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Fucus spiralis on full salinity upper eulittoral mixed substrata

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

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2015-10-07

A report from:

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

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This review can be cited as:

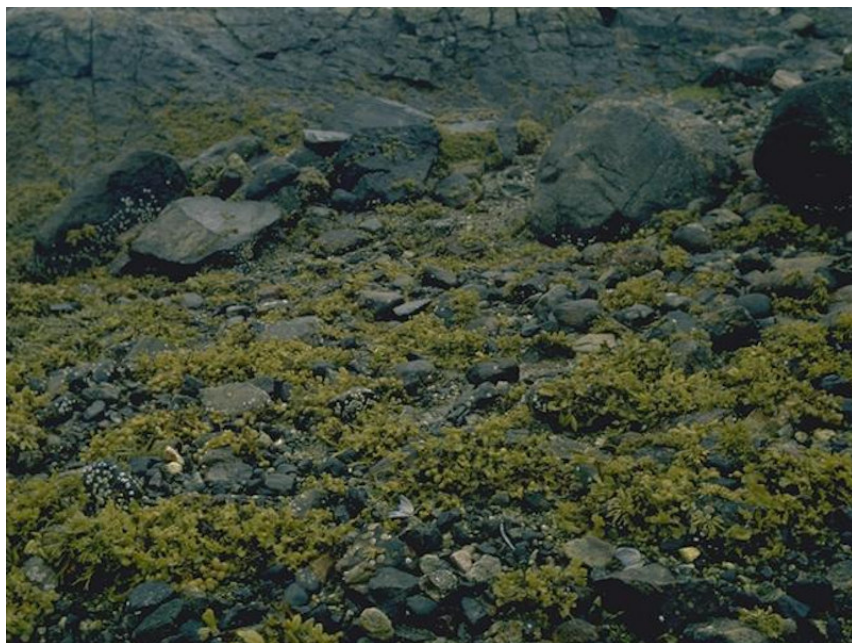
Perry, F., & d'Avack, E. 2015. [*Fucus spiralis*] on full salinity upper eulittoral mixed substrata. In Tyler-Walters H. and Hiscock K. (eds) *Marine Life Information Network: Biology and Sensitivity Key Information Reviews*, [on-line]. Plymouth: Marine Biological Association of the United Kingdom.

DOI <https://dx.doi.org/10.17031/marlinhab.1024.1>

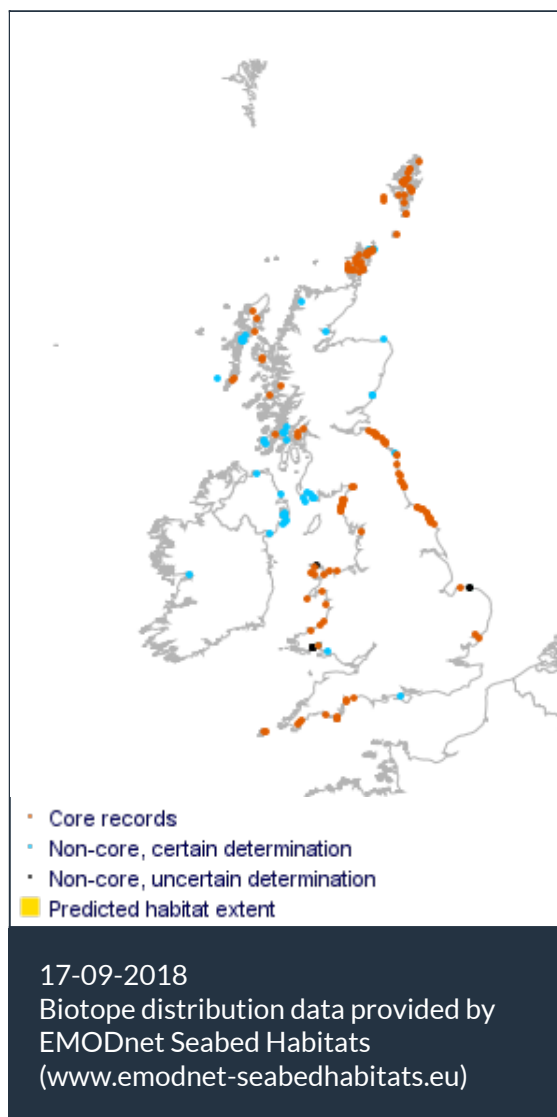


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Fucus spiralis on full salinity upper eu littoral mixed substrata
 Photographer: Francis Bunker
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Researched by Frances Perry & Emilia d'Avack Referred by Admin

Summary

☰ UK and Ireland classification

EUNIS 2008 A1.3122 *Fucus spiralis* on full salinity upper eu littoral mixed substrata
 JNCC 2015 LR.LLR.F.Fspi.X *Fucus spiralis* on full salinity upper eu littoral mixed substrata
 JNCC 2004 LR.LLR.F.Fspi.X *Fucus spiralis* on full salinity upper eu littoral mixed substrata
 1997 Biotope

🔍 Description

Moderately exposed to sheltered full salinity upper eu littoral mixed substrata characterized by a band of the wrack *Fucus spiralis*. Occasional clumps of the wrack *Pelvetia canaliculata* can be overgrowing the black lichen *Verrucaria maura* and the olive green lichen *Verrucaria mucosa*. On the more stable boulders underneath the fronds the red crust *Hildenbrandia rubra* can be found along with the barnacle *Semibalanus balanoides* and the limpet *Patella vulgata*. The winkles *Littorina littorea* and *Littorina saxatilis* can be found on and among the boulders and cobbles, while

amphipods and the crab *Carcinus maenas* can be present either underneath the boulders or among the brown seaweeds. The green seaweed *Ulva intestinalis* can occur in some abundance especially during the summer. (Information from Connor *et al.*, 2004; JNCC, 2015).

↓ Depth range

-

🏛️ Additional information

-

✓ Listed By

- none -

🔗 Further information sources

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Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

This biotope is characterized by a canopy of *Fucus spiralis*. Beneath the furoid canopy the barnacle *Semibalanus balanoides*, the limpet *Patella vulgata*, and a variety of littorinids are the dominant grazers. The upper eulittoral situation of these biotopes allows black lichens such as *Verrucaria maura* to be common. Cracks and fissures can create micro habitats within which environmental conditions are less severe; within these areas *Mytilus edulis* can be found. Other species of seaweeds, such as *Hildenbrandia rubra* and *Ulva intestinalis* can be found within this biotope but are not as common as *Fucus spiralis*.

Fucus spiralis acts as an ecosystem engineer in the biotope. The macroalgae forms a canopy that provides protection from desiccation for underlying fauna, in addition to providing a substratum for a diverse range of epifauna. As ecosystem engineers furoid algal canopies modify habitat conditions. This can facilitate the existence and survival of other intertidal species and therefore strongly influencing the structure and functioning of intertidal ecosystems (Jenkins *et al.*, 2008).

Resilience and recovery rates of habitat

Fucus spiralis is a relatively short lived perennial algae. Maximum lifespans of up to five years (S. H. Brawley, personal observation) have been recorded, but with an average lifespan of two years (Niemeck & Mathieson, 1976). Niemeck & Mathieson (1976) found that *Fucus spiralis* growth rates peaked in the summer, with fronds increasing in length between 1.9 – 2.8cm / month; and that the average increase in length for a year was 1.2cm / month. Variations in growth rate are found between the north east and north west Atlantic (Niemeck & Mathieson, 1976, Subrahmanyam, 1961, Hariot, 1909).

A ten month reproductive cycle has been recorded for *Fucus spiralis* populations in both New Hampshire and the Isle of Man (Niemeck & Mathieson, 1976, Subrahmanyam, 1961). The cycle starts in late January, when the receptacles appear, and concludes in the late summer, July or August, when the gametes are released (Niemeck & Mathieson, 1976). Both Niemeck & Mathieson (1976) and Subrahmanyam (1961) recorded that plants had to reach ~10 cm before forming receptacles, which was found to be at the end of the second year's growth.

No records of significant reductions in cover of *Fucus spiralis* are available. Little *et al.*, (1992) recorded a decline in the cover of *Fucus spiralis* in Lough Hyne between 1955-1990/91, but gave no indication of what may have caused the decline. Hawkins & Southward (1992) found that 2 - 5 years after the use of toxic dispersants to clean up oil from the Torrey Canyon oil spill furoids had returned in dense stands. These dense stands were even found on shores where the use of toxic dispersants was so thorough that re-colonization started from bare rock. Hartnoll & Hawkins (1985) and Hawkins & Hartnoll (1985) both reported that *Fucus spiralis* had the ability to recruit quickly to cleared rocky shores especially when grazers are absent. When grazers are excluded from areas of intertidal shores furoids can be found in zones, which in a balanced ecosystem, they do not normally occur (Burrows & Lodge, 1950, Southward & Southward, 1978). Furoid distributions return to their recognized zones when grazers are re-established on a shore (Burrows & Lodge, 1950, Southward & Southward, 1978).

Although intertidal shores can rapidly regain furoids it can take considerably longer for ecosystem function to return if grazers have also been lost (Hawkins & Southward, 1992). If the whole

community is removed, recovery is likely to occur at a much lower pace. Indeed, Hawkins & Southward (1992) found that, after the *M.V. Torrey Canyon* oil spill, it took between 10 and 15 years for the *Fucus* spp. to return to 'normal' levels of spatial and variation in cover on moderately exposed shores. Therefore, for factors which are likely to totally destroy the biotope, recoverability is likely to be low. Intertidal rocky shores can have high levels of water flow and mixing (Hawkins & Southward, 1992). Fucoids are broadcast spawners with external fertilization (Engle *et al.*, 2005) and research has shown that this reproductive method does allow for high fertilization rates (Serrao *et al.*, 1996a, Berndt *et al.*, 2002). The dispersal distance of fucoid eggs is generally within ca 0.5 m (Berndt *et al.*, 2002) because eggs are negatively buoyant, the sperm are negatively phototaxitic (Brawley *et al.*, 1999), and gametes are released during calm periods of weather when water movement is low.

Other species which are found within this biotope include the grazers *Semibalanus balanoides* and *Patella vulgata*. Both of these species can play an important role in structuring the community. *Semibalanus balanoides* is a small but long lived barnacle with a life expectancy of 3 – 6 years depending on shore height. Individuals on the low shore typically die in their third year, whereas those found from mean high water neaps downwards may live for five or six years. Individuals are hermaphrodites and reach sexual maturity between 1 – 2 years. Fertilization occurs between November – December in the British Isles. Fertilized eggs are retained brooded overwinter for dispersal in the spring plankton bloom. The planktonic stage of these organisms is 2 months long during which they can disperse up to 10 km. Reproductive success is affected by temperature, latitude, light, food availability, age, size, crowding, seaweed cover and pollution. High shore *Semibalanus balanoides* breed first and low shore specimens last (up to 12 days difference) (Barnes, 1989). Fertilization is prevented by temperatures above 10 °C and continuous light.

Local environmental conditions, including surface roughness (Hills & Thomason, 1998), wind direction (Barnes, 1956), shore height, wave exposure (Bertness *et al.*, 1991) and tidal currents (Leonard *et al.*, 1998) have been identified, among other factors, as factors affecting settlement of *Semibalanus balanoides*. Biological factors such as larval supply, competition for space, presence of adult barnacles (Prendergast *et al.*, 2009) and the presence of species that facilitate or inhibit settlement (Kendall, *et al.*, 1985, Jenkins *et al.*, 1999) also play a role in recruitment. Mortality of juveniles can be high but highly variable, with up to 90% of *Semibalanus balanoides* dying within ten days (Kendall *et al.*, 1985).

Successful recruitment of high number of *Semibalanus balanoides* individuals to replenish the population may be episodic (Kendall *et al.*, 1985). After settlement the juveniles are subject to high levels of predation as well as dislodgement from waves and sand abrasion depending on the area of settlement. *Semibalanus balanoides* may live up to 4 years in higher areas of the shore (Wethey, 1985). Predation rates are variable (see Petraitis *et al.*, 2003) and are influenced by a number of factors including the presence of algae (that shelters predators such as the dog whelk, *Nucella lapillus*, and the shore crab, *Carcinus maenas* and the sizes of clearings (as predation pressure is higher near canopies (Petraitis *et al.*, 2003).

On rocky shores, barnacles are often quick to colonize available gaps. Bennell (1981) observed that barnacles that were removed when the surface rock was scraped off in a barge accident at Amlwch, North Wales returned to pre-accident levels within 3 years. Petraitis & Dudgeon (2005) also found that *Semibalanus balanoides* quickly recruited (present a year after and increasing in density) to experimentally cleared areas within the Gulf of Maine, that had previously been dominated by *Ascophyllum nodosum*. However, barnacle densities were fairly low (on average 7.6 % cover), predation levels in smaller patches were high (Petraitis *et al.*, 2003). The success of

recruitment and settlement of *Semibalanus balanoides* to an intertidal shore can be affected by the components of the community itself (Beermann *et al.*, 2013). Barnacles are gregarious and larvae settle within areas where adults are present (Knight-Jones & Stevenson, 1950). The mechanism by which they are able to sense adults is chemosensory (Knight-Jones, 1953). Adults exude a protein named arthropodin, which the larvae can sense when they are searching for suitable substrates to settle on (Crisp & Meadows, 1962). The mortality rates for larvae who settle within an area containing a mosaic of adults is less than those who settle in areas without adults (Jenkins *et al.*, 1999). Macroalgae can have both positive and negative impacts on the success of barnacle larvae. Jenkins *et al.* (1999) investigated settlement and post settlement impacts of three macroalgae on *Semibalanus balanoides* cyprid larvae. The investigation found that *Fucus spiralis*, *Ascophyllum nodosum* and *Fucus serratus* all have negative impacts on the ability of larvae to settle due to the sweeping action of their fronds. Larvae which had settled underneath *Fucus serratus* had a mortality rate of 82 – 97% within a single high tide (Jenkins *et al.*, 1999). *Fucus serratus* also inhibited the settlement ability of larvae due to the dense low lying fronds. Although larvae which settle below a furoid canopy have a low chance of survival, mortality of barnacle spat is significantly lower under furoid canopies than in unprotected areas (Jenkins *et al.*, 1999, Beermann *et al.*, 2013).

The life expectancy of *Patella vulgata* depends on location. Those found under furoid canopies may only live for 2 – 3 years. In contrast, those which are found on bare rocks and have slower growth rates due to food limitations can live for 15 – 16 years. Maximum life expectancies have been estimated at 20 years. This species is a protandrous hermaphrodite, male sex organs can mature at nine months. However in northern England, limpets reach sexual maturity in their second year (Blackmore, 1969) and thereafter reproduce annually. The female reproductive organs can mature most often between 2 – 3 years, but in some situations they never mature. In Robin Hood's Bay, Lewis & Bowman (1975) observed spawning of *Patella vulgata* in the Autumn, with spatfall occurring in winter when desiccation pressures were lower.

Patella vulgata is mobile and can relocate to avoid the negative impacts of a pressure. Lewis (1954) found that on particular shores seasonal variations in temperature induced *Patella vulgata* to migrate further down rocky intertidal shores in the warmer months and further up the shore in winter months. However the ability to relocate depends on the shore type and roughness. *Patella vulgata* individuals also create home scars these are areas of rock where the limpet returns to repeatedly to rest when not feeding. The shell of the organism slowly wears down the rock to create a home scar which can reduce the level of desiccation (Davies, 1969) and the level of predation (Garrity & Levings, 1983). Mortality of these species can increase if they are unable to return to a home scar.

Re-colonization of *Patella vulgata* on rocky shores is rapid as seen by the appearance of limpet spat 6 months after the *Torrey Canyon* oil spill reaching peak numbers 4-5 years after the spill. However, although re-colonization was rapid, the alteration to the population structure (size and age class) persisted for about 15 years because of the complex cycles of dominance (see below) involving limpets, barnacles and algae (Hawkins & Southward, 1992, Lewis & Bowman, 1975). Hence the establishment of furoids if *Patella vulgata* and other grazers are absent.

Resilience assessment. *Fucus spiralis* attaches to the substratum by a holdfast, and is not able to relocate in response to an increase in a pressure. Therefore the resilience of a population to an increase in pressure which increases damage or mortality will depend on its ability to recruit and recolonize. If *Fucus spiralis* remains in small quantities after a disturbance event it is likely that recovery of ecosystem function will occur within 2 – 10 years. The high fertilization rates due to

Fucus spiralis being hermaphroditic would allow recruitment to take place within one year, Ang & Wreede (1992), and Hartnoll & Hawkins (1985). *Semibalanus balanoides* exhibits episodic and patchy recruitment. The evidence suggests that the size of the footprint of an impact and the magnitude will influence the recovery rates by mediating settlement and post-settlement recruitment. Barnacles are attracted to settle in the presence of adults of the same species (Prendergast *et al.*, 2009); so that the presence of adults will facilitate recovery. Resilience is assessed as 'High' (within 2 years) where resistance is 'High' (no significant impact). Recovery of *Patella vulgata* will depend on recolonization by larvae which have pelagic life stage. As *Patella vulgata* is a common, widespread species. Where the footprint of the impact is relatively small, larval supply from adjacent populations should support recolonization. Where source populations are very distant due to regional impacts or habitat discontinuities, larval supply and recovery could be affected.

However, changes and recovery trajectories following the removal of key species are unpredictable and interactions between the key species may be positive or negative. Limpets may enhance barnacle settlement by removing algae (Little *et al.*, 2009) or by depositing pedal mucus trails that attract larvae (Holmes *et al.*, 2005), or they may crush and displace newly settled individuals (Denley & Underwood, 1979). Barnacles may enhance survival of small limpets by moderating environmental stresses but they may also have negative effects on recruitment by occupying space and by limiting access to grazing areas. On the moderately wave exposed shores on which this biotope occurs, grazing may limit initial settlement of macroalgae but wave action will limit the presence of adults and larger species through, breakage and drag effects leading to loss. Mrowicki *et al.*, (2014) found that limpet and barnacle removal allowed ephemeral and furoid macroalgae to establish on sheltered and wave exposed shores in Ireland. Unlike the characteristic animal species macroalgae have short dispersal distances, over tens of metres (Dudgeon *et al.*, 2001) and therefore rapid recovery will require the presence of adults.

If the impacts of a pressure were so severe that re-colonization of the shore had to begin from scratch then it could take between 10 - 15 years for the ecosystem to return to a functional state similar to that prior to the disturbance. This estimate is taken from the evidence provided by Hawkins & Southward (1992) on the recovery of shores after the Torrey Canyon oil spill. A Resilience of 'Medium' has been given as it will take longer than two years for the biotope to return to a functional state equivalent to that prior to the disturbance event.

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

Fucus spiralis can tolerate temperatures from -0.5 to 28 °C. The species is well within its temperature range in the UK. Decreases in temperature are unlikely to have any effect because the species extends into northern Norway where water temperatures are cooler. Increase in temperature may be beneficial because the optimum temperature for growth of the species is 15 °C (Lüning, 1990). However, *Fucus spiralis* individuals were reported to suffer some damage during the unusually hot summer of 1983 when temperatures were on average 8.3 °C higher than normal (Hartnoll & Hawkins, 1985).

Long-term time studies in southern England suggest that *Patella vulgata* have become scarcer following warmer summers, while *Patella depressa* increase in abundance (Southward *et al.*, 1995). Increased temperatures may alter spawning cues and reproduction success in *Patella vulgata* populations.

Semibalanus balanoides is a 'northern' species, with a range which extends from Portugal or Northern Spain to the Arctic circle. Populations in the southern part of England are therefore relatively close to the southern edge of its geographic range.

Sensitivity assessment. *Fucus spiralis* is found in the middle of its natural temperature range in the British Isles and will be tolerant to an increase in 5 °C for one month or an increase of 2 °C for one year. At the benchmark of this pressure it is possible that there may be some reduction in the reproductive success of other species within the biotope. Resistance and consequently the resilience are assessed as 'High', so that the biotope is 'Not Sensitive' to this pressure at the pressure benchmark.

**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

Fucus spiralis can tolerate temperatures from -0.5 to 28 °C. The species is well within its temperature range in the UK. Decreases in temperature are unlikely to have any effect because the species extends into northern Norway where water temperatures are cooler. Increase in temperature may be beneficial because the optimum temperature for growth of the species is 15 degrees C (Lüning, 1990).

The distribution of both *Semibalanus balanoides* and *Patella vulgata* are 'northern' with their range extending from Portugal or Northern Spain to the Arctic circle. Over their range they are therefore subject to lower temperatures than in the UK, although distributions should be used cautiously as an indicator of thermal tolerance (Southward *et al.*, 1995). The barnacle *Semibalanus balanoides* is primarily a 'northern' species with an arctic-boreal distribution. Long-term time series show that recruitment success is correlated to lower sea temperatures (Mieszkowska *et al.*, 2014). Due to warming temperatures its range has been contracting northwards.

The limpet, *Patella vulgata* can also tolerate long periods of exposure to the air and consequently wide variations in temperature. Adults are also largely unaffected by short periods of extreme cold.

Sensitivity assessment. This species within this biotope including the characterizing species, *Fucus*

spiralis, are found in the middle of their natural temperature range in the British Isles and will therefore not be negatively affected by a decrease in 5 °C for one month or an increase of 2 °C for one year. Resistance and consequently the resilience are assessed as 'High'. Making the biotope 'Not Sensitive' to this pressure at the pressure benchmark.

Salinity increase (local)

Low

Q: Medium A: Medium C: Medium

Medium

Q: High A: High C: Medium

Medium

Q: Medium A: Medium C: Medium

This biotope occurs in areas of full salinity although it will be subject to variability due to rainfall. There are no reports of the biotope occurring in hypersaline areas such as rockpools, where evaporation in the summer causes salinity to increase. Therefore, as there is no requirement for the species within this biotope to be tolerant of a long-term increase in salinity any increase in salinity is likely to impact the functioning of the ecosystem.

Fucus spiralis populations in New Hampshire were reported to survive between 2 – 32psu (Niemeck & Mathieson, 1976). This species has also been shown to tolerate experimental salinities of 3 to 34 psu. Both experimental testing and natural range of this species suggests that the species would not be tolerant to long-term increases in salinities. There is no evidence concerning the ability of *Fucus spiralis* gametes to tolerate increases in salinity. However, Niemeck & Mathieson (1976) noted that the initiation and maturation of receptacles in *Fucus spiralis* populations in New Hampshire occurred during periods of high freshwater runoff in the spring.

Sensitivity assessment. *Fucus spiralis* is not reported from within any hyper-saline environments, and has not been found to survive experimentally above salinities of 34 psu. Consequently an increase in salinity within this biotope would lead to a detrimental effect on the *Fucus spiralis* population.

Resistance is assessed as 'Low', and resilience is ranked as 'Medium'. This gives the biotope an overall sensitivity assessment of 'Medium' to this pressure at the pressure benchmark.

Salinity decrease (local)

High

Q: High A: High C: Medium

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: Medium

Although the biotope occurs in areas of full salinity, the characterizing species *Fucus spiralis* can be found in conditions which are not fully saline.

Fucus spiralis populations in New Hampshire were reported to survive between 2 – 32psu (Niemeck & Mathieson, 1976). This species has also been shown to tolerate experimental salinities of 3 to 34 psu. Both experimental testing and natural range of this species suggests that the species would not be tolerant to long-term increases in salinities. There is no evidence concerning the ability of *Fucus spiralis* gametes to tolerate increases in salinity. However, Niemeck & Mathieson (1976) noted that the initiation and maturation of receptacles in *Fucus spiralis* populations in New Hampshire occurred during periods of high freshwater runoff in the spring.

Sensitivity assessment. *Fucus spiralis* can survive in reduced salinity environments and decrease in this pressure at the benchmark level is unlikely to have a negative impact on the species. The other species which are commonly found within this biotope are also able to cope with changes in salinity and can be found in variable salinities.

The resistance is 'High', and as there will be no effects for the biotope to recover from, the resilience is also 'High'. This gives a 'Not Sensitive' sensitivity score.

Water flow (tidal current) changes (local)

High

Q: Medium A: Medium C: Medium

High

Q: High A: High C: High

Not sensitive

Q: Medium A: Medium C: Medium

Water motion is a key determinant of marine macroalgal production, directly or indirectly influencing physiological rates and community structure (Hurd, 2000). Higher water flow rates increase mechanical stress on macroalgae by increasing drag. This can result in individuals being torn off the substratum. Once removed, the attachment cannot be reformed causing the death of the algae. Any sessile organism attached to the algae will also be lost. Fucooids are however highly flexible and are able to re-orientate their position in the water column to become more streamlined. This ability allows fucooids to reduce the relative velocity between algae and the surrounding water, thereby reducing drag and lift (Denny *et al.*, 1998).

Jonsson *et al.* (2006) found that flow speed of 7-8 m/s completely dislodged *Fucus spiralis* individuals larger than 10 cm. Smaller individuals are likely to better withstand increased water flow as they experience less drag. The risk of dislodgement is greater where algae are attached to pebbles instead of bedrock. Indeed if the substratum is less stable, such as a small stone or mussel shell, individuals may eventually reach a critical size when the drag force exceeds gravity and the plant will be moved together with its substratum (Malm, 1999).

Propagule dispersal, fertilization, settlement, and recruitment are also influenced by water movement (Pearson & Brawley, 1996). In addition, increased water flow will cause scour through greater sediment movement affecting in particular small life stages of macroalgae by removing new recruits from the substratum and hence reducing successful recruitment (Devinsky & Vols, 1978) (see 'siltation' pressures). Changes in water motion can thus strongly influence local distribution patterns of *Fucus* spp. (Ladah *et al.*, 2008)

On the other hand, a reduction in water flow can cause a thicker boundary layer resulting in lower absorption of nutrients and CO₂ by the macroalgae. Slower water movement can also cause oxygen deficiency directly impacting the fitness of algae (Olsenz, 2011).

Sensitivity assessment. The *Fucus spiralis* dominated biotopes are recorded in wave exposed to extremely sheltered shores, and water flows rates from negligible - 1.5 m/s (Connor *et al.*, 2004). A decrease in water flow is unlikely to be damaging as the biotope occurs at negligible water flow rates. On wave exposed shores the wave mediated flow is probably more important than tidal flow. Therefore a change in water flow of 0.1-0.2 m/s is unlikely to adversely affect the *Fucus spiralis* canopy or the biotope itself. Hence both resistance and resilience are considered to be 'High' and therefore, the biotope is recorded as 'Not sensitive' at the benchmark level.

Nevertheless, in wave exposed examples of the biotope where tidal flow is already at the limit for the biotopes range (1.5m/s) are probably more sensitive. In these cases, an increase may result change in the biotope to more tide-swept or barnacle dominated biotopes, resulting in loss of the biotope in these cases.

Emergence regime changes

Medium

Q: High A: Medium C: Medium

Medium

Q: High A: High C: Medium

Medium

Q: Medium A: Medium C: Medium

This biotope is found in the eulittoral zone and is subjected to cyclical immersion and emersion caused by the tides. During the initial stages of drying, when algae are exposed to air, photosynthetic rates increase due to the higher diffusion rate of CO₂ in air relative to water (Johnson *et al.*, 1974). However this peak in photosynthesis is usually followed by a gradual decline in the rate of photosynthesis as the surface of the alga dries, thereby preventing further dissolution and uptake of CO₂ (Beer & Kautsky 1992). Photosynthesis eventually ceases at a critical state of dehydration when the low water content of the thallus disrupts the functioning of the photosynthetic apparatus (Quadir *et al.* 1979).

Fucus spiralis dominates higher on the shore than *Fucus vesiculosus* or *Fucus serratus* as it is more tolerant of desiccation and emergence. *Fucus spiralis* can photosynthesise better in air than in water, as long as desiccation has not exceeded tolerated levels of water reduction (Madsen & Maberly, 1990). However this peak in photosynthesis is usually followed by a gradual decline in the rate of photosynthesis as the surface of the alga dries, thereby preventing further dissolution and uptake of CO₂ (Beer & Kautsky 1992). Photosynthesis eventually ceases at a critical state of dehydration when the low water content of the thallus disrupts the functioning of the photosynthetic apparatus (Quadir *et al.* 1979). An increase in the levels of immersion would mean that *Fucus spiralis* would eventually be out-competed by faster growing macroalgae species found lower down on the shore (Chapman, 1990, Lubchenco, 1980). It could be hypothesised that the less efficient photosynthesising of these two species in water is the reason that other plants can grow faster, and out-compete them. However an increase in emersion may shift the upper shore zone up the shore, even if this is the case it may take some time for the biotope to resume ecological function.

Changes in immersion and emersion times will also affect the ability of macroalgae to uptake nutrients. Hurd & Dring (1991) investigated the ability of macroalgae to uptake phosphate after desiccation. Results showed that macroalgae found higher on the shore were able to recover from desiccation and were able to resume uptake of phosphates faster (Hurd & Dring, 1991). They also hypothesised that patterns of zonation on intertidal rocky shores could be partially driven by the ranging sensitivities of nutrient uptake mechanisms in different species (Hurd & Dring, 1991).

Early life history stages are more susceptible to ultraviolet radiation compared to adults (Henry & Van Alstyne, 2004, Roleda *et al.*, 2007). Germlings are however protected from desiccation by the canopy of adults. A study by Brawley & Johnson (1991) showed that germling survival under adult canopy was close to 100% whereas survival on adjacent bare rock was close to 0% during exposure to aerial conditions. *Fucus* canopies are also likely to protect other underlying species. Changes in the community structure of other species (*Patella vulgata* and *Semibalanus balanoides*) are likely to occur if the canopy is removed.

Limpets are able to move down the shore although the loss of a home scar can increase the species vulnerability to predation (Garrity & Levings, 1983). Other mobile species would, such as Littorinids, would also be able to change their location on the shore with the changes in emergence regime.

Sensitivity assessment: A change in the level of emergence on the shore will affect *Fucus spiralis*, as well as other species within the biotope. Changes in the numbers of important species are likely to have profound effects on community structure and may result in loss of the biotope at the extremes of its range. For example, the upper limit of the biotope may lose furoid cover and change to an alternative biotope dominated by barnacles and limpets or lichens. *Fucus spiralis* can tolerate an emersion period of 1-2 days so an increase in time spent in air of 1 hour in per day may

limit growth and fecundity rather than survival.

The consequences of an increase in emersion are severe desiccation due to increased time in air. When these factors are combined with high temperatures and light can cause mortalities (Pearson *et al.*, 2009). This will lead to a decrease in the band of this biotope at the top of a rocky shore. It would also lead to an increase in the level of emersion of other algae further down the shore. Although there will be a period of mortality, in time it may result in a readjustment of biotopes further down the shore. An increase in immersion is likely to result in an upward movement of this biotope on the shore. Resistance is assessed as 'Medium' and resilience is 'Medium' giving an overall sensitivity assessment of 'Medium'.

Wave exposure changes (local)

High

Q: High A: Medium C: Medium

High

Q: High A: High C: High

Not sensitive

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). The fucoid dominated biotopes are limited to areas with moderately wave exposed to sheltered conditions. 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. Fucoids are permanently attached to the substratum and would not be able to re-attach if removed. Organisms living on the fronds and holdfasts will be washed away with the algae whereas free-living community components could find new habitat in surrounding areas. Wave exposure has been shown to limit size of fucoids (Blanchette, 1997) as smaller individuals create less resistance to waves. Jonsson (2006) reported that recruitment and survival of juvenile fucoids including *Fucus spiralis* were controlled indirectly by wave exposure, through higher limpet densities at exposed locations.

Different morphological forms of *Fucus spiralis* exist and dominate in areas with different environmental conditions. Niemeck & Mathieson (1976) noted that specimens of *Fucus spiralis* further up the shore tended to decrease in length and weight. These smaller forms of *Fucus spiralis* are recorded as *Fucus spiralis* f. *nanus*. Scott *et al.* (2001) noted that *Fucus spiralis* f. *nanus* plants had a relatively small number of short, thin blades that branched fewer times than *Fucus spiralis* plants. Observations by Scott *et al.*, (2001) also found *Fucus spiralis* f. *nanus* higher on the shore than *Fucus spiralis*. However the two morphotypes can overlap on the shore. Scott *et al.* (2001) suggested that forms of *Fucus spiralis* exist within a mosaic of stable phenotypes representing populations specifically adapted to the local environment. A change in wave height could induce changes in the morphology displayed by *Fucus spiralis* on the shore. Smaller individuals may become predominant due to the lower levels of drag induced by their smaller surface area.

As exposure increases the fucoid population will become dominated by small juvenile algae more resistant to this pressure than mature individuals. An increase in wave action beyond this would lead to dominance of the community by grazers and barnacles at the expense of fucoids. Of the *Fucus spiralis* dominated biotopes only the LR.LLR.F.Fspi would not be affected by a decrease in the level of wave height, as it is found into extremely sheltered conditions (Connor *et al.*, 2004). If any of these biotopes are found at the upper limit of their wave exposure tolerance, then a change in near shore significant wave height could force the biotope to change. *Fucus spiralis* biotopes found in situations with greater wave exposure, such as LR.MLR.BF.FspiB, include a greater quantity of barnacles and limpets. Other fucoid biotopes tend to shift away from *Fucus spiralis* and become more dominated by *Fucus serratus* and occasionally *Fucus vesiculosus*.

Sensitivity assessment. *Fucus spiralis* is sensitive to an increase in wave action, and the fucoid dominated biotopes are found in low energy shores. Increased wave exposure would result in losses of biomass and species richness and a change to moderate energy biotopes such as LR.MLR.BF.FspiB. However, a change in significant wave height of up to 5% is unlikely to result in a significant change in wave exposure, and the biotope is found from very wave sheltered up to wave exposed conditions. Hence, a resistance of 'High' is recorded, with a resilience of 'High' (representing little change from which to recover) and the biotope is probably 'Not sensitive' at the benchmark level. .

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

Radionuclide contamination	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR
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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
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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
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Cole *et al.* (1999) suggest possible adverse effects on marine species below oxygen levels of 4 mg/l and probable adverse effects below 2 mg/l. Sustained reduction of dissolved oxygen can lead to hypoxic (reduced dissolved oxygen) and anoxic (extremely low or no dissolved oxygen) conditions. Sustained or repeated episodes of reduced dissolved oxygen have the potential to severely degrade an ecosystem (Cole *et al.*, 1999). 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). If levels do drop below 4 mg/l negative effects on these organisms can be expected with adverse effects occurring below 2 mg/l (Cole *et al.*, 1999). Reduced oxygen levels are likely to inhibit photosynthesis and respiration but not cause a loss of the macroalgae population directly. However, small invertebrate epifauna may be lost, causing a reduction in species richness.

Josefson & Widbom (1988) investigated the response of benthic macro and meiofauna to reduced dissolved oxygen levels in the bottom waters of a fjord. At dissolved oxygen concentrations of 0.21 mg/l, the macrofaunal community was eradicated and was not fully re-established 18 months after the hypoxic event. Meiofauna seemed however unaffected by de-oxygenation. Kinne (1970) reported that reduced oxygen concentrations inhibit both algal photosynthesis and respiration. No specific information about the effects of de-oxygenation on the characteristic species was found. *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 along with other species within this biotope may be negatively impacted by reduced dissolved oxygen levels. At the level of the benchmark (2 mg/l for 1 week) mortalities could occur as a direct result of a change in this pressure. This biotope is found in moderately exposed to extremely sheltered locations. Where examples of this biotope are found in moderately exposed locations, water movement caused by waves will mean that there will be levels of water mixing, maintaining high oxygen levels. Examples of this biotope found in areas which are more sheltered from wave exposure will not have the same levels of water mixing. This could exacerbate the negative impacts of reduced oxygen levels at the benchmark of this pressure, and make the more sheltered versions of this biotope more sensitive. However, the biotope in occurs in the upper eulittoral and consequently a high proportion of time will be spent in air where oxygen is not limited so the metabolic processes of photosynthesis and respiration can take place. Therefore, resistance is assessed as 'High'. Hence, resilience is assessed as 'High', and the biotope as 'Not sensitive'.

Nutrient enrichment

High

Q: High A: High C: Medium

High

Q: High A: High C: Medium

Not sensitive

Q: High A: High C: Medium

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

Johnston & Roberts (2009) undertook a review and meta-analysis of the effect of contaminants on species richness and evenness in the marine environment. Of the 47 papers reviewed relating to nutrients as a contaminant, over 75% found that it had a negative impact on species diversity, <5% found increased diversity, and the remaining papers finding no detectable effect. Not all of the 47 papers considered the impact of nutrients on intertidal rocky shores. Yet this finding is still relevant as the meta-analysis revealed that the effect of marine pollutants on species diversity was 'remarkably consistent' between habitats (Johnston & Roberts, 2009). It was found that any single pollutant reduced species richness by 30-50% within any of the marine habitats considered

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

Major declines of *Fucus vesiculosus* have been reported from all over the Baltic Sea. These declines have been associated to eutrophication from nutrient enrichment (Kautsky *et al.*, 1986). 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). High nutrient levels may directly inhibit spore settlement and hinder the initial development of *Fucus vesiculosus* (Bergström *et al.*, 2003).

Changes in community composition on intertidal rocky shores can happen rapidly, and levels of wave exposure are not a controlling factor for the speed of these changes (Kraufvelin, 2007). However, well established and healthy communities on intertidal rocky shores can survive extended periods of time (Bokn *et al.*, 2002, 2003, Karez *et al.*, 2004, Kraufvelin, 2007, Kraufvelin *et al.*, 2006b).

There is little evidence available on the impacts of nutrient enrichment on the characterizing species of this biotope.

Sensitivity assessment. This biotope is sensitive to nutrient enrichment. The addition of high nutrient concentrations to this environment could lead to the overgrowth of the algae by ephemeral green algae and an increase in the number of grazers. However, if the biotope is well established and in a healthy state the biotope could have the potential to persist. The effect of an increase in this pressure to the benchmark level is unlikely to have a negative impact on the biotope. Therefore the resistance has been assessed as 'High'. As the resistance is high, there will be nothing for the biotope to recover from therefore the resilience is also 'High' and an overall sensitivity of 'Not Sensitive' at the benchmark level.

Organic enrichment **Medium** **Medium** **Medium**
 Q: High A: Medium C: Medium Q: High A: High C: Medium Q: High A: Medium C: Medium

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

Johnston & Roberts (2009) undertook a review and meta-analysis of the effect of contaminants on species richness and evenness in the marine environment. Of the 49 papers reviewed relating to sewage as a contaminant, over 70% found that it had a negative impact on species diversity, <5%

found increased diversity, and the remaining papers finding no detectable effect. Not all of the 49 papers considered the impact of sewage on intertidal rocky shores. Yet this finding is still relevant as the meta-analysis revealed that the effect of marine pollutants on species diversity was 'remarkably consistent' between habitats (Johnston & Roberts, 2009). It was found that any single pollutant reduced species richness by 30-50% within any of the marine habitats considered (Johnston & Roberts, 2009). Throughout their investigation, there were only a few examples where species richness was increased due to the anthropogenic introduction of a contaminant. These examples were almost entirely from the introduction of nutrients, either from aquaculture or sewage outfalls. However research into the impacts of organic enrichment from these sources on intertidal rocky shores often lead to shores lacking species diversity and the domination by algae with fast growth rates (Littler & Murray, 1975; Abou-Aisha *et al.*, 1995; Archambault *et al.*, 2001; Diez *et al.*, 2003; Arévalo *et al.*, 2007).

Major declines of *Fucus vesiculosus* have been reported from all over the Baltic Sea associated with eutrophication from nutrient enrichment (Kautsky *et al.*, 1986). 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). High nutrient levels may directly inhibit spore settlement and hinder the initial development of *Fucus vesiculosus* (Bergström *et al.*, 2003). Bellgrove *et al.* (2010) determined that coralline turfs out-competed fucoids at a site associated with organic enrichment caused by an ocean sewage outfall.

Changes in community composition on intertidal rocky shores can happen rapidly, and levels of wave exposure are not a controlling factor for the speed of these changes (Kraufvelin, 2007). However, well established and healthy communities on intertidal rocky shores can survive extended periods of time (Bokn *et al.*, 2002, 2003; Karez *et al.*, 2004; Kraufvelin *et al.*, 2006b; Kraufvelin, 2007).

Sensitivity assessment. Little empirical evidence was found to support an assessment of this biotope at this benchmark. The effect of a deposit of 100 gC/m²/yr will have different impacts depending if the deposition was chronic or acute. If the deposition is chronic growth rates may be enhanced and not create any significant negative effects on the biotope. The acute introduction of levels of organic carbon at the benchmark could lead to the overgrowth of the algae by ephemeral green algae and an increase in the number of grazers within a short period of time. Due to the negative impacts that can be experienced with the introduction of excess organic carbon both resistance and resilience have been assessed as 'Medium'. This gives an overall sensitivity score of 'Medium'.

A Physical Pressures

	Resistance	Resilience	Sensitivity
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

Stable boulders and cobbles dominate this biotope with some finer sediment fractions in-between. The characterizing species, *Fucus spiralis*, is attached to the larger more stable sediments. If these sediment particles were to reduce in size, there would be a loss of suitable habitat for the characterizing species and other associated species such as the barnacle *Semibalanus balanoides*, and the limpet *Patella vulgata*. The loss of these stable habitats would cause a shift in the biotope. The character may shift to a littoral sediment biotope. Alternatively, if there was an increase in the sediment particle size then there would be an increase in the amount of suitable substrate then the biotope may become more like LR.LLR.F.Fspi.FS or LR.LLR.F.Fspi.

Sensitivity assessment. Resistance is assessed as 'None'. As this pressure represents a permanent change, recovery is impossible as the suitable substratum for fucoids is lacking. Consequently, resilience is assessed as 'Very Low'. The habitat, therefore, scores a 'High' sensitivity. Although no specific evidence is described confidence in this assessment is 'High', due to the incontrovertible nature of this pressure.

Physical change (to another sediment type)

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 biotope is dominated by boulders and cobbles on bedrock with pebbles and finer fractions (i.e. gravel, sand and shell) between the boulders and cobbles. Although the biotope occurs on an overlay of mixed hard substrata, the biotope is technically a hard rock biotope and a 'change in sediment type' is '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 are epifauna or epiflora occurring on rock and would be sensitive to the removal of the habitat. However, the biotope is dominated by boulders and cobbles on bedrock with pebbles and finer fractions (i.e. gravel, sand, and shell) between the boulders and cobbles. Therefore, 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

Medium

Q: High A: High C: High

Medium

Q: High A: High C: High

These biotope groups are found in the upper intertidal shore. An area easily accessible by humans especially at low tide. Individual *Fucus* specimens are very flexible but not physically robust.

Fucoids are intolerant of abrasion from human trampling, which has been shown to reduce the cover of seaweeds on a shore (Holt *et al.*, 1997).

Araujo *et al.* (2009) found that trampling negatively affected *Fucus vesiculosus* abundance and reduced understorey species while promoting the colonization by ephemeral green algae. However, within a year of the disturbance event, *Fucus vesiculosus* recovered and greatly increased in cover becoming the dominant canopy forming species, replacing a pre-disturbance *Ascophyllum nodosum* community. The replacement of *Ascophyllum nodosum* with *Fucus vesiculosus* may have been due to the poor recovery rate of *Ascophyllum nodosum*. The increase in abundance suggests the competitive superiority of *Fucus vesiculosus* individuals in occupying newly available space in the disturbed patches. Similar results were found by Cervin *et al.* (2005) and Araujo *et al.* (2012) with *Fucus vesiculosus* outcompeting *Ascophyllum nodosum* after small-scale disturbances.

Brosnan (1993) investigated the effect of trampling on a number of algal species, including *Fucus distichus*, 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 / m² on stations on an intertidal rocky shore in the north-east of England were sufficient to reduce the abundance of fucoids (Fletcher & Frid, 1996). This reduction in the complexity of the algae community, in turn, reduced the microhabitat available for epiphytic species. Trampling pressure can thus result in an increase in the area of bare rock on the shore (Hill *et al.*, 1998). Chronic trampling can affect community structure with shores becoming dominated by algal turf or crusts (Tyler-Walters, 2005).

Pinn & Rodgers (2005) compared the biological communities found on two intertidal rocky shore ledges in Dorset. They found that the ledge which had a higher number of visitors had few branching algal species, including fucoids, but had greater abundances of crustose and ephemeral species (Pinn & Rodgers, 2005).

The densities of fucoids were recorded from the intertidal rocky shore at Wembury, Devon in 1930 (Colman, 1933) and 1973 (Boalch *et al.*, 1974). Boalch *et al.* (1974) found a reduction in fucoids on the shore at Wembury and that the average frond length of *Ascophyllum nodosum*, *Fucus vesiculosus* and *Fucus serratus* was smaller.

Fucus vesiculosus is able to 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 mean of recovery from population losses (McLachan & Chen, 1972).

Sensitivity assessment. Although no direct evidence on the effect on *Fucus spiralis* was found, surface abrasion via trampling has been shown to reduce the abundance and density of fucoids and other 'brown algal shrub' species in temperate shores worldwide (Tyler-Walters & Arnold, 2008). Abrasion of the substratum will cause a reduction in *Fucus* abundance resulting in 'Low' resistance. Several studies, however, found that the seaweed is able to quickly recolonize disturbed area, outcompeting other macroalgae such as *Ascophyllum nodosum*. Although *Fucus spiralis* may return

quickly, equilibrium within the ecosystem may not have been reached, therefore resistance is 'Medium' (see resilience above). Hence the biotope has a 'Medium' sensitivity to the pressure.

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. Changes in suspended particulate matter (SPM) affect water clarity and have a direct impact on photosynthesis fucoids. Irradiance below the light compensation point of photosynthetic species can compromise carbon accumulation (Middelboe *et al.*, 2006).

Fucus spiralis would be affected by turbidity as outlined above when immersed. However, *Fucus spiralis* can spend up to 90% of its time emersed and can photosynthesise more effectively in the air than in water (Madsen & Maberly, 1990). This doesn't mean that there wouldn't be any negative impacts on the characterizing species. Hence a change to this pressure at the benchmark is not likely to have any significant negative impacts on the characterizing species. It is likely that other species within this biotope who can only feed at high water may be more negatively affected. In particular filter feeding organisms will have their feeding apparatus clogged with suspended particles leading to a reduction in total ingestion and a reduced scope for growth especially since cleaning the feeding apparatus is likely to be energetically expensive.

Sensitivity assessment. Changes in suspended solids and a reduction in water clarity could have effect the biotope by hindering photosynthesis and growth in *Fucus spiralis*, but can photosynthesize when emersed. Therefore, resistance and resilience are assessed as 'High' and the biotope is probably 'Not sensitive' at the benchmark level.

Smothering and siltation rate changes (light)

Medium

Q: High A: Low C: Medium

High

Q: High A: Low C: Medium

Low

Q: High A: Low C: Medium

Sedimentation can directly affect assemblages inhabiting rocky shores in different ways, particularly by the burial/smothering and scour or abrasion of organisms. *Fucus spiralis* attaches to the substratum by a holdfast. This species is not able to relocate in response to increased sedimentation. Sediment deposition is commonly assumed to reduce macroalgal recruitment by: (1) reducing the amount of substratum available for attachment of propagules; (2) scour, removing attached juveniles and (3) burial, altering the light and/or the chemical microenvironment (Devanny & Volve, 1978, Eriksson & Johansson, 2003). Berger *et al.* (2003) demonstrated that both interference with sediment during settlement, and burial after attachment, were significant causes of mortality for *Fucus vesiculosus* germlings.

The state of the tide will determine the extent of the impact. Indeed, if smothering occurs at low tide when the algae are lying flat on the substratum, then most of the organism as well as the associated community will be covered by the deposition of fine material at the level of the benchmark. Smothering will prevent photosynthesis resulting in reduced growth and eventually death. If however smothering occurs whilst the alga is submerged standing upright then the photosynthetic surfaces of adult plants will be left uncovered. The resistance of this biotope to this pressure may vary with time of day. Germlings, however, 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.

Smothering will cause direct mortalities in the associated community, particularly in filter feeding sessile organisms unable to relocate. Low densities of herbivores on rocky shores have frequently been related with areas affected by sedimentation, the presence of herbivores is reduced since their feeding activity and movements might be limited (Airoldi & Hawkins, 2007; Schiel *et al.*, 2006)

This biotope occurs in sheltered to moderately exposed conditions. In areas with greater water flow, excess sediments can be readily removed, reducing the time of exposure to this pressure.

Sensitivity assessment. This pressure will have different impacts this biotope depending where on certain environmental gradients it is found. Wave exposure is especially important for this pressure as it is wave energy which will be able to remove sediment from the shore. Those biotopes within areas which are moderately exposed to waves will not be as negatively affected by this pressure as sediment will be removed by wave action relatively quickly, probably a few tidal cycles. Those biotopes which are sheltered or very sheltered from waves will retain sediment for longer, for several days at least, allowing greater negative effects to occur.

Resistance and resilience are assessed as 'Medium'. Resilience could be assessed as high if the biotope is found within a moderately exposed position, as wave surge would remove the sediment quickly and result in no long-term damage occurring to biotopes community. However, as this biotope can also be found in areas very sheltered from wave exposures the resilience score of 'Medium' is required. Overall the biotope has a 'Medium' sensitivity to smothering at the level of the benchmark.

Smothering and siltation rate changes (heavy)

Low

Q: High A: Medium C: Medium

Medium

Q: High A: Low C: Medium

Medium

Q: Medium A: Low C: Medium

Several studies found that increasing the vertical sediment burden negatively impacts fucoid survival and associated communities (Schiel *et al.*, 2006, Chapman & Fletcher, 2002). At the level of the benchmark (30 cm of fine material added to the seabed in a single event) smothering is likely to result in mortalities of understory algae, invertebrate grazers and young (germling) fucoids.

Sensitivity assessment. The negative effects of this pressure at the benchmark will be greater on examples of this biotope in more wave sheltered locations. This greater sensitivity is due to the greater amount of time it would take for the sediment to be removed via wave action. Resistance is assessed as 'Low' as many individuals exposed to siltation at the benchmark level are predicted to die. Resilience is assessed as 'Medium'. Overall the biotope has a 'Medium' sensitivity to siltation at the pressure benchmark.

Litter

Not Assessed (NA)

Q: NR A: NR C: NR

Not assessed (NA)

Q: NR A: NR C: NR

Not assessed (NA)

Q: NR A: NR C: NR

Not assessed.

Electromagnetic changes

No evidence (NEv)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

No evidence (NEv)

Q: NR A: NR C: NR

No evidence

Underwater noise changes

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Species characterizing this habitat do not have hearing perception but vibrations may cause an 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 *Fucus spiralis* is found in the middle its natural range in the British Isles an increase in the level of diffuse irradiation will not cause a negative impact on the species or the biotope. However, it is not clear how these findings may reflect changes in light levels from artificial sources, and whether observable changes would occur at the population level as a result. There is, therefore, 'No evidence' on which to base an assessment.

Barrier to species movement

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant – 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.

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 group.

	High	High	Not sensitive
Introduction or spread of invasive non-indigenous species	Q: High A: Medium C: Medium	Q: High A: High C: Medium	Q: High A: Medium C: Medium

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

The recent introduction of *Gracilaria vermiculophylla* to the Baltic Sea prompted an investigation into its possible impacts on *Fucus vesiculosus*. Hammann *et al.*, (2013) found that in the Baltic Sea *Gracilaria vermiculophylla* could impact *Fucus vesiculosus* through direct competition for resources, decreasing the half-life of germlings, and increasing the level of grazing pressure. 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 fucoids, and could become relevant to this specific biotope.

Sensitivity assessment. Although evidence often indicates that invasive non-native species (INNS) can have a negative impact native species, no evidence can be found on the impacts of INNS on *Fucus spiralis*, the characterizing species of this biotope. Evidence regarding other fucoids indicate that some mortality of characterizing species can occur through direct and indirect consequences of INNS being present. Due to the current lack of INNS which could cause a negative impact on this biotope resistance has been assessed as 'High' since invasive species have the potential to alter the recognizable biotope. Resilience has also been assessed as 'High'. This assessment naturally leads to the conclusion that the biotope is 'Not Sensitive' to this pressure. However, return to 'normal' conditions is highly unlikely if an invasive species came to dominate the biotope. Indeed recovery would only be possible if the majority of the NIS were removed (through either natural or unnatural process) to allow the re-establishment of other species. Therefore actual resilience will be much lower ('Low' to 'Very Low').

	High	High	Not sensitive
Introduction of microbial pathogens	Q: High A: Medium C: Medium	Q: Low A: NR C: NR	Q: Low A: NR C: NR

Very little is known about infections in *Fucus* (Wahl *et al.*, 2011). Coles (1958) identified parasitic nematodes that caused galls on *Fucus serratus* in the Southwest of Britain. But to date no mortalities have been associated to the introduction of microbial pathogens. Torchin *et al.*, (2002) suggests that there is potential for increased biotic interactions with parasites or pathogens in many marine systems.

Sensitivity assessment: Both resistance and resilience are assessed as 'High'; the biotope is therefore 'Not Sensitive' to this pressure. However the assessment has a low confidence score as more research is needed into the effects of microbial pathogen on *Fucus vesiculosus*.

Removal of target species

None

Q: Medium A: Medium C: Medium

Medium

Q: High A: High C: Medium

Medium

Q: Medium A: Medium C: Medium

Many macroalgae are harvested for their alginates, which are used in the cosmetic and pharmaceutical industries, for agricultural supply, water treatment, and for human food and health supplements (Bixler & Porse, 2010). A number of *Fucus* species are known to be exploited, including *Fucus serratus*, *Fucus gardneri*, and *Fucus vesiculosus* (Zemke-White & Ohne, 1999) There is little information available as to whether *Fucus spiralis* is collected for these reasons. However if there is collection of this characteristic species the effects are likely to be very similar to that caused by the removal of other Fucooids from intertidal rocky shores.

The commercial harvest removes seaweed canopies which will have important effects on the wider ecosystem. Stagnol *et al.*, (2013) investigated the effects of commercial harvesting of intertidal fucooids on ecosystem biodiversity and functioning. The study found that the removal of macroalgae 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. Suspension feeders were the most affected by the canopy removal as canopy-forming algae are crucial habitats for these species, most of them being sessile organisms. Other studies confirm that loss of canopy had both short and long-term consequences for benthic communities in terms of diversity resulting in shifts in community composition and a loss of ecosystem functioning such as primary productivity (Lilley & Schiel, 2006; Gollety *et al.*, 2008). Removal of the canopy caused bleaching and death of understorey red turfing algae. Stagnol *et al.* (2013) observed *Patella vulgata* recruiting in bare patches of disturbed plots. Experimental studies have shown that limpets control the development of macroalgae by consuming microscopic phases (Jenkins *et al.*, 2005) or the adult stages (Davies *et al.*, 2007). The increase in *Patella vulgata* abundance could thus limit the recruitment and growth of *F. serratus* on the impact zone.

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).

Fucooids may be directly removed or damaged by static or mobile gears that are targeting other species. These direct, physical impacts are assessed through the abrasion and penetration of the seabed pressures. The sensitivity assessment for this pressure considers any biological/ecological effects resulting from the removal of target species on this biotope.

Sensitivity assessment. The removal of *Fucus spiralis* would result in loss of the biotope. However as there is no direct evidence regarding their removal from intertidal shores the impact of this pressure is difficult to ascertain. The resistance to removal is 'None' due to the easy accessibility of the biotopes location and the inability of these species to evade collection. The resilience is 'Medium', giving an overall sensitivity score of 'Medium'.

Removal of non-target species

High

Q: Low A: NR C: NR

High

Q: Low A: NR C: NR

Not sensitive

Q: Low A: NR C: NR

The harvest of algae, crustaceans, molluscs and polychaetes from the intertidal shore is a widespread practice. *Fucus spiralis* has no known obligate relationships and the removal of non-target species will therefore not have a significant impact. Fucooids may be directly removed or damaged by static or mobile gears that are targeting other species. These direct, physical impacts are assessed through the abrasion and penetration of the seabed pressures. The sensitivity assessment for this pressure considers any biological/ecological effects resulting from the removal of non-target species on this biotope.

Sensitivity assessment: Resistance to this pressure is deemed 'High'. Resilience is also 'High' as there are no ecological impacts to recover from, resulting in a 'Not Sensitive' score. The assessment is based on expert knowledge resulting in a 'Low' confidence score.

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