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Ascophyllum nodosum and *Fucus vesiculosus* on variable salinity mid eulittoral rock

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

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***Ascophyllum nodosum* and *Fucus vesiculosus* on variable salinity mid eulittoral rock**
Photographer: Keith Hiscock
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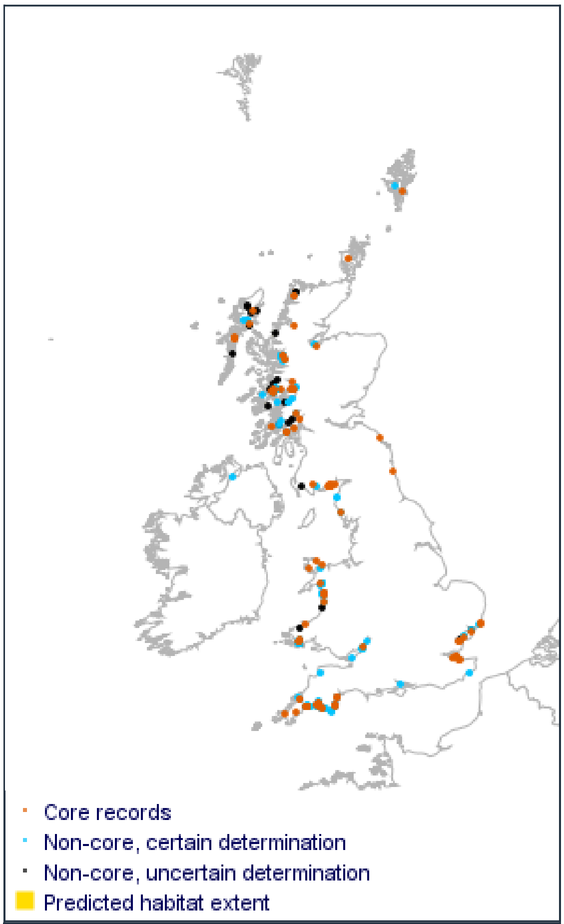

17-09-2018
Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

Researched by Frances Perry, Emilia d'Avack & Jacqueline Hill

Refereed by This information is not refereed

Summary

UK and Ireland classification

EUNIS 2008	A1.324	*Ascophyllum nodosum* and *Fucus vesiculosus* on variable salinity mid eulittoral rock
JNCC 2015	LR.LLR.FVS.AscVS	*Ascophyllum nodosum* and *Fucus vesiculosus* on variable salinity mid eulittoral rock
JNCC 2004	LR.LLR.FVS.AscVS	*Ascophyllum nodosum* and *Fucus vesiculosus* on variable salinity mid eulittoral rock
1997 Biotope	LR.SLR.F.Asc.VS	*Ascophyllum nodosum* and *Fucus vesiculosus* on variable salinity mid eulittoral rock

Description

Very sheltered to extremely sheltered mid eulittoral bedrock, boulders or cobbles subject to variable salinity characterized by an impoverished community dominated by a mixture of the wracks *Ascophyllum nodosum* and *Fucus vesiculosus*. Underneath the canopy are a few green seaweeds including *Ulva intestinalis* and *Cladophora* spp., while the red seaweed *Polysiphonia lanosa* can be found as an epiphyte on *Ascophyllum nodosum*. On the rock and among the boulders are the winkles *Littorina littorea* and *Littorina saxatilis*, the crab *Carcinus maenas*, the barnacles *Semibalanus balanoides* and *Austrominius modestus* and even the occasional mussel *Mytilus edulis*. Among the seaweeds and underneath the boulders a variety of gammarids can be found.

This biotope usually lies below the *Fucus spiralis* biotope (Fspi.VS) or the *Fucus ceranoides* dominated biotopes (Fcer) and above the variable salinity *Fucus serratus* dominated biotope (Fserr.VS), 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 can be more dense (Asc.FS). *Ascophyllum nodosum* can reach over 25 years of age and the communities are usually stable. *Fucus vesiculosus* or *Fucus serratus* can occur in patches where the *Ascophyllum nodosum* has been removed (Information from Connor *et al*., 2004; JNCC, 2015).

Depth range

Mid shore, Lower shore

Additional information

-

Listed By

- none -

Further information sources

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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 frequent within this biotope. The red seaweed *Polysiphonia lanosa* is a common epiphyte on *Ascophyllum nodosum.* This biotope occurs in variable salinity conditions so the diversity is impoverished when compared to full salinity counterpart (eg. Asc, Asc.FS). however, *Semibalanus balanoides* is found on the rock surfaces beneath the canopy. A number of littorinids and gammarids are found within this biotope and are important grazers, especially in the absence of *Patella* spp. (Jenkins et al., 2008). The crab *Carcinus maenas* is the 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). *Fucus vesiculosus* is also important to this 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 most dominant key structuring species *Ascophyllum nodosum* together with *Fucus vesiculosus*, 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 2.5×10^9 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 (2×10^{-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 fucoids (Keser *et al.*, 1981).

Fucoids (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 fucoid 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 fucoid canopy in the study area, recruitment was 10-50 times greater than it was on exposed surfaces and in tide pools. To determine if this difference was due to lower levels of mortality under the canopy or to restricted distribution capacity, newly settled recruits from under the canopy were relocated to alternative microhabitats. Mortality rates of the relocated germlings were higher in the more exposed locations. However, the difference was not great enough to explain the observed difference in the number of germlings within the two different microhabitats. Lamote & Johnson (2008) concluded that the number of recruits was greater from under the fucoid canopy because of restricted distribution abilities.

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 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).

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 a long 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 understorey 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 understorey 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 untaken by Ingólfsson & Hawkins (2008) in Iceland found that after removing an *Ascophyllum nodosum* canopy, the canopy could return within 7-8 years, yet the understorey 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).

Fucus vesiculosus growth rates can vary both spatially and temporally (Lehvo *et al.*, 2001). Temperature, exposure, and light availability are some of the factors that change in growth rates (Strömgren, 1977, Knight & Parke, 1950, Middelboe *et al.*, 2006). Strömgren (1977) investigated the effect of short-term increases in temperature on the growth rate of *Fucus vesiculosus*. It was found that the growth rate of the control sample kept at 7°C was 20 times lower than the sample introduced to temperatures of 35°C (Strömgren 1977). When the effect of temperature was investigated on the shore, relative growth rates in summer were found to be as high as 0.7%/day in summer, compared to less than 0.3%/day in winter (Lehvo *et al.*, 2001). For macroalgae, the trend is for shorter individuals in situations with greater wave exposure (Lewis, 1961, Stephenson & Stephenson, 1972, Hawkins *et al.*, 1992, Jonsson *et al.*, 2006). *Fucus vesiculosus* also comply with this trend, and growth rates mirror this difference in physiology. On Sgeir Bhuidhe, an exposed shore in Scotland, *Fucus vesiculosus* grew on average 0.31 cm/week. On a sheltered Scottish shore, the average increased to 0.68 cm/week (Knight & Parke, 1950).

In *Fucus vesiculosus t*he development of the receptacles takes three months from initiation to gamete release (Knight, 1947). On British shores, receptacles are initiated around December and may be present until late summer (Knight, 1947). *Fucus vesiculosus* is dioecious, and gametes are generally released into the seawater under calm conditions (Mann, 1972; Serrão et al., 2000) and the eggs are fertilized externally to produce a zygote. Serrão *et al.* (1997) determined that the wrack had a short-range dispersal capacity. Under calm conditions in which eggs are released, most eggs fall in the immediate vicinity of the parent plants. The egg becomes attached to the rock within a few hours of settlement and adhere firmly enough to resist removal by the next returning tide and germling may be visible to the naked eye within a couple of weeks (Knight & Parke, 1950). Despite the poor long-range dispersal, the species is highly fecund often bearing more than 1000 receptacles on each plant, which may produce more than one million eggs. On the coast of Maine, sampling on three separate occasions during the reproductive season revealed 100% fertilization on both exposed and sheltered shores (Serrão *et al.*, 2000). Fertilization is thus not considered as a limiting factor in reproduction in this species (Serrão *et al.*, 2000).

Mortality is extremely high in the early stages of germination until plants are 3 cm in length, due mostly to mollusc predation (Knight & Parke 1950). While *Fucus vesiculosus* may resist some degree of environmental stress, their long-term persistence depends on their reproductive ability as well as the survival and growth of early life history stages (germlings) that are generally more susceptible to natural and anthropogenic stressors than adults (Steen, 2004; Fredersdorf *et al.*, 2009). It is, therefore, necessary to include early life stage responses in the assessment of effects of environmental changes on fucoid algae as only considering fully developed adults specimens may lead to false conclusions (Nielsen *et al*., 2014). *Fucus vesiculosus* is also able to generate vegetative re-growth in response to wounding. McCook & Chapman (1992) experimentally damaged *Fucus vesiculosus* holdfasts to test the ability of the wrack to regenerate. The study found that vegetative sprouting of *Fucus vesiculosus* holdfasts made a significant addition to the regrowth of the canopy, even when holdfasts were cut to less than 2 mm tissue thickness. Four months after cutting, sprouts ranged from microscopic buds to shoots about 10 cm long with mature shoots widespread after 12 months. Vegetative re-growth in response to wounding has been suggested as an important mean of recovery from population losses (McLachan & Chen, 1972). The importance of regeneration will depend on the severity of the damage, not only in terms of the individuals but also in terms of the scale of canopy removal (McLachan & Chen, 1972).

Genetic diversity can influence the resilience of fucoids in particular when pressure persists over a long period. Genetically diverse populations are generally more resilient to changes in environmental conditions compared to genetically conserved populations. Tatarenkov *et al.* (2007) determined a high level of genetic variation in *Fucus vesiculosus* and extensive phenotypic variation. This could explain why the species is more successful than most fucoid species in colonizing marginal marine environments such as low-salinity estuaries, showing a range of morphological, physiological and ecological adaptations (Tatarenkov *et al.* 2005).

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 understorey community (Pocklington *et al*., 2018). 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. 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). *Fucus vesiculosus* and *Fucus serratus* colonized space left by the removal of *Ascophyllum* after 3-4 years (Jenkins *et al*., 1999; 2004). Therefore, *Fucus vesiculosus* cover would probably recover within a few years but the dominant *Ascophyllum* canopy would take considerably longer. 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 (Strömgren, 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.

In the North East Atlantic, *Fucus vesiculosus* occurs from Northern Russia to Morocco (Powell, 1963). *Fucus vesiculosus* can tolerate temperatures as high as 30°C (Lüning, 1990) and did not show any sign of damage during the extremely hot UK summer of 1983 when average temperatures were 8°C hotter than normal (Hawkins & Hartnoll, 1985). *Fucus vesiculosus* also tolerates extended periods of freezing in the northern part of its range.

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* and *Fucus vesiculosus* are found in the middle of their habitat range in the British Isles. Although the range of *Ascophyllum* 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 (Strömgren, 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 the North East Atlantic, *Fucus vesiculosus* occurs from Northern Russia to Morocco (Powell, 1963). *Fucus vesiculosus* can tolerate temperatures as high as 30°C (Lüning, 1990) and did not show any sign of damage during the extremely hot UK summer of 1983 when average temperatures were 8°C hotter than normal (Hawkins & Hartnoll, 1985). *Fucus vesiculosus* also tolerates extended periods of freezing in the northern part of its range. 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* and *Fucus vesiculosus* are found in the middle of their habitat range in the British Isles. They are unlikely to be affected by a short-term change of 5°C for one month or 2°C for a year in UK waters. *Ascophyllum* 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.**

Salinity increase (local)	No evidence (NEv) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

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) (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). *Fucus vesiculosus* is well adapted to cope with varying salinities and can grow in full saline to brackish conditions. Bäck *et al.* (1991) compared *Fucus vesiculosus* individuals from Atlantic and Baltic populations. Both populations were able to withstand a wide range of salinities in laboratory cultures. The Atlantic population showed better growth in higher salinities and virtually no growth at 5 ppt. Those individuals kept at 5 ppt mortality occurred after seven weeks. In contrast, the Baltic wracks grew better in conditions with lower salinities. But growth was negligible at the highest tested salinity of

45 ppt (Bäck *et al.*, 1991). Growth rates for *Fucus serratus* are maximal at a salinity of 20 psu with the critical limit for recruitment set at 7 psu (Malm *et al.*, 2001). *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.

Salinity decrease (local)	High Q: High A: Medium C: Medium	High Q: High A: High C: High	Not sensitive 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 fucoids (Munda, 1964). The rate of fructification in *Ascophyllum nodosum* has been measured to increase in diluted seawater (Munda, 1964).

Fucus vesiculosus is well adapted to cope with varying salinities and can grow in full saline to brackish conditions. *Fucus vesiculosus* is the dominant large perennial seaweed in the Baltic Sea growing in salinities down to 4 psu (Kautsky, 1992). Bäck *et al.* (1991) compared *Fucus vesiculosus* individuals from Atlantic and the Baltic populations. Both populations were able to withstand a wide range of salinities in laboratory cultures, yet some differences were recorded. The Atlantic population showed better growth in higher salinities and virtually no growth at 5 ppt. Those individuals kept at 5 ppt mortality occurred after seven weeks. In contrast, the Baltic wracks grew better in conditions with lower salinities (Back *et al.*, 1991). Serrao *et al.* (1996a) found that lower salinities can negatively affect both the fertilization rates and recruitment success of *Fucus vesiculosus*. Serrao *et al.* (1996a) also concluded that the osmotic tolerances of *Fucus vesiculosus* gametes limit the species distribution in the Baltic Sea.

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 salinity (18 – 40 ppt) (Connor *et al*., 2004). A decrease in salinity at the benchmark would create a reduced salinity regime (18-30) for 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. Similarly, *Fucus vesiculosus* is also found in estuarine conditions and can survive for seven weeks at 5 ppt (Back *et al*., 1991). 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. Fucoids are highly flexible but not physically robust and an increase in water flow could cause mechanical damage, breaking fronds or even dislodging whole algae from the substratum. Fucoids are, however, highly flexible and able to re-orientate their position in the water column to become more streamlined. This ability allows fucoids to reduce the relative velocity between algae and the surrounding water, thereby reducing drag and lift (Denny *et al*., 1998). Fucoids are permanently attached to the substratum and would not be able to re-attach if removed. Organisms living on the fronds and holdfasts will be washed away with the algae whereas free-living community components could find new habitat in surrounding areas. Wave exposure has been shown to limit the size of fucoids (Blanchette, 1997) as smaller individuals create less resistance to water movement, water flow likely exerts a very similar pressure on fucoids.

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 (Devinny & 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.FVS.AscVS) is recorded tidal currents ranging moderately strong (1 - 3knots; 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 fucoid 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).

Fucus vesiculosus can tolerate desiccation until the water content is reduced to ~30%. If desiccation occurs beyond this level, irreversible damage occurs. Individuals at the top of the shore probably live at the upper limit of their physiological tolerance and therefore, are likely to be unable to tolerate increased desiccation and would be displaced by more physiologically tolerant species. Tolerance to this pressure is likely to vary on a geographical scale. Gylle *et al.* (2009) found that *Fucus vesiculosus* populations that occur naturally in fully saline conditions had a higher emersion stress tolerance compared to brackish populations. Early life history stages are more susceptible to this pressure compared to adults (Henry & Van Alstyne, 2004). Germlings are, however, protected from desiccation by the canopy of adults. Brawley & Jonhnson (1991) showed that germling survival under the adult canopy was close to 100% whereas survival on the adjacent bare rock was close to 0% during exposure to aerial conditions.

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 fucoid population will become dominated by small juvenile algae and dwarf forms of macroalgae which are more resistant to strong wave action. An increase in wave action beyond the tolerance of these fucoid species leads to a further increase in the abundance of robust fucoids, such as *Fucus spiralis* f. *nana* and red seaweeds, such as *Corallina officinalis* (Connor *et al*., 2004).

Ascophyllum nodosum cannot resist very heavy wave action so exposure to wave action is an important factor controlling the distribution of the species, and therefore this biotope. This biotope is found in 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^{-1} 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 (Devinny & 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 fucoid cover would result in major changes to the associated community, especially attached epifauna and understorey algae.

A recent study investigated the combined impacts of wave action and grazing on macroalgae distribution (Jonsson *et al.*, 2006). It suggested that recruitment and survival of juvenile *Fucus vesiculosus* is controlled indirectly by wave exposure, through higher limpet densities at exposed locations (Jonsson *et al.*, 2006). *Fucus vesiculosus* has shown to adapt its morphology to wave exposure to help cope with the stress. For instance, Bäck (1993) observed shorter individuals with narrow fronds on exposed shores lacking bladders to reduce drag. An alternative coping strategy for wave induced forces is thallus toughening. In the North Sea and the Baltic Sea, thalli from exposed *Fucus vesiculosus* were 30% more resistant to tear and breakage compared to those from more sheltered sites (Nietsch, 2009). Furthermore, *Fucus vesiculosus* is able to regenerate from holdfasts (Malm & Kautsky, 2003). *Fucus vesiculosus* can grow in its canopy-forming state in biotopes found in moderately exposed conditions (Connor et al., 2004). Moderately exposed conditions are considerably higher than what is experienced within this biotope, which suggests that *Fucus vesiculosus* would not be affected by an increase in the pressure at the benchmark within this biotope.

Sensitivity assessment. As this is a very to extremely sheltered biotope a further decrease in wave exposure is unlikely. An increase in wave action is likely to adversely affect *Ascophyllum nodosum* cover. Although Connor *et al.* (2004) note that an increase in wave exposure to 'sheltered' could result in a denser *Ascophyllum* canopy (similar to Asc.FS), 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
Transition elements & organo-metal contamination	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

This pressure is **Not assessed** but evidence is presented where available.

Hydrocarbon & PAH contamination	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

This pressure is **Not assessed** but evidence is presented where available.

Synthetic compound contamination	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

This pressure is **Not assessed** but evidence is presented where available.

Radionuclide contamination	No evidence (NEv) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

No evidence.

Introduction of other substances	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

This pressure is **Not assessed**.

De-oxygenation	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low

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 very 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 eulittoral 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 (Olsenz, 2011). Nutrient enriched environments can not only increase algae abundance but the abundance of grazing species (Kraufvelin, 2007).

White *et al.* (2011) investigated the effects of nutrient effluent from land-based finfish farms on the morphologies of *Ascophyllum nodosum* in the vicinity of the outfall pipes. It was estimated that the nitrogen effluent from the farm was 1500 kg/yr. The background levels of nitrite at the test site were 300 µM. In comparison, the ambient nitrite levels in south-west Nova Scotia are 3 µM

(White *et al.*, 2011). *Ascophyllum nodosum* at the test sites were found to be younger than those at the control sites, but significantly larger. This experiment suggested that nutrient effluent could have positive impacts on *Ascophyllum nodosum*. Yet it must be noted that the effect of the effluent on the rest of the biological community was not studied. Major declines of *Fucus vesiculosus* were reported from all over the Baltic Sea associated with eutrophication from nutrient enrichment (Kautsky *et al.*, 1986). In experimental rocky shore communities, Krauflin *et al*. (2006) found only minor effects on the fucoid community structure as a response to high nutrient levels during the first three years of the experiment. However, during the 4th year of exposure *Fucus serratus* started to decline and population consequently crashed in the 5th year. The study observed full recovery of the algal canopy and animal community in less than two years after conditions returned to normal (Krauflin *et al.*, 2006).

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 led 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 fucoid fronds by biofilms (Olsenz, 2011). Nutrient enriched environments cannot only increase algae abundance but the abundance of grazing species (Kraufvelin, 2007). Bellgrove *et al.* (2010) found that coralline turfs out-competed fucoids at a site associated with organic enrichment caused by an ocean sewage outfall.

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 µM. In comparison, the ambient nitrite levels in south-west Nova Scotia are 3 µM (White *et al.*, 2011). *Ascophyllum nodosum* at the test sites were found to be younger than those at the control sites, but significantly larger. This experiment suggested that nutrient effluent could have positive impacts on *Ascophyllum nodosum*. Yet it must be noted that the effect of the effluent on the rest of the biological community was not studied. Major declines of *Fucus vesiculosus* were reported from all over the Baltic Sea associated with eutrophication from nutrient enrichment (Kautsky *et al.*, 1986). In experimental rocky shore communities, Krauflin *et al.* (2006) found only minor effects on the fucoid community structure as a response to high nutrient levels during the first three years of the experiment. However, during the 4th year of exposure *Fucus serratus* started to decline and population consequently crashed in the 5th year. The study observed full recovery of the algal canopy and animal community in less than two years after conditions returned to normal (Krauflin *et al.*, 2006).

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'.**

Physical Pressures

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

All marine habitats and benthic species are considered to have a resistance of **'None'** to this pressure and to be unable to recover from a permanent loss of habitat (resilience is **'Very low'**). Sensitivity within the direct spatial footprint of this pressure is, therefore **'High'**. Although no specific evidence is described confidence in this assessment is 'High', due to the incontrovertible nature of this pressure.

Physical change (to another seabed type)	None Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High

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* and *Fucus vesiculosus* 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.

Physical change (to another sediment type)	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

Not relevant.

Habitat structure changes - removal of substratum (extraction)	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

The species characterizing this biotope occur on rock and would be sensitive to the removal of the habitat. However, extraction of rock substratum is considered unlikely and this pressure is considered to be 'Not relevant' to hard substratum habitats.

Abrasion/disturbance of the surface of the substratum or seabed	Low Q: High A: High C: High	Low Q: High A: Medium C: Medium	High Q: High A: Medium C: Medium

Trampling on the rocky shore has been observed to reduce fucoid 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. Fucoids are intolerant of abrasion from human trampling, which has been reported to reduce the cover of seaweeds on a shore (Holt *et al.*, 1997; Tyler-Walters & Arnold, 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^2 on stations on an intertidal rocky shore in northeast England were sufficient to reduce the abundance of fucoids (Fletcher & Frid, 1996). This reduction in the complexity of the algae community, in turn, reduced the microhabitat available for epiphytic species. Trampling pressure can thus result in an increase in the area of bare rock on the shore (Hill *et al*., 1998). Chronic trampling can affect community structure with shores becoming dominated by algal turf or crusts (Tyler-Walters & Arnold, 2008).

Fucus vesiculosus can generate vegetative regrowth in response to wounding from physical disturbance. McCook & Chapman (1992) experimentally tested the recovery of damaged *Fucus vesiculosus*. The study found that vegetative sprouting of *Fucus vesiculosus* holdfasts made a significant addition to the regrowth of the canopy, even when holdfasts were cut to less than 2 mm tissue thickness. Four months after cutting, sprouts ranged from microscopic buds to shoots about 10 cm long with mature shoots widespread after 12 months. Vegetative regrowth in response to wounding has been suggested as an important means of recovery from population losses (McLachan & Chen, 1972).

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 fucoids, but had greater abundances of crustose and ephemeral species (Pinn & Rodgers, 2005). The densities of fucoids were recorded from the intertidal rocky shore at Wembury, Devon in 1930 (Colman, 1933) and 1973 (Boalch *et al*., 1974). Boalch *et al*. (1974) found a reduction in fucoids on the shore at Wembury (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. The distribution of both *Ascophyllum nodosum* and *Fucus vesiculosus* occur along a depth gradient that strongly correlates with light penetration. In areas with low sedimentation, *Fucus vesiculosus* can survive down to 9-10 m depth (Eriksson & Bergstrom, 2005). Changes in suspended solids affecting water clarity may have a direct impact on the photosynthesising capabilities of *Fucus vesiculosus*. Kõuts *et al.* (2006) found decreases in light intensity in the vicinity of the dredging site resulted in the net decline of *Fucus vesiculosus* biomass. A decrease in light penetration in the Kiel Fjord caused by an increase in phytoplankton density and shading from filamentous algae caused an upward shift of the lower depth limit of *Fucus vesiculosus* (Rohde *et al.*, 2008).

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 fucoid 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 (Devinny & Volse, 1978, Eriksson & Johansson, 2003). Eriksson & Johansson (2003) found that sedimentation had a significant negative effect on the recruitment success of *Fucus vesiculosus*. Even fine sediment fractions can reduce the successful attachment of fucoids by as much as 90% (Schiel & Foster, 2006).

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. Airoldi & 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^2). At 200 mg/cm^2 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.

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

Not assessed.

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

No evidence.

Underwater noise changes	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

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

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

Increased levels of diffuse irradiation correlate with increased growth in macroalgae (Aguilaria *et al*., 1999). Levels of diffuse irradiation increase in summer, and with a decrease in latitude. As *Ascophyllum nodosum* is found in the middle its natural range in the British Isles an increase in the level of diffuse irradiation will not 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.

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

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

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

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

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

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* and *Fucus vesiculosus* 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 inveretebrates 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 fucoids, 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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