001. *A guide to commercially important seaweeds on the Irish coast*. Bord Iascaigh Mhara: Dun Laoghaire.

Munda, I., 1964. *The influence of salinity on the chemical composition, growth and fructification of some Fucaceae*. New York: Pergamon Press.

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

Norton, T.A. (ed.), 1985. *Provisional Atlas of the Marine Algae of Britain and Ireland*. Huntingdon: Biological Records Centre, Institute of Terrestrial Ecology.

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

Olsenz, J.L., 2011. Stress ecology in *Fucus*: abiotic, biotic and genetic interactions. *Advances in Marine Biology*, **59** (57), 37.

Pearson, G.A. & Brawley, S.H., 1996. Reproductive ecology of *Fucus distichus* (Phaeophyceae): an intertidal alga with successful

- external fertilization. *Marine Ecology Progress Series*. Oldendorf, **143** (1), 211-223.
- Pearson, G.A., Lago-Leston, A. & Mota, C., 2009. Frayed at the edges: selective pressure and adaptive response to abiotic stressors are mismatched in low diversity edge populations. *Journal of Ecology*, **97** (3), 450-462.
- Petraitis, P.S. & Dudgeon, S.R., 2005. Divergent succession and implications for alternative states on rocky intertidal shores. *Journal of Experimental Marine Biology and Ecology*, **326** (1), 14-26.
- Phillippi, A., Tran, K. & Perna, A., 2014. Does intertidal canopy removal of *Ascophyllum nodosum* alter the community structure beneath? *Journal of Experimental Marine Biology and Ecology*, **461**, 53-60.
- Pinn, E.H. & Rodgers, M., 2005. The influence of visitors on intertidal biodiversity. *Journal of the Marine Biological Association of the United Kingdom*, **85** (02), 263-268.
- Printz, H.S., 1959. Investigations of the failure of recuperation and re-populating in cropped *Ascophyllum* areas. *Avhandlingar utgitt av Det Norske Videnskap-Akademi i Oslo* No. 3.
- Pybus, C., 1977. The ecology of *Chondrus crispus* and *Gigartina stellata* (Rhodophyta) in Galway Bay. *Journal of the Marine Biological Association of the United Kingdom*, **57**, 609-628.
- Raffaelli, D. & Hawkins, S., 1999. *Intertidal Ecology* 2nd edn.. London: Kluwer Academic Publishers.
- Raffaelli, D.G. & Hawkins, S.J., 1996. *Intertidal Ecology* London: Chapman and Hall.
- Rees, H.L., Waldock, R., Matthiessen, P. & Pendle, M.A., 2001. Improvements in the epifauna of the Crouch estuary (United Kingdom) following a decline in TBT concentrations. *Marine Pollution Bulletin*, **42**, 137-144.
- Rita, A., Isabel, S.-P., Serrao, E.A. & Per, Å., 2012. Recovery after trampling disturbance in a canopy-forming seaweed population. *Marine Biology*, **159** (3), 697-707.
- Robbins, I.J. 1985b. Ascidian growth rate and survival at high inorganic particulate concentrations. *Marine Pollution Bulletin*, **16**, 365-367.
- Robins, M.W., 1968. The ecology of *Alcyonium* species in the Scilly Isles. *Report of the Underwater Association*, **3**, 67-71
- Rohde, S., Hiebenthal, C., Wahl, M., Karez, R. & Bischof, K., 2008. Decreased depth distribution of *Fucus vesiculosus* (Phaeophyceae) in the Western Baltic: effects of light deficiency and epibionts on growth and photosynthesis. *European Journal of Phycology*, **43** (2), 143-150.
- Scanlan, C.M. & Wilkinson, M., 1987. The use of seaweeds in biocide toxicity testing. Part 1. The sensitivity of different stages in the life-history of *Fucus* and of other algae, to certain biocides. *Marine Environmental Research*, **21**, 11-29.
- Schiel, D.R. & Foster, M.S., 2006. The population biology of large brown seaweeds: ecological consequences of multiphase life histories in dynamic coastal environments. *Annual Review of Ecology, Evolution, and Systematics*, 343-372.
- Schonbeck, M. & Norton, T., 1979. Drought-hardening in the upper-shore seaweeds *Fucus spiralis* and *Pelvetia canaliculata*. *Journal of Ecology*, **67**, 687-696.
- Schonbeck, M.W. & Norton, T.A., 1978. Factors controlling the upper limits of furoid algae on the shore. *Journal of Experimental Marine Biology and Ecology*, **31**, 303-313.
- Scrosati, R. & DeWreede, R.E., 1998. The impact of frond crowding on frond bleaching in the clonal intertidal alga *Mazzaella cornucopiae* (Rhodophyta, Gigartinales) from British Columbia, Canada. *Journal of Phycology*, **34** (2), 228-232.
- Scrosati, R., Garbary, D.J. & McLachlan, J., 1994. Reproductive ecology of *Chondrus crispus* (Rhodophyta, Gigartinales) from Nova Scotia, Canada. *Botanica Marina*, **37**, 293-300.
- Seip, K.L., 1980. A computational model for growth and harvesting of the marine alga *Ascophyllum nodosum*. *Ecological Modelling*, **6**, 189-199.
- Sharp, G., 1987. *Ascophyllum nodosum* and its harvesting in Eastern Canada. *FAO Fisheries Technical Paper*, **281**, 3-46.
- Smith, J.E. (ed.), 1968. 'Torrey Canyon'. *Pollution and marine life*. Cambridge: Cambridge University Press.
- Southward, A.J. & Southward, E.C., 1978. Recolonisation of rocky shores in Cornwall after use of toxic dispersants to clean up the Torrey Canyon spill. *Journal of the Fisheries Research Board of Canada*, **35**, 682-706.
- Staehr, P.A., Pedersen, M.F., Thomsen, M.S., Wernberg, T. & Krause-Jensen, D., 2000. Invasion of *Sargassum muticum* in Limfjorden (Denmark) and its possible impact on the indigenous macroalgal community. *Marine Ecology Progress Series*, **207**, 79-88.
- Stafford, R. & Davies, M.S., 2005. Spatial patchiness of epilithic biofilm caused by refuge-inhabiting high shore gastropods. *Hydrobiologia*, **545** (1), 279-287.
- Steen, H. & Rueness, J., 2004. Comparison of survival and growth in germlings of six furoid species (Fucales, Phaeophyceae) at two different temperature and nutrient levels. *Sarsia*, **89**, 175-183.
- Stengel, D.B. & Dring, M.J., 1997. Morphology and *in situ* growth rates of plants of *Ascophyllum nodosum* (Phaeophyta) from different shore levels and responses of plants to vertical transplantation. *European Journal of Phycology*, **32**, 193-202.
- Stephenson, T.A. & Stephenson, A., 1972. Life between tidemarks on rocky shores. *Journal of Animal Ecology*, **43** (2), 606-608.
- Strömngren, T., 1977. Short-term effect of temperature upon the growth of intertidal Fucales. *Journal of Experimental Marine Biology and Ecology*, **29**, 181-195.
- Strömngren, T., 1979a. The effect of copper on the increase in length of *Ascophyllum nodosum*. *Journal of Experimental Marine Biology and Ecology*, **37**, 153-159.

- Strömngren, T., 1979b. The effect of zinc on the increase in length of five species of intertidal Fucales. *Journal of Experimental Marine Biology and Ecology*, **40**, 95-102.
- Strömngren, T., 1980a. The effect of dissolved copper on the increase in length of four species of intertidal furoid algae. *Marine Environmental Research*, **3**, 5-13.
- Strömngren, T., 1980b. The effect of lead, cadmium and mercury on the increase in length of five intertidal Fucales. *Journal of Experimental Marine Biology and Ecology*, **43**, 107-119.
- Sundene, O., 1973. Growth and reproduction in *Ascophyllum nodosum* (Phaeophyceae). *Norwegian Journal of Botany*, **20**, 249-255.
- Suryono, C.A. & Hardy, F.G., 1997. Studies on the distribution of *Fucus ceranoides* L. (Phaeophyta, Fucales) in estuaries on the north-east coast of England. *Transactions of the Natural History Society of Northumbria*, **57**, 153-168.
- Svane, I, Havenhund, J.N. & Jorgensen, A.J., 1987. Effects of tissue extract of adults on metamorphosis in *Ascidia mentula* O.F. Mueller and *Ascidella scabra* (O.F. Müller). *Journal of Experimental Marine Biology and Ecology*, **110**, 171-181.
- Svensson, C.J., Pavia, H. & Åberg, P., 2009. Robustness in life history of the brown seaweed *Ascophyllum nodosum* (Fucales, Phaeophyceae) across large scales: effects of spatially and temporally induced variability on population growth. *Marine Biology*, **156** (6), 1139-1148.
- Thompson, G.A. & Schiel, D.R., 2012. Resistance and facilitation by native algal communities in the invasion success of *Undaria pinnatifida*. *Marine Ecology, Progress Series*, **468**, 95-105.
- Tyler-Walters, H., 2005. *Laminaria hyperborea* with dense foliose red seaweeds on exposed infralittoral rock. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]*: Plymouth: Marine Biological Association of the United Kingdom. 2015(20/05/2015). <http://www.marlin.ac.uk/habitatsbasicinfo.php?habitatid=171&code=1997>
- Ugarte, R., Sharp, G. & Moore, B., 2006. Changes in the brown seaweed *Ascophyllum nodosum* (L.) Le Jolis. plant morphology and biomass produced by cutter rake harvests in souther New Brunswick, Canada. *Journal of applied Phycology*, **18**, 351-359.
- 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.
- Vadas, R.L., Keser, M. & Larson, B., 1978. Effects of reduced temperatures on previously stressed populations of an intertidal alga. In *Energy and environmental stress in aquatic systems* (eds. J.H. Thorp & J.W. Gibbons), DOE Symposium Series 48 (CONF-721114), pp. 434-451., Washington DC: U.S. Government Printing Office.
- Vadas, R.L., Wright, W.A. & Miller, St. L., 1990. Recruitment in *Ascophyllum nodosum*: wave action as a source of mortality. *Marine Ecology Progress Series*, **61**, 263-272.
- Vethaak, A.D., Cronie, R.J.A. & van Soest, R.W.M., 1982. Ecology and distribution of two sympatric, closely related sponge species, *Halichondria panicea* (Pallas, 1766) and *H. bowerbanki* Burton, 1930 (Porifera, Demospongiae), with remarks on their speciation. *Bijdragen tot de Dierkunde*, **52**, 82-102.
- Wapstra, M. & van Soest, R.W.M., 1987. Sexual reproduction, larval morphology and behaviour in demosponges from the southwest of the Netherlands. Berlin: Springer-Verlag.
- Watson, D.C. & Norton, T.A., 1987. The habitat and feeding preferences of *Littorina obtusata* (L.) and *Littorina mariae* Sacchi et Rastelli. *Journal of Experimental Marine Biology and Ecology*, **112**, 61-72.
- White, K.L., Kim, J.K. & Garbary, D.J., 2011. Effects of land-based fish farm effluent on the morphology and growth of *Ascophyllum nodosum* (Fucales, Phaeophyceae) in southwestern Nova Scotia. *Algae*, **26** (3), 253-263.
- Wilce, R., Foertch, J., Grocki, W., Kilar, J., Levine, H. & Wilce, J., 1978. Benthic studies in the vicinity of pilgrim nuclear power station, 1969-1977. *Boston Edison Co.*, 307-656 pp.