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# *Ascophyllum nodosum* on very sheltered mid eulittoral rock

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

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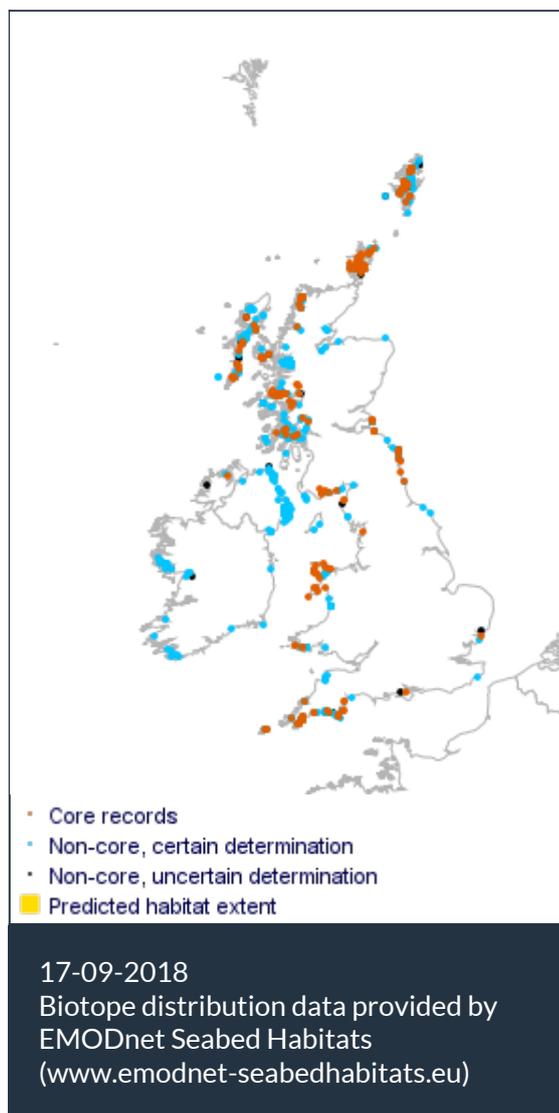


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*Ascophyllum nodosum* on very sheltered mid eu littoral rock  
 Photographer: David Connor  
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Researched by Frances Perry & Jacqueline Hill

Refereed by Prof. Stuart Jenkins

## Summary

### ☰ UK and Ireland classification

**EUNIS 2008** A1.314 *Ascophyllum nodosum* on very sheltered mid eu littoral rock

**JNCC 2015** LR.LLR.F.Asc *Ascophyllum nodosum* on very sheltered mid eu littoral rock

**JNCC 2004** LR.LLR.F.Asc *Ascophyllum nodosum* on very sheltered mid eu littoral rock

**1997 Biotope** LR.SLR.F.Asc *Ascophyllum nodosum* on very sheltered mid eu littoral rock

### 🔍 Description

Sheltered to extremely sheltered mid eu littoral rock with the wrack *Ascophyllum nodosum*. The red seaweed *Polysiphonia lanosa* is often found growing as an epiphyte on the *Ascophyllum nodosum* fronds while disturbed areas among the *Ascophyllum nodosum* is colonized by the wrack *Fucus vesiculosus* and the green seaweed *Ulva intestinalis*, barnacle *Semibalanus balanoides*, the limpet *Patella vulgata* and *Littorina littorea* can all be found on the bedrock underneath the *Ascophyllum nodosum* canopy along with coralline crusts. The

whelk *Nucella lapillus* can be found preying on the barnacles and limpets. Two variants of the LR.LLR.F.Asc biotope are described. These are the full salinity (Asc.FS) and mixed substrata (Asc.X) biotopes. Similar biotopes have been identified as tide-swept (AscT) and variable salinity (AscVS). The unique loose lying growth form *Ascophyllum nodosum* ecad *mackayi* is found on very sheltered shores (Asc.mac).

This biotope is usually found between the wrack *Fucus spiralis* (Fspi) and *Fucus serratus* dominated biotopes (Fserr), although on some shores a narrow zone of *Fucus vesiculosus* (Fves) may occur immediately above the *Ascophyllum nodosum*. With increasing wave exposure the *Ascophyllum nodosum* canopy is replaced by *Fucus vesiculosus* (FvesB; Fves). LR.LLR.F.Asc can occur on more exposed shores, where there is localised shelter. *Ascophyllum nodosum* communities are generally very stable communities with individual plants reaching ages of more than 25 years on shores with little wave-action. (Information adapted from Connor *et al.*, 2004; JNCC, 2015).

### ↓ Depth range

Mid shore, Lower shore

### Additional information

*Ascophyllum nodosum* communities support high levels of biodiversity (Jenkins *et al.*, 1999; Pocklington *et al.*, 2018) and are characterized by a diverse understory of red algae, together with sessile and mobile invertebrates. The understory may include, depending on location, red algae such as *Osmundia pinnatifida*, *Lomenataria articulata*, *Mastocarpus stellatus*, *Chondrus crispus*, *Gelidium* spp. and encrusting corallines; green algae such as *Cladophora rupestris* and *Ulva* spp.; sessile invertebrates such as *Semibalanus balanoides*, *Perforatus perforatus*, *Spirorbis spirorbis*; and mobile species such as *Carcinus maenas*, *Patella vulgata*, *Littorina littorea*, *Littoria obtusata* and *Phocus lineatus* (Jenkins *et al.*, 1999; Pocklington *et al.*, 2018). Disturbed areas may also be colonized by *Fucus serratus* or *Fucus vesiculosus* depending on wave exposure and shore height (Jenkins *et al.*, 1999, 2004; Pocklington *et al.*, 2018).

### ✓ Listed By

- none -

### Further information sources

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## Habitat review

### Ecology

#### Ecological and functional relationships

While physical factors, especially the degree of exposure to wave action and amount of emersion, clearly influence the distribution and abundance of species on rocky shores, biological factors are described here.

- *Ascophyllum nodosum* is of great ecological importance in the North Atlantic because of its high abundance on most sheltered rocky shores, where it must be a major contributor to the oxygen budget of shallow waters to a wide range of intertidal animals (Stengel & Dring, 1997). This species, and other macroalgae, increase the amount of space available for attachment, provide shelter from wave action, desiccation and heat, and may be an important food source.
- Sheltered conditions favour the growth of furoid algae and allow the maintenance of a more or less total and permanent canopy (Hartnoll & Hawkins, 1985). Communities on sheltered shores are much more stable than those of moderately exposed shores where a mosaic of patches of furoid cover, dense barnacles and limpets are subject to small scale temporal variations. The biotope may also be present on sheltered areas of more exposed shores.
- Grazing on rocky shores can exert significant controlling influences on the algal vegetation, particularly by patellid limpets and littorinid snails which are usually the most prominent graders (Hartnoll & Hawkins, 1985; Raffaelli & Hawkins, 1996; Jenkins *et al.*, 1999, 2008). There may also significant effects caused by 'mesograzers' - amphipods such as *Hyale prevostii* and isopods, which are much smaller but may occur in high densities (Brawley, 1992b). The exclusion of furoids from exposed shores, and hence the presence of dense beds of furoids on sheltered shores, results from grazing pressure on exposed shores. A dynamic balance exists between furoids, and limpets plus barnacles and is mediated by wave action. In wave sheltered conditions the balance shifts in favour of the furoids and in wave exposure the balance shifts towards limpets, barnacles and mussels. Limpet grazing normally prevents furoids from extending onto wave exposed headlands. The *Ascophyllum* canopy indirectly affects limpet grazing but allows the development on a diverse understorey of red algae that reduce the grazing range of limpets (Raffaelli & Hawkins, 1996; Jenkins *et al.*, 1999, 2004; Cervin *et al.*, 2005; Jenkins *et al.*, 2008).
- Grazing pressure varies with latitude. Southern European shores support a diverse grazing community of limpets and trochids (top-shells) but this diversity decreases with increasing latitude so that algal domination of shores increase to the north and Icelandic shores lack limpets and trochid grazers (Jenkins *et al.*, 2008). Patellid limpets are also absent in the western Atlantic where it is thought that littorinid grazing may be a dominant grazer (Jenkins *et al.*, 2008).
- The presence of a dense furoid canopy inhibits the settlement of barnacles by blocking larval recruitment limiting larval (cyprid) access to the substratum and by 'sweeping' the rock of colonizers (Raffaelli & Hawkins, 1996; Jenkins & Hawkins, 2003).
- There is a close association between *Ascophyllum nodosum* and the snail *Littorina obtusata*. The snail grazes away some epiphytes, thereby reducing the hydrodynamic loadings on plants and decreasing the detachment rate during storms. Although the snail also consumes the algal thallus, this does not appear to affect the performance of the plant. *Ascophyllum* produces noxious secondary chemical (polyphenols) which deter most

grazers, but which attract *L. obtusata*. It is one of the few grazers to actually consume the thallus tissue as others feed on epiphytes (Norton *et al.*, 1990 cited in Raffaelli & Hawkins, 1996). *Littorina littorea* may be an important grazer of small fucoid plants and germlings and where it occurs in high abundance may delay colonization of fucoids (Lewis, 1964).

### Seasonal and longer term change

Sheltered conditions favour the growth of fucoid algae and allow the maintenance of a more or less total and permanent canopy (Hartnoll & Hawkins, 1985) so that communities on sheltered rocky shores tend to have a high level of stability both seasonally and in the longer term. *Ascophyllum nodosum* has a very long lifespan where individual fronds can survive for 10-15 years and the holdfast for several decades which also contributes to the stability of the biotope. Åberg (1992a,b) concluded that the maximum lifespan of *Ascophyllum nodosum* in two sites in Sweden was 40-60 years, based on demographics and modelling. Furthermore, Åberg (1992a,b) suggested that 10% of sub-populations could survive as long as 120 yrs and that the mean extinction time for subpopulations was ca 163 yrs, based on his simulations. Other fucoid plants found in the biotope, such as *Fucus vesiculosus* and *Fucus serratus* have lifespans in the order of 3-5 years. However, growth rates do show seasonal changes. For example, in Strangford Lough in Northern Ireland, Stengel & Dring (1997) observed the growth of *Ascophyllum nodosum* to be highly seasonal with low growth rates during November and December, and highest growth rates in late spring and early summer. A decline in growth in mid-summer was observed at all shore levels. Reproduction occurs in spring with the development of receptacles and juveniles arrive on the shore in spring. Of the animal species present, *Hyale prevostii* may increase in numbers during the reproductive period when juveniles are released from brood pouches of the females, whilst littorinids and limpets are unlikely to show significant seasonal change. Although present in small numbers in the biotope, barnacles are likely to show increased abundance after settlement in the spring.

### Habitat structure and complexity

*Ascophyllum nodosum* communities support high levels of biodiversity (Jenkins *et al.*, 1999; Pocklington *et al.*, 2018) and are characterized by a diverse understory of red algae, together with sessile and mobile invertebrates. The understory may include, depending on location, red algae such as *Osmundia pinnatifida*, *Lomentaria articulata*, *Mastocarpus stellatus*, *Chondrus crispus*, *Gelidium* spp. and encrusting corallines; green algae such as *Cladophora rupestris* and *Ulva* spp.; sessile invertebrates such as *Semibalanus balanoides*, *Perforatus perforatus*, *Spirorbis spirorbis*; and mobile species such as *Carcinus maenas*, *Patella vulgata*, *Littorina littorea*, *Littoria obtusata* and *Phocus lineatus* (Jenkins *et al.*, 1999; Pocklington *et al.*, 2018). Disturbed areas may also be colonized by *Fucus vesiculosus* or *Fucus serratus* depending on wave exposure and shore height (Jenkins *et al.*, 1999, 2004; Pocklington *et al.*, 2018). The fronds themselves provide space for attachment of encrusting or sessile epifauna and epiphytic algae and provide shelter from wave action, desiccation and heat for invertebrates and understory algae (Jenkins *et al.*, 1999; Pocklington *et al.*, 2018). Crevices in the bedrock and overhangs on fucoid rocky shores also increase habitat complexity by providing refugia for a variety of species.

### 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). Production rates of *Ascophyllum nodosum* in Nova Scotia were estimated to be between 0.61 and 2.82 kg/m<sup>2</sup>; (Cousens, 1984). Only about 10% of the primary production is directly cropped by herbivores

(Raffaelli & Hawkins, 1999). Macroalgae, such as *Ascophyllum nodosum* and other fucoids, exude considerable amounts of dissolved organic carbon which are 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. 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.

## Recruitment processes

Many rocky shore species, plant and animal, possess a planktonic stage: gamete, spore or larvae which float in the plankton before settling and metamorphosing into adult form. This strategy allows species to rapidly colonize new areas that become available such as gaps created by storms. For these organisms it has long been evident that recruitment from the pelagic phase is important in governing the density of populations on the shore (Little & Kitching, 1996). Both the demographic structure of populations and the composition of assemblages may be profoundly affected by variation in recruitment rates.

- *Ascophyllum nodosum* takes five years to become sexually mature (Sundene, 1973). As many as  $2.5 \times 10^9$  eggs  $m^2$ /year may be produced in a mature stand of *Ascophyllum nodosum* (Åberg & Pavia, 1997). However, Åberg & Pavia (1997) estimated that ca one hundred millionths of eggs survive ( $2 \times 10^{-8}$ ) to become 1.5-year-old recruits (Åberg & Pavia, 1997). Dudgeon & Petraitis (2005) reported that germling survivorship depended on the size of the cleared area and that mortality exceeded 99.9% in the first year. Also, they estimated that it could take a minimum of 13 years for an individual to replace itself. Lazo *et al.* (1994) found that predation by grazers can reduce annual recruit survival rates to 0.01%. Other factors that affect the survival rates of recruited *Ascophyllum nodosum* include; their susceptibility to sedimentation (Airoldi, 2003); inability to tolerate desiccation at low tide (Brawley & Johnson, 1991), and inter and intraspecific density-dependent competition of germlings (Choi & Norton, 2005). Cervin *et al.* (2005) reported that recruitment and subsequent growth was promoted by loss of the algal canopy and erosion of the algal turf.
- Recruitment of *Patella vulgata* fluctuates from year to year and from place to place. Fertilization is external and the larvae is pelagic for up to two weeks before settling on rock at a shell length of about 0.2 mm. Winter breeding occurs only in southern England, in the north of Scotland it breeds in August and in north-east England in September.
- Barnacle recruitment can be very variable because it is dependent on a suite of environmental and biological factors, such as wind direction and success depends on settlement being followed by a period of favourable weather. Long-term surveys have produced clear evidence of barnacle populations responding to climatic changes. During warm periods *Chthamalus* spp. predominate, whilst *Semibalanus balanoides* does better during colder spells (Hawkins *et al.*, 1994). Release of *Semibalanus balanoides* larvae takes place between February and April with peak settlement between April and June. Release of larvae of *Chthamalus montagui* takes place later in the year, between May and August.

Some of the species living in the biotope do not have pelagic larvae, but instead have direct development of larvae producing their offspring as 'miniature adults'. For example, *Nucella lapillus* and some winkles do this, as do all amphipods. Adult populations of these species are governed by conditions on the shore and will generally have a much smaller dispersal range.

## Time for community to reach maturity

Numerous studies 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), Cervin *et al.* (2005) and Ingólfsson & Hawkins (2008). 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'. Jenkins *et al.* (1999, 2004) removed the canopy and holdfasts from quadrats and found that the understory of red algae diminished together with the diversity of mobile and sessile invertebrates. Although *Ascophyllum* showed high recruitment it was slow to recover and cleared areas were dominated by *Fucus serratus* and *Fucus vesiculosus* and a mixed canopy of *Fucus* sp and *Ascophyllum nodosum* was present 12 years later. Neither the density of *Ascophyllum* canopy nor the understory community of red algae had recovered after 12 years of study. Cervin *et al.* (2005) noted that loss of the canopy and underlying turf promoted *Ascophyllum* recruitment but that the mixed *Fucus serratus* and *Fucus vesiculosus* canopy dominated after seven years because the *Ascophyllum* recruits were too slow-growing to form a canopy. The twenty-year study undertaken by Ingólfsson & Hawkins (2008) in Iceland found that after removing an *Ascophyllum nodosum* canopy, the canopy could return within 7-8 years, yet the understory community of *Cladophora* spp. had still not recovered after 20 years. Similarly, Petraitis & Dudgeon (2005) reported that succession was dependent on clearing size and that large clearings (8 metres in diameter) were quickly colonized by *Fucus vesiculosus* and *Semibalanus balanoides* but that the dominant *Ascophyllum* canopy had not recovered after 5.5 years (the duration of the study).

## Additional information

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## Preferences & Distribution

### Habitat preferences

<b>Depth Range</b>	Mid shore, Lower shore
<b><a href="#">Water clarity preferences</a></b>	High clarity / Low turbidity, Medium clarity / Medium turbidity, No preference
<b>Limiting Nutrients</b>	Nitrogen (nitrates), Phosphorus (phosphates)
<b>Salinity preferences</b>	Full (30-40 psu), Variable (18-40 psu)
<b>Physiographic preferences</b>	Enclosed coast / Embayment
<b>Biological zone preferences</b>	Mid eulittoral
<b>Substratum/habitat preferences</b>	Bedrock, 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 Weak (negligible), Weak < 1 knot (<0.5 m/sec.)
<b>Wave exposure preferences</b>	Extremely sheltered, Sheltered, Very sheltered
<b>Other preferences</b>	

## Additional Information

### Species composition

#### Species found especially in this biotope

- [Ascophyllum nodosum](#)

#### 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

This biotope is characterized by a dense canopy of *Ascophyllum nodosum*. The fucoid *Fucus vesiculosus* is also common within this biotope. The red seaweed *Polysiphonia lanosa* is a common epiphyte on *Ascophyllum nodosum*. The sheltered nature of this biotope allows *Ascophyllum nodosum* ecad *mackayi* to form on rare occasions. The barnacle *Semibalanus balanoides* is found on the rock surfaces beneath the canopy, along with the limpet species *Patella vulgata*. Both of these species are important in the structuring of the biological community on rocky intertidal ecosystems (Hawkins, 1983). A number of littorinids are found within this biotope and are important grazers. The crab *Carcinus maenas* and the dog whelk *Nucella lapillus* are dominant predators.

*Ascophyllum nodosum* is the key structuring species of this biotope. This species acts as an ecosystem engineer and the canopy that their fronds create modify habitat conditions (Jenkins *et al.*, 2008; Pocklington *et al.*, 2018). Although *Fucus vesiculosus* is important to this biotope, its loss from the biotope would not result in loss of the biotope. The fucoid canopy provides protection from desiccation for the various underlying seaweeds 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 influences the structure and function of intertidal ecosystems (Cervin *et al.*, 2005; Jenkins *et al.*, 2008; Pocklington *et al.*, 2018). 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 120 years in areas free from ice scour (Åberg, 1992a,b). However, individual fronds are more likely to last for 15 -20 years, after which they break off and new fronds grow from the holdfast. The average age within populations of *Ascophyllum nodosum* is high, and there is little population turn over (Schiel & Foster, 2006). Åberg (1992a,b) concluded that the maximum lifespan of *Ascophyllum nodosum* in two sites in Sweden was 40-60 years, based on demographics and modelling. Furthermore, Åberg (1992a,b) suggested that 10% of sub-populations could survive as long as 120 yrs and that the mean extinction time for subpopulations was ca 163 yrs, based on his models. *Ascophyllum nodosum* takes five years to become sexually mature (Sundene, 1973). As many as  $2.5 \times 10^9$  eggs  $m^2$ /year may be produced in a mature stand of *Ascophyllum nodosum* (Åberg & Pavia, 1997). However, Åberg & Pavia (1997) estimated that ca one hundred millionths of eggs survive ( $2 \times 10^{-8}$ ) to become 1.5-year-old recruits (Åberg & Pavia, 1997). Dudgeon & Petraitis (2005) reported that germling survivorship depended on the size of the cleared area and that mortality exceeded 99.9% in the first year. Also, they estimated that it could take a minimum of 13 years for an individual to replace itself. Lazo *et al.* (1994) found that predation by grazers can reduce annual recruit survival rates to 0.01%. Other factors that affect the survival rates of recruited *Ascophyllum nodosum* include; their susceptibility to sedimentation (Airoldi, 2003); inability to tolerate desiccation at low tide (Brawley & Johnson, 1991), and inter and intraspecific density-dependent competition of germlings (Choi & Norton, 2005).

Choi & Norton (2005) examined the competitive interactions between the germlings of *Ascophyllum nodosum* and *Fucus vesiculosus*. Experiments undertaken on the Isle of Man and in the laboratory found that growth rates of both species decreased as the density of germlings

increased. 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*. It was the growth rate of *Ascophyllum nodosum* that led to *Fucus vesiculosus* being more competitive on the shore. However, Choi & Norton (2005) found that the presence of *Fucus vesiculosus* increased the survival of *Ascophyllum nodosum* when exposed to desiccation stress. This showed that the presence of a mixed culture could either facilitate germling survival or lead to competitive exclusion under different environmental conditions (Choi & Norton, 2005). Competition is reversed in mature ecosystems where *Ascophyllum nodosum* plants can out-compete furoids (Keser *et al.*, 1981).

Furoids (inc. *Ascophyllum nodosum*) have a low dispersal capacity, which suggests 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 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. The attachment success of *Ascophyllum nodosum* was very poor at current speeds of over 20 cm/s (Vadas *et al.*, 1992). Therefore, calm conditions typical of wave sheltered habitats are required for successful recruitment in *Ascophyllum nodosum*. Lamote & Johnson (2008) studied temporal and spatial variation in recruitment of furoid algae (including *Ascophyllum nodosum*). They found that recruitment to artificial substrata located in different micro-habitats along a semi-exposed shore was noticeably different. Under the furoid 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 furoid canopy because of restricted distribution abilities.

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 in Long Island Sound in 1984 caused by water temperatures from two power plant thermal discharge pipes exceeding 27-28°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, there was no recovery of the population in the 18 years since the mortality event at the end of Keser *et al.*'s (2005) study. Keser *et al.* (2005) reported that similar mortality events were observed near other power plant thermal discharge pipes in Maine (Vadas *et al.*, 1978) and Massachusetts (Wilce *et al.*, 1978).

Keser *et al.* (1981) recorded the levels of re-growth exhibited by *Ascophyllum nodosum* and *Fucus vesiculosus* after experimental harvesting in Maine. Harvesting was simulated by cutting fronds to three different lengths, that is, frond removed to the holdfast, to 15 cm from the holdfast and to 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; 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 that 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. Almost all (95%) of young *Ascophyllum nodosum* individuals cut back to 15 cm and 25 cm regrew. In almost all populations measured within the experiment, repeat harvests resulted in lower biomass yields (Keser *et al.*, 1981). Printz (1959) also carried out harvesting experiments where fronds were cut back to 25 cm, 15 cm and 5 cm from the holdfast. 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. Individuals that had been trimmed back to 5 cm showed almost no change a year after the harvesting event. 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 further down the thallus (Printz, 1959).

Baardseth (1970) also reported slow re-growth of *Ascophyllum nodosum* after harvesting from the holdfast. Harvesting was found to destroy beds for extended periods where *Ascophyllum nodosum* was harvested from the bed by scrapping it from the substratum. On shores where *Ascophyllum nodosum* had been removed, re-colonization was dominated by *Fucus vesiculosus*, with 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. *Fucus vesiculosus* and *Fucus spiralis* were the first species to colonize a breakwater built in Norway (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).

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 and suggested 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 that affect the survival or growth of large sexually reproductive *Ascophyllum nodosum* could have severe negative effects on regional abundance and biomass of the species.

There is considerable evidence to suggest that if *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; cited in Phillippi *et al.*, 2014) but that removed at the holdfast, flush to the substratum (or the holdfast is removed) recovery takes many years (Phillippi *et al.*, 2014). Numerous studies 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), Cervin *et al.* (2005) and Ingólfsson & Hawkins (2008). 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'. Jenkins *et al.* (1999, 2004) removed the canopy and holdfasts from quadrats and found that the understory of red algae diminished together with the diversity of mobile and sessile invertebrates. Although *Ascophyllum* showed high recruitment it was slow to recover and cleared areas were dominated by *Fucus serratus* and *Fucus vesiculosus* and a mixed canopy of *Fucus* sp and *Ascophyllum nodosum* was present 12 years later. Neither the density of *Ascophyllum* canopy nor the understory community of red algae had recovered after 12 years of study. Cervin *et al.* (2005) noted that loss of the canopy and underlying turf promoted *Ascophyllum* recruitment but that the mixed *Fucus serratus* and *Fucus vesiculosus* canopy dominated after seven years because the *Ascophyllum* recruits were too slow-growing to form a canopy. The twenty-year study undertaken by Ingólfsson & Hawkins (2008) in Iceland found that after removing an *Ascophyllum nodosum* canopy, the canopy could return within 7-8 years, yet the understory community of *Cladophora* spp. had still not recovered after 20 years. Similarly, Petraitis & Dudgeon (2005) reported that succession was dependent on clearing size and that large clearings (8 metres in diameter) were quickly colonized by *Fucus vesiculosus* and *Semibalanus balanoides* but that the dominant *Ascophyllum* canopy had not recovered after 5.5 years (the duration of the study).

*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 been dominated by *Ascophyllum nodosum* previously. 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 six 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 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 vary. However, *Ascophyllum nodosum* takes a long time to recover and provides suitable habitat for the associated understory community (Pocklington *et al.*, 2018). Pocklington *et al.* (2018) examined community disturbance after removal of 100%, 50%, 24.5% and 0% of *Ascophyllum nodosum* fronds (but not holdfasts). They concluded that a pulse disturbance (frond removal) of 50% loss of fronds increased the temperature under the canopy significantly and decreased the abundance of mobile invertebrates such as *Littorina obtusata*. Sessile taxa such as *Osmundia pinnatifida* and encrusting corallines could withstand a 75% loss of fronds but declined by half if 100% were removed. Therefore, the recovery of this biotope hinges on the recovery of the sufficient cover of the *Ascophyllum nodosum* canopy.

**Resilience assessment.** *Ascophyllum nodosum* has high egg and juvenile mortality rates, slow growth, and can take over five years to reach reproductive maturity. Small scale perturbations (e.g. frond removal; Keser *et al.*, 1981; Pocklington *et al.*, 2018) and small scale clearances (e.g. Cervin *et al.*, 2005; Jenkins *et al.*, 1999, 2004; Petraitis & Dudgeon, 2005) have been shown to affect the community significantly. Minor disturbances that result in the cutting of the frond only may allow regrowth in within two to three years depending on the length remaining, shelter and grazing pressure, based on Keser *et al.* (1981) and Phillippi *et al.* (2014). However, even small scale disturbances similar to the clearance studies (i.e. the removal of small patches, flush with the substratum and/or including the holdfast, within the bed), may require over 12 years for partial recovery of the *Ascophyllum* canopy and its associated community (Jenkins *et al.*, 1999;

2004; Cervin *et al.*, 2005). Mass mortality due to ice scour (Åberg (1992a,b) or thermal effluent (Keser *et al.*, 2005) would probably require over 18 years for partial, if any, recovery (Keser *et al.*, 2005). Therefore, where resistance to a specific pressure is assessed as Medium (<25% loss) or Low (25-75% loss) or 'None' (>75% loss) then resilience is probably 'Low' (10-25 years). An **exception** is made for permanent or ongoing (long-term) pressures where recovery is not possible as the pressure is irreversible, and resilience is assessed as 'Very low' by default.

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

## Hydrological Pressures

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

Schonbeck & Norton (1979) demonstrated that fucoids can increase tolerance in response to a 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. The juvenile life stages of organisms can be less tolerant of 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 and Iceland and west into the Kattegat on the shores of Sweden. *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. The growth of *Ascophyllum nodosum* has been measured between 2.5 and 35°C with an optimum between 10 and 17°C (Strömngren, 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 27-28°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 and 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 fucoids 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 *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 this species can extend down to Portugal, a short term acute temperature increase, leaving no time for acclimation, might be expected to result in some damage to or mortality of *Ascophyllum*, especially if the increase occurred during the summer months. However, the observations of Hawkins & Hartnoll (1985) suggest otherwise. Therefore, resistance is assessed as 'High' at the benchmark (an increase of 5°C for one month) in UK waters. Resilience is assessed as 'High' so that sensitivity is assessed as a 'Not sensitive' at the benchmark level.

**Temperature decrease  
(local)**

High

Q: High A: High C: Medium

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: Medium

Schonbeck & Norton (1979) demonstrated that fucoids can increase tolerance in response to a 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. The juvenile life stages of organisms can be less tolerant of 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 and Iceland and west into the Kattegat on the shores of Sweden. The 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 and 23°C. *Ascophyllum nodosum* was reported to survive freezing to -20°C (MacDonald *et al.*, 1974, cited in Åberg, 1992a).

A large number of the species found within this biotope 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, mobile species such as *Carcinus maenas* have the opportunity to move away from areas if physical conditions become too harsh. Hence, 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. It is unlikely to be affected by a short-term change of 5°C for one month or 2°C for a year in UK waters as it survives harsher winter conditions in northern waters of Iceland and in Sweden where populations are subject to ice scour (Åberg, 1992a,b; Ingólfsson & Hawkins, 2008). Therefore, resistance is assessed as **'High'** at the benchmark (an increase of 5°C for one month) in UK waters. Resilience is assessed as **'High'** so that sensitivity is assessed as a **'Not sensitive'** at the benchmark level.

<b>Salinity increase (local)</b>	<b>No evidence (NEv)</b>	<b>Not relevant (NR)</b>	<b>No evidence (NEv)</b>
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

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 rainfall at low tide and evaporation from rock pools causing hypersaline 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 recorded from variable (18 – 35 ppt) and fully saline conditions (30 -40 ppt) (Connor *et al.*, 2004). Consequently, an increase in salinity could 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. 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 (Newell, 1979). Consequently, an increase in salinity within the benchmark may not cause negative impacts. *Semibalanus balanoides* can tolerate salinities between 12 and 50 psu; below and above this cirral activity ceases (Foster, 1970). *Carcinus maenas* is mobile can move to suitable conditions on the shore.

**Sensitivity assessment.** 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. However, **no evidence** on the effects of hypersaline conditions on *Ascophyllum nodosum* or its associated community was found.

<b>Salinity decrease (local)</b>	<b>High</b>	<b>High</b>	<b>Not sensitive</b>
	Q: High A: Medium C: Medium	Q: High A: High C: High	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 rainfall at low tide and evaporation from rock pools causing hypersaline 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 8 psu (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 seven 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 furoids (Munda, 1964). The 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 (Newell, 1979). Consequently, a decrease in salinity within the benchmark of this pressure may not cause significant mortalities. For example, *Semibalanus balanoides* can tolerate salinities between 12 and 50 psu, below and above this cirral activity ceases (Foster, 1970). *Carcinus maenas* is a mobile species and can move to suitable conditions on the shore.

**Sensitivity assessment.** This biotope is recorded from both variable (18 – 40 ppt) and fully saline conditions (30 -40 ppt) (Connor *et al.*, 2004). A decrease in salinity at the benchmark would create a reduced salinity regime (18-30) for a period of a year. As *Ascophyllum nodosum* occurs in estuarine conditions, inhabits areas subject to salinities as low as 8 psu, and can tolerate seven days at a salinity of 5 (Laffoley & Hiscock, 1993; Connan & Stengel, 2011) it is unlikely to suffer a reduction in abundance due to a reduction in salinity at the benchmark level. Therefore, resistance is assessed as 'High' at the benchmark so that resilience is assessed as 'High' and sensitivity as 'Not sensitive' at the benchmark level.

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

High

Q: High A: Medium C: Medium

High

Q: High A: High C: High

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. Furoids 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. Furoids are, however, highly flexible and able to re-orientate their position in the water column to become more streamlined. This ability allows furoids to reduce the relative velocity between algae and the surrounding water, thereby reducing drag and lift (Denny *et al.*, 1998). Furoids 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 the size of furoids (Blanchette, 1997) as smaller individuals create less resistance to water movement, water flow likely exerts a very similar pressure on furoids.

*Fucus vesiculosus* individuals of 10 cm or larger have been recorded to be completely removed at 7-8 m/s (Jonsson *et al.*, 2006). Flow rates at which adult *Ascophyllum nodosum* are removed are not known. However, Thompson & Wernberg (2005) provide strong evidence of an increase in the

break force required to remove algae with an increase in thallus size. Consequently, the force required to remove *Ascophyllum nodosum* from the shore is likely to be comparable to that of *Fucus vesiculosus* as both are large macroalgae with similar thallus sizes.

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. The attachment success of *Ascophyllum nodosum* was poor at current speeds of over 20 cm/s (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 could 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).

**Sensitivity assessment.** This biotope (LR.LLR.F.Asc) is recorded tidal currents ranging from 1 - 3 knots (0.5 - 1.5 m/s) (Connor *et al.*, 2004). Also, *Ascophyllum nodosum* is recorded in tide-swept conditions (e.g. LR.HLR.FT.AscT) in strong (1.5-3 m/s) to very strong (>3 m/s) water flow. Therefore, a change in the current flow of 0.1-0.2 m/s is unlikely to have an impact on many examples of this biotope. Hence, resistance and resilience have been assessed as '**High**' and the biotope is assessed as '**Not Sensitive**' at the benchmark level.

#### Emergence regime changes

**Low**

Q: High A: High C: High

**Low**

Q: High A: High C: Medium

**High**

Q: High A: High 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 large tides and result in rapid changes that do not allow for macroalgae to acclimate (Raffaelli & 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 that 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 several intertidal macroalgae fall within Portugal. Lima

*et al.* (2007) mapped the readjustment 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 a 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 than the warm adapted species.

Information regarding the effect of changes in the level of exposure on *Ascophyllum nodosum* germlings was not available. Germlings would be protected from desiccation stresses due to air exposure 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, an increase in the emergence time for a year is likely to change in the height of the biotope on the shore, with the top of the biotope being most sensitive to change as it is already at the upper tolerance limits. Conversely, a decrease in emergence may allow the biotope to increase its extent up the shore. Overall, an increase in emergence 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 the return of ecosystem function taking considerably longer. Therefore, the resistance of this biotope has been assessed as 'Low' and resilience as 'Low' so that sensitivity is assessed as 'High' to changes in emergence regime at the pressure benchmark.

#### Wave exposure changes (local)

Medium

Q: Medium A: Medium C: Medium

Medium

Q: High A: Medium C: Medium

Medium

Q: Medium A: Medium C: Medium

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 the size of fucoids (Blanchette, 1997) as smaller individuals create less resistance to waves. As exposure to waves increases the furoid 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 furoid 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 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 (Devlinny & Volse, 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 furoid 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 furoid cover, especially of *Ascophyllum nodosum*. The biotope would probably be lost if wave exposure increased 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 resilience is probably '**Medium**', sensitivity is also assessed as '**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>	<b>No evidence (NEv)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>No evidence (NEv)</b> Q: NR A: NR C: NR
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No evidence.

<b>Introduction of other substances</b>	<b>Not Assessed (NA)</b> Q: NR A: NR C: NR	<b>Not assessed (NA)</b> Q: NR A: NR C: NR	<b>Not assessed (NA)</b> Q: NR A: NR C: NR
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This pressure is **Not assessed**.

<b>De-oxygenation</b>	<b>High</b> Q: Low A: NR C: NR	<b>High</b> Q: High A: High C: High	<b>Not sensitive</b> 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 a mid-eulittoral position 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 deoxygenation. 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* would not be negatively affected by a decrease in oxygen within the water column 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 the crab *Carcinus maenas* would 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. However, barnacles can completely recolonize within three years (Bennell, 1981). The sheltered to extremely sheltered conditions that are characteristic of this biotope mean that water mixing is not very strong. Therefore, water movement within this area will not reverse any oxygen depletion quickly, possibly exacerbating any negative effects. However, the biotope occurs in the mid-littoral so that emergence will mitigate the effects of hypoxic surface waters. Therefore, resistance is assessed as 'High'. Hence, resilience is assessed as 'High', and the biotope is assessed

as 'Not sensitive'.

## Nutrient enrichment

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not sensitive

Q: NR A: NR C: NR

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

Johnston & Roberts (2009) undertook a review and meta-analysis of the effect of contaminants on species richness and evenness in the marine environment. Of the 47 papers reviewed relating to nutrients as a contaminant, over 75% found that it had a negative impact on species diversity, <5% found increased diversity, and the remaining papers finding no detectable effect. 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 effects of marine pollutants on species diversity were '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 (Olsen, 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 1500 kg/yr. The background levels of nitrite at the test site were 300  $\mu$ M. In comparison, the ambient nitrite levels in south-west Nova Scotia are 3  $\mu$ M (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 *et al.*, 2006; Kraufvelin, 2007).

**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 effects of marine pollutants on species diversity were '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 *et al.*, 2006; Kraufvelin, 2007).

**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 assessment 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 areas. 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, and reclassification of the biotope. Therefore, resistance is assessed as '**None**'. As this pressure represents a permanent change, recovery is impossible as a suitable substratum for the biological community of this biotope is lacking. Hence, resilience is assessed as '**Very low**' and sensitivity is assessed as '**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 sediment type)</b>	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR
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Not relevant.

<b>Habitat structure changes - removal of substratum (extraction)</b>	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR
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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 the 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. Furoids 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, 2008).

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 northeast England were sufficient to reduce the abundance of furoids (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 & Arnold, 2008).

Pinn & Rodgers (2005) compared the biological communities found on two intertidal rocky shore ledges in Dorset. They found that the ledge that had a higher number of visitors had few branching algal species, including furoids, but had greater abundances of crustose and ephemeral species (Pinn & Rodgers, 2005). The densities of furoids 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 furoids on the shore at Wembury (accessed by the public) and that the average frond length of *Ascophyllum nodosum* was smaller.

*Ascophyllum nodosum* seems to be particularly intolerant of damage from trampling (Flavell, 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, 2008). Araujo *et al.* (2009) found that trampling negatively affected both *Ascophyllum nodosum* abundances and reduced understorey species and promoted 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 Jenkins *et al.* (2004), 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. They concluded that trampling caused significant damage to both the macroalgae and the understorey 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 assessed as '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 over 12 years. Hence, resilience is assessed as 'Low' and sensitivity as '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 hard 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)**

High

Q: Medium A: Medium C: Medium

High

Q: High A: High C: High

Not sensitive

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 sufficient water content (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 sufficient water content. Therefore, photosynthesis and consequently growth will not be greatly affected. The level of water movement through wave exposure and tidal streams is unlikely to be high enough to cause any significant damage through

scour. Hence, resistance and resilience have been assessed as **'High'**. The sensitivity of this biotope to this pressure at the benchmark is assessed as **'Not Sensitive'**.

### Smothering and siltation rate changes (light)

**Medium**

Q: Medium A: Medium C: Medium

**Medium**

Q: High A: High 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 photosynthesising. 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 level of water flow caused by tidal movements and wave exposure within this biotope will mean that the sediment won't 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 micro-environment (Deviny & Volsse, 1978, Eriksson & Johansson, 2003).

*Ascophyllum nodosum* is intolerant of sediment movement. Daly & Mathieson (1977) compared two rocky shores that 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 smothered by 5 cm. The level of water movement within this biotope is not excessive and consequently deposited sediment will persist over a number of tides before it is all entrained and removed. This is likely to cause some damage to the characterizing species and the other associated species. Therefore, resistance is assessed as **'Medium'**. Resilience is probably **'Low'** so that sensitivity is assessed as **'Medium'** at the level of the benchmark.

### Smothering and siltation rate changes (heavy)

**Low**

Q: Medium A: Medium C: Medium

**Low**

Q: High A: High C: Medium

**High**

Q: Medium A: Medium C: Medium

Several studies found that increasing the vertical sediment burden negatively impact fucoids 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 understorey algae, invertebrate grazers and young (germling) fucoids. Water movement will remove sediment but within this biotope is it likely to take a number of tidal cycles. Resistance and resilience are assessed as 'Low' and sensitivity as 'High' to siltation at the pressure benchmark.

<b>Litter</b>	<b>Not Assessed (NA)</b> Q: NR A: NR C: NR	<b>Not assessed (NA)</b> Q: NR A: NR C: NR	<b>Not assessed (NA)</b> Q: NR A: NR C: NR
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Not assessed.

<b>Electromagnetic changes</b>	<b>No evidence (NEv)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>No evidence (NEv)</b> Q: NR A: NR C: NR
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No evidence.

<b>Underwater noise changes</b>	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR
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Species characterizing this habitat do not have hearing perception but vibrations may cause an impact, however, no studies exist to support an assessment.

<b>Introduction of light or shading</b>	<b>No evidence (NEv)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>No evidence (NEv)</b> Q: NR A: NR C: NR
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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 negatively impact 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.

Cervin *et al.* (2005) noted that loss of canopy and degradation of the underlying turf promoted the recruitment of *Ascophyllum nodosum* to experimental plots. They also reported that *Ascophyllum* recruits had low growth rates in shade, under the canopy, that prevented the development of mature *Ascophyllum* plants. The modal size of *Ascophyllum* plants without canopy after six years was over twice that of individuals that grew under an intact canopy and the maximum size was six times greater (Cervin *et al.*, 2005). It is possible that artificial shading, e.g. from a jetty, could slow the growth of *Ascophyllum* and decrease its ability to compensate for grazing or its ability to out-compete other fucoids. However, no evidence was found to support an assessment.

<b>Barrier to species movement</b>	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR
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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

Not relevant.

** Biological Pressures**

Resistance

Resilience

Sensitivity

**Genetic modification & translocation of indigenous species**

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Key characterizing species within this biotope are not cultivated or translocated. 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, the 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.*, 2010 cited in Thomsen *et al.*, 2013). This species invades wave sheltered, shallow water areas, and have been found in biotopes naturally dominated by fucoid 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 fucoid biotopes and could become relevant to this specific biotope.

**Sensitivity assessment.** Fucoid species have been negatively affected by both the direct and indirect consequences of INNS being present. However, no evidence was found on the impacts of INNS on *Ascophyllum nodosum* within this biotope. Literature for this pressure should be revisited.

**Introduction of microbial pathogens**

No evidence (NEv)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

No evidence (NEv)

Q: NR A: NR C: NR

No evidence.

## Removal of target species

**Low**

Q: High A: High C: Medium

**Medium**

Q: High A: High C: Medium

**Medium**

Q: High A: High C: Medium

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

Stagnol *et al.* (2013) investigated the effects of commercial harvesting of intertidal fucoids 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 fucoid 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, Phillipi *et al.*, 2014; Pocklington *et al.*, 2018). Phillippi *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 (Phillippi *et al.*, 2014). However, Pocklington *et al.* (2018) examined community disturbance after removal of 100%, 50%, 245% and 0% of *Ascophyllum nodosum* fronds (but not holdfasts). They concluded that a pulse disturbance (frond removal) of 50% loss of fronds increased the temperature under the canopy significantly and decreased the abundance of mobile invertebrates such as *Littorina obtusata*. Sessile taxa such as *Osmundia pinnatifida* and encrusting corallines could withstand a 75% loss of fronds but declined by half if 100% were removed.

Keser *et al.* (1981) recorded the levels of re-growth exhibited by *Ascophyllum nodosum* and *Fucus vesiculosus* after experimental harvesting in Maine. Harvesting was simulated by cutting fronds to three different lengths, that is, frond removed to the holdfast, to 15 cm from the holdfast and to 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; 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 that 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. Almost all (95%) of young *Ascophyllum nodosum* individuals cut back to 15 cm and 25 cm regrew. In almost all populations measured within the experiment, repeat harvests resulted in lower biomass yields (Keser *et al.*, 1981). Printz (1959) also carried out harvesting experiments where fronds were cut back to 25 cm, 15 cm and 5 cm from the holdfast. 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. Individuals that had been trimmed back to 5 cm showed almost no change a year after the harvesting event. When the 5 cm individuals where 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 further down the thallus (Printz, 1959). There is considerable evidence to suggest that if *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; cited in Phillippi *et al.*, 2014). However, Keser *et al.* (1981) noted that repeated annual harvest reduced biomass and suggested staggering annual harvest between sites to prevent large-scale destruction of the resource.

**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* probably has a 'Low' resistance to removal as it is easy to locate and has no escape strategy. However, resilience to harvesting (the removal of fronds above the holdfast) is probably 'Medium' (2-10 years) depending on the cut length, site, grazing pressure and age-size composition of the population (Keser *et al.*, 1981; Phillippi *et al.*, 2014). Therefore, sensitivity is assessed as 'Medium'.

#### Removal of non-target species

**Low**

Q: High A: High C: Medium

**Low**

Q: High A: High C: Medium

**High**

Q: High A: High C: Medium

Direct, physical impacts from harvesting, trampling or removal are assessed through the abrasion and penetration of the seabed pressures. This pressure focuses on the biological effects of the incidental (accidental) removal of a proportion of the dominant members of the community. Loss of the *Ascophyllum* canopy has been shown to alter the understorey community of sessile and mobile invertebrates and red algal turf species significantly (Jenkins *et al.*, 1999, 2004; Cervin *et al.*, 2005; Phillippi *et al.*, 2014; Pocklington *et al.*, 2018). Subsequent recovery of the community results in intermediary communities, dominated by space and grazers or dominated by other furoids, that may not correspond to this biotope.

**Sensitivity assessment.** Removal of a large percentage of the dominant characterizing species would alter the character of the biotope. The resistance to incidental removal is assessed as 'Low' due to the easy accessibility of the biotopes location and the inability of the species to evade removal. Therefore, resilience is assessed as 'Low' and sensitivity is as 'High'.

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