



MarLIN

Marine Information Network

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

Fucus serratus and red seaweeds on moderately exposed lower eulittoral rock

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

Emilia d'Avack and Dr Harvey Tyler-Walters

2015-08-21

A report from:

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

Please note. This MarESA report is a dated version of the online review. Please refer to the website for the most up-to-date version [<https://www.marlin.ac.uk/habitats/detail/43>]. All terms and the MarESA methodology are outlined on the website (<https://www.marlin.ac.uk>)

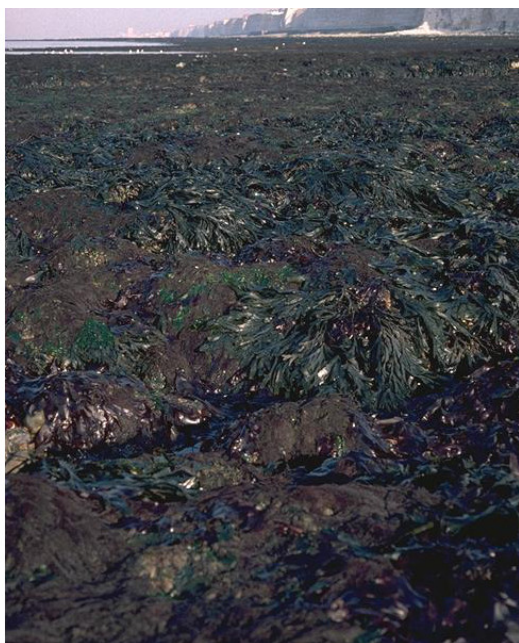
This review can be cited as:

d'Avack, E.A.S & Tyler-Walters, H., 2015. [*Fucus serratus*] and red seaweeds on moderately exposed lower eulittoral rock. 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.43.1>



The information (TEXT ONLY) provided by the Marine Life Information Network (MarLIN) is licensed under a Creative Commons Attribution-Non-Commercial-Share Alike 2.0 UK: England & Wales License. Note that images and other media featured on this page are each governed by their own terms and conditions and they may or may not be available for reuse. Permissions beyond the scope of this license are available [here](https://www.marlin.ac.uk). Based on a work at www.marlin.ac.uk

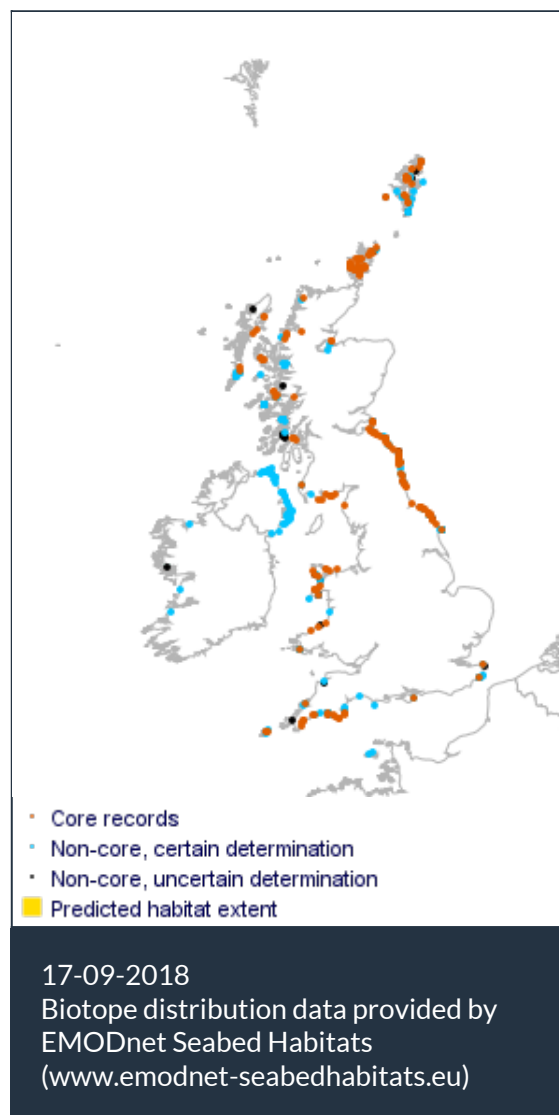
(page left blank)



Fucus serratus and red seaweeds on moderately exposed lower eulittoral rock

Photographer: Joint Nature Conservation Committee

Copyright: Joint Nature Conservation Committee (JNCC)



Researched by Emilia d'Avack and Dr Harvey Tyler-Walters

Refereed by Admin

Summary

UK and Ireland classification

EUNIS 2008	A1.2141	<i>Fucus serratus</i> and red seaweeds on moderately exposed lower eulittoral rock
JNCC 2015	LR.MLR.BF.Fser.R	<i>Fucus serratus</i> and red seaweeds on moderately exposed lower eulittoral rock
JNCC 2004	LR.MLR.BF.Fser.R	<i>Fucus serratus</i> and red seaweeds on moderately exposed lower eulittoral rock
1997 Biotope	LR.MLR.BF.Fser.R	<i>Fucus serratus</i> and red seaweeds on moderately exposed lower eulittoral rock

Description

Moderately exposed lower eulittoral bedrock characterized by mosaics of the wrack *Fucus serratus* and turf-forming red seaweeds including *Osmundea pinnatifida*, *Mastocarpus*

stellatus or *Corallina officinalis*. The hydroid *Dynamena pumilacan* occur in dense populations on the *Fucus serratus* fronds whilst the sponge *Halichondria panicea* can cover the bedrock beneath. Underneath the canopy a number of other red seaweeds may be present including *Palmaria palmata*, *Lomentaria articulata*, *Membranoptera alata* and *Chondrus crispus*. Green seaweeds such as *Cladophora rupestris*, *Ulva intestinalis* and *Ulva lactuca* are present though usually in small numbers. In addition, such shores provide a greater number of permanently damp refuges between the stones and underneath the seaweed canopy. Within these micro-habitats species such as the limpet *Patella vulgata*, the barnacle *Semibalanus balanoides* or the whelk *Nucella lapillus* can be found in lower abundance than higher up the shore. If a few boulders are present then the winkle *Littorina littorea* and the crab *Carcinus maenas* can be found on or underneath the boulders. (Information taken from Connor *et al.*, 2004; JNCC, 2015).

↓ Depth range

Lower shore

Additional information

-

✓ Listed By

- none -

Further information sources

Search on:



Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

This biotope group is dominated by the brown seaweed *Fucus serratus*, with an association of red seaweeds (inc. *Osmundea pinnatifida*, *Mastocarpus stellatus*, *Palmaria palmata* and *Corallina officinalis*). *Fucus serratus* provides habitat and food for a highly diverse community of species (Fredriksen *et al.*, 2005). As ecosystem engineers furoid algal canopies modify habitat conditions, facilitating the existence and survival of other intertidal species and therefore strongly influencing the structure and functioning of coastal ecosystems (Jenkins *et al.*, 2008). Associated fauna include the limpet *Patella vulgata*, the barnacle *Semibalanus balanoides*, the whelk *Nucella lapillus*, the anemone *Actinia equina* and the sponge *Halichondria panicea*.

The loss of *Fucus serratus* canopy will have both short and long-term consequences for associated benthic communities, resulting in the loss of biogenic habitat, reduction in diversity, simplification of vertical structure and reduction or loss of ecosystem functioning such as primary productivity (Lilley & Schiel, 2006). The removal of macroalgae canopy exposes understory species to sunlight and aerial conditions resulting in bleaching and eventual die backs, especially for encrusting corallines, bryozoans and hydroids (Hawkins & Harkin, 1985).

The assessments are based largely on the sensitivity of *Fucus serratus*, as this is the key species characterizing the biotope and providing habitat. Other species associated with the biotope are found in a range of hard substratum biotopes, therefore, although these species contribute to the structure and function of the biotope they are not considered key species and are not specifically assessed. Connor *et al.* (2004) note that this biotope may vary seasonally, e.g. the red seaweed abundance is likely to be lower in winter and higher in spring and summer and severe storms may change this biotope to a *Fucus serratus* dominated (e.g. MLR.BF.Fser) or red seaweed dominated biotope.

Resilience and recovery rates of habitat

The loss of *Fucus serratus* canopy will have both short and long-term consequences for associated benthic communities, resulting in the loss of habitat, reduction in diversity, simplification of vertical structure and reduction or loss of ecosystem functioning such as primary productivity (Hawkins & Harkin, 1985; Lilley & Schiel, 2006). The removal of macroalgae canopy exposes understory species to sunlight and aerial conditions during low tides resulting in bleaching and eventual die backs.

Schiel & Foster (2006) observed long-term demographic lags in recovery after important losses of furoids. Recovery of lost or severely reduced species can be slow, with species replacement common. Indeed loss of furoids can cause systems shifts to a state dominated by low-lying turf or filamentous ephemeral algae (Airoidi *et al.*, 2008; Mangialajo *et al.*, 2008; Perkol-Finkel & Airoidi, 2010). Turf algae, especially corallines, are often highly resilient and positively associated with perturbed areas, and can recover and reach greater abundance compared to prior disturbance conditions (Bulleri *et al.*, 2002; Bertocci *et al.*, 2010). These turf algae can then prevent canopy recovery by inhibiting recruitment. 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 *Fucus serratus* on the impact zone. Stagnol *et al.* (2013) found that opportunistic ephemeral green

algae such as *Ulva* sp. responded positively to disturbance (removal of the canopy). These green ephemeral algae are major competitors of *Fucus serratus* for space colonization and nutrient uptake. Blooms of ephemeral algae facilitated by disturbance may then slow the development of longer-lived perennial algae, especially fucoids.

Disturbance is a structuring factor in intertidal habitats. Perturbation events often remove organisms, increasing mortality, and also release resources such as space, nutrients and light that may enhance the appearance of new colonists (Connell *et al.*, 1997). As a result of these contrasting effects, post-disturbance communities are frequently different from initial communities in terms of composition and dominance of species. Overall, disturbance causes a shift towards a disturbance tolerant seaweed community (Little *et al.*, 2009). The changes in dominant species and community structure take some time to develop and, although some effects occur rapidly, many are manifested over a period of several years (Schiel & Lilley, 2011). Hawkins & Southward (1992) found that, after the *Torrey Canyon* oil spill, it took between 10 and 15 years for the *Fucus* sp. to return to 'normal' levels of spatial and variation in cover on moderately exposed shores. Therefore, for pressures that totally destroy the biotope, recoverability is likely to be low.

Fucus serratus is dioecious, perennial and reproduces sexually. Reproduction commences in late spring/early summer and continues through summer and autumn, peaking in August - October. Eggs and sperm are released into the water and fertilization occurs in the water column. The zygote then develops into a minute plant that can then settle onto the substratum. Arrontes (1993) determined that the dispersal of *Fucus serratus* gametes and fertilized eggs was restricted to within 1–2 m from the parent. Average annual expansion rates for *Fucus serratus* have been estimated at 0.3 to 0.6 km per year (Coyer *et al.*, 2006; Brawley *et al.*, 2009). Dispersal is highly limited as the negatively buoyant eggs are fertilized almost immediately after release and dispersal by rafting reproductive individuals is unlikely (Coyer *et al.*, 2006). *Fucus serratus* does not float, and thus mature detached individuals cannot transport reproductive material to distant sites as might be the case for other brown algae. However *Fucus serratus* is found on all British and Irish coasts so there are few mechanisms isolating populations. While poor dispersal is true for medium or large spatial scales (hundreds of metres to kilometres), recruitment at short distances from parental patches is very efficient, as most propagules settle in the vicinity of parent plants (Arrontes, 2002).

In kelp canopy removal experiments in the Isle of Man, Hawkins & Harkin (1985) observed a rapid increase in the number of *Palmaria palmata* sporelings and the species came to dominate cleared plots within five months. Rhodophyceae have non flagellate, and non-motile spores that stick on contact with the substratum. Norton (1992) noted that algal spore dispersal is probably determined by currents and turbulent deposition. However, red algae produce large numbers of spores that may settle close to the adult especially where currents are reduced by an algal turf or in kelp forests. It is likely that this species could recolonize an area from adjacent populations within a short period of time in ideal conditions. However, since the dispersal range of spores is limited because the female does not release carpospores and needs to be close to the adult male population, recolonization from distant populations would probably take much longer.

Chondrus crispus has an extended reproductive period (e.g. Pybus, 1977; Fernandez & Menendez, 1991; Scrosati *et al.*, 1994) and produces large numbers of spores (Fernandez & Menendez, 1991). Recovery of a population of *Chondrus crispus* following a perturbation is likely to be largely dependent on whether holdfasts remain, from which new thalli can regenerate (Holt *et al.*, 1995). In addition, the spores of red algae are non-motile (Norton, 1992) and therefore entirely reliant on the hydrographic regime for dispersal. Hence, similar to *Fucus serratus*, *Chondrus crispus* would normally only recruit from local populations slowing down the recovery of remote populations.

Minchinton *et al.* (1997) documented the recovery of *Chondrus crispus* after a rocky shore in Nova Scotia, Canada, was totally denuded by an ice scouring event. Initial recolonization was dominated by diatoms and ephemeral macroalgae, followed by fucoids and then perennial red seaweeds. After 2 years, *Chondrus crispus* had re-established approximately 50% cover on the lower shore and after 5 years it was the dominant macroalga at this height, with approximately 100% cover. Minchinton *et al.* (1997) concluded that although *Chondrus crispus* was a poor colonizer, it was the best competitor.

The larvae of the sea squirt *Ascidella aspersa* have a short free-swimming planktonic stage. Fertilization to settlement and metamorphosis is estimated to only take about 24 hours at 20 °C (Niermann-Kerkenberg & Hofmann, 1989). The sea squirt *Ascidella scabra* has a high fecundity and settles readily, probably for an extended period from spring to autumn. Svane (1988) describes it as "an annual ascidian" and demonstrated recruitment onto artificial and scraped natural substrata. It is also likely that *Ascidella scabra* larvae are attracted by existing populations and settle near to adults (Svane *et al.*, 1987). Fast growth means that a dense cover could be established within about 2 months. However, if mortality occurs at a time when larvae are not being produced, other species may settle and dominate in the freed spaces. The settlement of new colonies of the breadcrumb sponge *Halichondria panicea* is likely to occur within one year with growth rate ranging from 0.1 to 0.4 cm²/day. Knowlton & Highsmith (2005) found a rapid response to tissue damage from nudibranch grazing with the sponge recovering within 4 weeks from grazing impacts.

Resilience assessment. *Fucus serratus* is the main structural species as its removal will lead cause the decline of associated species and eventually to a change towards a different biotope. If the entire population of *Fucus serratus* is lost other species may come to dominate. Where resistance is 'None', then resilience is 'Low' based on the low long-distance dispersal range of *Fucus serratus*. Re-establishment of the seaweed may depend on the ability to out-compete other species and this may be dependent on suitable environmental conditions. Upon arrival, the success of the new population is explained by: (1) rapid establishment of monospecific patches in the immediate vicinity of the founding plants, (2) high colonization rates of disturbed areas, (3) the ability to recruit to undisturbed canopies, (4) the ability to outgrow resident canopy species (particularly *Fucus vesiculosus*) and (5) the increase in size and number of dispersal centres (Arrontes, 2002).

If some of the population remains it is unlikely that other species will come to dominate due to efficient recruitment over short distance. Removal of some of the adult canopy will allow the understorey germling to grow faster. After experimental (small scale 2 sq. metre) canopy removal of *Fucus serratus* on a moderately exposed shore, the *Fucus serratus* cover recovered within one year and both *Fucus serratus* and *Palmaria palmata* dominated the area (Hawkins & Harkin, 1985). Therefore, recovery from small scale disturbance will probably have take no more than two years. Therefore when resistance is 'Medium', recovery will be very fast resulting in a 'High' resilience score due to very efficient colonization of areas adjacent to *Fucus serratus* patches. If resistance is assessed as 'High', resilience is automatically 'High' as there are not impacts to recover from.

Moderately strong tidal currents, characteristic of this biotope, encourage communities of sponges and ascidians. Changes to the hydrological regime are therefore likely to directly influence the presence of these species. Once removed, these species are however likely to rapidly recolonize due to planktonic larvae thereby facilitating recruitment. Most species associated with this biotope are poor long distance dispersers. However the moderately strong tidal currents of this biotope enable these species to disperse over greater distances than in slow flowing

environments.

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: Low C: Medium	High Q: High A: Low C: Medium	Not sensitive Q: High A: Low C: Medium

Most fucoids are cold-temperate species (Lüning, 1984), and temperatures above 20°C are generally considered unsuitable for these algae (Zou *et al.*, 2012). The effect of high temperature stress on photosynthesis in brown algae is related to inactivation of enzymes and the induction of reactive oxygen species (ROS), leading to photoinhibition (Suzuki & Mittler, 2006). Growth rates of adult brown macroalgae may be affected by temperature through the increase in metabolic rates (Nygard & Dring, 2008). However, *Fucus serratus* is found along the Atlantic coast of Europe from Svalbard to Portugal and on the shores of north-east America. The seaweed is thus well within its thermal range in the British Isles. Nielsen *et al.* (2014) found no negative effects on growth rates of adult *Fucus serratus* to water temperatures of 22 °C (based on a laboratory experiment with specimen collected from Firth of Forth, Scotland) and Arrontes (1993) observed that *Fucus serratus* survived in laboratory experiments for 1 week at 25 °C. Nielsen *et al.* (2014) did, however, report that germlings were negatively affected by increased temperature indicating that early life stages are more vulnerable than mature algae to this pressure.

Several studies have observed adverse effects of *Fucus serratus* as a result to warm thermal stress in terms of growth, physiological performance and reproductive output in Spain and Portugal (Pearson *et al.*, 2009; Viejo *et al.*, 2011; Martínez *et al.*, 2012). Jueterbock *et al.* (2014) determined that these negative impacts can be explained by restricted within-population genetic diversity. South west Ireland and Brittany are hot-spots of genetic diversity (Coyer *et al.*, 2003; Hoarau *et al.*, 2007) and may thus be more resilient to changes in temperature. Phenotypic plasticity therefore plays an important role in determining the sensitivity of individual populations to changes in temperature.

Sensitivity assessment. An increase in acute or chronic temperature above average British and Irish temperatures is not likely to have a detrimental effect of *Fucus serratus* and associated communities, based on global distribution. However, it should be noted that phenotypic plasticity will influence the tolerance of individual population. Resistance and resilience are therefore both assessed as 'High' (no impacts to recover from). The biotope group is 'Not Sensitive' to a change in temperature at the pressure benchmark.

Temperature decrease (local)**High**

Q: High A: Medium C: Low

High

Q: High A: High C: High

Not sensitive

Q: High A: Medium C: Low

Lüning (1984) reported that *Fucus serratus* survived in the laboratory for a week a range temperature between 0°C and 25°C. *Fucus serratus* is found along the Atlantic coast of Europe from Svalbard to Portugal and on the shores of north-east America. The seaweed is thus well within its thermal range in the British Isles. Lüning (1984) placed this species in his 'Cold temperature North Atlantic group'.

Sensitivity assessment. A decrease in acute or chronic temperature above average British and Irish temperatures is not likely to have a detrimental effect of *Fucus serratus* and associated communities, based on global distribution. However, it should be noted that phenotypic plasticity will influence the tolerance of individual population. Resistance and resilience are therefore both assessed as 'High' (no impacts to recover from). The biotope group is 'Not Sensitive' to a change in temperature at the pressure benchmark.

Salinity increase (local)**High**

Q: Medium A: Medium C: Medium

High

Q: High A: Low C: Medium

Not sensitive

Q: Medium A: Low C: Medium

This biotope group is found in the intertidal and is therefore likely to experience cyclical periods of hypo- and hyper-salinity. Fucoids are able to compensate for changes in salinity by adjusting internal ion concentrations. However this will occur at a cost, reducing photosynthetic rate and hence affecting the growth rate of the seaweed. Growth rates for *Fucus serratus* are maximal at a salinity of 20 psu with the critical limit for recruitment set at 7 psu (Malm *et al.*, 2001).

Sensitivity assessment. *Fucus serratus*, commonly inhabit narrow fjords where salinity can vary widely along a spatial (kms) and/or temporal (hours to daily) scale. At the level of the benchmark both resistance and resilience are assessed as 'High' (no impacts to recover from). The biotope group is therefore 'Not Sensitive' to a decrease in salinity at the pressure benchmark.

Salinity decrease (local)**High**

Q: High A: High C: High

High

Q: High A: High C: Medium

Not sensitive

Q: High A: High C: Medium

This biotope group is found in the intertidal and is therefore likely to experience cyclical periods of hypo- and hyper-salinity. Fucoids are able to compensate for changes in salinity by adjusting internal ion concentrations. However this will occur at a cost, reducing photosynthetic rate and hence affecting the growth rate of the seaweed. Growth rates for *Fucus serratus* are maximal at a salinity of 20 psu with the critical limit for recruitment set at 7 psu (Malm *et al.*, 2001).

Sufficient salinity is essential for successful fertilization and germination in *Fucus* (e.g., Brawley, 1992; Serrão *et al.*, 1999). Malm *et al.* (2001) found that fertilization success in *Fucus serratus* decreased substantially with strongly reduced salinity. Indeed the study found that fertilisation success was 87% at 9 psu but declined to 5% at 6 psu (Malm *et al.*, 2001). Reduced salinity does also affect dispersal by decreasing swimming performance of fucoid sperm (Serrão *et al.*, 1996).

Sensitivity assessment. *Fucus serratus*, commonly inhabit narrow fjords where salinity can vary widely along a spatial (kms) and/or temporal (hours to daily) scale. A reduction in salinity at the level benchmark (e.g. from 'Full' to 'Reduced' for one year) could have beneficial effects on *Fucus serratus* as growth rates are maximal below full saline conditions. Other characterizing species

associated with this biotope are also likely to be tolerant of a reduction in salinity. Resistance and resilience are therefore both assessed as 'High' (no impacts to recover from). The biotope group is 'Not Sensitive' to a decrease in salinity at the pressure benchmark.

Water flow (tidal current) changes (local)

High

Q: Medium A: Low C: Medium

High

Q: Medium A: Low C: Medium

Not sensitive

Q: Medium A: Low 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 increases mechanical stress on macroalgae by increasing drag. This can result in individuals being torn off the substratum. Once removed, algae cannot re-attach and will die. Any sessile organism attached to the algae is also lost.

Fucoids are highly flexible and are able to reorientate their position in the water column to become more streamlined, which reduces the relative velocity between the algae and the surrounding water, thereby reducing drag and lift (Denny *et al.*, 1998). Jonsson *et al.* (2006) found that a flow speed of 7-8 m/s completely dislodged *Fucus vesiculosus* and *Fucus spiralis* individuals larger than 10 cm. Smaller individuals are likely to better withstand increased water flow as they experience less drag. Propagule dispersal, fertilization, settlement, and recruitment are also influenced by water movement (Pearson & Brawley, 1996). In addition, increased water flow will cause scour, though increased sediment movement, affecting in particular small life stages of macroalgae by removing new recruits from the substratum and hence reducing successful recruitment (Devlin & Volse, 1978) (see 'siltation' pressures). Changes in water motion can thus strongly influence local distribution patterns of *Fucus* spp. (Ladah *et al.*, 2008). 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 (Wahl *et al.*, 2011).

Sensitivity assessment. An increase in water flow to or above 7 m/s is likely to dislodge algae resulting in a net reduction of habitat provided by this biotope. The biotopes is recorded from moderately strong (0.5-1.5 m/s) to weak (<0.5 m/s) tidal streams so that the a change of 0.1-0.2 m/s is unlikely to be significant, especially in the moderately wave exposed conditions. Therefore, resistance is considered to be 'High', so that resilience is 'High' and the biotope is overall 'Not sensitive' at the benchmark level.

Emergence regime changes

Low

Q: High A: High C: Medium

High

Q: High A: Medium C: Medium

Low

Q: High A: Medium C: Medium

This biotope group is found in the eulittoral zone from MTL (mean tide level) to MLWN (mean low water neap) and is therefore subjected to cyclical immersion and emersion over the tidal cycle. Fucoids can tolerate periodic desiccation but only to a limited extent. *Fucus serratus* is more susceptible to desiccation than other *Fucus* species that are located further up the shore and subjected more frequently to aerial exposure (Schonbeck & Norton, 1978). In experiments, (Schonbeck & Norton, 1978; *Fucus serratus* did not survive translocation further up the shore, e.g. in the *Fucus spiralis* belt. The critical water content for *Fucus serratus* is estimated at 40% with water losses past this point causing irreversible damage. Beer *et al.* (2014) found that *Fucus serratus* could not regain any positive photosynthetic rates after rehydrating from 10% water content. The

upper shore extent of *Fucus serratus* populations may be replaced by species more tolerant of desiccation and more characteristic of the mid-eulittoral such as *Fucus vesiculosus* or *Ascophyllum nodosum*.

Early life history stages will be more susceptible to this pressure (Henry & Van Alstyne, 2004). 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* canopy is also likely to protect other underlying species to a great extent. Mortalities of other component of the community will however occur if the canopy is removed (see 'abrasion' pressure).

Sensitivity assessment. Severe desiccation and associated osmotic stress can increase mortality (Perason *et al.*, 2009). Other species better able to tolerate desiccation will competitively displace *Fucus serratus* following changes in emergence regime. Juvenile stages are more susceptible but are largely protected from desiccation by the canopy of adults. Resistance is thus assessed as 'Low', as most of the *Fucus serratus* cover will probably be lost or replaced by other species. Resilience is thus assessed as 'High'. The biotope groups as a 'Low' sensitivity to changes in emersion regime at the level of the benchmark.

Wave exposure changes (local)

High

Q: High A: Low C: Medium

High

Q: High A: Low C: Medium

Not sensitive

Q: High A: Low C: Medium

This biotope is limited to coasts with moderate exposure or less. *Fucus serratus* is highly flexible but not physically robust and an increase in wave exposure above this level will cause mechanical damage, breaking fronds or even dislodging algae from the substratum. Furoids are permanently attached to the substratum and would not be able to re-attach if removed. Organisms living on the fronds and holdfasts will be washed away with the algae whereas free-living community components could find new habitat in surrounding areas. Wave exposure has been shown to limit size of furoids (Blanchette, 1997) as smaller individuals create less resistance to wave. Mature plants are therefore more sensitive to this pressure. As exposure increases the furoid population would become dominated by small juvenile algae. An increase in wave action beyond this would lead to dominance of the community by grazers and barnacles at the expense of furoids. Increased wave can also reduce light penetration thereby lower overall photosynthesis (see 'changes in suspended solids' pressure). A reduction in wave action would have little effect as the species is naturally found in sheltered conditions.

Sensitivity assessment. *Fucus serratus* and associated communities are sensitive to an increase in wave action as increased exposure would result in important losses both in biomass and species richness. However, a 3-5% change in significant wave height is unlikely to be significant and the biotope is considered to be 'Not sensitive' at the benchmark level.

⚗ Chemical Pressures

Resistance

Not Assessed (NA)

Q: NR A: NR C: NR

Resilience

Not assessed (NA)

Q: NR A: NR C: NR

Sensitivity

Not assessed (NA)

Q: NR A: NR C: NR

Transition elements & organo-metal contamination

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

No evidence (NEv)

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: Low A: NR C: NR

Not sensitive

Q: Low A: Low C: Low

Sustained reduction of dissolved oxygen can lead to hypoxic or anoxic conditions. Sustained or repeated episodes of reduced dissolved oxygen have the potential to severely degrade an ecosystem (Cole *et al.*, 1999). Little information on the effect of deoxygenation on fucoids was found.

Sensitivity assessment. The macroalgal component of the biotope produce oxygen via photosynthesis in light and respire in darkness and are exposed to air at low tide. Therefore, hypoxic conditions in the water column may be alleviated by aerial exposure at low tide. Also, wave action will result in mixing and aeration of the water column. The epifaunal community is probably more sensitive to hypoxia, so that hypoxic conditions will probably reduce species richness but the biotope will remain. Therefore, a resistance of 'High' is suggested, with a resistance of 'High' and resultant sensitivity of 'Not sensitive'.

Nutrient enrichment

High

Q: High A: High C: Medium

High

Q: High A: Low C: Medium

Not sensitive

Q: High A: Low C: Medium

Nutrient enrichment generally stimulates ephemeral macroalgae growth (Duarte, 1995). This stimulation of annual ephemerals may accentuate the competition for light and space and hinder perennial species development or harm their recruitment (Kraufvelin *et al.*, 2007). Kraufvelin *et al.* (2006) found only minor effect on the fucoid community structure as a response to high nutrient levels during the first 3 years of the experiment. During the 4th year of exposure however, *Fucus serratus* started to decline and population consequently crashed in the 5th year. The study observed full recovery of algal canopy and animal community in less than 2 year after conditions returned to normal. The results indicate that established rocky shore communities of perennial algae with

associated fauna are able to persist for several years, even at very high nutrient levels, but that community shifts may suddenly occur if eutrophication continues. They also indicate that rocky shore communities have the ability to return rapidly to natural undisturbed conditions after the termination of nutrient enhancement.

Sensitivity assessment. The benchmark of this pressure (compliance with WFD 'good' status) allows for a slightly less diverse community of red, green and brown seaweeds with cover variable depending on local physical conditions. Therefore, at the level of the benchmark both resistance and resilience are assessed as 'High'. The biotope group is therefore 'Not Sensitive' to this pressure at the pressure benchmark.

Organic enrichment	Medium	High	Low
	Q: Low A: NR C: NR	Q: High A: Low C: Medium	Q: Low A: Low C: Low

Organic enrichment can stimulate the production of primary consumers and may lead to eutrophication (see 'nutrient enrichment' pressure). Husa *et al.* (2014) found that the macroalgal communities beyond the immediate proximity of fish farms in Hardangerfjord, Norway, seemed to be little affected by the deposition of organic matter from the salmon farming industry. Bellgrove *et al.* (2010) however determined that coralline turfs out-competed fucoids at a site associated with organic enrichment caused by an ocean sewage outfall.

Sensitivity assessment. At the level of the benchmark, resistance is assessed as 'Medium' as some mortalities are likely to occur. Recovery will be rapid resulting in 'High' resilience score. The biotope has thus a 'Low' sensitivity to organic enrichment at the level of the benchmark.

A Physical Pressures

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

This biotope occurs on rock substratum. A change towards a sedimentary substratum would lead to the direct loss of suitable attachment areas resulting in the loss of *Fucus serratus* 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 to biotopes found on hard rock substratum.

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

Not relevant to biotopes found on hard rock substratum.

Abrasion/disturbance of the surface of the substratum or seabed

Low

Q: High A: Low C: Medium

Medium

Q: High A: Low C: Medium

Medium

Q: High A: Low C: Medium

The biotope group is found in the lower intertidal, an area easily accessible by humans especially at low tide. Most macroalgae are very flexible but not physically robust. The trampling of shores by humans will result in increased breakage of algal thalli, decreased thallus height and a net reduction in biomass (see Tyler-Walters & Arnold, 2005 for review).

In the UK, Boalch *et al.* (1974) and Boalch & Jephson (1981) noted a reduction in the cover of fucoids at Wembury, south Devon, when compared to surveys conducted by Colman (1933). The size ranges of *Ascophyllum nodosum*, *Fucus vesiculosus* and *Fucus serratus* were skewed to smaller length, and the abundance of *Ascophyllum nodosum* in particular was reduced (Boalch & Jephson, 1981). It was suggested that visitor pressure, especially after the construction of a car park, was responsible for the reduced cover of fucoids (Boalch *et al.*, 1974). They suggested that the raised edges of the slatey rock severed fronds when the rocks were walked over. However, no quantitative data was provided.

Pinn & Rodgers (2005) compared a heavily visited ledge with a less visited ledge at Kimmeridge Bay, Dorset. Although the mean species richness was similar at both sites, the total number of species was greater at the less utilized site. Comparatively, the heavily utilized ledge displayed a reduction in larger, branching algal species (e.g. *Fucus serratus*) and increased abundances of ephemeral and crustose species (e.g. *Ulva linza* and *Lithothamnium* spp. respectively). Fletcher and Frid (1996a; 1996b) examined the effects of persistent trampling on two sites on the north east coast of England. The trampling treatments used were 0, 20, 80, and 160 steps per m² per spring tide for 8 months between March and November. Using multivariate analysis, they noted that changes in the community dominated by fucoids (*Fucus vesiculosus*, *Fucus spiralis* and *Fucus serratus*) could be detected within 1 to 4 months of trampling, depending on intensity. Intensive trampling (160 steps/m² /spring tide) resulted in a decrease in species richness at one site. The area of bare substratum also increased within the first two months of trampling but declined afterwards, although bare space was consistently most abundant in plots subject to the greatest trampling (Fletcher & Frid, 1996a, 1996b). The abundance of fucoids was consistently lower in trampled plots than in untrampled plots. Fletcher and Frid (1996a) noted that the species composition of the algal community was changed by as little as 20 steps per m² per spring tide of continuous trampling since recolonization could not occur. A trampling intensity of 20 steps per m² per spring tide could

be exceeded by only five visitors taking the same route out and back again across the rocky shore in each spring tide. Both of the sites studied receive hundreds of visitors per year and damage is generally visible as existing pathways, which are sustained by continuous use (Fletcher & Frid, 1996a, 1996b). However, the impact was greatest at the site with the lower original abundance of furoids.

Brosnan & Crumrine (1994) noted that trampling significantly reduced algal cover within 1 month of trampling. Foliose algae were particularly affected and decreased in cover from 75% to 9.1% in trampled plots. *Mastocarpus papillatus* decreased in abundance from 9% to 1% in trampled plots but increased in control plots. *Fucus distichus* decreased in the summer months only to recover in winter but in trampled plots remained in low abundance (between 1 and 3% cover). Trampling resulted in a decrease in cover of *Pelvetiopsis limitata* from 16% to 1.5%. *Iridaea cornucopiae* decreased from 38 to 14% cover within a month and continued to decline to 4-8% cover. However, after trampling ceased, recovery of algal cover including *Iridaea cornucopiae* and *Mastocarpus papillatus* was rapid (ca 12 months) (Brosnan & Crumrine, 1994). Fletcher & Frid (1996a; 1996b) reported a decrease in the understory algal community of encrusting coralline algae and red algae, which was probably an indirect effect due to increased desiccation after removal of the normally protective furoid canopy (see Hawkins & Harkin, 1985) by trampling. They also noted that opportunistic algae (e.g. *Ulva* sp.) increased in abundance. Schiel & Taylor (1999) also observed a decrease in understory algae (erect and encrusting corallines) after 25 or more tramples, probably due to an indirect effect of increased desiccation as above. However, Schiel & Taylor (1999) did not detect any variation in other algal species due to trampling effects. Similarly, Keough & Quinn (1998) did not detect any effect of trampling on algal turf species.

Algal turfs seem to be relatively tolerant of the direct effects of trampling (based on the available evidence) and some species may benefit from removal of canopy forming algae (Tyler-Walters, 2005). Their tolerance may result from their growth form as has been shown for vascular plants and corals (Liddle, 1997). Brosnan (1993) suggested that algal turf dominated areas (on shores usually dominated by furoids) were indicative of trampling on the rocky shores of Oregon. However, tolerance is likely to vary with species and their growth form and little species specific data was found. Furthermore, algal turfs may suffer negative indirect effects where they form an understory below canopy forming species.

Conversely, furoid algae are particularly intolerant of trampling, depending on intensity. Furoid algae demonstrate a rapid (days to months) detrimental response to the effects of trampling, depending on species, which has been attributed to either the breakage of their fronds across rock surfaces (Boalch *et al.*, 1974) or their possession of small discoid holdfasts that offer little resistance to repeated impacts (Brosnan & Crumrine, 1992; Fletcher & Frid, 1996b). Foliose species such as *Mastocarpus papillatus*, *Pelvetiopsis limitata* and *Iridaea cornucopiae* are also likely to be intolerant of trampling (Brosnan & Crumrine, 1994). Brosnan (1993) suggested that the presence or absence of foliose algae (e.g. furoids) could be used to indicate the level of trampling on the rocky shores of Oregon.

Once *Fucus serratus* has been removed, understory algae will become exposed. Macroalgae canopies buffer the effects of high temperatures and water loss on organisms below their fronds in particular when exposed to air. For instance Bertness *et al.* (1999) determined that substratum temperatures were on average 8-10°C lower under the canopy than on bare rock. Desiccation of understory algae will create bare patches (see 'changes in emergence regime' pressure). These bare patches can lead to invasions by grazing limpets which in turn can promote

even greater changes in community composition (Little *et al.*, 2009). The removal of macoralgae canopy due to abrasion will thus have a direct impact on the entire community. However cracks and crevices are ideal places for germlings to develop and sessile species to settle as these sites may be protected from abrasion. Stagnol *et al.* (2013) found that opportunistic ephemeral green algae such as *Ulva* sp. responded positively to disturbance. These green ephemeral algae are major competitors of *Fucus serratus* for space colonization and nutrient uptake. Blooms of ephemeral algae facilitated by disturbance may then slow the development of longer-lived perennial algae, especially fucoids. Disturbance is a structuring factor in intertidal habitats. Perturbation events often remove organisms, increase mortality, and release resources such as space, nutrients and light that may enhance the appearance of new colonists (Connell *et al.*, 1997). As a result of these contrasting effects, post-disturbance communities are frequently different from initial communities in terms of composition and dominance of species. Overall, disturbance causes a shift towards a disturbance tolerant seaweed community (Little *et al.*, 2009).

Epifaunal species have been found to be particularly adversely affected by physical disturbance, either due to direct damage or modification of the habitat (Jennings & Kaiser, 1998). Similarly, Dayton (1971) observed greatly reduced abundance of species living on, under, and among fucoids following large disturbance events. Hydroids, bryozoans and encrusting fauna are easily ripped from the substratum and are unlikely to re-attach and will die. The shells of limpets, tubeworms and periwinkles may be crushed by the weight and force of the abrasion. However, some epifaunal species have been reported to exhibit increased abundances on high fishing effort areas, probably due to their ability to colonize and grow rapidly (Bradshaw *et al.*, 2000). For instance *Ascidella* species had increased in abundance in an area subject to scallop dredging (Bradshaw *et al.*, 2002). The breadcrumb sponge *Halichondria panicea* is attached to the substratum and will not survive abrasion and physical disturbance. Hiscock (1983) noted that a community, under conditions of scour and abrasion from stones and boulders moved by storms, developed into a community consisting of fast growing species such as *Spirobranchus triqueter* due to decreased competition. A shift in community composition is thus expected immediately after the disturbance event.

The effects of trampling are dependent on intensity, expressed as frequency and force per unit area of the impacting 'foot print' (see Liddle, 1997, Tyler-Walters & Arnold, 2008). Clearly, mechanical abrasion due to vehicles, jack-up-barges, or grounding vessels will exceed the abrasive 'intensity' of trampling by humans or livestock.

Sensitivity assessment. Physical disturbance resulting from activities such as trampling (by humans and livestock) or abrasive activities (e.g. vehicles, jack-up-barges, or grounding vessels) could cause a significant loss of fucoid cover and an important reduction in species abundance and diversity. Resistance is thus assessed as 'Low'. If some *Fucus serratus* population remain recovery will be fairly. However recruitment mortality, grazing by limpets and the presence of turfs and encrusting algae can slow down and limit recovery. Resilience is thus assessed as 'Medium'. The biotope therefore scores a 'Medium' sensitivity to abrasion pressure. If the entire population of *Fucus serratus* is removed, other species may come to dominate and the recovery will take considerably longer. Re-establishment of the seaweed may depend on the ability to out-compete other species and this may be dependent on suitable environmental conditions.

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 occur on hard rock which is resistant to subsurface penetration. Therefore, this pressure is not relevant but any penetrative activities may cause 'abrasion', which is discussed above.

Changes in suspended solids (water clarity)

Medium

Q: Medium A: Medium C: Medium

High

Q: High A: Low C: Medium

Low

Q: Medium A: Low C: Medium

Light is an essential resource for all photo-autotrophic organisms. Changes in suspended solids affecting water clarity will have a direct impact on photosynthesis in *Fucus serratus*. Irradiance below the light compensation point of photosynthetic species can compromise carbon accumulation (Middelboe *et al.*, 2006). However turbidity is only relevant when the biotope is covered with water as seaweed photosynthesis declines on emersion and recommences when recovered with water. Increased siltation may cover the frond surface of *Fucus serratus* with a layer of sediment further reducing photosynthesis and growth rate. Sediment deposition can also interfere with attachment of microscopic stages of seaweeds reducing recruitment (see 'siltation' pressures). In extreme turbidity, such as found in the Bristol Channel, *Fucus serratus* is excluded from the bottom of the intertidal (below 2m above chart datum) due to the lack of light for sustained growth (Chapman, 1995).

Other characterizing species will also be adversely 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 reducing water clarity are likely to have adverse effects on the biotope group reducing *Fucus serratus* photosynthesis as well as species richness. Resistance is thus assessed as 'Medium' at the benchmark level. Once conditions return to 'normal' *Fucus serratus* is likely to rapidly regain photosynthesis and growth rate. Associated communities will also rapidly 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 thus assessed as 'High'. Overall this biotope group scores a 'Low' sensitivity to this pressure.

Smothering and siltation rate changes (light)

Medium

Q: Low A: NR C: NR

High

Q: High A: Medium C: Low

Low

Q: Low A: Low C: Low

Sedimentation can directly affect assemblages inhabiting rocky shores by the burial/smothering and scour/abrasion of organisms. *Fucus serratus* is attached to the substratum by a holdfast is thus not able to relocate in response to increased sedimentation. Smothering will prevent photosynthesis resulting in reduced growth and eventually death. Sedimentation of bedrock can impede attachment of *Fucus* embryos as well as decrease survival and growth of juvenile through both scour and burial (Schiel *et al.*, 2006). An increase in the vertical sediment overburden can also reduce growth whilst hindering the regeneration abilities of adults (Umar *et al.*, 1998).

The state of the tide will mediate the extent of impact. 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 deposit of fine material at the level of the benchmark. However, if 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 group to this pressure may thus 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. Smothering will cause direct mortalities in the associated community, particularly in sessile organisms unable to relocate. Lower densities of herbivores have also been attributed to increased sedimentation as silt will reduce their feeding activity and limit their movements (Airoidi & Hawkins, 2007; Schiel *et al.*, 2006). The biotope group 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.

The burrowing mechanisms of the piddocks *Pholas dactylus* and *Barnea candida* and other Pholads, mean that the burrows have a narrow entrance excavated by the juvenile. As the individual grows and excavates deeper the burrow widens resulting in a conical burrow from which the adult cannot emerge. *Petricolaria pholadiformis* excavates a cylindrical burrow (Ansell, 1970) and hence may be able to relocate in sandy sediments, however although burrowing mechanisms have been studied, however no evidence was found to suggest this species can re-emerge through sediments and re-bury. Piddocks cannot therefore emerge from layers of deposited silt as other more mobile bivalves can.

No examples of direct empirical evidence or experiments on mortality rates have been found. Sometimes the substratum in which piddocks reside is covered by a thin layer of loose sandy material, through which the piddocks maintain contact with the surface via their siphons. It is likely that the piddocks would be able to extend their siphons through loose material, particularly where tidal movements shift the sand around. *Pholas dactylus* have been found living under layers of sand in Aberystwyth, Wales, (Knight, 1984) and in Eastbourne, with their siphons protruding at the surface (Pinn *et al.*, 2008). *Barnea candida* has also been found to survive being covered by shallow layers of sand in Merseyside (Wallace & Wallace, 1983). Wallace & Wallace (1983) were unsure as to how long the *Barnea candida* could survive smothering but noted that, on the coast of the Wirral, the piddocks have survived smothering after periods of rough weather. Where smothering is constant, survival can be more difficult. The redistribution of loose material following storms off Whitstable Street, in the Thames Estuary, is thought to be responsible for the suffocation of many *Petricolaria pholadiformis* and it is possible that this species may be the most intolerant of the three piddock species associated with this biotope. However, it was not known how deep the layer of 'loose material' was, nor how long it lasted for or what type of material it was made up of.

Indirect indications for the impacts of siltation are provided by studies of Witt *et al.*, (2004) on the impacts of harbour dredge disposal. *Petricola pholadiformis* was absent from the disposal area, and Witt *et al.*, (2004) cite reports by Essink (1996, not seen) that smothering of *Petricola pholadiformis* from siltation could lead to mortality within a few hours. Hebda (2011) also identified that sedimentation may be one of the key threats to *Barnea truncata* populations. At Agigea (Micu, 2007) reported that smothering of clay beds by sand and finer sediments had removed populations of *Pholas dactylus*. In this area sand banks up to 1m thick frequently shift position driven by storm events and currents (Micu, 2007). Similar smothering was described in the case of *Barnea candida* populations boring into clay beds (Gomoiu & Muller 1962, cited from Micu, 2007).

Species comprising, and living within the dense algal mat are likely to be intolerant of smothering. Sporelings would certainly be adversely affected as Vadas *et al.* (1992) stated that algal spores and propagules are adversely affected by a layer of sediment, which can exclude up to 98% of light.

Sensitivity assessment. As piddocks are essentially sedentary and as siphons are relatively short, siltation from fine sediments rather than sands, even at low levels for short periods could be lethal.

Resistance to siltation is assessed as 'Low' for piddocks and the algal mat although effects would be mitigated where water currents and wave exposure rapidly removed the overburden and this will depend on shore height and local hydrodynamic conditions. Resilience is assessed as 'Medium' (2-10 years) for piddocks and sensitivity is therefore assessed as 'Medium'.

Sensitivity assessment. Burial will lower survival and germination rates of spores and cause some mortality in early life stages. Adults are more resistant but will experience a decrease in growth and photosynthetic rates. Resistance is therefore assessed as 'Medium'. Recovery will be rapid once conditions return to normal, resulting in a 'High' resilience score. Overall the biotope group 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

Low

Q: Medium A: Low C: Medium

High

Q: Medium A: Low C: Medium

Several studies found that increasing the vertical sediment burden negatively impact fucoids survival and associated communities (see above). At the level of the benchmark (30 cm of fine material added to the seabed in a single event) smothering could result in significant mortalities, especially in sheltered examples of the biotope where the sediment burden could remain for many tidal cycles. Resistance is assessed as 'Low' as all individuals exposed to siltation at the benchmark level are predicted to die and consequent resilience as 'Low'. Sensitivity based on combined resistance and resilience is therefore assessed as 'High'.

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 was found.

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

Fucus serratus and associated species have no hearing perception but vibrations may cause an impact, however no studies exist to support an assessment

Introduction of light or shading

Medium

Q: Low A: NR C: NR

High

Q: Low A: NR C: NR

Low

Q: Low A: Low C: Low

Fucoids are dependent on light, so that changes in light intensity are likely to affect photosynthesis, growth, competition and survival. Chapman (1995) noted that too little or too much light are likely to be stresses. There is considerable literature on the light compensation point of marine algae (see Luning, 1990) but it is difficult to correlate such evidence with 'shading', as light saturation and compensation points depend on light availability, light quality, season and turbidity. As fucoids are out-competed in sublittoral conditions, it is likely that permanent shading

would affect their growth and allow them to be out-competed by other, more shade tolerant species, within the affected area. Therefore a resistance of 'Medium' is suggested albeit at low confidence. Resilience is likely to be 'High' so that sensitivity is 'Low'.

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. Note collision by grounding vessels is addressed under 'surface abrasion'.

Visual disturbance

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant



Biological Pressures

Resistance

Resilience

Sensitivity

Genetic modification & translocation of indigenous species

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

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

Introduction or spread of invasive non-indigenous species

Medium

Q: High A: Medium C: Medium

Low

Q: Low A: NR C: NR

Medium

Q: Low A: Low C: Low

Thompson & Schiel (2012) found that native fucoids showed high resistance to invasions by the Japanese kelp *Undaria pinnatifida*. However cover of *Fucus serratus* was inversely correlated with the cover of *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 Portuguese oyster *Magallana gigas* was introduced in England in 1926 for cultivation purposes and is now found in the wild. The species can form dense beds covering large patches on the shore. In areas where the biotope coincides with the distribution of *Magallana gigas*, i.e. the south coast of Devon and coast of Essex, the oyster could become dominant.

Sensitivity assessment. Resistance is assessed as 'Medium' since invasive species have the potential to alter the recognizable biotope. Recovery would be rapid once conditions return to normal, resulting in a 'High' resilience. However, return to 'normal' conditions is highly unlikely if an invasive species would come to dominate the biotope. Indeed recovery would only be possible if the majority of the INIS 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') resulting in an overall 'Medium' sensitivity score.

Introduction of microbial pathogens

High

Q: Low A: NR C: NR

High

Q: Low A: NR C: NR

Not sensitive

Q: Low A: NR C: NR

Very little is known about infections in *Fucus* (Wahl *et al.*, 2012). Coles (1958) identified parasitic nematodes that caused galls on *Fucus serratus* in south west Britain. More recently, Zuccaro *et al.* (2008) detected a number of fungal species associated with *Fucus serratus*. So far no mortalities have been associated to the introduction of microbial pathogens. However, the potential for increased biotic interactions involving parasites or pathogens is on the rise in many marine systems (Torchin *et al.*, 2002). 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 serratus* and associated communities.

Removal of target species

Low

Q: High A: High C: High

Medium

Q: High A: Medium C: High

Medium

Q: High A: Medium C: High

Fucus serratus is one of several harvested and exploited algal species. Seaweeds were collected from the middle of the 16th century for the iodine industry. Nowadays seaweeds 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).

The commercial harvest removes seaweed canopies which will have important direct and indirect effects on the wider ecosystem. Stagnol *et al.* (2013) investigated the effects of commercial harvesting of intertidal *Fucus serratus* 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 *Fucus serratus* on the impact zone. Due to the high intolerance of macroalgae communities to human exploitation, the European Union put in place a framework to regulate the exploitation of algae establishing an organic label that implies that 'harvest shall not cause any impact on ecosystems' (no. 710/2009 and 834/2007).

Sensitivity assessment. Removal of the *Fucus serratus* canopy will have a negative impact on the diversity of animal community and the productivity of the area. The harvesting impact on the animal community was amplified by the settlement of an ephemeral canopy of *Ulva* spp., a seasonal opportunistic green alga (ref). Resistance is thus assessed as 'Low'. If some *Fucus serratus* population remain recovery will be fairly rapid. However recruitment mortality, grazing by limpets and the presence of turfs and encrusting algae can slow down and limit recovery. A switch to a disturbance community will also slow the recovery of *Fucus serratus* and associated community. Resilience is thus assessed as 'Medium'. The biotope therefore scores a 'Medium' sensitivity to this pressure.

If the entire population of *Fucus serratus* is removed, other species may come to dominate and the recovery will take considerably longer. Re-establishment of the seaweed may depend on the ability to out-compete other species and this may be dependent on suitable environmental conditions.

Removal of non-target species

High

Q: Low A: NR C: NR

High

Q: Low A: NR C: NR

Not sensitive

Q: Low A: Low C: Low

The harvest of algae, crabs, snails, mussels, and many species of fish from the shore is a widespread practice. *Fucus serratus* has no known obligate relationships and the removal of non-target species will therefore not have a significant impact. Removal of *Fucus* as by-catch is unlikely and direct removal is addressed under 'removal of target species'. 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.

Fucoids may be directly removed or damaged by static or mobile gears that are targeting other species, as well as access (trampling) across the biotope. 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.

Bibliography

- Airolidi, L. & Hawkins, S.J., 2007. Negative effects of sediment deposition on grazing activity and survival of the limpet *Patella vulgata*. *Marine Ecology Progress Series*, **332**, 235-240.
- Airolidi, L., Balata, D. & Beck, M.W., 2008. The Gray Zone: relationships between habitat loss and marine diversity and their applications in conservation. *Journal of Experimental Marine Biology and Ecology*, **366** (1), 8-15.
- Arrontes, J., 1993. Nature of the distributional boundary of *Fucus serratus* on the north shore of Spain. *Marine Ecology Progress Series*, **93**, 183-183.
- Arrontes, J., 2002. Mechanisms of range expansion in the intertidal brown alga *Fucus serratus* in northern Spain. *Marine Biology*, **141** (6), 1059-1067.
- Beer, S., Björk, M. & Beardall, J., 2014. *Photosynthesis in the Marine Environment*. John Wiley & Sons.
- Bertness, M.D., Leonard, G.H., Levine, J.M., Schmidt, P.R. & Ingraham, A.O., 1999. Testing the relative contribution of positive and negative interactions in rocky intertidal communities. *Ecology*, **80** (8), 2711-27.
- Bertocci, I., Arenas, F., Matias, M., Vaselli, S., Araújo, R., Abreu, H., Pereira, R., Vieira, R. & Sousa-Pinto, I., 2010. Canopy-forming species mediate the effects of disturbance on macroalgal assemblages on Portuguese rocky shores. *Marine Ecology Progress Series*, **414**, 107-116.
- Bixler, H.J. & Porse, H., 2010. A decade of change in the seaweed hydrocolloids industry. *Journal of Applied Phycology*, **23** (3), 321-335.
- Blanchette, C.A., 1997. Size and survival of intertidal plants in response to wave action: a case study with *Fucus gardneri*. *Ecology*, **78** (5), 1563-1578.
- Boalch, G.T. & Jephson, N.A., 1981. A re-examination of the seaweeds on Colman's traverses at Wembury. *Proceedings of the International Seaweed Symposium*, **8**, 290-293.
- Boalch, G.T., Holme, N.A., Jephson, N.A. & Sidwell, J.M.C., 1974. A resurvey of Colman's intertidal traverses at Wembury, South Devon. *Journal of the Marine Biological Association of the United Kingdom*, **5**, 551-553.
- Brawley, S.H., 1992a. Fertilization in natural populations of the dioecious brown alga *Fucus ceranoides* and the importance of the polyspermy block. *Marine Biology*, **113** (1), 145-157.
- Brawley, S.H. & Johnson, L.E., 1991. Survival of furoid embryos in the intertidal zone depends upon developmental stages and microhabitat. *Journal of Phycology*, **27** (2), 179-186.
- Brawley, S.H., Coyer, J.A., Blakeslee, A.M., Hoarau, G., Johnson, L.E., Byers, J.E., Stam, W.T. & Olsen, J.L., 2009. Historical invasions of the intertidal zone of Atlantic North America associated with distinctive patterns of trade and emigration. *Proceedings of the National Academy of Sciences*, **106** (20), 8239-8244.
- Brosnan, D.M., 1993. The effect of human trampling on biodiversity of rocky shores: monitoring and management strategies. *Recent Advances in Marine Science and Technology*, **1992**, 333-341.
- Brosnan, D.M. & Crumrine, L.L., 1992. Human impact and a management strategy for Yaquina Head Outstanding Natural Area (summary only). A report to the Bureau of Land Management, Department of the Interior, Salem, Oregon.
- Brosnan, D.M. & Crumrine, L.L., 1994. Effects of human trampling on marine rocky shore communities. *Journal of Experimental Marine Biology and Ecology*, **177**, 79-97.
- Bulleri, F., Benedetti-Cecchi, L., Acunto, S., Cinelli, F. & Hawkins, S.J., 2002. The influence of canopy algae on vertical patterns of distribution of low-shore assemblages on rocky coasts in the northwest Mediterranean. *Journal of Experimental Marine Biology and Ecology*, **267** (1), 89-106.
- Cole, S., Codling, I.D., Parr, W. & Zabel, T., 1999. Guidelines for managing water quality impacts within UK European Marine sites. *Natura 2000 report prepared for the UK Marine SACs Project*. 441 pp., Swindon: Water Research Council on behalf of EN, SNH, CCW, JNCC, SAMS and EHS. [UK Marine SACs Project.], <http://www.ukmarinesac.org.uk/>
- Coles, J.W., 1958. Nematodes parasitic on sea weeds of the genera *Ascophyllum* and *Fucus*. *Journal of the Marine Biological Association of the United Kingdom*, **37** (1), 145-155.
- Colman, J., 1933. The nature of the intertidal zonation of plants and animals. *Journal of the Marine Biological Association of the United Kingdom*, **18**, 435-476.
- Connell, J.H., Hughes, T.P. & Wallace, C.C., 1997. A 30-year study of coral abundance, recruitment, and disturbance at several scales in space and time. *Ecological Monographs*, **67** (4), 461-488.
- Connor, D.W., Allen, J.H., Golding, N., Howell, K.L., Lieberknecht, L.M., Northen, K.O. & Reker, J.B., 2004. The Marine Habitat Classification for Britain and Ireland. Version 04.05. ISBN 1 861 07561 8. In JNCC (2015), *The Marine Habitat Classification for Britain and Ireland Version 15.03*. [2019-07-24]. Joint Nature Conservation Committee, Peterborough. Available from <https://mhc.jncc.gov.uk/>
- Coyer, J., Hoarau, G., Skage, M., Stam, W. & Olsen, J., 2006a. Origin of *Fucus serratus* (Heterokontophyta; Fucaceae) populations in Iceland and the Faroes: a microsatellite-based assessment. *European Journal of Phycology*, **41** (2), 235-246.
- Coyer, J., Peters, A., Stam, W. & Olsen, J., 2003. Post-ice age recolonization and differentiation of *Fucus serratus* L. (Phaeophyceae; Fucaceae) populations in Northern Europe. *Molecular Ecology*, **12** (7), 1817-1829.

- Davies, A.J., Johnson, M.P. & Maggs, C.A., 2007. Limpet grazing and loss of *Ascophyllum nodosum* canopies on decadal time scales. *Marine Ecology Progress Series*, **339**, 131-141.
- Dayton, P.K., 1971. Competition, disturbance, and community organization: the provision and subsequent utilization of space in a rocky intertidal community. *Ecological Monographs*, **41** (4), 351-389.
- Denny, M., Gaylord, B., Helmuth, B. & Daniel, T., 1998. The menace of momentum: dynamic forces on flexible organisms. *Limnology and Oceanography*, **43** (5), 955-968.
- Devinny, J. & Volse, L., 1978. Effects of sediments on the development of *Macrocystis pyrifera* gametophytes. *Marine Biology*, **48** (4), 343-348.
- Duarte, C.M., 1995. Submerged aquatic vegetation in relation to different nutrient regimes. *Ophelia*, **41** (1), 87-112.
- Fernandez, C. & Menendez, M.P., 1991. Ecology of *Chondrus crispus* on the northern coast of Spain. 2. Reproduction. *Botanica Marina*, **34**, 303-310.
- Fletcher, H. & Frid, C.L.J., 1996b. The response of an inter-tidal algal community to persistent trampling and the implications for rocky shore management. In Jones, P.S., Healy, M.G. & Williams, A.T. (ed.) *Studies in European coastal management*, Cardigan, Wales: Samara Publishing
- Fletcher, H. & Frid, C.L.J., 1996a. Impact and management of visitor pressure on rocky intertidal algal communities. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **6**, 287-297.
- Fredersdorf, J., Müller, R., Becker, S., Wiencke, C. & Bischof, K., 2009. Interactive effects of radiation, temperature and salinity on different life history stages of the Arctic kelp *Alaria esculenta* (Phaeophyceae). *Oecologia*, **160** (3), 483-492.
- Fredriksen, S., Christie, H. & Andre Sæthre, B., 2005. Species richness in macroalgae and macrofauna assemblages on *Fucus serratus* L. (Phaeophyceae) and *Zostera marina* L. (Angiospermae) in Skagerrak, Norway. *Marine Biology Research*, **1** (1), 2-19.
- Gollety, C., Migne, A. & Davoult, D., 2008. Benthic metabolism on a sheltered rocky shore: Role of the canopy in the carbon budget. *Journal of Phycology*, **44** (5), 1146-1153.
- Haring, R.N., Dethier, M.N. & Williams, S.L., 2002. Desiccation facilitates wave-induced mortality of the intertidal alga *Fucus gardneri*. *Marine Ecology Progress Series*, **232**, 75-82.
- Hawkins, S.J. & Harkin, E., 1985. Preliminary canopy removal experiments in algal dominated communities low on the shore and in the shallow subtidal on the Isle of Man. *Botanica Marina*, **28**, 223-30.
- Hawkins, S.J. & Southward, A.J., 1992. The Torrey Canyon oil spill: recovery of rocky shore communities. In *Restoring the Nations Marine Environment*, (ed. G.W. Thorpe), Chapter 13, pp. 583-631. Maryland, USA: Maryland Sea Grant College.
- Henry, B.E. & Van Alstyne, K.L., 2004. Effects of UV radiation on growth and phlorotannins in *Fucus gardneri* (Phaeophyceae) juveniles and embryos. *Journal of Phycology*, **40** (3), 527-533.
- Hoarau, G., Coyer, J., Veldsink, J., Stam, W. & Olsen, J., 2007. Glacial refugia and recolonization pathways in the brown seaweed *Fucus serratus*. *Molecular Ecology*, **16** (17), 3606-3616.
- Hurd, C.L., 2000. Water motion, marine macroalgal physiology, and production. *Journal of Phycology*, **36** (3), 453-472.
- Jenkins, C., Haas, M., Olson, A. & Ruesink, J., 2002. Impacts of trampling on a rocky shoreline of San Juan Island, Washington, USA. *Natural Areas Journal*, **22** (4), 260-269.
- Jenkins, S., Coleman, R., Della Santina, P., Hawkins, S., Burrows, M. & Hartnoll, R., 2005. Regional scale differences in the determinism of grazing effects in the rocky intertidal. *Marine Ecology Progress Series*, **287**, 77-86.
- Jenkins, S.R., Moore, P., Burrows, M.T., Garbary, D.J., Hawkins, S.J., Ingólfsson, A., Sebens, K.P., Snelgrove, P.V., Wetthey, D.S. & Woodin, S.A., 2008. Comparative ecology of North Atlantic shores: do differences in players matter for process? *Ecology*, **89** (11), 3-523.
- JNCC, 2015. The Marine Habitat Classification for Britain and Ireland Version 15.03. (20/05/2015). Available from <https://mhc.jncc.gov.uk/>
- Jonsson, P.R., Granhag, L., Moschella, P.S., Åberg, P., Hawkins, S.J. & Thompson, R.C., 2006. Interactions between wave action and grazing control the distribution of intertidal macroalgae. *Ecology*, **87** (5), 1169-1178.
- Josefson, A. & Widbom, B., 1988. Differential response of benthic macrofauna and meiofauna to hypoxia in the Gullmar Fjord basin. *Marine Biology*, **100** (1), 31-40.
- Jueterbock, A., Kollias, S., Smolina, I., Fernandes, J.M., Coyer, J.A., Olsen, J.L. & Hoarau, G., 2014. Thermal stress resistance of the brown alga *Fucus serratus* along the North-Atlantic coast: Acclimatization potential to climate change. *Marine Genomics*, **13**, 27-36.
- Keough, M.J. & Quinn, G.P., 1998. Effects of periodic disturbances from trampling on rocky intertidal algal beds. *Ecological Applications*, **8** (1), 141-161.
- Knowlton, A.L. & Highsmith, R.C., 2005. Nudibranch-sponge feeding dynamics: Benefits of symbiont-containing sponge to *Archidoris montereyensis* (Cooper, 1862) and recovery of nudibranch feeding scars by *Halichondria panicea* (Pallas, 1766). *Journal of Experimental Marine Biology and Ecology*, **327** (1), 36-46.
- Kraufvelin, P., Moy, F.E., Christie, H. & Bokn, T.L., 2006. Nutrient addition to experimental rocky shore communities revisited: delayed responses, rapid recovery. *Ecosystems*, **9** (7), 1076-1093.
- Kraufvelin, P., Ruuskanen, A., Nappu, N. & Kiirikki, M., 2007. Winter colonisation and succession of filamentous algae and possible relationships to *Fucus vesiculosus* settlement in early summer. *Estuarine Coastal and Shelf Science*, **72**, 665-674.

- Ladah, L., Feddersen, F., Pearson, G. & Serrão, E., 2008. Egg release and settlement patterns of dioecious and hermaphroditic furoid algae during the tidal cycle. *Marine Biology*, **155** (6), 583-591.
- Lamote, M., Johnson, L.E. & Lemoine, Y., 2007. Interspecific differences in the response of juvenile stages to physical stress: fluorometric responses of furoid embryos to variation in meteorological conditions. *Journal of Phycology*, **43** (6), 1164-1176.
- Liddle, M.J., 1997. *Recreational ecology. The ecological impact of outdoor recreation and ecotourism*. London: Chapman & Hall.
- Lilley, S.A. & Schiel, D.R., 2006. Community effects following the deletion of a habitat-forming alga from rocky marine shores. *Oecologia*, **148** (4), 672-681.
- Little, C., Williams, G.A. & Trowbridge, C.D., 2009. *The biology of rocky shores*: Oxford University Press New York.
- Lüning, K., 1990. *Seaweeds: their environment, biogeography, and ecophysiology*: John Wiley & Sons.
- Lüning, K., 1984. Temperature tolerance and biogeography of seaweeds: the marine algal flora of Helgoland (North Sea) as an example. *Helgolander Meeresuntersuchungen*, **38**, 305-317.
- Malm, T., Kautsky, L. & Engkvist, R., 2001. Reproduction, recruitment and geographical distribution of *Fucus serratus* L. in the Baltic Sea. *Botanica Marina*, **44** (2), 101-108.
- Mangialajo, L., Chiantore, M. & Cattaneo-Vietti, R., 2008. Loss of furoid algae along a gradient of urbanisation, and structure of benthic assemblages. *Marine Ecology Progress Series*, **358**, 63.
- Martínez, B., Arenas, F., Rubal, M., Burgués, S., Esteban, R., García-Plazaola, I., Figueroa, F., Pereira, R., Saldaña, L. & Sousa-Pinto, I., 2012. Physical factors driving intertidal macroalgae distribution: physiological stress of a dominant furoid at its southern limit. *Oecologia*, **170** (2), 341-353.
- Middelboe, A.L., Sand-Jensen, K. & Binzer, T., 2006. Highly predictable photosynthetic production in natural macroalgal communities from incoming and absorbed light. *Oecologia*, **150** (3), 464-476.
- Minchinton, T.E., Schiebling, R.E. & Hunt, H.L., 1997. Recovery of an intertidal assemblage following a rare occurrence of scouring by sea ice in Nova Scotia, Canada. *Botanica Marina*, **40**, 139-148.
- Nielsen, S.L., Nielsen, H.D. & Pedersen, M.F., 2014. Juvenile life stages of the brown alga *Fucus serratus* L. are more sensitive to combined stress from high copper concentration and temperature than adults. *Marine Biology*, **161** (8), 1895-1904.
- Niermann-Kerkenberg, E. & Hofmann, D.K., 1989. Fertilization and normal development in *Ascidella aspersa* (Tunicata) studied with Nomarski-optics. *Helgoländer Meeresuntersuchungen*, **43**, 245-258.
- Norton, T.A., 1992. Dispersal by macroalgae. *British Phycological Journal*, **27**, 293-301.
- Nygård, C.A. & Dring, M.J., 2008. Influence of salinity, temperature, dissolved inorganic carbon and nutrient concentration on the photosynthesis and growth of *Fucus vesiculosus* from the Baltic and Irish Seas. *European Journal of Phycology*, **43** (3), 253-262.
- Pearson, G.A. & Brawley, S.H., 1996. Reproductive ecology of *Fucus distichus* (Phaeophyceae): an intertidal alga with successful external fertilization. *Marine Ecology Progress Series*. Oldendorf, **143** (1), 211-223.
- Pearson, G.A., Lago-Leston, A. & Mota, C., 2009. Frayed at the edges: selective pressure and adaptive response to abiotic stressors are mismatched in low diversity edge populations. *Journal of Ecology*, **97** (3), 450-462.
- Perkol-Finkel, S. & Airoidi, L., 2010. Loss and recovery potential of marine habitats: an experimental study of factors maintaining resilience in subtidal algal forests at the Adriatic Sea. *PLoS One*, **5** (5), e10791.
- Pinn, E.H. & Rodgers, M., 2005. The influence of visitors on intertidal biodiversity. *Journal of the Marine Biological Association of the United Kingdom*, **85** (02), 263-268.
- Pybus, C., 1977. The ecology of *Chondrus crispus* and *Gigartina stellata* (Rhodophyta) in Galway Bay. *Journal of the Marine Biological Association of the United Kingdom*, **57**, 609-628.
- Schiel, D.R. & Foster, M.S., 2006. The population biology of large brown seaweeds: ecological consequences of multiphase life histories in dynamic coastal environments. *Annual Review of Ecology, Evolution, and Systematics*, 343-372.
- Schiel, D.R. & Lilley, S.A., 2011. Impacts and negative feedbacks in community recovery over eight years following removal of habitat-forming macroalgae. *Journal of Experimental Marine Biology and Ecology*, **407** (1), 108-115.
- Schiel, D.R. & Taylor, D.I., 1999. Effects of trampling on a rocky intertidal algal assemblage in southern New Zealand. *Journal of Experimental Marine Biology and Ecology*, **235**, 213-235.
- Schiel, D.R., Wood, S.A., Dunmore, R.A. & Taylor, D.I., 2006. Sediment on rocky intertidal reefs: effects on early post-settlement stages of habitat-forming seaweeds. *Journal of Experimental Marine Biology and Ecology*, **331** (2), 158-172.
- Schonbeck, M.W. & Norton, T.A., 1978. Factors controlling the upper limits of furoid algae on the shore. *Journal of Experimental Marine Biology and Ecology*, **31**, 303-313.
- Scrosati, R., Garbary, D.J. & McLachlan, J., 1994. Reproductive ecology of *Chondrus crispus* (Rhodophyta, Gigartinales) from Nova Scotia, Canada. *Botanica Marina*, **37**, 293-300.
- Serrão, E.A., Brawley, S.H., Hedman, J., Kautsky, L. & Samuelsson, G., 1999. Reproductive success of *Fucus vesiculosus* (Phaeophyceae) in the Baltic Sea. *Journal of Phycology*, **35** (2), 254-269.
- Stagnol, D., Renaud, M. & Davoult, D., 2013. Effects of commercial harvesting of intertidal macroalgae on ecosystem biodiversity and functioning. *Estuarine, Coastal and Shelf Science*, **130**, 99-110.
- Steen, H., 2003. Apical hair formation and growth of *Fucus evanescens* and *F. serratus* (Phaeophyceae) germlings under various

nutrient and temperature regimes. *Phycologia*, **42** (1), 26-30.

Suzuki, N. & Mittler, R., 2006. Reactive oxygen species and temperature stresses: a delicate balance between signaling and destruction. *Physiologia Plantarum*, **126** (1), 45-51.

Svane, I., Havenhund, J.N. & Jorgensen, A.J., 1987. Effects of tissue extract of adults on metamorphosis in *Ascidia mentula* O.F. Mueller and *Ascidella scabra* (O.F. Müller). *Journal of Experimental Marine Biology and Ecology*, **110**, 171-181.

Thompson, G.A. & Schiel, D.R., 2012. Resistance and facilitation by native algal communities in the invasion success of *Undaria pinnatifida*. *Marine Ecology, Progress Series*, **468**, 95-105.

Torchin, M., Lafferty, K. & Kuris, A., 2002. Parasites and marine invasions. *Parasitology*, **124** (07), 137-151.

Tyler-Walters, H., 2005b. Assessment of the potential impacts of coasteering on rocky intertidal habitats in Wales. *Report to Cyngor Cefn Gwlad Cymru / Countryside Council for Wales from the Marine Life Information Network (MarLIN)*. Marine Biological Association of the United Kingdom, Plymouth, 129 pp.

Tyler-Walters, H. & Arnold, C., 2008. Sensitivity of Intertidal Benthic Habitats to Impacts Caused by Access to Fishing Grounds. *Report to Cyngor Cefn Gwlad Cymru / Countryside Council for Wales from the Marine Life Information Network (MarLIN)* [Contract no. FC 73-03-327], Marine Biological Association of the UK, Plymouth, 48 pp. Available from: www.marlin.ac.uk/publications

Umar, M., McCook, L. & Price, I., 1998. Effects of sediment deposition on the seaweed *Sargassum* on a fringing coral reef. *Coral Reefs*, **17** (2), 169-177.

Viejo, R.M., Martínez, B., Arrontes, J., Astudillo, C. & Hernández, L., 2011. Reproductive patterns in central and marginal populations of a large brown seaweed: drastic changes at the southern range limit. *Ecography*, **34** (1), 75-84.

Wahl, M., Jormalainen, V., Eriksson, B.K., Coyer, J.A., Molis, M., Schubert, H., Dethier, M., Karez, R., Kruse, I., Lenz, M., Pearson, G., Rohde, S., Wikström, S.A. & Olsen, J.L., 2011. Chapter Two - Stress Ecology in *Fucus*: Abiotic, Biotic and Genetic Interactions. In Lesser, M. (ed.) *Advances in Marine Biology*. **59**, 37-105.

Zou, D., Liu, S., Du, H. & Xu, J., 2012. Growth and photosynthesis in seedlings of *Hizikia fusiformis* (Harvey) Okamura (Sargassaceae, Phaeophyta) cultured at two different temperatures. *Journal of Applied Phycology*, **24** (5), 1321-1327.

Zuccaro, A., Schoch, C.L., Spatafora, J.W., Kohlmeyer, J., Draeger, S. & Mitchell, J.I., 2008. Detection and identification of fungi intimately associated with the brown seaweed *Fucus serratus*. *Applied and Environmental Microbiology*, **74** (4), 931-941.