Fucus spiralis on exposed to moderately exposed upper eulittoral rock

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

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***Fucus spiralis* on exposed to moderately exposed upper eulittoral rock**
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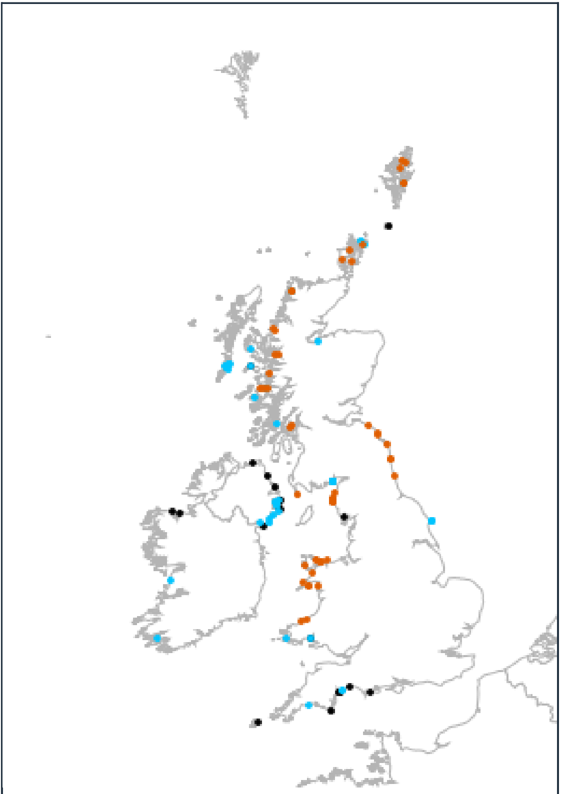

17-09-2018
Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

Researched by Frances Perry & Emilia d'Avack **Refereed by** This information is not refereed.

Summary

UK and Ireland classification

EUNIS 2008	A1.212	*Fucus spiralis* on full salinity exposed to moderately exposed upper eulittoral rock
JNCC 2015	LR.MLR.BF.FspiB	*Fucus spiralis* on exposed to moderately exposed upper eulittoral rock
JNCC 2004	LR.MLR.BF.FspiB	*Fucus spiralis* on exposed to moderately exposed upper eulittoral rock
1997 Biotope	LR.SLR.F.Fspi	*Fucus spiralis* on moderately exposed to very sheltered upper eulittoral rock

Description

Exposed to moderately exposed upper eulittoral bedrock characterized by a band of the spiral wrack *Fucus spiralis* overlying the black lichen *Verrucaria maura* and the olive green lichen *Verrucaria mucosa*. Underneath the fronds of *Fucus spiralis* is a community consisting of the limpet *Patella vulgata*, the winkles *Littorina saxatilis* and *Littorina littorea*, the mussel *Mytilus edulis* and the barnacle *Semibalanus balanoides.* The whelk *Nucella lapillus* can be found in cracks and crevices preying on the mussels and barnacles. During the summer months ephemeral green seaweeds such as *Ulva* (syn. *Enteromorpha*) *intestinalis* can be common. The insect *Anurida maritima* can be present in this zone taking shelter in cracks and crevices when the tide comes in. (Information taken from Connor *et al.*, 2004; JNCC, 2015).

Depth range

Upper shore, Mid 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 *Fucus spiralis* and *Semibalanus balanoides.* The interactions between these species create the barnacle fucoid mosaic characteristic of this biotope. In upper shore locations, where this biotope is found, *Fucus spiralis* is the dominant fucoid species. The dominant barnacle species is *Semibalanus balanoides*. The limpet *Patella vulgata* also plays an important role as a grazer on the shore and contributes to the regulation of algal patches. Ecological relationships within these biotopes are very complex resulting in dynamic and patchy communities.

As ecosystem engineers fucoid algal canopies modify habitat conditions. This facilitates the survival of other intertidal species and therefore strongly influences the structure and functioning of intertidal ecosystems (Jenkins *et al*., 2008). The dominant grazing species is *Patella vulgata*, which strongly affects the distribution of the fucoid canopies. Other important grazing species include littorinid snails which can be prominent on algae fronds. The filter feeding barnacle *Semibalanus balanoides* can be very common within this biotope; although its distribution can be very patchy. The mussel *Mytillus edulis* and the insect *Anurida maritima* can be found in crevices and fissures in the bed rock and boulders. The most obvious predator in this biotope is the dogwhelk *Nucella lapillus*. In summer months the ephemeral green algae *Ulva intestinalis* can be common.

Resilience and recovery rates of habitat

Fucoids dominate sheltered intertidal rocky shores due to the lack of damage from wave action (Jonsson *et al*., 2006), good recruitment (Southward & Southward, 1978) and the limited recruitment of grazers (Jenkins *et al*., 1999). An increase to moderate wave exposure destabilizes the balance between fucoids, limpets and barnacles (Hartnoll & Hawkins, 1985), and results in a dynamic equilibrium between fucoid and barnacle dominance, mediated by physical wave action, and natural variation in grazing and recruitment. For example, limpets graze on algae and prevent algal growth but fucoid patches encourage the recruitment of juvenile limpets. Newly settled barnacles are reduced in number by limpets but are able to settle due to the removal of fast growing, and competitively superior ephemeral algae. Barnacles reduce limpet foraging efficiency allowing algal escapes. Dogwhelks thin-out barnacles, allowing limpets to more effectively reduce algal cover. The sweeping by fucoid fronds reduces barnacle settlement (Raffaelli & Hawkins, 1996). Hence, these biotopes exist in a state of dynamic equilibrium in which biological or physical changes can create quite drastic effects on the pattern of the community (Southward & Southward, 1978) and so biotopes are subject to change and may cycle between different biotopes or sub-biotopes. In addition there is also natural variation, and patchiness within intertidal rocky shores (Burrow & Lodge, 1950, Raffaelli & Hawkins, 1996). Hartnoll & Hawkins (1985) found that within test areas on a moderately exposed intertidal rocky shore a natural cycling of species on the mid shore took 6 – 7 years. Southward (1956) recorded a similar cycle taking five years.

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, Subrahmanyan, 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, Subrahmanyan, 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 Subrahmanyan (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 fucoids 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 fucoids can be found in zones, which in a balanced ecosystem, they do not normally occur (Burrows & Lodge, 1950, Southward & Southward, 1978). Fucoid 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 fucoids 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.

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 macroalgaes 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 fucoid canopy have a low chance of survival, mortality of barnacle spat is significantly lower under fucoid 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 fucoid 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 fucoids 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 fucoid 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.

Overall, where populations of the characterizing species remain after disturbance, then recovery is likely to be rapid (Hartnoll & Hawkins 1985) within 1-3 years. Similarly, if the natural cycle in species abundance (from fucoid to barnacle dominance) takes 5-7 years (Southward, 1956; Hartnoll & Hawkins, 1985) then resilience would be considered to be 'High' to 'Medium' depending on the degree of disturbance. However, where the disturbance causes a severe decline in the characteristic species (resistance is ‘None’) then recovery is likely to be prolonged (resilience is ‘Low’). Southward & Southward (1978) recorded that after the *M.V. Torrey Canyon* oil spill recovery of intertidal shores to their previous ecosystem function recovery can take 10 –15 years.

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 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. However this could be an inaccurate assessment of tolerance due to the possibility of individuals being acclimatized to their specific location. Increases 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 may be tolerant to an increase in 5 °C for one month or an increase of 2 °C for one year. It must be taken into consideration that there may be a level of acclimatization within *Fucus spiralis* to a specific area, and that a localized increase in temperature may have negative impacts on a local population. 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 if an increase in temperature were to occur. 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. However this could be an inaccurate assessment of tolerance due to the possibility of individuals being acclimatized to their specific location.

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. It must be taken into consideration that there may be a level of acclimatization within *Fucus spiralis* to a specific area, and that a localized increase in temperature may have negative impacts on a local population. Resistance and consequently the resilience are assessed as 'High'. Making the biotope 'Not Sensitive' to this pressure at the pressure benchmark.

Salinity increase (local)	Medium 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.

Semibalanus balanoides are tolerant of a wide range of salinities, and have the ability to isolate them-selves from water by closing their opercular valves (Foster, 1971b). They can also withstand large changes in salinity over moderately long periods of time by falling into a "salt sleep" and can be found on shores (example from Sweden) with large fluctuations in salinity around a mean of 24 (Jenkins *et al.*, 2001).

Sensitivity assessment. This biotope is found in fully marine conditions, and an increase in salinity, would create a hyper-saline environment. There are no records of this biotope being found in hyper-saline conditions. Therefore an increase in salinity may decrease the biodiversity of the biotope, and may even cause a shift in biotope. Both resistance and resilience are thus assessed as 'Medium'. The biotope is '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* and *Semibalanus balanoides* 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.

Semibalanus balanoides are tolerant of a wide range of salinities and can survive periodic emersion in freshwater, e.g. from rainfall or freshwater run-off, by closing their opercular valves (Foster, 1971b). They can also withstand large changes in salinity over moderately long periods of time by falling into a "salt sleep" and can be found on shores (example from Sweden) with large fluctuations in salinity around a mean of 24 (Jenkins *et al.*, 2001).

Similarly, most of the associated species (e.g. *Mytilus edulis)* are found in a wide range of salinities and are probably tolerant of variable or reduced salinity. The intertidal interstitial invertebrates and epifauna probably experience short-term fluctuating salinities, with reduced salinities due to rainfall and freshwater runoff when emersed. Prolonged reduction in salinity, e.g. from full to reduced due to e.g. freshwater runoff, is likely to reduce the species richness of the biotope due to loss of less tolerant red algae and some intolerant invertebrates. However, the dominant species will probably survive and the integrity of the biotope is likely to be little affected. Areas of freshwater runoff in the intertidal promote the growth of ephemeral greens, probably due to their tolerance of low salinities and inhibition of grazing invertebrates.

Sensitivity assessment. Both *Fucus spiralis* and *Semibalanus balanoides* can survive in reduced salinity environments and decrease in this pressure at the benchmark level is unlikely to cause significant mortalities of 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. However a reduction in the salinity scale may affect the distribution of species by altering their reproductive and growth ability, but not have any significant negative effect. There is no *Fucus spiralis* and *Semibalanus balanoides* biotope in variable salinity. Both the resilience and resistance are assessed as 'High', giving an overall sensitivity of 'Not Sensitive' at this particular benchmark.

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. Fucoids are however highly flexible and are able to re-orientate their position in the water column to become more streamlined. This ability allows fucoids to reduce the relative velocity between algae and the surrounding water, thereby reducing drag and lift (Denny *et al.*, 1998).

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 though greater sediment movement affecting in particular small life stages of macroalgae 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)

On the other hand, a reduction in water flow can cause a thicker boundary layer resulting in lower absorption of nutrients and CO_2 by the macroalgae. Slower water movement can also cause oxygen deficiency directly impacting the fitness of algae (Olsenz, 2011).

Growth and reproduction of *Semibalanus balanoides* is influenced by food supply and water velocity (Bertness *et al.*, 1991). Laboratory experiments demonstrated that barnacle feeding behaviour altered over different flow rates but that barnacles fed at a variety of flow speeds (Sanford *et al.*, 1994). Flow tank experiments using velocities of 0.03, 0.07 and 0.2 m/s showed that a higher proportion of barnacles fed at higher flow rates (Sanford *et al.*, 1994). Feeding was passive, meaning the cirri were held out to the flow to catch particles; although active beating of the cirri to generate feeding currents occurs in still water (Crisp & Southward, 1961). Field observations at sites in southern New England (USA) that experience a number of different measured flow speeds, found that *Semibalanus balanoides* from all sites responded quickly to higher flow speeds, with a higher proportion of individuals feeding when current speeds were higher. Barnacles were present at a range of sites, varying from sheltered sites with lower flow rates (maximum observed flow rates <0.06- 0.1 m/s), a bay site with higher flow rates (maximum observed flows 0.2-0.3 m/s) and open coast sites (maximum observed flows 0.2-0.4 m/s). Recruitment was higher at the site with flow rates of 0.2-0.3 m/s (although this may be influenced by supply) and at higher flow microhabitats within all sites. Both laboratory and field observations indicate that flow is an important factor with effects on feeding, growth and recruitment in *Semibalanus balanoides* (Sanford *et al.*, 1994, Leonard *et al.*, 1998), however, the results suggest that flow is not a limiting factor determining the overall distribution of barnacles as they can adapt to a variety of flow speeds.

Sensitivity assessment. This biotope is characteristic of exposed to moderately wave exposed conditions where water movement from wave action will greatly exceed the strength of any possible tidal flow. Based on the available evidence the characterizing species *Fucus spiralis* and *Semibalanus balanoides* are able to adapt to high flow rates and the biotope is therefore considered to be 'Not sensitive' to an increase in water flow. A decrease in water flow may have some effects on recruitment and growth, but this is not considered to be lethal at the pressure benchmark and resistance is therefore assessed as 'High' and resilience as 'High' by default, so that the biotope is considered to be 'Not sensitive'.

Emergence regime changes	Medium Q: High A: Medium C: Medium	Medium Q: High A: High C: Medium	Medium Q: Medium A: Medium C: Medium

Emergence regime is a key factor structuring intertidal biotopes. Increased emergence may reduce habitat suitability for characterizing species. Changes in emergence can lead to; greater exposure to desiccation and reduced feeding and photosynthesising opportunities for the characterizing species.

During the initial stages of drying, when algae are exposed to air, photosynthetic rates increase due to the higher diffusion rate of CO_2 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 CO_2 (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 CO_2 (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 & Jonhnson (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.

Semibalanus balanoides is less tolerant of desiccation stress than *Chthamalus* barnacle species and consequently appears in zones lower on the shore. However the presence of a fucoid canopy within this biotope means desiccation stress is less severe on the underlying population and enables them to survive (Raffaelli & Hawkins, 1996). An increase in desiccation may lead to a change in the fucoid canopy, but as long as there is a canopy to moderate the physical environmental factors then *Semibalanus balanoides* can prevail The presence of a version on this biotope further up the shore gives credence to this theory (Connor *et al*., 2004).

Decreased emergence would reduce desiccation stress and allow the attached suspension feeders more feeding time. However predation pressure on barnacles is likely to increase where these are submerged for longer periods and may prevent colonisation of lower zones. *Semibalanus balanoides* is able to extend its range into lower zones when protected from predation by the dogwhelk, *Nucella lapillus* (Connell, 1961). Competition from large fucoids and red algal turfs can also prevent *Semibalanus balano*ides from extending into lower shore levels (Hawkins, 1983). Decreased emergence is likely to lead to the habitat the biotope is found in becoming more suitable for the lower shore species generally found below the biotope, leading to replacement.

The mobile species present within the biotope, including *Nucella lapillus*, *Patella vulgata* and the littorinids would be able to relocate to preferred shore levels.

Sensitivity assessment: An increase in emersion will lead to greater desiccation due to increased time in air. When these factors are combined with high temperatures and light, mortalities may occur (Pearson *et al*., 2009). A change in the level of emergence on the shore at the bench mark level will affect *Fucus spiralis* and *Semibalanus balanoides* as well as other species within the biotope. However the effects may not be severe as the species within the upper eulittoral zone are higher adapted to tolerate dessication. For example, *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. However at the upper limits of the biotope there may be mortality. 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.

No direct evidence was found to assess the sensitivity of *Semibalanus balanoides* to changes in wave exposure at the pressure benchmark.

If an example of this biotope was found at the upper limit of the wave exposure tolerance, then a change in near shore significant wave height could force the biotope to change. *Fucus spiralis* biotopes are not found in situations with greater wave exposure, except for LR.HLR.FR.Fdis which is only found in Scotland. It is not possible to tell which biotope the increase in wave exposure would change to but it would definitely be in the LR.HLR biotope categories (Connor et al., 2004).

Sensitivity assessment. *Fucus spiralis* is sensitive to an increase in wave action, and the fucoid and barnacle dominated biotopes are found on moderate energy shores. Where increases in wave height caused wave exposure to become greater than exposed the biotope would be change and it may result in the loss of *Fucus spiralis*. However, a change in significant wave height of up to 5% is unlikely to result in a significant change in the biotope if the example of the biotope is found in the middle of its tolerance to wave exposure. Consequently, 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

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

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 deoxygenation 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. However, the biotope in question occurs in the upper eulittoral and consequently, a high proportion of time will be spent in the air where oxygen is not limited so the metabolic processes of photosynthesis and respiration can take place. Also, the biotope occurs in moderately wave exposed to exposed conditions so that aeration of the water column due to wave action and water flow will further mitigate deoxygenation. 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 Q: High A: Medium C: Medium	Medium Q: High A: High C: Medium	Medium Q: High A: Medium C: Medium

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

Johnston & Roberts (2009) undertook a review and meta-analysis of the effect of contaminants on species richness and evenness in the marine environment. Of the 49 papers reviewed relating to sewage as a contaminant, over 70% found that it had a negative impact on species diversity, <5% found increased diversity, and the remaining papers finding no detectable effect. Not all of the 49 papers considered the impact of sewage on intertidal rocky shores. Yet this finding is still relevant as the meta-analysis revealed that the effect of marine pollutants on species diversity was 'remarkably consistent' between habitats (Johnston & Roberts, 2009). It was found that any single pollutant reduced species richness by 30-50% within any of the marine habitats considered (Johnston & Roberts, 2009). Throughout their investigation, there were only a few examples where species richness was increased due to the anthropogenic introduction of a contaminant. These examples were almost entirely from the introduction of nutrients, either from aquaculture or sewage outfalls. However research into the impacts of organic enrichment from these sources on intertidal rocky shores often lead to shores lacking species diversity and the domination by algae with fast growth rates (Littler & Murray, 1975; Abou-Aisha *et al.*, 1996; 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’.

Physical Pressures

	Resistance	Resilience	Sensitivity
Physical loss (to land or freshwater habitat)	Low 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. A change towards a sedimentary or soft rock substratum would lead to the direct loss of suitable attachment areas resulting in the loss of *Fucus spiralis*, *Semibalanus balanoides* and associated communities. Resistance is assessed as ‘None’. As this pressure represents a permanent change, recovery is impossible as 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

‘Not Relevant’ for bedrock biotopes.

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

This biotope is 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 colonisation 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 / m^2 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 month 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).

Semibalanus balanoides typically occur on the rock surfaces where they will be exposed to abrasion. Although they are protected by hard shells or plates, abrasion may damage and kill individuals or detach these. All removed barnacles would be expected to die as there is no mechanism for these to reattach. The effects of trampling on barnacles appears to be variable with some studies not detecting significant differences between trampled and controlled areas (Tyler-Walters & Arnold, 2008). However, this variability may be related to differences in trampling intensities and abundance of populations studied. The worst case incidence was reported by Brosnan & Crumrine (1994) who reported that a trampling pressure of 250 steps in a 20x20 cm plot one day a month for a period of a year significantly reduced barnacle cover at two study sites. Barnacle cover reduced from 66% to 7% cover in 4 months at one site and from 21% to 5% within 6 months at the second site. Overall barnacles were crushed and removed by trampling. Barnacle cover remained low until recruitment the following spring. Long *et al*. (2011) also found that heavy trampling (70 humans/km^{-}shoreline/hr) led to reductions in barnacle cover. Single step experiments provide a clearer, quantitative indication of sensitivity to direct abrasion. Povey & Keough (1991) in experiments on shores in Mornington peninsula, Victoria, Australia, found that in single step experiments 10 out of 67 barnacles, (*Chthamlus antennatus* about 3mm long), were crushed. However, on the same shore, the authors found that limpets may be relatively more resistant to abrasion from trampling. Following step and kicking experiments, few individuals of the limpet *Cellana trasomerica*, (similar size to *Patella vulgata*) suffered damage or relocated (Povey & Keough, 1991). One kicked limpet (out of 80) was broken and 2 (out of 80) limpets that were stepped on could not be relocated the following day (Povey & Keough, 1991). Trampling may lead to indirect effects on limpet populations, Bertocci *et al*., (2011) found that the effects of trampling on *Patella* sp. increased temporal and spatial variability of in abundance. The experimental plots were sited on a wave-sheltered shore dominated by *Ascophyllum nodosum*. On these types of shore, trampling in small patches, that removes macroalgae and turfs, will indirectly enhance habitat suitability for limpets by creating patches of exposed rock for grazing. Pinn & Rodgers (2005) compared abundances of *Patella* sp. on frequently visited rocky ledges and less visited ledges. They found that limpet abundances on the ledge which was visited more frequently by humans had lower abundances of limpets. The use of 'limpet protection zones', where trampling was minimised, helped populations of limpets recover. Also strengthening the evidence that human trampling was the cause of the population reduction in the first instance.

Shanks & Wright (1986), found that even small pebbles (<6 cm) that were thrown by wave action in Southern California shores could create patches in *Chthamalus fissus* aggregations and could smash owl limpets (*Lottia gigantea*). Average, estimated survivorship of limpets at a wave exposed site, with many loose cobbles and pebbles allowing greater levels of abrasion was 40% lower than at a sheltered site. Severe storms were observed to lead to almost total destruction of local populations of limpets through abrasion by large rocks and boulders.

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 spiralis* and *Semibalanus balanoides.* Although barnacles may be more resistant to this pressure the biotope will still be damaged or altered if *Fucus spiralis* is removed, consequently 'Low' resistance has been allocated. Although

Fucus spiralis may return quickly, equilibrium within the ecosystem may not have been reached, therefore resistance is ‘Medium’. 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 rock, which is resistant to subsurface penetration. Therefore, ‘penetration’ is **'Not relevant'**. The assessment for abrasion at the surface only is, therefore, considered to equally represent sensitivity to this pressure’. Please refer to ‘abrasion’ above.

Changes in suspended solids (water clarity)	Medium Q: Medium A: Medium C: Medium	Medium Q: High A: High C: Medium	Medium Q: Medium A: Medium C: Medium

Light is an essential resource for all photo-autotrophic 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 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.

Semibalanus balanoides may be adversely affected. As a filter feeding organism their feeding apparatus can become 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. Seapy & Littler (1982) found that a sediment inundation on an intertidal rocky shore caused a decrease in species diversity. One of the species on which the deposition of sediment was noted to have a notable negative impact was on the barnacle species *Tetraclita rubescens.*

Sensitivity assessment. Changes in suspended solids reducing water clarity will have adverse effects on the biotope hindering photosynthesis and growth as well as reducing species richness. Resistance is thus assessed as ‘Medium’. Once conditions return to 'normal' algae are likely to rapidly regain photosynthesising capabilities as well as growth rate. Associated communities will also recover as most of the intolerant species produce planktonic larvae and are, therefore, likely to be able to recolonize quickly from surrounding areas. Resilience is assessed as ‘Medium’. Overall this biotope group scores a ‘Medium’ sensitivity.

Smothering and siltation rate changes (light)	Medium Q: High A: Medium C: Medium	High Q: High A: High C: High	Low Q: Medium A: Medium C: Medium

Sedimentation can directly affect assemblages inhabiting rocky shores in different ways, particularly by the burial/smothering and scour/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 micro-environment (Devinny & Volse, 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 impact. Indeed, if smothering occurs at low tide when the algae is lying flat on the substratum, then most of the organism as well as the associated community will be covered by the deposition of fine material at the level of the benchmark. Smothering will prevent photosynthesis resulting in reduced growth and eventually death. If however smothering occurs whilst the alga is submerged standing upright 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). *Semibalanus balanoides*is found permanently attached to hard substrata and is a suspension feeder. This species, therefore, has no ability to escape from silty sediments which would bury individuals and prevent feeding and respiration. However, no direct evidence for sensitivity to siltation was found.

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. Burial will lower survival and germination rates of spores and cause some mortality in early life stages of *Fucus spiralis*. Adults are more resistant but will experience a decrease in growth and photosynthetic rates. No evidence for the impact of burial on *Semibalanus balanoides* can be found. However considering that the benchmark of this pressure is 5 cm of sediment deposition and this species never exceeds 1.5 cm in height, even the largest individual would be entirely smothered. Consequently inhibiting filter feeding and respiration entirely. Therefore this pressure could lead to mortality if the sediment is not removed within a few tidal cycles

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 is assessed as ‘Medium’. As the biotope is found within a moderately wave exposed to exposed position, wave surge would remove the sediment quickly and result in no long-term damage occurring to biotopes community. This gives the biotope a resilience of 'High'. Overall the biotope has a 'Low' 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: High C: Medium	Medium Q: High A: Medium 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 understorey 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 and resilience are assessed as 'Medium'. Overall the biotope has a 'Medium' sensitivity to siltation at the pressure benchmark.

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

Not assessed

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

No evidence.

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

Species characterizing this habitat do not have hearing perception but vibrations may cause an 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

Species characterizing this habitat have no hearing perception but vibrations may cause an impact, however no studies exist 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

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 assessed.

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.

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

The Australasian barnacle *Austrominius* (previously *Elminius*) *modestus* was introduced to British waters on ships during the second world war. However, its overall effect on the dynamics of rocky shores has been small as *Austrominius modestus* has simply replaced some individuals of a group of co-occurring barnacles (Raffaelli & Hawkins, 1999). Although present, monitoring indicates it has not outnumbered native barnacles in the Isle of Cumbrae (Gallagher *et al*., 2015) although it may dominate in estuaries where it is more tolerant of lower salinities than *Semibalanus balanoides* (Gomes-Filho, *et al*., 2010).

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* or *Semibalanus balanoides* within locations similar to that found within 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').

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	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 Fucoids 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 fucoids 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).

Fucoids 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.

Semibalanus balanoides is not a targeted species. *Patella vulgata* however is an important characterizing and structuring species within this biotope. *Patella vulgata* grazing can control the character of the shore by grazing algae and newly settled barnacle larvae. Even a small, localised temporary absence of limpets (Southward, 1956; Southward, 1964; Hawkins, 1981; Hawkins *et al*., 1983) can alter the biological assemblage. Significant limpet kills resulting from the widespread use of dispersants after the *Torrey Canyon* oil spill dramatically altered rocky shore communities. *Laminaria digitata*, for example, was able to extend 2m up shore in the absence of limpets and there were dense growths of ephemeral green seaweeds followed by equally dense growth of fucoids (Southward & Southward, 1978; Hawkins & Southward, 1992).

Sensitivity assessment. The removal of *Fucus spiralis* canopy will significantly change the community composition of the biotope. However as there is no evidence toregarding their removal from intertidal shores the impact of this pressure is difficult to ascertain. The targeted removal of the important grazing species *Patella vulgata* may have more negative impacts on the community structure. 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. *Patella vulgata*, and many other species have a ‘Low’ resistance to removal as both of them are easy to locate and have no escape strategy. Resilience is ‘Medium’, however recovery will only be able to start when the pressure is removed from the shore i.e. harvesting is no longer occurring. A sensitivity of ‘Medium’ is recorded.

Removal of non-target species	None Q: Medium A: Medium C: Medium	Medium Q: Medium A: Medium C: Medium	Medium Q: High A: Medium C: Medium

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

Sensitivity assessment. Removal of a large percentage of the characterizing species would alter the character of the biotope. The resistance to removal is ‘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’.

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