



MarLIN

Marine Information Network

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

Saccharina latissima and red seaweeds on infralittoral sediments

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

Thomas Stamp

2015-10-05

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/1033>]. All terms and the MarESA methodology are outlined on the website (<https://www.marlin.ac.uk>)

This review can be cited as:

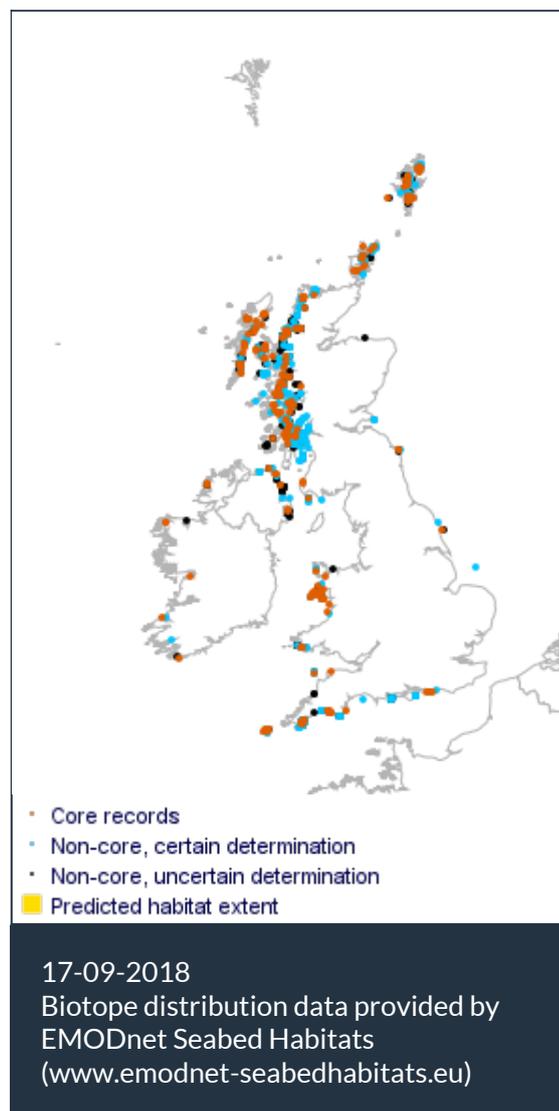
Stamp, T.E., 2015. [*Saccharina latissima*] and red seaweeds on infralittoral sediments. In Tyler-Walters H. and Hiscock K. (eds) *Marine Life Information Network: Biology and Sensitivity Key Information Reviews*, [on-line]. Plymouth: Marine Biological Association of the United Kingdom.

DOI <https://dx.doi.org/10.17031/marlinhab.1033.1>



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](#). Based on a work at www.marlin.ac.uk

(page left blank)



Researched by Thomas Stamp Refereed by Admin

Summary

☰ UK and Ireland classification

EUNIS 2008	A5.521	<i>Laminaria saccharina</i> and red seaweeds on infralittoral sediments
JNCC 2015	SS.SMp.KSwSS.SlatR	<i>Saccharina latissima</i> and red seaweeds on infralittoral sediments
JNCC 2004	SS.SMp.KSwSS.LsacR	<i>Laminaria saccharina</i> and red seaweeds on infralittoral sediments
1997 Biotope	SS.IMX.KSwMx.LsacX	<i>Laminaria saccharina</i> , <i>Chorda filum</i> and filamentous red seaweeds on sheltered infralittoral sediment

🔍 Description

On infralittoral mixed muddy substrata communities characterized by the kelp *Saccharina latissima* and mixed filamentous and foliose red algae can be found. This biotope contains a number of sub-biotopes

distinguished by the degree of either wave or tidal exposure. In moderately strong tidal streams in exposed areas *Laminaria* is sparse and dense stands of red seaweeds are found attached to the boulders and cobbles that make up a large proportion of the sediment (SlatR.CbPb). As the degree of wave and/or tidal exposure decreases there is a change in community structure, with the density of *Laminaria* and the diversity of red algal species increasing (SlatR.Gv). As the environment becomes more stable a number of brown algal species are able to inhabit this environment and a rich infauna develops (SlatR.Sa). In the most sheltered examples of this biotope a diverse muddy sediment infauna can be found and the 'Trailliella' phase of *Bonnemaisonia hamifera* may develop (SlatR.Mu).

↓ Depth range

0-5 m, 5-10 m, 10-20 m

Additional information

-

✓ Listed By

- none -

Further information sources

Search on:



Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

SS.SMp.KSwSS.SlatR (plus sub-biotopes) and SS.SMp.KSwSS.SlatCho typically occur on a mixture of shallow sediments and rock fractions. The mobility of the sediment and rock fractions allow *Saccharina latissima* (syn. *Laminaria saccharina*), *Chorda filum* and other red and brown seaweeds to grow on small stones and shells. *Saccharina latissima* and *Chorda filum* are important canopy forming species within these biotopes. Four sub-biotopes are present within the SS.SMp.KSwSS.SlatR biotope complex, which are largely distinguished by the degree of tidal flow and wave action. As the degree of wave and/or tidal exposure decreases there is a change in community structure, with the density of *Saccharina latissima* and the diversity of red algal species increasing. A decrease in tidal flow results in increased sediment stability which in turn facilitates mature macro-algae communities.

In undertaking this assessment of sensitivity, account is taken of knowledge of the biology of all characterizing species in the biotope. For this sensitivity assessment *Saccharina latissima*, *Chorda filum* are the primary foci of research, however it is recognized that the red seaweed communities of SS.SMp.KSwSS.SlatR also define these biotopes. Examples of important species groups are mentioned where appropriate.

Resilience and recovery rates of habitat

Saccharina latissima (syn. *Laminaria saccharina*) and *Chorda filum* are opportunistic seaweeds which have relatively fast growth rates. *Saccharina latissima* is a perennial kelp which can reach maturity in 15-20 months ((Sjötun, 1993) and has a life expectancy of 2-4 years (Parke, 1948). *Chorda filum* is an annual seaweed, completing its life cycle in a single season (Novaczek *et al.*, 1986). *Saccharina latissima* is widely distributed in the north Atlantic from Svalbard to Portugal (Birket *et al.*, 1998; Connor *et al.*, 2004; Bekby & Moy 2011; Moy & Christie 2012). *Chorda filum* is widely distributed across the northern hemisphere (Algae Base, 2015). In the North Atlantic, *Chorda filum* is recorded from Svalbard (Fredriksen *et al.*, 2014) to Northern Portugal (Araújo *et al.*, 2009).

Saccharina latissima and *Chorda filum* have heteromorphic life strategies (Edwards, 1998). Mature sporophytes broadcast spawn zoospores from reproductive structures known as sori (South & Burrows, 1967; Birket *et al.*, 1998). Zoospores settle onto rock and develop into gametophytes, which following fertilization germinate into juvenile sporophytes. *Laminarian* zoospores are expected to have a large dispersal range. However, zoospore density and the rate of successful fertilization decreases exponentially with distance from the parental source (Fredriksen *et al.*, 1995). Hence, recruitment can be influenced by the proximity of mature kelp beds producing viable zoospores (Kain, 1979; Fredriksen *et al.*, 1995). *Saccharina latissima* recruits appear in late winter early spring beyond which is a period of rapid growth, during which sporophytes can reach a total length of 3 m (Werner & Kraan, 2004). In late summer and autumn growth rates slow and spores are released from autumn to winter (Parke, 1948; Lüning, 1979; Birket *et al.*, 1998). The overall length of the sporophyte may not change during the growing season due to marginal erosion but growth of the blade has been measured at 1.1 cm/day, with a total length addition of ≥ 2.25 m per year (Birkett *et al.*, 1998). *Chorda filum* recruits appear from February (South & Burrows, 1967) after which is a period of rapid growth during which sporophytes can reach a length of ≤ 6 m (South & Burrows, 1967). In culture, *Chorda filum* can reach reproductive maturity and produce zoospores within 186 days (ca 6 months) of settlement but the time taken to reach maturity may be locally variable (South & Burrows, 1967). In nature, sporophytes growth

slows/stops from October and sporophytes may begin to die off (South & Burrows, 1967; Novaczek *et al.*, 1986).

Saccharina lattisma can be quite ephemeral in nature and appear early in algal succession. For example, Lienaas & Christie (1996) removed *Strongylocentrotus droebachiensis* from “Urchin Barrens” and observed a succession effect. Initially the substratum was colonized by filamentous algae, after a couple of weeks these were out-competed and the habitat dominated by *Saccharina latissimi*. However, this was subsequently out-competed by *Laminaria hyperborea*. In the Isle of Man, Kain (1975) cleared sublittoral blocks of *Laminaria hyperborea* at different times of the year for several years. The first colonizers and succession community differed between blocks and at what time of year the blocks were cleared. *Saccharina lattisma* was an early colonizer, but within 2 years of clearance, the blocks were dominated by *Laminaria hyperborea*.

In 2002, a 50.7-83% decline of *Saccharina latissima* was discovered in the Skaggerak region, South Norway (Moy *et al.*, 2006; Moy & Christie, 2012). Survey results indicated a sustained shift from *Saccharina latissima* communities to those of ephemeral filamentous algal communities. The reason for the community shift was unknown, but low water movement in wave and tidally sheltered areas combined with the impacts of dense human populations, e.g. increased land run-off, was suggested to be responsible for the dominance of ephemeral turf macro-algae. Multiple stressors such as eutrophication, increasing regional temperature, increased siltation and overfishing may also be acting synergistically to cause the observed habitat shift.

Resilience assessment. *Saccharina latissima*, *Chorda filum* have the potential to rapidly recover following disturbance. *Saccharina latissima* has been shown to be an early colonizer within algal succession, appearing within 2 weeks of clearance, and can reach sexual maturity within 15-20 months. *Chorda filum* has rapid growth rates, capable of reaching sexual maturity within a year. Resilience has therefore been assessed as ‘**High**’.

Hydrological Pressures

	Resistance	Resilience	Sensitivity
Temperature increase (local)	None Q: High A: High C: High	High Q: High A: High C: High	Medium Q: High A: High C: High

The temperature isotherm of 19-20°C has been reported as limiting *Saccharina latissima* geographic distribution (Müller *et al.*, 2009). Gametophytes can develop in ≤23°C (Lüning, 1990) however the optimal temperature range for sporophyte growth is 10-15 °C (Bolton & Lüning, 1982). Bolton & Lüning (1982) experimentally observed that sporophyte growth was inhibited by 50-70% at 20 °C and following 7 days at 23 °C all specimens completely disintegrated. In the field *Saccharina latissima* has shown significant regional variation in its acclimation to temperature changes, for example Gerard & Dubois (1988) observed sporophytes of *Saccharina latissima* which were regularly exposed to ≥20 °C could tolerate these temperatures, whereas sporophytes from other populations which rarely experience ≥17 °C showed 100% mortality after 3 weeks of exposure to 20 °C. Therefore the response of *Saccharina latissima* to a change in temperatures is likely to be locally variable.

In experiments, Lüning (1980) observed that *Chorda filum* could not reproduce at 15-20 °C but found that sporophytes could tolerate ≤26 °C.

Northern to southern Sea Surface Temperature (SST) ranges from 8-16 °C in summer and 6-13 °C

in winter in the UK (Beszczynska-Möller & Dye, 2013). The effect of this pressure is likely to be regionally variable.

Sensitivity assessment. Ecotypes of *Saccharina latissima* have been shown to have different temperature optimums (Dubois, 1988). Both a 2 & 5 °C increase in temperature when combined with high UK summer temperatures in the south of the UK could cause large scale mortality of *Saccharina latissima* and inhibit *Chorda filum* reproduction. Resistance has been assessed as 'None', Resilience as 'High'. Sensitivity has been assessed as 'Medium'.

Temperature decrease (local)

High

Q: High A: High C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: High

Saccharina latissima and *Chorda filum* are widespread throughout the arctic. *Saccharina latissima* has a lower temperature threshold for sporophyte growth at 0°C (Lüning, 1990). *Chorda filum* sporophytes can also tolerate 0 °C, Novaczek *et al.*, (1986) observed that 99% of newly settled zoospores died at 0 °C but sporophytes transferred from 5°C to 0°C remained healthy and continued to grow for a period of 2 months. Novaczek *et al.*, (1986) therefore demonstrated that sporophytes could tolerate exposure to low ($\geq 0^\circ\text{C}$) temperatures, but that exposure could have negative effects on larval survival and recruitment processes. Subtidal red algae can survive at -2°C (Lüning, 1990; Kain & Norton, 1990). The distribution and temperature tolerances of these species suggests they likely be unaffected by temperature decreases assessed within this pressure.

Sensitivity assessment. Resistance has been assessed as 'High', resilience as 'High'. Sensitivity has been assessed as 'Not Sensitive'.

Salinity increase (local)

Medium

Q: Low A: NR C: NR

High

Q: High A: High C: High

Low

Q: NR A: NR C: NR

Karsten (2007) tested the photosynthetic ability of *Saccharina latissima* under acute 2 and 5 day exposure to salinity treatments ranging from 5-60 psu. A control experiment was also carried at 34 psu. *Saccharina latissima* showed high photosynthetic ability at >80% of the control levels between 25-55 psu. However, Birkett *et al.* (1998) suggested that kelps are stenohaline and therefore long-term increases in salinity may be detrimental.

Chorda filum can be found in rock pools (South & Burrows, 1967). High air temperatures cause surface evaporation of water from rock pools, so that salinity steadily increases. The extent of temperature and salinity change is affected by the frequency and time of day at which tidal inundation occurs. If high tide occurs in early morning and evening the diurnal temperature follows that of the air, whilst high water at midday suddenly returns the temperature to that of the sea (Pyefinch, 1943). It should be noted however that local populations may be acclimated to the prevailing salinity regime and may therefore exhibit different tolerances to other populations subject to different salinity conditions and therefore caution should be used when inferring tolerances. However, it is likely that *Chorda filum* is tolerant of short-term salinity increases.

Sensitivity assessment. The evidence suggests that *Saccharina latissima* and *Chorda filum* can tolerate short-term exposure to hypersaline conditions ($\geq 40\%$ MNCR full salinity). An increase in salinity to $\geq 40\%$ may however be above the optima for characterizing species and cause a decline in growth, and possibly loss of red algae and a reduction in species diversity. Resistance has been assessed as 'Medium', resilience as 'High'. The sensitivity of this biotope to an increase in salinity

has been assessed as 'Low'.

Salinity decrease (local)

Medium

Q: High A: High C: High

High

Q: High A: High C: High

Low

Q: High A: High C: High

Karsten (2007) tested the photosynthetic ability of *Saccharina latissima* under acute 2 and 5 day exposure to salinity treatments ranging from 5-60 psu. A control experiment was also carried at 34 psu. *Saccharina latissima* showed high photosynthetic ability at >80% of the control levels between 25-55 psu. Hyposaline treatment of 10-20 psu led to a gradual decline of photosynthetic ability. After 2 days at 5 psu *Saccharina latissima* showed a significant decline in photosynthetic ability at approx. 30% of control. After 5 days at 5 psu *Saccharina latissima* specimens became bleached and showed signs of severe damage. The experiment was conducted on *Saccharina latissima* from the Arctic, and the authors suggest that at extremely low water temperatures (1-5°C) macroalgae acclimation to rapid salinity changes could be slower than at temperate latitudes. It is therefore possible that resident *Saccharina latissima* of the UK maybe be able to acclimate to salinity changes more effectively.

Chorda filum is tolerant of low salinities (Wilce, 1959; Hayren, 1940; Norton & South, 1969), and has been recorded at Björholm, Finland at a salinity as low as 5.15‰ (Hayren, 1940). Norton & South (1969) observed that *Chorda filum* could develop sporophytes at ≥5‰ under laboratory conditions, however at low salinities the time taken to develop into sporophytes took 65 days at 5‰, or 16 days at 35‰. It was also noted that below 9‰ sporophytes did not grow above 2 mm in length.

Sensitivity assessment. A decrease in one MNCR salinity scale from "Full Salinity" (30-40psu) to "Reduced Salinity" (18-30 psu) would inhibit *Saccharina lattissima* photosynthesis and hence growth. *Chorda filum* is highly tolerant of low salinity and is unlikely to be affected at the bench mark level. However, a shift to reduced salinity conditions is likely to result in a change in the infauna community and an overall reduction in species diversity. Therefore, resistance has been assessed as 'Medium' resilience as 'High'. Sensitivity of this biotope to a decrease in salinity has been assessed as 'Low'.

Water flow (tidal current) changes (local)

High

Q: High A: High C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: High

Peteiro & Freire (2013) measured *Saccharina latissima* growth from 2 sites, the 1st had maximal water velocities of 0.3 m/sec and the 2nd 0.1 m/sec. At site 1 *Saccharina latissima* had significantly larger biomass than at site 2 (16 kg/m to 12 kg/m respectively). Peteiro & Freire (2013) suggested that faster water velocities were beneficial to *Saccharina latissima* growth. However, Gerard & Mann (1979) measured *Saccharina latissima* productivity at greater water velocities and found *Saccharina latissima* productivity is reduced in moderately strong tidal streams (≤1 m/sec) when compared to weak tidal streams (<0.5 m/sec).

Chorda filum sporophytes often grow on unstable objects, such as pebbles and shell. Owing to the typically unstable substratum which *Chorda filum* grows on, whole populations can be moved during storms and deposited in more sheltered locations where development will continue (South & Burrows, 1967). The survival of *Chorda filum* sporophytes following transport of their attached substrata indicates the species is relatively tolerant to changes in water flow or wave action.

As highlighted by Connor *et al.*, (2004) large increases in tidal flow (>0.5 m/s) are likely to influence biotope structure and smaller changes in tidal flow (e.g. 0.1-0.2m/s) are not likely to have a significant effect on the characterizing species. A change in tidal flow of 0.1-0.2 m/sec in low energy biotopes e.g. SS.SMp.KSwSS.SlatR.Mu, may however remove finer sediment fractions (e.g. mud) and may therefore change the biotope. However, evidence is lacking and a change in tidal velocities is not likely to result in a significant change to the dominant species.

Sensitivity assessment. Resistance has been assessed as 'High', resilience as 'High'. Sensitivity has been assessed as 'Not Sensitive'.

Emergence regime changes

Medium

Q: Medium A: High C: High

High

Q: High A: Low C: High

Low

Q: Medium A: Low C: High

SS.SMp.KSwSS.SlatR and SS.SMp.KSwSS.SlatCho are recorded from 0-10m, while SlatR can extend to 20m (Connor *et al.*, 2004). Therefore the upper limit of the biotopes in the sub-littoral fringe (South & Burrows, 1967; White & Marshall, 2007) could be exposed during some low tides.

An increase in emergence will result in an increased risk of desiccation and mortality of *Saccharina latissima* and *Chorda filum*. Removal of macroalgae canopy may also increase desiccation and mortality of the undergrowth red seaweed community (Hawkins & Harkin, 1985). Providing that suitable substrata are present, the biotope is likely to re-establish further down the shore within a similar emergence regime to that which existed previously.

Sensitivity assessment. Resistance has been assessed as 'Medium'. Resilience as 'High'. The sensitivity of this biotope to a change in emergence is considered as 'Low'.

Wave exposure changes (local)

High

Q: High A: High C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: High

Birkett *et al.*, (1998) suggested that *Saccharina latissima* is rarely present in areas of wave exposure, where it is out-competed by *Laminaria hyperborea*. *Chorda filum* sporophytes often grow on unstable objects, such as pebbles and shell. Owing to the typically unstable substratum which *Chorda filum* grows on, whole populations can be moved during storms and deposited in more sheltered locations where development will continue (South & Burrows, 1967).

A large increase in near-shore wave height is likely to significantly influence biotope structure. As highlighted by Connor *et al.*, (2004) sub-biotopes within SS.SMp.KSwSS.SlatR are largely distinguished by wave exposure

Sensitivity assessment. A large scale increase in local wave height may increase local sediment mobility, potentially increase dislodgment or relocation of the characterizing species (South & Burrows, 1967; Birkett *et al.*, 1998b). However, an increase in nearshore significant wave height of 3-5% is not likely to have a significant effect on biotope structure. Resistance has been assessed as 'High', Resilience as 'High'. Sensitivity has been assessed as '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

Bryan (1984) suggested that the general order for heavy metal toxicity in seaweeds is: Organic Hg > inorganic Hg > Cu > Ag > Zn > Cd > Pb. Cole *et al.*, (1999) reported that Hg was very toxic to macrophytes. Similarly, Hopkin & Kain (1978) demonstrated sub-lethal effects of heavy metals on kelp gametophytes and sporophytes, including reduced growth and respiration. Sheppard *et al.* (1980) noted that increasing levels of heavy metal contamination along the west coast of Britain reduced species number and richness in holdfast fauna, except for suspension feeders which became increasingly dominant. Gastropods may be relatively tolerant of heavy metal pollution (Bryan, 1984). Although macroalgae species may not be killed, except by high levels of contamination, reduced growth rates may impair the ability of the biotope to recover from other environmental disturbances. Thompson & Burrows (1984) observed the growth of *Saccharina latissima* sporophyte growth was significantly inhibited at 50 µg Cu /l, 1000 µg Zn/l and 50 µg Hg/l. Zoospores were found to be more intolerant and significant reductions in survival rates were observed at 25 µg Cu/l, 1000 µg Zn/l and 5 µg/l.

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

The mucilaginous slime layer coating of *Laminarians* may protect them from smothering by oil. Hydrocarbons in solution reduce photosynthesis and may be algicidal. However, Holt *et al.* (1995) reported that oil spills in the USA and from the 'Torrey Canyon' had little effect on kelps. Similarly, surveys of subtidal communities at a number sites between 1-22.5m below chart datum showed no noticeable impacts of the Sea Empress oil spill and clean up (Rostron & Bunker, 1997) or during experimental release of untreated oil in Baffin Island, Canada (Cross *et al.*, 1987). Laboratory studies of the effects of oil and dispersants on several red algae species (Grandy 1984) concluded that they were all sensitive to oil/ dispersant mixtures, with little differences between adults, sporelings, diploid or haploid life stages.

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

O'Brian & Dixon (1976) suggested that red algae were the most sensitive group of macrophytes to oil and dispersant contamination (see Smith, 1968). *Saccharina latissima* has also been found to be sensitive to antifouling compounds. Johansson (2009) exposed samples of *Saccharina latissima* to several antifouling compounds, observing chlorothalonil, DCOIT, dichlofluanid and tolylfluanid inhibited photosynthesis. Exposure to Chlorothalonil and tolylfluanid, was also found to continue inhibiting oxygen evolution after exposure had finished, and may cause irreversible damage.

Smith (1968) observed that epiphytic and benthic red algae were intolerant of dispersant or oil contamination during the Torrey Canyon oil spill; only the epiphytes *Cryptopleura ramosa* and

Spermothamnion repens and some tufts of *Jania rubens* survived together with *Osmundea pinnatifida*, *Gigartina pistillata* and *Phyllophora crispa* from the sublittoral fringe.

Radionuclide contamination

Not relevant (NR)

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: Medium A: High C: High

High

Q: Medium A: High C: High

Not sensitive

Q: Medium A: High C: High

Reduced oxygen concentrations can 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). A rapid recovery from a state of low oxygen is expected if the environmental conditions are transient. If levels do drop below 4 mg/l negative effects on these organisms can be expected with adverse effects occurring below 2mg/l (Cole *et al.*, 1999).

Sensitivity Assessment. Reduced oxygen levels are likely to inhibit photosynthesis and respiration but not cause a loss of the macroalgae population directly. Resistance has been assessed as 'High', Resilience as 'High'. Sensitivity has been assessed as 'Not sensitive' at the benchmark level.

Nutrient enrichment

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not sensitive

Q: NR A: NR C: NR

Conolly & Drew (1985) found *Saccharina latissima* sporophytes had relatively higher growth rates when in close proximity to a sewage outlet in St Andrews, UK, compared to other sites along the east coast of Scotland. At St Andrews nitrate levels were 20.22µM, which represents an approx. 25% increase compared to other sites (approx. 15.87 µM). Handå *et al.* (2013) also reported *Saccharina latissima* sporophytes grew approx. 1% faster per day when in close proximity to Norwegian salmon farms, where elevated ammonium could be readily absorbed by sporophytes. Read *et al.* (1983) reported after the installation of a new sewage treatment works, which reduced the suspended solid content of liquid effluent by 60% in the Firth of Forth, *Saccharina latissima* became abundant where previously it had been absent. Bokn *et al.* (2003) conducted a nutrient loading experiment on intertidal fucoids. Within 3 years of the experiment no significant effect was observed in the communities, however 4-5 years into the experiment a shift occurred from perennials to ephemeral algae. Although Bokn *et al.* (2003) focussed on fucoids the results could indicate that long-term (>4 years) nutrient loading can result in community shift to ephemeral algae species. Disparities between the findings of the aforementioned studies are likely to be related to the level of organic enrichment.

Johnston & Roberts (2009) conducted a meta-analysis, which reviewed 216 papers to assess how a

variety of contaminants (including sewage and nutrient loading) affected 6 marine habitats (including subtidal reefs). A 30-50% reduction in species diversity and richness was identified from all habitats exposed to the contaminant types. Johnston & Roberts (2009) however also highlighted that macroalgal communities are relative tolerant to contamination, but that contaminated communities can have low diversity assemblages which are dominated by opportunistic and fast growing species (Johnston & Roberts, 2009 and references therein).

Sensitivity assessment. Although short-term exposure (<4 years) to nutrient enrichment may not affect seaweeds directly, indirect effects such as turbidity may significantly affect photosynthesis and result in reduced growth and reproduction and increased competition form fast growing but ephemeral species. However, this biotope is considered to be '**Not sensitive**' at the pressure benchmark, that assumes compliance with good status as defined by the WFD.

Organic enrichment

Medium

Q: Medium A: High C: High

High

Q: Medium A: High C: High

Low

Q: Medium A: Medium C: High

Read *et al.* (1983) reported after the installation of a new sewage treatment works, which reduced the suspended solid content of liquid effluent by 60% in the Firth of Forth, *Saccharina latissima* became abundant where previously it had been absent. Bokn *et al.* (2003) conducted a nutrient loading experiment on intertidal fucoids. Within 3 years of the experiment no significant effect was observed in the communities, however 4-5 years into the experiment a shift occurred from perennials to ephemeral algae. Although Bokn *et al.* (2003) focussed on fucoids the results could indicate that long-term (>4 years) nutrient loading can result in community shift to ephemeral algae species. Disparities between the findings of the aforementioned studies are likely to be related to the level of organic enrichment.

Johnston & Roberts (2009) conducted a meta-analysis, which reviewed 216 papers to assess how a variety of contaminants (including sewage and nutrient loading) affected 6 marine habitats (including subtidal reefs). A 30-50% reduction in species diversity and richness was identified from all habitats exposed to the contaminant types. Johnston & Roberts (2009) however also highlighted that macroalgal communities are relatively tolerant to contamination, but that contaminated communities can have low diversity assemblages which are dominated by opportunistic and fast growing species (Johnston & Roberts, 2009 and references therein). Organic enrichment may also result in phytoplankton blooms that increase turbidity and therefore may negatively impact photosynthesis.

Sensitivity assessment. Although short-term exposure (<4 years) to organic enrichment may not affect seaweeds directly, indirect effects such as turbidity may significantly affect photosynthesis, and result in reduced growth and reproduction and increased competition form fast growing but ephemeral species Resistance has been assessed as '**Medium**', resilience as '**High**'. Sensitivity has been assessed as '**Low**'.

A Physical Pressures

Resistance

None

Q: High A: High C: High

Resilience

Very Low

Q: High A: High C: High

Sensitivity

High

Q: High A: High C: High

Physical loss (to land or freshwater habitat)

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

If sediment were replaced with rock or artificial substrata, this would represent a fundamental change to the biotope (Macleod *et al.*, 2014). All the characterizing species within this biotope can grow on rock biotopes (Birkett *et al.*, 1998; Connor *et al.*, 2004), however SS.SMp.KSwSS are by definition sediment biotopes and introduction of rock would change them into a rock based habitat complex, and the biotope would be lost

Sensitivity assessment. Resistance to the pressure is considered 'None', and resilience 'Very low'. Sensitivity has been assessed as 'High'

Physical change (to another sediment type)

None

Q: Low A: NR C: NR

Very Low

Q: High A: High C: High

High

Q: Low A: Low C: Low

SS.SMp.KSwSS are sediment based biotopes. Stabilised cobbles, pebbles, gravel and shell fractions provide a substrate for macro-algae to dominate the community (Connor *et al.*, 2004). An increase in the dominance of smaller sediment fractions e.g. sand and/or mud will likely smother the existing biotope, inhibit successive re-colonisation of macro-algae and/or increase the sediment scour.

Sensitivity assessment. Resistance has been assessed as 'None', resilience as **Very low** (the pressure is a permanent change), and sensitivity as **High**.

Habitat structure changes - removal of substratum (extraction)

None

Q: Low A: NR C: NR

High

Q: High A: High C: High

Medium

Q: Low A: Low C: Low

SS.SMp.KSwSS.SlatR (plus sub-biotopes), SS.SMp.KSwSS.SlatCho can be found on a varied mixture of sediment and rock fractions. Extraction of substratum to 30 cm is likely to remove small sediment fractions (e.g. gravel) and may mobilize the remaining larger rock fractions (e.g. boulders) causing high mortality within the resident community. All characterizing species have rapid growth rates and are likely to recover within 2 years.

Sensitivity assessment. Resistance has been assessed as 'None', Resilience as 'High'. Sensitivity has been assessed as 'Medium'.

Abrasion/disturbance of the surface of the substratum or seabed

None

Q: Low A: NR C: NR

Medium

Q: High A: High C: High

Medium

Q: Low A: Low C: Low

Abrasion of the substratum e.g. from bottom or pot fishing gear, cable laying etc. may cause localised mobility of the substrata and mortality of the resident community. The effect would be

situation dependent, however, if bottom fishing gear were towed over a site it may mobilise a high proportion of the rock substrata and cause high mortality in the resident community.

Sensitivity assessment. Resistance has been assessed as 'None', Resilience as 'High'. Sensitivity has been assessed as 'Medium'.

Penetration or disturbance of the substratum subsurface

None

Q: Low A: NR C: NR

High

Q: High A: High C: High

Medium

Q: Low A: Low C: Low

Penetration and/or disturbance of the substrate below the surface of the seabed, may cause localised mobility of the substrata and mortality of the resident community.

Sensitivity assessment. Resistance has been assessed as 'None', Resilience as 'High'. Sensitivity has been assessed as 'Medium'.

Changes in suspended solids (water clarity)

Low

Q: High A: High C: High

High

Q: High A: High C: High

Low

Q: High A: High C: High

Suspended Particle Matter (SPM) concentration has a positive linear relationship with sub surface light attenuation (K_d) (Devlin *et al.*, 2008). Light availability and water turbidity are principal factors in determining depth range at which macro-algae can be found (Birkett *et al.*, 1998b). Light penetration influences the maximum depth at which laminarians can grow and it has been reported that laminarians grow at depths at which the light levels are reduced to 1 percent of incident light at the surface. Maximal depth distribution of laminarians therefore varies from 100 m in the Mediterranean to only 6-7m in the silt laden German Bight. In Atlantic European waters, the depth limit is typically 35 m. In very turbid waters the depth at which kelp is found may be reduced, or in some cases excluded completely (e.g. Severn Estuary), because of the alteration in light attenuation by suspended sediment (Lüning, 1990; Birkett *et al.* 1998b). Laminarians show a decrease of 50% photosynthetic activity when turbidity increases by 0.1/m (light attenuation coefficient = 0.1-0.2/m; Staehr & Wernberg, 2009).

Sensitivity Assessment. A decrease in turbidity is likely to support enhanced growth (and possible habitat expansion) and is therefore not considered in this assessment. An increase in water turbidity is likely to primarily affect photosynthesis therefore growth and density of the canopy forming seaweeds. Resistance to this pressure is defined as 'Low' and resilience to this pressure is defined as 'High' at the benchmark level due to the scale of the impact. Hence, this biotope is regarded as having a sensitivity of 'Low'.

Smothering and siltation rate changes (light)

High

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

Smothering by sediment e.g. 5 cm material during a discrete event, is unlikely to damage mature examples of *Saccharina latissima* and *Chorda filum* but may provide a physical barrier to zoospore settlement and therefore could negatively impact on recruitment processes (Moy & Christie, 2012). Laboratory studies showed that kelp and gametophytes can survive in darkness for between 6-16 months at 8 °C and would probably survive smothering by a discrete event and once returned to normal conditions gametophytes resumed growth or maturation within 1 month

(Dieck, 1993).

SS.SMp.KSwSS biotopes are all recorded in moderately strong tidal streams to negligible (≤ 1.5 m/sec) (Connor *et al.*, 2004). In tidally exposed biotopes deposited sediment is unlikely to remain for more than a few tidal cycles (due to water flow or wave action). In sheltered biotopes deposited sediment could remain however are unlikely to remain for longer than a year.

Sensitivity assessment. Resistance has been assessed as '**High**', resilience as '**High**'. Sensitivity has been assessed as '**Not Sensitive**'.

Smothering and siltation rate changes (heavy)

Medium

Q: **Low** A: **NR** C: **NR**

High

Q: **Low** A: **NR** C: **NR**

Low

Q: **Low** A: **NR** C: **NR**

Smothering by sediment e.g. 30 cm material during a discrete event, is unlikely to damage mature examples of *Saccharina latissima* and *Chorda filum* but may provide a physical barrier to zoospore settlement and therefore could negatively impact on recruitment processes (Moy & Christie, 2012). Laboratory studies showed that kelp and gametophytes can survive in darkness for between 6-16 months at 8°C and would probably survive smothering by a discrete event and once returned to normal conditions gametophytes resumed growth or maturation within 1 month (Dieck, 1993).

SS.SMp.KSwSS biotopes are all recorded in moderately strong tidal streams to negligible (≤ 1.5 m/sec) (Connor *et al.*, 2004). In tidally exposed biotopes deposited sediment is unlikely to remain for more than a few tidal cycles (due to water flow or wave action). In sheltered biotopes deposited sediment could remain however are unlikely to remain for longer than a year.

Sensitivity assessment. Resistance has been assessed as '**Medium**', resilience as '**High**'. Sensitivity has been assessed as '**Low**'.

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. There is no evidence to suggest that litter would affect kelp.

Electromagnetic changes

Not relevant (NR)

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**

Not relevant

Introduction of light or shading

Low

Q: **Low** A: **NR** C: **NR**

Medium

Q: **Low** A: **NR** C: **NR**

Medium

Q: **Low** A: **Low** C: **Low**

There is no evidence to suggest that anthropogenic light sources would affect macro-algae. Shading of the biotope (e.g. by construction of a pontoon, pier etc.) could adversely affect the biotope in areas where the water clarity is also low, and tip the balance to shade tolerant species, resulting in the loss of the biotope directly within the shaded area, or a reduction in seaweed abundance.

Sensitivity assessment. Resistance is probably '**Low**', with a '**Medium**' resilience and a sensitivity of '**Medium**', albeit with 'low' confidence due to the lack of direct evidence.

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 the dispersal of spores. But spore 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. Collision from grounding vessels is addressed under abrasion above.

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	No evidence (NEv) Q: NR A: NR C: NR

At the time of writing there is **no evidence** for translocation of *Saccharina latissima*, *Chorda filum* over significant geographic distances.

Introduction or spread of invasive non-indigenous species	None Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High
--	--	--	--

Undaria pinnatifida has received a large amount of research attention as a major Invasive Non Indigenous Species (INIS) which could out-compete native UK kelp habitats (see Farrell & Fletcher, 2006; Thompson & Schiel, 2012, Brodie *et al.*, 2014; Hieser *et al.*, 2014). *Undaria pinnatifida* was first recorded in the UK, Hamble Estuary, in June 1994 (Fletcher & Manfredi, 1995) and has since spread to a number of British ports. *Undaria pinnatifida* is an annual species, sporophytes appear in Autumn and grow rapidly throughout winter and spring during which they can reach a length of 1.65m (Birket *et al.*, 1998). Farrell & Fletcher (2006) suggested that native short lived species that

occupy similar ecological niches to *Undaria pinnatifida*, such as *Saccharina latissima* or *Chorda filum*, are likely to be worst affected and out-competed by *Undaria pinnatifida*. Where present an abundance of *Undaria pinnatifida* has corresponded to a decline in *Saccharina latissima* (Farrel & Fletcher, 2006) and *Laminaria hyperborea* (Hieser *et al.*, 2014).

In New Zealand, Thompson & Schiel (2012) observed that native fucoids could out-compete *Undaria pinnatifida* and re-dominate the substratum. However, Thompson & Schiel (2012) suggested the fucoid recovery was partially due to an annual *Undaria pinnatifida* die back, which as noted by Heiser *et al.*, (2014) does not occur in Plymouth sound, UK. *Undaria pinnatifida* was successfully eradicated on a sunken ship in Clatham Islands, New Zealand, by applying a heat treatment of 70 °C (Wotton *et al.*, 2004) however numerous other eradication attempts have failed, and as noted by Fletcher & Farrell, (1999) once established *Undaria pinnatifida* resists most attempts of long-term removal. The biotope is unlikely to fully recover until *Undaria pinnatifida* is fully removed from the habitat, which as stated above is unlikely to occur.

Sensitivity assessment. Resistance to the pressure is considered ‘**Low**’, and resilience ‘**Very low**’. The sensitivity of this biotope to introduction of microbial pathogens is assessed as ‘**High**’.

Introduction of microbial pathogens

Low

Q: **Low** A: **NR** C: **NR**

High

Q: **High** A: **Low** C: **High**

Low

Q: **Low** A: **Low** C: **Low**

Laminarians may be infected by the microscopic brown alga *Streblonema acidioides*. Infected algae show symptoms of Streblonema disease, i.e. alterations of the blade and stipe ranging from dark spots to heavy deformations and completely crippled thalli. Infection can reduce growth rates of host algae (Peters & Scaffelke, 1996). The marine fungi *Eurychasma spp* can also infect early life stages of *Laminarians* however the effects of infection are unknown (Müller *et al.*, 1999).

Sensitivity assessment. Resistance to the pressure is considered ‘**Low**’, and resilience ‘**High**’. The sensitivity of this biotope to introduction of microbial pathogens is assessed as ‘**Low**’.

Removal of target 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**

This pressure has been assessed as ‘**Not relevant**’.

There has been recent commercial interest in *Saccharina latissima* as a consumable called “sea vegetables” (Birket *et al.*, 1998). However, *Saccharina latissima* sporophytes are typically matured on ropes (Handå *et al.* 2013) and not directly extracted from the seabed, as with *Laminaria hyperborea* (Christie *et al.*, 1998). No evidence has been found for commercial extraction of *Chorda filum*.

Removal of non-target species

None

Q: **Low** A: **NR** C: **NR**

High

Q: **High** A: **High** C: **High**

Medium

Q: **Low** A: **Low** C: **Low**

Low level disturbances (e.g. solitary anchors) are unlikely to cause harm to the biotope as a whole, due to the impact’s small footprint. Thus evidence to assess the resistance of SS.SMp.KSwSS.SlatR (plus sub-biotopes), SS.SMp.KSwSS.SlatCho to non-targeted removal is limited. It is assumed that incidental non-targeted catch (e.g. by trawls or dredges) could mobilise sediment, remove large

kelp species, overturn boulders and cobbles and bury smaller seaweeds and cause high mortality within the affected area.

Sensitivity assessment. Resistance has been assessed as '**None**', Resilience as '**High**'. Sensitivity has been assessed as '**Medium**'.

Bibliography

- Araújo, R., Vaselli, S., Almeida, M., Serrão, E. & Sousa-Pinto, I., 2009. Effects of disturbance on marginal populations: human trampling on *Ascophyllum nodosum* assemblages at its southern distribution limit. *Marine Ecology Progress Series*, **378**, 81-92.
- Bekkby, T. & Moy, F.E., 2011. Developing spatial models of sugar kelp (*Saccharina latissima*) potential distribution under natural conditions and areas of its disappearance in Skagerrak. *Estuarine Coastal and Shelf Science*, **95** (4), 477-483.
- Beszczynska-Möller, A., & Dye, S.R., 2013. ICES Report on Ocean Climate 2012. In *ICES Cooperative Research Report*, vol. 321 pp. 73.
- Birkett, D.A., Maggs, C.A., Dring, M.J. & Boaden, P.J.S., 1998b. Infralittoral reef biotopes with kelp species: an overview of dynamic and sensitivity characteristics for conservation management of marine SACs. *Natura 2000 report prepared by Scottish Association of Marine Science (SAMS) for the UK Marine SACs Project.*, Scottish Association for Marine Science. (UK Marine SACs Project, vol V.). Available from: <http://www.ukmarinesac.org.uk/publications.htm>
- Bokn, T.L., Duarte, C.M., Pedersen, M.F., Marba, N., Moy, F.E., Barrón, C., Bjerkgeng, B., Borum, J., Christie, H. & Engelbert, S., 2003. The response of experimental rocky shore communities to nutrient additions. *Ecosystems*, **6** (6), 577-594.
- Bolton, J.J. & Lüning, K., 1982. Optimal growth and maximal survival temperatures of Atlantic *Laminaria* species (Phaeophyta) in culture. *Marine Biology*, **66**, 89-94.
- Bower, S.M., 1996. *Synopsis of Infectious Diseases and Parasites of Commercially Exploited Shellfish: Bald-sea-urchin Disease*. [On-line]. Fisheries and Oceans Canada. [cited 26/01/16]. Available from: <http://www.dfo-mpo.gc.ca/science/aah-saa/diseases-maladies/bsudsu-eng.html>
- Brodie J., Williamson, C.J., Smale, D.A., Kamenos, N.A., Mieszkowska, N., Santos, R., Cunliffe, M., Steinke, M., Yesson, C. & Anderson, K.M., 2014. The future of the northeast Atlantic benthic flora in a high CO₂ world. *Ecology and Evolution*, **4** (13), 2787-2798.
- Bryan, G.W., 1984. Pollution due to heavy metals and their compounds. In *Marine Ecology: A Comprehensive, Integrated Treatise on Life in the Oceans and Coastal Waters*, vol. 5. *Ocean Management*, part 3, (ed. O. Kinne), pp.1289-1431. New York: John Wiley & Sons.
- Burrows, M.T., Smale, D., O'Connor, N., Rein, H.V. & Moore, P., 2014. Marine Strategy Framework Directive Indicators for UK Kelp Habitats Part 1: Developing proposals for potential indicators. *Joint Nature Conservation Committee*, Peterborough. Report no. 525.
- Casas, G., Scrosati, R. & Piriz, M.L., 2004. The invasive kelp *Undaria pinnatifida* (Phaeophyceae, Laminariales) reduces native seaweed diversity in Nuevo Gulf (Patagonia, Argentina). *Biological Invasions*, **6** (4), 411-416.
- Christie, H., Fredriksen, S. & Rinde, E., 1998. Regrowth of kelp and colonization of epiphyte and fauna community after kelp trawling at the coast of Norway. *Hydrobiologia*, **375/376**, 49-58.
- Cole, S., Codling, I.D., Parr, W., Zabel, T., 1999. Guidelines for managing water quality impacts within UK European marine sites [On-line]. *UK Marine SACs Project*. [Cited 26/01/16]. Available from: http://www.ukmarinesac.org.uk/pdfs/water_quality.pdf
- 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/>
- Connor, D.W., Dalkin, M.J., Hill, T.O., Holt, R.H.F. & Sanderson, W.G., 1997a. Marine biotope classification for Britain and Ireland. Vol. 2. Sublittoral biotopes. *Joint Nature Conservation Committee, Peterborough, JNCC Report no. 230, Version 97.06.*, *Joint Nature Conservation Committee, Peterborough, JNCC Report no. 230, Version 97.06.*
- Conolly N.J. & Drew, E.A., 1985. Physiology of *Laminaria*. III. Effect of a coastal eutrophication on seasonal patterns of growth and tissue composition in *Laminaria digitata* and *L. saccharina*. *Marine Ecology, Pubblicazioni della Stazione Zoologica di Napoli I*, **6**, 181-195.
- Cross, W.E., Wilce, R.T. & Fabijan, M.F., 1987. Effects of experimental releases of oil and dispersed oil on Arctic nearshore macrobenthos. III. Macroalgae. *Arctic*, 211-219.
- Dauvin, J.C., Bellan, G., Bellan-Santini, D., Castric, A., Francour, P., Gentil, F., Girard, A., Gofas, S., Mahe, C., Noel, P., & Reviers, B. de., 1994. Typologie des ZNIEFF-Mer. Liste des parametres et des biocoenoses des cotes francaises metropolitaines. 2nd ed. *Secretariat Faune-Flore, Museum National d'Histoire Naturelle, Paris (Collection Patrimoines Naturels, Serie Patrimoine Ecologique, No. 12)*. Coll. Patrimoines Naturels, vol. 12, Secretariat Faune-Flore, Paris.
- Davies, C.E. & Moss, D., 1998. European Union Nature Information System (EUNIS) Habitat Classification. *Report to European Topic Centre on Nature Conservation from the Institute of Terrestrial Ecology, Monks Wood, Cambridgeshire*. [Final draft with further revisions to marine habitats.], Brussels: European Environment Agency.
- Dayton, P.K., Tegner, M.J., Parnell, P.E. & Edwards, P.B., 1992. Temporal and spatial patterns of disturbance and recovery in a kelp forest community. *Ecological Monographs*, **62**, 421-445.
- Devlin, M.J., Barry, J., Mills, D.K., Gowen, R.J., Foden, J., Sivyer, D. & Tett, P., 2008. Relationships between suspended particulate material, light attenuation and Secchi depth in UK marine waters. *Estuarine, Coastal and Shelf Science*, **79** (3), 429-439.
- Dieck, T.I., 1992. North Pacific and North Atlantic digitate *Laminaria* species (Phaeophyta): hybridization experiments and

- temperature responses. *Phycologia*, **31**, 147-163.
- Dieck, T.I., 1993. Temperature tolerance and survival in darkness of kelp gametophytes (Laminariales: Phaeophyta) - ecological and biogeographical implications. *Marine Ecology Progress Series*, **100**, 253-264.
- Edwards, A., 1980. Ecological studies of the kelp *Laminaria hyperborea* and its associated fauna in south-west Ireland. *Ophelia*, **9**, 47-60.
- Elnor, R.W. & Vadas, R.L., 1990. Inference in ecology: the sea urchin phenomenon in the northwest Atlantic. *American Naturalist*, **136**, 108-125.
- Engel, C.R. & Destombe, C., 2002. Reproductive ecology of an intertidal red seaweed, *Gracilaria gracilis*: influence of high and low tides on fertilization success. *Journal of the Marine Biological Association of the UK*, **82** (02), 189-192.
- Erwin, D.G., Picton, B.E., Connor, D.W., Howson, C.M., Gilleece, P. & Bogues, M.J., 1990. Inshore Marine Life of Northern Ireland. Report of a survey carried out by the diving team of the Botany and Zoology Department of the Ulster Museum in fulfilment of a contract with Conservation Branch of the Department of the Environment (N.I.), Ulster Museum, Belfast: HMSO.
- Farrell, P. & Fletcher, R., 2006. An investigation of dispersal of the introduced brown alga *Undaria pinnatifida* (Harvey) Suringar and its competition with some species on the man-made structures of Torquay Marina (Devon, UK). *Journal of Experimental Marine Biology and Ecology*, **334** (2), 236-243.
- Fletcher, R.L. & Manfredi, C., 1995. The occurrence of *Undaria pinnatifida* (Phaeophyceae, Laminariales) on the South Coast of England. *Botanica Marina*, **38** (4), 355-358.
- Fletcher, R.L., 1996. The occurrence of 'green tides' - a review. In *Marine Benthic Vegetation. Recent changes and the Effects of Eutrophication* (ed. W. Schramm & P.H. Nienhuis). Berlin Heidelberg: Springer-Verlag. [Ecological Studies, vol. 123].
- Fredriksen, S., Bartsch, I. & Wiencke, C., 2014. New additions to the benthic marine flora of Kongsfjorden, western Svalbard, and comparison between 1996/1998 and 2012/2013. *Botanica Marina*, **57** (3), 203-216.
- Fredriksen, S., Sjøtun, K., Lein, T.E. & Rueness, J., 1995. Spore dispersal in *Laminaria hyperborea* (Laminariales, Phaeophyceae). *Sarsia*, **80** (1), 47-53.
- Frieder, C., Nam, S., Martz, T. & Levin, L., 2012. High temporal and spatial variability of dissolved oxygen and pH in a nearshore California kelp forest. *Biogeosciences*, **9** (10), 3917-3930.
- Gerard, V.A. & Du Bois, K.R., 1988. Temperature ecotypes near the southern boundary of the kelp *Laminaria saccharina*. *Marine Biology*, **97**, 575-580.
- Gerard, V.A. & Mann, K.H., 1979. Growth and production of *Laminaria longicuris* (Phaeophyta) populations exposed to different intensities of water movement 1. *Journal of Phycology*, **15** (1), 33-41.
- Gomez, J.L.C. & Miguez-Rodriguez, L.J., 1999. Effects of oil pollution on skeleton and tissues of *Echinus esculentus* L. 1758 (Echinodermata, Echinoidea) in a population of A Coruna Bay, Galicia, Spain. In *Echinoderm Research 1998. Proceedings of the Fifth European Conference on Echinoderms, Milan, 7-12 September 1998*, (ed. M.D.C. Carnevali & F. Bonasoro) pp. 439-447. Rotterdam: A.A. Balkema.
- Gorman, D., Bajjouk, T., Populus, J., Vasquez, M. & Ehrhold, A., 2013. Modeling kelp forest distribution and biomass along temperate rocky coastlines. *Marine Biology*, **160** (2), 309-325.
- Grandy, N., 1984. *The effects of oil and dispersants on subtidal red algae*. Ph.D. Thesis. University of Liverpool.
- Algae base, 2015. *Halidrys siliquosa* (Linnaeus) Lyngbye. (16 October 2015).
http://www.algaebase.org/search/species/detail/?species_id=27255&sk=0&from=results
- Hammer, L., 1972. Anaerobiosis in marine algae and marine phanerogams. In *Proceedings of the Seventh International Seaweed Symposium, Sapporo, Japan, August 8-12, 1971* (ed. K. Nisizawa, S. Arasaki, Chihara, M., Hirose, H., Nakamura V., Tsuchiya, Y.), pp. 414-419. Tokyo: Tokyo University Press.
- Handå, A., Forbord, S., Wang, X., Broch, O.J., Dahle, S.W., Storseth, T.R., Reitan, K.I., Olsen, Y. & Skjermo, J., 2013. Seasonal and depth-dependent growth of cultivated kelp (*Saccharina latissima*) in close proximity to salmon (*Salmo salar*) aquaculture in Norway. *Aquaculture*, **414**, 191-201.
- Harkin, E., 1981. Fluctuations in epiphyte biomass following *Laminaria hyperborea* canopy removal. In *Proceedings of the Xth International Seaweed Symposium, Gøteborg, 11-15 August 1980* (ed. T. Levring), pp.303-308. Berlin: Walter de Gruyter.
- 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.
- Hayward, P.J. 1988. *Animals on seaweed*. Richmond, Surrey: Richmond Publishing Co. Ltd. [Naturalists Handbooks 9].
- Heiser, S., Hall-Spencer, J.M. & Hiscock, K., 2014. Assessing the extent of establishment of *Undaria pinnatifida* in Plymouth Sound Special Area of Conservation, UK. *Marine Biodiversity Records*, **7**, e93.
- Hiscock, K. & Mitchell, R., 1980. *The Description and Classification of Sublittoral Epibenthic Ecosystems*. In *The Shore Environment, Vol. 2, Ecosystems*, (ed. J.H. Price, D.E.G. Irvine, & W.F. Farnham), 323-370. London and New York: Academic Press. [Systematics Association Special Volume no. 17(b)].
- Holt, T.J., Jones, D.R., Hawkins, S.J. & Hartnoll, R.G., 1995. The sensitivity of marine communities to man induced change - a scoping report. *Countryside Council for Wales, Bangor, Contract Science Report*, no. 65.
- Hopkin, R. & Kain, J.M., 1978. The effects of some pollutants on the survival, growth and respiration of *Laminaria hyperborea*.

Estuarine and Coastal Marine Science, **7**, 531-553.

JNCC, 2015. The Marine Habitat Classification for Britain and Ireland Version 15.03. (20/05/2015). Available from <https://mhc.jncc.gov.uk/>

JNCC, 2015. The Marine Habitat Classification for Britain and Ireland Version 15.03. (20/05/2015). Available from <https://mhc.jncc.gov.uk/>

JNCC (Joint Nature Conservation Committee), 1999. *Marine Environment Resource Mapping And Information Database (MERMAID): Marine Nature Conservation Review Survey Database*. [on-line] <http://www.jncc.gov.uk/mermaid>

Johansson, P., 2009. Effects of intermittent exposure of marine pollutants on sugar kelp and periphyton. Department of Plant and Environmental Sciences, University of Gothenburg.

Johnston, E.L. & Roberts, D.A., 2009. Contaminants reduce the richness and evenness of marine communities: a review and meta-analysis. *Environmental Pollution*, **157** (6), 1745-1752.

Jones, C.G., Lawton, J.H. & Shackak, M., 1994. Organisms as ecosystem engineers. *Oikos*, **69**, 373-386.

Jones, D.J., 1971. Ecological studies on macro-invertebrate communities associated with polluted kelp forest in the North Sea. *Helgolander Wissenschaftliche Meeresuntersuchungen*, **22**, 417-431.

Jones, L.A., Hiscock, K. & Connor, D.W., 2000. Marine habitat reviews. A summary of ecological requirements and sensitivity characteristics for the conservation and management of marine SACs. *Joint Nature Conservation Committee, Peterborough. (UK Marine SACs Project report.)*. Available from: <http://www.ukmarinesac.org.uk/pdfs/marine-habitats-review.pdf>

Jones, N.S. & Kain, J.M., 1967. Subtidal algal recolonisation following removal of *Echinus*. *Helgolander Wissenschaftliche Meeresuntersuchungen*, **15**, 460-466.

Kain, J.M., 1964. Aspects of the biology of *Laminaria hyperborea* III. Survival and growth of gametophytes. *Journal of the Marine Biological Association of the United Kingdom*, **44** (2), 415-433.

Kain, J.M. & Svendsen, P., 1969. A note on the behaviour of *Patina pellucida* in Britain and Norway. *Sarsia*, **38**, 25-30.

Kain, J.M., 1971a. Synopsis of biological data on *Laminaria hyperborea*. *FAO Fisheries Synopsis*, no. 87.

Kain, J.M., 1975a. Algal recolonization of some cleared subtidal areas. *Journal of Ecology*, **63**, 739-765.

Kain, J.M., 1979. A view of the genus *Laminaria*. *Oceanography and Marine Biology: an Annual Review*, **17**, 101-161.

Kain, J.M., 1987. Photoperiod and temperature as triggers in the seasonality of *Delesseria sanguinea*. *Helgolander Meeresuntersuchungen*, **41**, 355-370.

Kain, J.M., & Norton, T.A., 1990. Marine Ecology. In *Biology of the Red Algae*, (ed. K.M. Cole & Sheath, R.G.). Cambridge: Cambridge University Press.

Kain, J.M., Drew, E.A. & Jupp, B.P., 1975. Light and the ecology of *Laminaria hyperborea* II. In *Proceedings of the Sixteenth Symposium of the British Ecological Society, 26-28 March 1974. Light as an Ecological Factor: II* (ed. G.C. Evans, R. Bainbridge & O. Rackham), pp. 63-92. Oxford: Blackwell Scientific Publications.

Karsten, U., 2007. Research note: salinity tolerance of Arctic kelps from Spitsbergen. *Phycological Research*, **55** (4), 257-262.

Kinne, O., 1977. International Helgoland Symposium "Ecosystem research": summary, conclusions and closing. *Helgoländer Wissenschaftliche Meeresuntersuchungen*, **30**(1-4), 709-727.

Kitching, J., 1941. Studies in sublittoral ecology III. *Laminaria* forest on the west coast of Scotland; a study of zonation in relation to wave action and illumination. *The Biological Bulletin*, **80** (3), 324-337

Kregting, L., Blight, A., Elsässer, B. & Savidge, G., 2013. The influence of water motion on the growth rate of the kelp *Laminaria hyperborea*. *Journal of Experimental Marine Biology and Ecology*, **448**, 337-345.

Kruuk, H., Wansink, D. & Moorhouse, A., 1990. Feeding patches and diving success of otters, *Lutra lutra*, in Shetland. *Oikos*, **57**, 68-72.

Lüning, K., 1979. Growth strategy of three *Laminaria* species (Phaeophyceae) inhabiting different depth zones in the sublittoral region of Hegloland (North Sea). *Marine Ecological Progress Series*, **1**, 195-207.

Lang, C. & Mann, K., 1976. Changes in sea urchin populations after the destruction of kelp beds. *Marine Biology*, **36** (4), 321-326.

Lein, T.E., Sjutun, K. & Wakili, S., 1991. Mass - occurrence of a brown filamentous endophyte in the lamina of the kelp *Laminaria hyperborea* (Gunnerus) Foslie along the south western coast of Norway *Sarsia*, **76**, 187-193.

Leinaas, H.P. & Christie, H., 1996. Effects of removing sea urchins (*Strongylocentrotus droebachiensis*): stability of the barren state and succession of kelp forest recovery in the east Atlantic. *Oecologia*, **105**(4), 524-536.

Lobban, C.S. & Harrison, P.J., 1997. *Seaweed ecology and physiology*. Cambridge: Cambridge University Press.

Lüning, K., 1990. *Seaweeds: their environment, biogeography, and ecophysiology*: John Wiley & Sons.

Lüning, K., 1980. Critical levels of light and temperature regulating the gametogenesis of three laminaria species (Phaeophyceae). *Journal of Phycology*, **16**, 1-15.

Müller, R., Laepple, T., Bartsch, I. & Wiencke, C., 2009. Impact of oceanic warming on the distribution of seaweeds in polar and cold-temperate waters. *Botanica Marina*, **52** (6), 617-638.

Mann, K.H., 1982. Kelp, sea urchins, and predators: a review of strong interactions in rocky subtidal systems of eastern Canada, 1970-1980. *Netherlands Journal of Sea Research*, **16**, 414-423.

- Miller III, H.L., Neale, P.J. & Dunton, K.H., 2009. Biological weighting functions for UV inhibition of photosynthesis in the kelp *Laminaria hyperborea* (Phaeophyceae) 1. *Journal of Phycology*, **45** (3), 571-584.
- Moore, P.G., 1973a. The kelp fauna of north east Britain I. Function of the physical environment. *Journal of Experimental Marine Biology and Ecology*, **13**, 97-125.
- Moore, P.G., 1973b. The kelp fauna of north east Britain. II. Multivariate classification: turbidity as an ecological factor. *Journal of Experimental Marine Biology and Ecology*, **13**, 127-163.
- Moore, P.G., 1978. Turbidity and kelp holdfast Amphipoda. I. Wales and S.W. England. *Journal of Experimental Marine Biology and Ecology*, **32**, 53-96.
- Moore, P.G., 1985. Levels of heterogeneity and the amphipod fauna of kelp holdfasts. In *The Ecology of Rocky Coasts: essays presented to J.R. Lewis, D.Sc.* (ed. P.G. Moore & R. Seed), 274-289. London: Hodder & Stoughton Ltd.
- Moy, F., Alve, E., Bogen, J., Christie, H., Green, N., Helland, A., Steen, H., Skarbøvik, E. & Stålnacke, P., 2006. Sugar Kelp Project: Status Report No 1. *SFT Report TA-2193/2006, NIVA Report 5265 (in Norwegian, with English Abstract)*, 36 pp.
- Moy, F.E. & Christie, H., 2012. Large-scale shift from sugar kelp (*Saccharina latissima*) to ephemeral algae along the south and west coast of Norway. *Marine Biology Research*, **8** (4), 309-321.
- Müller, U., 1999. The vertical zonation of adpressed diatoms and other epiphytic algae on *Phragmites australis*. *European Journal of Phycology*, **34**, 487-496.
- NBN, 2015. National Biodiversity Network 2015(20/05/2015). <https://data.nbn.org.uk/>
- Nichols, D., 1981. The Cornish Sea-urchin Fishery. *Cornish Studies*, **9**, 5-18.
- Norderhaug, K., 2004. Use of red algae as hosts by kelp-associated amphipods. *Marine Biology*, **144** (2), 225-230.
- Norderhaug, K.M. & Christie, H.C., 2009. Sea urchin grazing and kelp re-vegetation in the NE Atlantic. *Marine Biology Research*, **5** (6), 515-528.
- Norderhaug, K.M., Christie, H. & Fredriksen, S., 2007. Is habitat size an important factor for faunal abundances on kelp (*Laminaria hyperborea*)? *Journal of Sea Research*, **58** (2), 120-124.
- Nordheim, van, H., Andersen, O.N. & Thissen, J., 1996. Red lists of Biotopes, Flora and Fauna of the Trilateral Wadden Sea area, 1995. *Helgolander Meeresuntersuchungen*, **50** (Suppl.), 1-136.
- Norton, T.A. & South, G.R., 1969. Influence of reduced salinity on the distribution of two laminarian algae. *Oikos*, **20**, 320-326
- Norton, T.A., 1992. Dispersal by macroalgae. *British Phycological Journal*, **27**, 293-301.
- Norton, T.A., Hiscock, K. & Kitching, J.A., 1977. The Ecology of Lough Ine XX. The *Laminaria* forest at Carrigathorna. *Journal of Ecology*, **65**, 919-941.
- Novaczek, I., Bird, C. & McLachlan, J., 1986. The effect of temperature on development and reproduction in *Chorda filum* and *C. tomentosa* (Phaeophyta, Laminariales) from Nova Scotia. *Canadian Journal of Botany*, **64** (11), 2414-2420.
- O'Brien, P.J. & Dixon, P.S., 1976. Effects of oils and oil components on algae: a review. *British Phycological Journal*, **11**, 115-142.
- Parke, M., 1948. Studies on British Laminariaceae. I. Growth in *Laminaria saccharina* (L.) Lamour. *Journal of the Marine Biological Association of the United Kingdom*, **27**, 651-709.
- Pedersen, M.F., Nejrup, L.B., Fredriksen, S., Christie, H. & Norderhaug, K.M., 2012. Effects of wave exposure on population structure, demography, biomass and productivity of the kelp *Laminaria hyperborea*. *Marine Ecology Progress Series*, **451**, 45-60.
- Penfold, R., Hughson, S., & Boyle, N., 1996. *The potential for a sea urchin fishery in Shetland*. <http://www.nafc.ac.uk/publish/note5/note5.htm>, 2000-04-14
- Peteiro, C. & Freire, O., 2013. Biomass yield and morphological features of the seaweed *Saccharina latissima* cultivated at two different sites in a coastal bay in the Atlantic coast of Spain. *Journal of Applied Phycology*, **25**(1), 205-213.
- Peters, A.F. & Schaffelke, B., 1996. *Streblonema* (Ectocarpales, Phaeophyceae) infection in the kelp *Laminaria saccharina* in the western Baltic. *Hydrobiologia*, **326/327**, 111-116.
- Philippart, C.J., Anadón, R., Danovaro, R., Dippner, J.W., Drinkwater, K.F., Hawkins, S.J., Oguz, T., O'Sullivan, G. & Reid, P.C., 2011. Impacts of climate change on European marine ecosystems: observations, expectations and indicators. *Journal of Experimental Marine Biology and Ecology*, **400** (1), 52-69.
- Raffaelli, D. & Hawkins, S., 1999. *Intertidal Ecology* 2nd edn.. London: Kluwer Academic Publishers.
- Read, P.A., Anderson, K.J., Matthews, J.E., Watson, P.G., Halliday, M.C. & Shiells, G.M., 1983. Effects of pollution on the benthos of the Firth of Forth. *Marine Pollution Bulletin*, **14**, 12-16.
- Rebello, J., Ohno, M., Critchley, A. & Sawamura, M., 1996. Growth rates and agar quality of *Gracilaria gracilis* (Stackhouse) Steentoft from Namibia, Southern Africa. *Botanica Marina*, **39** (1-6), 273-280.
- Reed, R.H. & Russell, G., 1978. Salinity fluctuations and their influence on "bottle brush" morphogenesis in *Enteromorpha intestinalis* (L.) Link. *British Phycological Journal*, **13**, 149-153.
- Rinde, E. & Sjøtun, K., 2005. Demographic variation in the kelp *Laminaria hyperborea* along a latitudinal gradient. *Marine Biology*, **146** (6), 1051-1062.
- Rostron, D.M. & Bunker, F. St P.D., 1997. An assessment of sublittoral epibenthic communities and species following the *Sea Empress* oil spill. A report to the Countryside Council for Wales from Marine Seen & Sub-Sea Survey., Countryside Council for Wales,

Bangor, CCW Sea Empress Contact Science, no. 177.

Schiel, D.R. & Foster, M.S., 1986. The structure of subtidal algal stands in temperate waters. *Oceanography and Marine Biology: an Annual Review*, **24**, 265-307.

Sheppard, C.R.C., Bellamy, D.J. & Sheppard, A.L.S., 1980. Study of the fauna inhabiting the holdfasts of *Laminaria hyperborea* (Gunn.) Fosl. along some environmental and geographical gradients. *Marine Environmental Research*, **4**, 25-51.

Sivertsen, K., 1997. Geographic and environmental factors affecting the distribution of kelp beds and barren grounds and changes in biota associated with kelp reduction at sites along the Norwegian coast. *Canadian Journal of Fisheries and Aquatic Sciences*, **54**, 2872-2887.

Sjøtun, K., Christie, H. & Helge Fosså, J., 2006. The combined effect of canopy shading and sea urchin grazing on recruitment in kelp forest (*Laminaria hyperborea*). *Marine Biology Research*, **2** (1), 24-32.

Sjøtun, K. & Schoschina, E.V., 2002. Gametophytic development of *Laminaria* spp. (Laminariales, Phaeophyta) at low temperatures. *Phycologia*, **41**, 147-152.

Sjøtun, K., Fredriksen, S., Lein, T.E., Runess, J. & Sivertsen, K., 1993. Population studies of *Laminaria hyperborea* from its northern range of distribution in Norway. *Hydrobiologia*, **260/261**, 215-221.

Smale, D.A., Burrows, M.T., Moore, P., O'Connor, N. & Hawkins, S.J., 2013. Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. *Ecology and evolution*, **3** (11), 4016-4038.

Smale, D.A., Wernberg, T., Yunnice, A.L. & Vance, T., 2014. The rise of *Laminaria ochroleuca* in the Western English Channel (UK) and comparisons with its competitor and assemblage dominant *Laminaria hyperborea*. *Marine ecology*.

Smith, J.E. (ed.), 1968. 'Torrey Canyon'. *Pollution and marine life*. Cambridge: Cambridge University Press.

Somerfield, P.J. & Warwick, R.M., 1999. Appraisal of environmental impact and recovery using *Laminaria* holdfast faunas. *Sea Empress, Environmental Evaluation Committee., Countryside Council for Wales, Bangor, CCW Sea Empress Contract Science, Report no. 321*.

South, G.H. & Burrows, E.M., 1967. Studies on marine algae of the British Isles. 5. *Chorda filum* (L.) Stckh. *British Phycological Bulletin*, **3**, 379-402.

Steneck, R.S., Graham, M.H., Bourque, B.J., Corbett, D., Erlandson, J.M., Estes, J.A. & Tegner, M.J., 2002. Kelp forest ecosystems: biodiversity, stability, resilience and future. *Environmental conservation*, **29** (04), 436-459.

Steneck, R.S., Vavrincic, J. & Leland, A.V., 2004. Accelerating trophic-level dysfunction in kelp forest ecosystems of the western North Atlantic. *Ecosystems*, **7** (4), 323-332.

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.

Vadas, R.L. & Elner, R.W., 1992. *Plant-animal interactions in the north-west Atlantic*. In *Plant-animal interactions in the marine benthos*, (ed. D.M. John, S.J. Hawkins & J.H. Price), 33-60. Oxford: Clarendon Press. [Systematics Association Special Volume, no. 46].

Vadas, R.L., Johnson, S. & Norton, T.A., 1992. Recruitment and mortality of early post-settlement stages of benthic algae. *British Phycological Journal*, **27**, 331-351.

Van den Hoek, C., 1982. The distribution of benthic marine algae in relation to the temperature regulation of their life histories. *Biological Journal of the Linnean Society*, **18**, 81-144.

Vost, L.M., 1983. The influence of *Echinus esculentus* grazing on subtidal algal communities. *British Phycological Journal*, **18**, 211.

Werner, A. & Kraan, S., 2004. Review of the potential mechanisation of kelp harvesting in Ireland. *Marine Environment and Health Series*, (No. 17).

Whittick, A., 1983. Spatial and temporal distributions of dominant epiphytes on the stipes of *Laminaria hyperborea* (Gunn.) Fosl. (Phaeophyta: Laminariales) in S.E. Scotland. *Journal of Experimental Marine Biology and Ecology*, **73**, 1-10.

Wotton, D.M., O'Brien, C., Stuart, M.D. & Fergus, D.J., 2004. Eradication success down under: heat treatment of a sunken trawler to kill the invasive seaweed *Undaria pinnatifida*. *Marine Pollution Bulletin*, **49** (9), 844-849.