



# MarLIN

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# *Alaria esculenta* and *Laminaria digitata* on exposed sublittoral fringe bedrock

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

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**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/214>]. All terms and the MarESA methodology are outlined on the website (<https://www.marlin.ac.uk>)

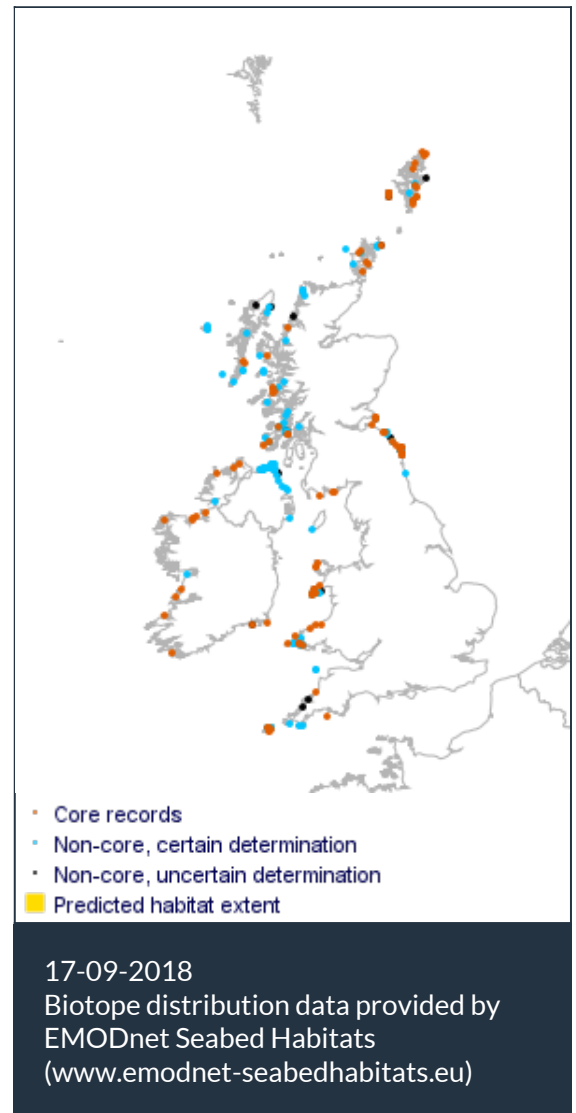
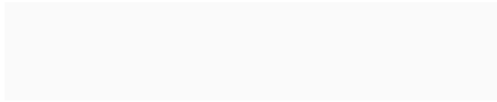
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Researched by Thomas Stamp

Refereed by This information is not refereed.

## Summary

### ☰ UK and Ireland classification

EUNIS 2008	A3.1112	<i>Alaria esculenta</i> and <i>Laminaria digitata</i> on exposed sublittoral fringe bedrock
JNCC 2015	IR.HIR.KFaR.Ala.Ldig	<i>Alaria esculenta</i> and <i>Laminaria digitata</i> on exposed sublittoral fringe bedrock
JNCC 2004	IR.HIR.KFaR.Ala.Ldig	<i>Alaria esculenta</i> and <i>Laminaria digitata</i> on exposed sublittoral fringe bedrock
1997 Biotope	IR.EIR.KFaR.Ala.Ldig	<i>Alaria esculenta</i> and <i>Laminaria digitata</i> on exposed sublittoral fringe bedrock

### 🔍 Description

Exposed sublittoral fringe bedrock characterized by a mixture of *Laminaria digitata* and *Alaria esculenta* with anemones, mussels *Mytilus edulis* and barnacles growing over a coralline algal crust.

The bryozoan crust *Umbronula littoralis* is typical of this zone on the shore and the barnacle *Verruca stroemia* may be present. This biotope also occurs on less exposed steep and vertical shores where a localised increase in wave action restricts the growth of *L. digitata*. As a result of this increased wave action the *L. digitata* plants are usually small and often show signs of damage. EIR.Ala.Ldig represents an intermediate on the wave exposure gradient, with pure stands of *Alaria esculenta* (EIR.Ala.Myt) being found on more exposed shores and pure *Laminaria digitata* (MIR.Ldig) on more sheltered shores. This biotope has a greater abundance of *Mytilus edulis*, limpets and coralline algae compared with MIR.Ldig. In contrast with the more exposed EIR.Ala.Myt, this biotope has a greater diversity of foliose red algae, including *Cryptopleura ramosa*, *Osmundea (Laurencia) pinnatifida* and *Lomentaria articulata*. This biotope usually occurs immediately above a sublittoral *Laminaria hyperborea* forest (EIR.LhypR or MIR.Lhyp), although a narrow band of *L. digitata* (MIR.Ldig) may occur between these two zones. On exposed shores in the north, *Alaria* alone tends to occupy the sublittoral fringe. A number of different biotopes may be found above EIR.Ala.Ldig; most commonly these are *Himanthalia elongata* (ELR.Him), a red algal turf (MLR.R) or a *Fucus serratus*-red algal mosaic (MLR.Fser.R).

### ↓ Depth range

Lower shore, 0-5 m

### Additional information

-

### ✓ Listed By

- none -

### Further information sources

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## Sensitivity review

### Sensitivity characteristics of the habitat and relevant characteristic species

IR.HIR.KFaR.Ala and IR.HIR.KFaR.AlaAnCrSp (plus associated sub-biotopes) are characterized by the northern/boreal kelp *Alaria esculenta* and are indicative of very wave exposed sublittoral bedrock. IR.HIR.KFaR.Ala occurs predominantly on sublittoral fringe bedrock to a depth of 1-2 m. However, at extremely exposed sites wave action can prevent competition from *Laminaria hyperborea* in the infralittoral zone and the *Alaria esculenta* defined biotopes IR.HIR.KFaR.Ala.Myt and IR.HIR.KFaR.AlaAnCrSp can extend to a depth of 15-35 m. In slightly less wave exposed conditions *Laminaria digitata* can compete with *Alaria esculenta* and in the sub-biotope; IR.HIR.KFaR.Ala.Ldig, the two species form a mixed canopy.

The understory community beneath *Alaria esculenta* canopies is defined by the degree of wave exposure at the site. Common understory species across *Alaria esculenta* biotopes are encrusting coralline algae and *Corallina officinalis* turf. IR.HIR.KFaR.AlaAnCrSp has only been recorded on steep/vertical bedrock at Rockall, Scotland. Extreme wave exposure at Rockall excludes *Laminaria hyperborea* and IR.HIR.KFaR.AlaAnCrSp extends from 14-35 m, and the rock surface is covered by a dense turf of anthozoans such as *Sagartia elegans*, *Phellia gausapata* and *Corynactis viridis*, encrusting sponges and coralline algae. In the sub-biotope IR.HIR.KFaR.Ala.Myt, *Mytilus edulis* is an abundant component of the understory, while patches of anthozoans and the hydroid *Tubularia* spp. occur in more wave-surfed areas. In the mixed *Alaria esculenta* & *Laminaria digitata* biotope IR.HIR.KFaR.Ala.Ldig, the red seaweeds; *Palmaria palmata*, *Mastocarpus stellatus* and *Chondrus crispus* are predominant features of the understory.

In undertaking this assessment of sensitivity, an account is taken of knowledge of the biology of all characterizing species/taxa in the biotope. In this sensitivity assessment, *Alaria esculenta* is the primary focus of research, as in the dominant characteristic species, without which the biotope would not be recognized. However, *Laminaria digitata*, plus understory species *Corallina officinalis*, encrusting algae, *Mytilus edulis* and red seaweeds also define IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus their associated sub-biotopes. Examples of important species groups are mentioned where appropriate.

### Resilience and recovery rates of habitat

*Alaria esculenta* is a perennial kelp found in the North Atlantic (Birkett *et al.*, 1998b) which dominates the sublittoral fringe in areas exposed to severe wave action or where water surges along the sides of gullies or steep/vertical bedrock (Lewis, 1964; Connor *et al.*, 2004). In extreme wave action *Laminaria digitata* and *Laminaria hyperborea* are likely to become damaged and die back, whereas morphological features and high growth rates allow *Alaria esculenta* to survive in such conditions (Birkett *et al.*, 1998). *Alaria esculenta* has a compact holdfast, a flexible "short" stipe and a flexible frond with a conspicuous reinforcing midrib (Birkett *et al.*, 1998b). Maximum growth rates are recorded in April-May which can exceed 20 cm/month (Birkett *et al.*, 1998b). From June-July growth rates slow and continual erosion along the frond margins can reduce the sporophyte to a holdfast, stipe and short length of blade, in which state the sporophyte overwinters. In extremely wave exposed conditions, especially in winter months, the blade may be reduced to just the midrib. The sporophyte can reach a total length of 4 m (Werner & Kraan, 2004), fronds can reach a total length of 2 m, however, growth rates are locally variable and are more typically 30-90cm in length (Birkett *et al.*, 1998b). *Alaria esculenta* can reach maturity rapidly in 10-14 months and lives for 4-7 years (Birkett *et al.*, 1998b; Baardseth, 1956).

*Alaria esculenta* has a heteromorphic life history (Fredersdorf *et al.*, 2009). Between November to March a vast number of meiotic haploid zoospores are released from sori located on sporophylls (found at the top of the stipe). Zoospore dispersal is greatly influenced by local water movements and zoospore densities. Laminarian spores also need to settle in high density so that the resultant gametophytes are close enough to cross-fertilize (Fredriksen *et al.*, 1995). Recruitment of *Alaria esculenta* may, therefore, be influenced by the proximity of mature sporophytes producing viable zoospores (Kain, 1979; Fredriksen *et al.*, 1995). Laminarians are expected to disperse zoospores over considerable distances. However, *Alaria esculenta* may have a lower dispersal capacity than other Laminarians due to the basal location of the sporophylls Norton (1992). Sundene (1962) agreed with Norton (1992) in a *Alaria esculenta* translocation experiment conducted in a Norwegian fjord, observing that *Alaria esculenta* germlings were restricted to within 10m of the parental source.

*Alaria esculenta* is an opportunistic colonizing species (Kain 1975a; Hawkins & Harkin 1985; Hill, 1993; Engelen, 2010). *Alaria esculenta* can settle on bare surfaces, including mobile boulders and in deeper water than the infralittoral fringe *Alaria esculenta* often appears early in the algal succession (ca 3 months after clearance of dominant algae) before being out-competed by other kelp species (in moderately wave exposed shores). During kelp canopy removal experiments in the Isle of Man, Hawkins & Harkin (1985) found that in moderately wave exposed areas cleared of *Laminaria digitata* (the dominant canopy forming species). *Alaria esculenta* became the dominant canopy algae within 9 months (October - June) and *Laminaria digitata* did not re-establish dominance within the study period (15 months). In areas of moderate to sheltered wave exposure *Alaria esculenta* colonized the blocks within 1 month of clearance and reached 25% coverage within 5 months but within 7 months *Laminaria digitata* had out-competed *Alaria esculenta* and re-established dominance within the community reaching ~90-95% coverage. Kain (1975a) conducted a similar experiment to Hawkins & Harkin (1985), however over a longer time period (>2 year). *Laminaria digitata* was cleared from moderately wave exposed concrete blocks at Port Erin, Isle of Man, and the subsequent "succession" of algae communities was documented. Following clearance *Laminaria digitata* was considered re-established two years after removal, while the understory red seaweed species returned one year later. Engelen (2010) observed a similar recovery time in Brittany, France. Patches of *Laminaria digitata* (0.25m<sup>2</sup>) were removed. *Laminaria digitata* returned to conditions prior to removal within 18-24 months, although competition for space by *Saccorhiza polyschides* reduced recovery rates in the first year of recolonization. Engelen (2010) stated that *Laminaria digitata* forest recovery rates varied between seasons, with autumn recovery being more rapid than spring (taking a minimum of 12 months).

The dispersal of *Laminaria digitata*'s spores and subsequent successful recruitment has been recorded 600 m from reproductive individuals (Chapman, 1981). The growth rate of *Laminaria digitata* changes with the seasons. Growth is rapid from February to July, slower in August to January, and occurs diffusely in the lamina (or blade) (Kain, 1979). Zoospores are produced at temperatures lower than 18°C with a minimum of 10 weeks a year between 5-18°C needed to ensure spore formation (Bartsch, 2013). Thus, temperature and by default season impacts the level of reproductive activity. Furthermore, experimental clearance experiments of *Laminaria digitata* (Kain 1975a; Hawkins & Harkin 1985; Hill 1993; Engelen, 2010) found that following clearance *Laminaria digitata* re-colonization takes 12-24 months. Interspecific competition from ephemeral algae was also found to slow recovery times (Engelen, 2010).

*Corallina officinalis* produces spores over a protracted period and can colonize artificial substratum within one week in the intertidal (Harlin & Lindbergh, 1977; Littler & Kauker, 1984). The crustose base enables *Corallina officinalis* to survive extreme wave exposure and damage (loss of fronds),

and to take advantage (colonize) of space left after winter storms have removed competing macroalgae (Littler & Kauker, 1984). The mobile interstitial fauna of the coralline turf is reduced by trampling (Brown & Taylor, 1999) but is likely to recruit to or recolonize the turf from the surrounding communities. Encrusting and erect corallines are also known to stimulate the settlement of a variety of marine invertebrate larvae and algal spores. *Corallina officinalis* is capable of colonizing new substratum rapidly. In experimental plots, 15 percent cover of fronds returned within 3 months (Littler & Kauker, 1985) and Brown & Taylor (1999) noted that the articulated coralline algal turf community on a New Zealand shore returned to normal levels within 3 months of trampling events, although they suggested that a return to its previous cover may take longer.

Resilience assessment. *Alaria esculenta* is an opportunistic and rapidly colonizing species (see above) capable of growing 20 cm/month in optimal conditions, reaching maturity within 10-14 months, and often appearing early in the algal succession (c. 3 months after clearance of dominant algae). In canopy removal experiments in the Isle of Man, Hawkins & Harkin (1985) found that areas cleared of *Laminaria digitata* (moderately exposed) *Alaria esculenta* became the dominant canopy algae within 9 months (October - June). *Corallina officinalis* is capable of colonizing new substratum rapidly. In experimental plots, 15% cover of fronds returned within three months (Littler & Kauker, 1985) and Brown & Taylor (1999) noted that the articulated coralline algal turf community on a New Zealand shore returned to normal levels within three months of trampling events, although they suggested that a return to its previous cover may take longer. Therefore, the resilience of IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus associated sub-biotopes has been assessed as **High**.

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 recognizable 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)	None Q: Medium A: High C: Low	High Q: High A: Low C: High	Medium Q: Medium A: Low C: Low

*Alaria esculenta* is a northern/boreal species that has been recorded from Brittany, France to Northern Norway (Birkett *et al.*, 1998b). Sea temperature regulates metabolism and reproduction and defines the regional distribution of *Alaria esculenta* (Fredersdorf *et al.*, 2009). The southern limit of *Alaria esculenta* has been defined at the 20°C isotherm (Munda & Lüning, 1977; Fredersdorf *et al.*, 2009), however, it is common north of the 16°C isotherm (Munda & Lüning, 1977). As a result of this upper temperature threshold, *Alaria esculenta* is largely absent from the southern North Sea and English channel where summer temperatures can exceed 16°C.

Munda & Lüning (1977) observed temperatures of 16-17°C sustained over 2 weeks in Helgoland,

Germany, were lethal to resident *Alaria esculenta*. Experimental observations showed that acute exposure to  $\geq 21^{\circ}\text{C}$  is lethal to *Alaria esculenta* causing bleaching and disintegration (Sundene, 1962; Fredersdorf *et al.*, 2009). At its northern range edge (Svalbard) it is a prominent macroalga on sublittoral fringe bedrock. At these latitudes average, summer temperature can reach  $5^{\circ}\text{C}$ , with an average annual sea temperature of  $3^{\circ}\text{C}$  (1980-2014, Beszczynska-Möller & Dye, 2013). Experimental observations conducted by Fredersdorf *et al.* (2009) found the optimal temperature for sporophyte photosynthesis was within the range of  $13\text{-}17^{\circ}\text{C}$ , however, the optimal temperature for *Alaria esculenta* germination is  $2\text{-}12^{\circ}\text{C}$  (Fredersdorf *et al.*, 2009).

*Alaria esculenta* has an approximate mid-range within southern Norway (60 deg 65 deg North) (Birkett *et al.*, 1998b), and as such IR.HIR.KFaR.Ala and IR.HIR.KFaR.AlaAnCrSp (plus associated sub-biotopes) have a southerly distribution when considering the geographic distribution of *Alaria esculenta*. Throughout the UK northern to southern Sea Surface Temperature (SST) ranges from  $8\text{-}16^{\circ}\text{C}$  in summer and  $6\text{-}13^{\circ}\text{C}$  in winter (Beszczynska-Möller & Dye, 2013). The available evidence suggests that the effects of an increase in temperature would be seasonally variable, with higher impacts during periods of spore release (Nov-march) and germination. A  $5^{\circ}\text{C}$  increase in temperature for one month may cause high mortality, limit photosynthetic ability plus germination rates. A  $2^{\circ}\text{C}$  increase in temperature for one year may limit germination; however sporophyte photosynthetic ability may not be dramatically affected. Temperature increases of  $2\text{-}5^{\circ}\text{C}$  at the southern extreme of *Alaria esculenta*' range (Brittany, France) is likely to cause high mortality.

*Corallina officinalis* may tolerate between minus  $4$  to  $28^{\circ}\text{C}$  (Lüning, 1990). Abrupt temperature changes ( $10^{\circ}\text{C}$  in California, Seapy & Littler 1984;  $4.8$  to  $8.5^{\circ}\text{C}$ , Hawkins & Hartnoll, 1985) resulted in dramatic declines. However, in both cases recovery was rapid, suggesting that the crustose bases survived. Therefore, both *Alaria esculenta* and *Corallina officinalis* are probably intolerant of acute short-term temperature change of  $5^{\circ}\text{C}$  for a month. Long-term change of  $2^{\circ}\text{C}$  may reduce the southern limit of the population of *Alaria esculenta*.

**Sensitivity assessment.** Resistance to the pressure is considered 'None', and resilience 'High'. The sensitivity of this biotope to an increase in temperature has been assessed as 'Medium'. This sensitivity assessment takes into account a one month temperature increase of  $5^{\circ}\text{C}$ . The effects of a  $2^{\circ}\text{C}$  increase in temperature for one year is likely to have less of an impact. In the later scenario, resistance would be assessed as 'Medium', and resilience 'High'. Sensitivity would be assessed as 'Low'.

#### Temperature decrease (local)

High

Q: High A: Medium C: Medium

High

Q: High A: Low C: High

Not sensitive

Q: High A: Low C: Medium

*Alaria esculenta* is a northern/boreal species that has been recorded from Brittany, France to Northern Norway (Birkett *et al.*, 1998b). Sea temperature has been cited as an influential abiotic stressor; responsible for regulating metabolism and reproduction, plus defining the regional distribution of *Alaria esculenta* (Fredersdorf *et al.*, 2009). At *Alaria*'s northern range edge (Svalbard) it is a prominent macro-algae on sublittoral fringe bedrock. At these latitudes, average summer temperature can reach  $5^{\circ}\text{C}$ , and average annual sea temperature  $3^{\circ}\text{C}$  (1980-2014, Beszczynska-Möller & Dye, 2013). Experimental observations conducted by Fredersdorf *et al.*, (2009) found the optimal temperature for sporophyte photosynthesis was within the range of  $13\text{-}17^{\circ}\text{C}$ , however, the optimal temperatures for *Alaria esculenta* germination is  $2\text{-}12^{\circ}\text{C}$  (Fredersdorf *et al.*, 2009).

*Alaria esculenta* has an approximate mid-range within southern Norway (60 deg to 65 deg North) (Birkett *et al.*, 1998b), and as such IR.HIR.KFaR.Ala and IR.HIR.KFaR.AlaAnCrSp (plus associated



sub-biotopes) have a southerly distribution when considering the geographic distribution of *Alaria esculenta*. Throughout the UK northern to southern Sea Surface Temperature (SST) ranges from 8-16°C in summer and 6-13°C in winter (Beszczynska-Möller & Dye, 2013). A 5°C decrease in temperature for one month at *Alaria esculenta*' approximate mid-range may affect the photosynthetic ability of sporophytes, however not impact germination and hence recruitment. A 2°C increase in temperature for one year at *Alaria esculenta*' approximate mid-range is not likely to significantly affect *Alaria esculenta*.

**Sensitivity assessment.** Resistance to the pressure is considered 'High', and resilience 'High'. The sensitivity of this biotope to an increase in temperature has been assessed as 'Not Sensitive'.

### Salinity increase (local)

**Medium**

Q: Medium A: High C: High

**High**

Q: High A: Low C: High

**Low**

Q: Medium A: Low C: High

Lüning (1990) suggest that kelps are stenohaline, their general tolerance to salinity as a phenotypic group covering 16-50 psu over a 24 hr period. Optimal growth probably occurs between 30-35 psu (MNCR category-Full Salinity) and growth rates are likely to be affected by periodic salinity stress.

Karsten (2007) tested the photosynthetic ability of *Alaria esculenta* under acute 2 and 5 day exposure to salinity treatments ranging from 5-60 psu. A control experiment was also carried at 34 PSU. Between 10-50 psu *Alaria esculenta* showed high photosynthetic ability at 83-94% of the control. Hypersaline treatments with 55-60 psu led to a 30% reduction in photosynthetic ability, ~70% of the control level. At 5 psu *Alaria esculenta* showed a low photosynthetic ability at 15.8% of the control. After 5 days at 5 psu, all *Alaria esculenta* specimens were bleached and none survived. Karsten (2007) suggested that *Alaria esculenta* photosynthetic ability is highly affected by acute exposure to hyposaline conditions (<10 psu). The effect of long-term salinity changes (>5 days) or the effect of salinity >60 psu on *Alaria esculenta*' photosynthetic ability was not tested. The experiment was conducted in the Arctic, and the authors suggest that at extremely low water temperatures (1-5°C) macro-algal acclimation to rapid salinity changes could be slower than at temperate latitudes. It is, therefore, possible that *Alaria esculenta* maybe be able to acclimate to salinity changes more effectively and quicker in UK waters, however, evidence for this is limited.

*Corallina officinalis* is restricted to full salinity waters in the Baltic and grows maximally between 33 and 38 psu in Texan lagoons (Kinne 1971a). This biotope is likely to be exposed to short-term freshwater runoff at low tide but is likely to be intolerant of long-term changes in salinity, which are likely to depress its upper limit and reduce the extent of the population.

**Sensitivity assessment.** IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus associated sub-biotopes have been recorded exclusively in full salinity (30-40‰) (Connor *et al.*, 2004). Karsten (2007) suggests that at salinities ranging from 10-50 psu *Alaria esculenta* photosynthetic ability was high. At salinities >50 psu, photosynthetic ability was reduced by 30% but no mortality of the specimens was recorded. Resistance to the pressure is considered 'Medium', as other characterizing species (e.g. sponges, ascidians) are likely to be more sensitive to hypersaline conditions and resilience 'High'. The sensitivity of this biotope to an increase in salinity has been assessed as 'Low'.

### Salinity decrease (local)

**Medium**

Q: Medium A: High C: High

**High**

Q: High A: Low C: High

**Low**

Q: Medium A: Low C: High

Lüning (1990) suggest that kelps are stenohaline, their general tolerance to salinity as a phenotypic group covering 16-50 psu over a 24 hr period. Optimal growth probably occurs between 30-35 psu (MNCR category-Full Salinity) and growth rates are likely to be affected by periodic salinity stress.

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**Sensitivity assessment.** IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus associated sub-biotopes have been recorded exclusively in full salinity (30-40‰) (Connor *et al.*, 2004). Karsten (2007) suggests that at salinities ranging from 10-50 PSU *Alaria esculenta* photosynthetic ability was high. At 5 PSU *Alaria esculenta* showed a dramatic decline in photosynthetic ability and after 5 days specimens bleached and did not survive. Sundene (1962) also noted that *Alaria esculenta* sporophytes grew poorly below 25 PSU. A decrease of one MNCR salinity scale to "Reduced Salinity" (18-30‰) may reduce growth rates, however not cause high mortality of *Alaria esculenta*. Resistance to the pressure is therefore considered '**Medium**', as other characterizing species (e.g. sponges, ascidians) are likely to be more sensitive to hyposaline conditions, and resilience '**High**'. The sensitivity of this biotope to an increase in salinity has been assessed as '**Low**'.

**Water flow (tidal current) changes (local)**

**Medium**

Q: Low A: NR C: NR

**High**

Q: High A: Low C: High

**Low**

Q: Low A: NR C: NR

*Alaria esculenta* dominates the sublittoral fringe in areas exposed to severe wave action or where water surges along the sides of gullies/steep bedrock faces (Lewis, 1964; Connor *et al.*, 2004). The high wave exposure that defines IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus associated sub-biotopes damages other laminarians and generally excludes them. In less wave exposed locations *Alaria esculenta* is out-competed by other Laminarians, e.g. *Laminaria digitata* and *Laminaria hyperborea* (Connor *et al.*, 2004). IR.HIR.KFaR.AlaAnCrSp and IR.HIR.KFaR.Ala plus associated sub-biotopes are recorded within moderately strong (0.5-1.5 m/sec)-weak (<0.5 m/sec) tidal streams, but have been recorded in very strong (>3 m/sec) tidal streams. Therefore, elevated tidal flows (>3 m/sec) may increase *Alaria esculenta* dislodgment (Birkett *et al.*, 1998b).

Increased tidal flow may remove fronds of *Corallina officinalis* however calcification is thought to be

an adaptation to mechanical damage (Littler & Kauker, 1984). Increases in water flow rate may facilitate the colonization of filter feeding organisms within the understory and IR.HIR.KFaR.Ala.Myt may dominate over IR.HIR.KFaR.Ala.Ldig. Decreases in water flow are likely to have the opposite effect (Connor *et al.* 2004). Changes in the water flow regimes under kelp canopies can modify larval supply and settlement (Eckman, 1983), and affect the growth and survival of *Mytilus edulis* (Eckman & Duggins, 1991). *Mytilus edulis* settlement has been found significantly higher in close proximity to *Alaria esculenta* and is thought to increase beneath the canopy (Bégin *et al.*, 2004). Therefore any loss of *Alaria esculenta*, as a result of changes to local water movements, may affect *Mytilus edulis* recruitment.

**Sensitivity assessment.** IR.HIR.KFaR.AlaAnCrSp and IR.HIR.KFaR.Ala plus associated sub-biotopes are found in a wide range of tidal flows but exclusively in wave disturbed areas, which generally exclude other laminarians. Changes in tidal flow are not likely to independently affect the dominance of *Alaria esculenta*, however, may affect the understory community. Nevertheless, wave exposure is the dominant source of water movement in these biotope, and a change in water flow of 0.1-0.2 m/s is unlikely to be significant. Therefore, resistance has been assessed as 'High' and resilience 'High'. Sensitivity has been assessed as 'Not Sensitive' at the benchmark level.

#### Emergence regime changes

Low

Q: Low A: NR C: NR

High

Q: High A: Low C: High

Low

Q: Low A: NR C: NR

An increase in emergence will result in an increased risk of desiccation. Increased immersion may allow IR.HIR.KFaR.Ala biotopes to extend higher up the shore. However, *Alaria esculenta* forest will come under increased competition from *Laminaria hyperborea* in the shallow infralittoral. In this scenario IR.HIR.KFaR.Ala biotope distribution may shift on the shore, however, biotope structure will remain.

*Alaria esculenta* may extend into the lower eulittoral in extremely wave exposed conditions. However, these marginal populations have a reduced age range in comparison to subtidal populations due to desiccation increasing mortality of *Alaria esculenta* at low tide. An increase in desiccation is likely to remove *Alaria esculenta*. The resultant loss of canopy would expose *Corallina officinalis* turf and macrofaunal crust to desiccation and/or damage by high light intensity (bleaching). Hawkins & Harkin (1985) noted that encrusting corallines and *Corallina officinalis* often die when their protective algal canopy is removed. Severe damage was noted in *Corallina officinalis* as a result of unusually hot and sunny weather in the UK summer 1983 (Hawkins & Hartnoll, 1985). *Laminaria digitata* is likely to be intolerant of desiccation and destruction of its meristem (base of the blade), caused by increased wave action at low tide, will kill the sporophyte. Therefore, both IR.HIR.KFaR.Ala.Myt and IR.HIR.KFaR.Ala.Ldig are likely to be highly intolerant of increases in desiccation and the upper limit of the population would be depressed. Desiccation is unlikely to be relevant in IR.HIR.KFaR.AlaAnCrSp due to its depth (15-35 m BCD) (Connor *et al.*, 2004).

**Sensitivity assessment.** Resistance to this pressure is considered 'Low', and resilience 'High'. The sensitivity of this biotope to a change in emergence is considered as 'Low'.

#### Wave exposure changes (local)

None

Q: High A: High C: High

High

Q: High A: Low C: High

Medium

Q: High A: Low C: High

*Alaria esculenta* dominates the sublittoral fringe in areas exposed to severe wave action or where water surges along the sides of gullies (Lewis, 1964). A decrease in local wave height will increase

spatial competition from other laminarians (Connor *et al.*, 2004). Increased wave exposure may remove fronds of *Corallina officinalis* however calcification is thought to an adaptation to mechanical damage (Little & Kauker, 1984) and the fronds grow as a compact (short) turf in wave exposed conditions.

IR.HIR.KFaR.AlaAnCrSp occurs at one site, Rockall, Scotland where extreme oceanic swell excludes *Laminaria hyperborea* in the infralittoral from 14-35 m. IR.HIR.KFaR.Ala.Myt occurs predominantly on sublittoral fringe bedrock in very exposed to exposed wave exposure. Extremely wave exposed variants of IR.HIR.KFaR.Ala.Myt can extend to 15 m BCD where *Alaria esculenta* replaces *Laminaria hyperborea* as the assemblage dominant, and *Mytilus edulis* is a common understory species in the sublittoral fringe variant (Bégin *et al.*, 2004, Connor *et al.*, 2004) but as depth increases *Tubularia spp.* becomes more abundant. IR.HIR.KFaR.Ala.Ldig occurs predominately at exposed-moderately wave exposed sites, where *Laminaria digitata* can spatially compete with *Alaria esculenta* (Connor *et al.*, 2004).

**Sensitivity assessment.** The abundance of *Alaria esculenta* is highly affected by the degree of wave exposure at a site. Within IR.HIR.KFaR.Ala, increasing wave exposure may favour IR.HIR.KFaR.Ala.Myt over IR.HIR.KFaR.Ala.Ldig (Connor *et al.* 2004). Further increases in wave exposure may cause damage to *Laminaria hyperborea*, allowing *Alaria esculenta* to dominate the infralittoral. Kelp clearance experiments have shown that at moderate or lower wave exposure sites *Laminaria digitata* can out-compete *Alaria esculenta* so that a decrease in wave exposure is likely to result in loss of the *Alaria* dominated biotopes. *Alaria* dominated biotopes are, therefore, sensitive to any activity or event that reduces incident wave energy. However, a change of 3-5% in significant wave height (the benchmark) is unlikely to be significant in the wave exposed conditions favoured by these biotopes. Therefore, resistance is recorded as 'High', with a 'High' resilience, resulting in an assessment of '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.

Johnston & Roberts (2009) conducted a meta-analysis, which reviewed 216 papers to assess how a variety of contaminants (including metal contamination) affected six marine habitats (including intertidal and subtidal reefs). A 30-50% reduction in species diversity and richness was identified from all habitats exposed to the contaminant types. Johnston & Roberts (2009) also highlighted that macroalgal communities are relatively tolerant to contamination but that metal and nutrient impacted intertidal communities can have low diversity assemblages which are dominated by opportunistic and fast growing species (Johnston & Roberts, 2009).

Mercury (organic > inorganic) is highly toxic to macrophytes (Bryan, 1984; Cole *et al.*, 1999). Mercury and copper were lethal at 0.05 mg/l and 0.1 mg/l respectively and toxic at 0.05 mg/l and 0.01 mg/l respectively in *Laminaria hyperborea*. Zinc and Cadmium were lethal at 5 mg/l and 10 mg/l respectively. The presence of alginates in kelp tissue is thought to sequester heavy metals in a biologically unavailable form. It is likely that laminarians such as *Alaria esculenta* are relatively

tolerant of heavy metals except at high concentrations at high levels. Little information on heavy metal tolerance of corallines was found.

### 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 coating on kelp fronds is thought to protect them from coatings of oil. Hydrocarbons in solution reduce photosynthesis and may be algicidal. Reduction in photosynthesis is dependent on the type of oil, its concentration and length of exposure, oil-water mixture and irradiance in experimental trials (Lobban & Harrison, 1994). Subtidal populations are only exposed to oil emulsions or oil adsorbed particles. Kelps are relatively insensitive to dispersants (Birkett *et al.*, 1998b) e.g. *Laminaria digitata* exposed to diesel oil at 0.130 mg/l reduced growth by 50% in a 2 year experiment. No growth inhibition was noted at 0.03 mg/l and the plants recovered completely in oil free conditions. *Corallina officinalis*, however, exhibited dramatic bleaching after the *Sea Empress* oil spill and died after the *Torrey Canyon* spill (Crump *et al.*, 1999; Smith, 1968). Encrusting corallines and *Corallina officinalis* recovered from the *Sea Empress* spill quickly, bleaching only affecting the fronds or surface of crustose forms. Grazing gastropods, e.g. limpets are highly intolerant of oil spillage and if not killed are narcotized and washed offshore and/or consumed by predators. The lower littoral populations are likely to be most vulnerable to an oil spill and sublittoral fringe would be particularly affected at low tide. Although *Alaria esculenta* may not be affected severely, the articulated coralline turf may be lost but recover quickly although the red algae may be intolerant. Grazers such as limpets, barnacles and meiofaunal crustaceans may also be lost from the community.

### 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.

Cole *et al.* (1999) suggested that macrophytes are generally intolerant of herbicides such as atrazine, simazine, diuron and linuron. For example, atrazine was lethal to *Laminaria hyperborea* sporophytes at 1mg/l and suppressed growth at 0.01 mg/l (Hopkin & Kain, 1978). Smith (1968) noted that *Corallina officinalis* was killed in areas of heavy spraying after the *Torrey Canyon* oil spill and affected at 6 m depth in areas of high wave action. High water specimens were more affected than low water specimens, presumably because they are emmersed for longer and had more contact with oil and dispersants. Gastropods are known to be highly sensitive to endocrine disrupters such as TBT. Crustaceans (e.g. amphipods, isopods, ostracods, copepods and barnacles) are also susceptible to endocrine disruption by synthetic chemicals. It is, therefore, likely that some taxa within IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus associated sub-biotopes, especially grazing invertebrates and meiofauna will be intolerant of synthetic chemical contamination.

### 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: High A: Medium C: High

High

Q: High A: Medium C: High

Not sensitive

Q: High A: Medium C: High

Reduced oxygen concentrations have been shown to inhibit both photosynthesis and respiration in macroalgae (Kinne, 1977). Despite this, macroalgae are thought to buffer the environmental conditions of low oxygen, thereby acting as a refuge for organisms in oxygen depleted regions especially if the oxygen depletion is short-term (Frieder *et al.*, 2012). A rapid recovery from a state of low oxygen is expected if the conditions are transient, which is likely given the wave exposed distribution of defines IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus associated sub-biotopes. 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). Reduced oxygen levels are likely to inhibit photosynthesis and respiration but not cause a loss of the macroalgae population directly. However, small invertebrate epifauna may be lost, causing a reduction in species richness.

**Sensitivity assessment.** Due to the mixing experienced in strongly wave exposed environments, resistance has been assessed as “**High**” resilience as “**High**”. Sensitivity has been assessed as “**Not Sensitive**” at the pressure 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

Organic enrichment is associated with eutrophication, increased siltation and turbidity (Fletcher, 1996). Eutrophication is associated with loss of perennial algae and replacement by mussels or opportunistic algae (Fletcher, 1996). Johnston & Roberts (2009) conducted a meta-analysis that reviewed 216 papers to assess how a variety of contaminants (including sewage and nutrient loading) affected 6 marine habitats (including intertidal and subtidal reefs). A 30-50% reduction in species diversity and richness was identified from all habitats exposed to the contaminant types. Johnston & Roberts (2009) also highlighted that macroalgal communities are relatively tolerant to contamination, but that metal and nutrient impacted intertidal communities can have low diversity assemblages which are dominated by opportunistic and fast growing species (Johnston & Roberts, 2009). However due to the high wave exposure that defines IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus associated sub-biotopes, it is likely that additional organic input to the system may be dispersed out of the biotope’s local vicinity (Johnston & Roberts, 2009). Increased nutrients may favour *Mytilus edulis* in IR.HIR.KFaR.Ala.Myt which may increase in cover and abundance. *Corallina officinalis* is also tolerant of polluted waters (Kindig & Littler, 1980).

**Sensitivity assessment.** IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus associated sub-biotopes are however considered “**Not Sensitive**” at the benchmark level, which assumes compliance with good status as defined by the WFD.

**Organic enrichment**

Medium

Q: High A: Medium C: High

High

Q: High A: Medium C: High

Low

Q: High A: Medium C: High

Organic enrichment is associated with eutrophication, increased siltation and turbidity (Fletcher, 1996). Eutrophication is associated with loss of perennial algae and replacement by mussels or opportunistic algae (Fletcher, 1996). Johnston & Roberts (2009) conducted a meta-analysis that reviewed 216 papers to assess how a variety of contaminants (including sewage and nutrient loading) affected six marine habitats (including intertidal and subtidal reefs). A 30-50% reduction in species diversity and richness was identified from all habitats exposed to the contaminant types. Johnston & Roberts (2009) also highlighted that macroalgal communities are relatively tolerant to contamination, but that contaminated intertidal communities can have low diversity assemblages which are dominated by opportunistic and fast growing species (Johnston & Roberts, 2009). Due to the high wave exposure that defines IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus associated sub-biotopes, it is likely that additional organic input to the system may be dispersed out of the biotope's local vicinity (Johnston & Roberts, 2009). Increased nutrients may favour *Mytilus edulis* in IR.HIR.KFaR.Ala.Myt which may increase in cover and abundance. *Corallina officinalis* is also tolerant of polluted waters (Kindig & Littler, 1980).

**Sensitivity assessment.** Resistance has been assessed as “**Medium**”, (to represent potential changes in species diversity), resilience as “**High**”. Sensitivity has been assessed as “**Low**”.

## A Physical Pressures

	Resistance	Resilience	Sensitivity
Physical loss (to land or freshwater habitat)	<b>None</b> Q: High A: High C: High	<b>Very Low</b> Q: High A: High C: High	<b>High</b> 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)	<b>None</b> Q: High A: High C: High	<b>Very Low</b> Q: High A: High C: High	<b>High</b> Q: High A: High C: High
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If rock substrata were replaced with sedimentary substrata this would represent a fundamental change in habitat type, which *Alaria esculenta* would not tolerate (Birkett *et al.*, 1998b). The biotope would be lost.

**Sensitivity assessment.** Resistance to the pressure is considered ‘**None**’, and resilience ‘**Very low**’ or ‘**None**’. The sensitivity of this biotope to change from hard rock or artificial substrata to sedimentary or soft rock substrata is assessed as ‘**High**’.

Physical change (to another sediment type)	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR	<b>Not relevant (NR)</b> Q: NR A: NR C: NR
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**Not Relevant** to hard rock biotopes.

**Habitat structure changes - removal of substratum (extraction)**

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not Relevant to hard rock biotopes.

**Abrasion/disturbance of the surface of the substratum or seabed**

Medium

Q: Low A: NR C: NR

High

Q: High A: Low C: High

Low

Q: Low A: NR C: NR

The sublittoral fringe is unlikely to be significantly impacted by trampling due to its position of the lower shore but may be prone to abrasion from moorings or low tide landings. Given its resilience to wave action *Alaria esculenta* is unlikely to be significantly damaged by abrasion although the understory coralline turf may suffer some damage. The coralline turf meiofauna will probably be lost as a result of trampling. Moderate trampling on articulated coralline algal turf in the New Zealand intertidal (Brown & Taylor, 1999; Schiel & Taylor, 1999) resulted in reduced turf height, declines in turf densities, and loss of crustose bases in some case probably due to loss of the canopy algae and resultant desiccation. Calcification is thought to an adaptation to grazing and sediment scour (Littler & Kauker, 1984).

If exposed to moorings, groundings, or passing fishing gear, the resultant abrasion may result in the physical removal of a proportion of the *Alaria esculenta* canopy. Depending on the scale of the impact, although no evidence of this impact was found. However, *Alaria esculenta* has been shown to be an opportunistic colonizing species, capable of rapid recovery (see resilience section).

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

**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

Not Relevant to hard rock biotopes.

**Changes in suspended solids (water clarity)**

Medium

Q: Low A: NR C: NR

High

Q: High A: Low C: High

Low

Q: Low A: Low C: Low

Suspended Particle Matter (SPM) concentration has a linear relationship with sub surface light attenuation (Kd) (Devlin *et al.*, 2008). Light penetration influences the maximum depth at which kelp species 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 6-7 m in the silt laden German Bight. In European Atlantic waters the depth limit is typically 35 m.

*Alaria esculenta* is not found in areas of siltation and sediment scour (Birkett *et al.* 1998b). Increased siltation and sediment scour inhibits photosynthesis and algal growth, interfere with spore or larval recruitment plus smother germlings and gametophytes (Fletcher, 1996). However, the high degree of wave exposure that typically defines IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus



associated sub-biotopes is likely to clear suspended sediments relatively quickly. If low water clarity is persistent and wave exposure decreased then low energy silted kelp biotopes (IR.LIR.K) may proliferate. Once siltation returns to its pre-effect level the biotope is likely to recover its canopy within a year and the rest of the community in no more than five years. Increased siltation will also increase turbidity. Increased sediment may benefit *Mytilus edulis* and its abundance may increase in IR.HIR.KFaR.Ala.Myt although large individuals are likely to be removed by wave action.

Increased turbidity is likely to reduce the depth to which *Alaria esculenta* can grow. However, an increase of one level in WFD water clarity scale for a period of one year is unlikely to affect the population since *Alaria esculenta's* lower limit, is generally determined by competition from other Laminarians rather than light penetration.

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

### Smothering and siltation rate changes (light)

**High**

Q: Medium A: Low C: High

**High**

Q: High A: Low C: High

**Not sensitive**

Q: Medium A: Low C: Medium

Due to their size juvenile sporophytes, germlings, gametophytes and spores are likely to be inundated by deposition of 5cm during a discrete event but the high wave exposure that defines the distribution of IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala (plus associated sub-biotopes deposited sediments) are likely to be removed rapidly and any effects of inundation are likely to be temporary.

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

### Smothering and siltation rate changes (heavy)

**High**

Q: Medium A: Low C: Medium

**High**

Q: High A: Low C: High

**Not sensitive**

Q: Medium A: Low C: Medium

Due to their size juvenile sporophytes, germlings, gametophytes and spores are likely to be inundated by deposition of 30cm during a discrete event but the high wave exposure that defines the distribution of IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala (plus associated sub-biotopes deposited sediments) are likely to be removed rapidly and any effects of inundation are likely to be temporary.

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

### 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

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

High

Q: High A: High C: High

Low

Q: Low A: NR C: NR

There was no evidence to suggest that anthropogenic light sources would affect IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus associated sub-biotopes. Shading (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 laminarian abundance from forest to park type biotopes.

**Sensitivity assessment.** Resistance is probably 'Low', with a 'High' resilience and a sensitivity of 'High', 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

No evidence was found

**Introduction or spread of invasive non-indigenous species****High**

Q: High A: High C: High

**High**

Q: High A: High C: High

**Not sensitive**

Q: High A: High C: High

The Japanese kelp *Undaria pinnatifida* (wakame) has recently spread to the south coast of England from Brittany where it was introduced for aquaculture. It may spread in the ballast water of commercial or recreational boats and shipping. Field studies within New Zealand found that the physical structure of coralline turfing algae substantially aided the establishment of *Undaria pinnatifida* in the intertidal. The physical structure of coralline turfing algae (e.g. *Corallina officinalis*) retains moisture, provide a physical barrier to grazers, and create a physically complex habitat on which algal spores can settle (Thompson & Schiel, 2012). Once established *Undaria pinnatifida* has been associated with declines in native kelp abundance (e.g. *Laminaria hyperborea*, Heiser *et al.*, 2014). In the UK *Undaria pinnatifida* has to date only been recorded from predominantly sheltered locations e.g. harbours (Thompson & Schiel, 2012). The high wave exposure which defines IR.HIR.KFaR.AlaAnCrSp & IR.HIR.KFaR.Ala plus associated sub-biotopes may inhibit the establishment of *Undaria pinnatifida* However colonization of *Undaria pinnatifida* within UK habitats needs further study (Birkett *et al.* 1998, Heiser *et al.*, 2014).

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

**Introduction of microbial pathogens****High**

Q: Medium A: Medium C: Low

**High**

Q: High A: High C: High

**Not sensitive**

Q: Medium A: Medium C: Low

*Streblonema* sp. is associated with spot disease in kelps and has been found growing on *Alaria esculenta* (Lein *et al.* 1991) but no incidence of *Alaria esculenta* spot disease was found. *Corallina officinalis* may host several epiphytes of which *Titanoderma corallinae* is thought to cause tissue damage. Hyperplasia or gall growths are often seen as dark spots on *Laminaria digitata* and have been associated with endophytic brown filamentous algae. There is no evidence in the literature that infection by microbial pathogens results in the mass death of kelp populations and the kelp themselves are known to regulate bacterial infections through iodine metabolism (Cosse *et al.*, 2009).

**Removal of target species****None**

Q: High A: High C: High

**Medium**

Q: High A: High C: High

**Medium**

Q: High A: High C: High

*Alaria esculenta* has recently received commercial interest as a consumable product called "Sea Vegetables" or "Atlantic Wakame Kelp". However, no studies examining the effect of commercial extraction of *Alaria esculenta* biotopes were found. Removal of the algal canopy would expose the understory fauna and flora to increased desiccation. Experimental macroalgal canopy removal experiments conducted in the Isle of Man (Hawkings & Harkin, 1985) found that following removal of the macroalgal canopy the understory encrusting red algae became bleached and died within a week. *Mytilus edulis* settlement has also been found significantly higher in close proximity to *Alaria esculenta* and is thought to increase beneath *Alaria esculenta* canopies (Bégin *et al.*, 2004). Therefore, any loss of *Alaria esculenta*, as a result of commercial extraction, may dramatically affect the understory community.

Traditionally *Laminaria digitata* was added to agricultural lands as fertilizers; now *Laminaria* species

are used in a range of different products, with its alginates used in the cosmetic, pharmaceutical and agri-food industries (Kervarec *et al.*, 1999; McHugh, 2003). *Laminaria digitata* is harvested with a 'Scoubidou' (a curved iron hook which is mechanically operated) in France. This device is considered to be selective- only harvesting individuals older than 2 years (Arzel, 2002). France reportedly harvests 75,000t kelp, mainly consisting of *Laminaria digitata* annually (FAO, 2007). The loss of *Laminaria digitata* would represent as significant change to IR.HIR.KFaR.Ala.Ldig.

*Corallina officinalis* is collected for medical purposes; the fronds are dried and converted to hydroxyapatite and used as bone forming material (Ewers *et al.*, 1987). It is also sold as a powder for use in the cosmetic industry. Moderate trampling on articulated coralline algal turf in the New Zealand intertidal (Brown & Taylor, 1999; Schiel & Taylor, 1999) resulted in reduced turf height, declines in turf densities, and loss of crustose bases in some case probably due to loss of the canopy algae and resultant desiccation. Calcification is thought to be an adaptation to grazing and sediment scour (Littler & Kauker 1984). *Corallina officinalis* produces spores over a protracted period and can colonize artificial substratum within one week in the intertidal (Harlin & Lindbergh 1977; Littler & Kauker, 1984). The crustose base enables *Corallina officinalis* to survive loss of fronds.

**Sensitivity assessment.** There is little published evidence for the effects of commercial harvesting of *Alaria esculenta*. If it is assumed that all canopy forming kelp are removed then resistance would be assessed as 'None', resilience would be assessed as 'Medium'. Sensitivity has been assessed as 'Medium'. Within IR.HIR.KFaR.AlaAnCrSp and IR.HIR.KFaR.Ala.Myt, monospecific canopies of *Alaria esculenta* are expected to recover quicker than mixed canopies of *Laminaria digitata* (as in IR.HIR.KFaR.Ala.Ldig). Sensitivity of the latter would be assessed as follows; resistance 'None', resilience as 'High', Sensitivity as 'Medium'.

#### Removal of non-target species

None

Q: High A: High C: High

Medium

Q: High A: High C: High

Medium

Q: High A: High C: High

Incidental/accidental removal of *Alaria esculenta* is likely to cause similar effects to that of direct harvesting; hence, the same evidence has been used for both pressure assessments.

*Alaria esculenta* has recently received commercial interest as a consumable product called "Sea Vegetables" or "Atlantic Wakame Kelp". However, no studies examining the effect of commercial extraction of *Alaria esculenta* biotopes were found. Removal of the algal canopy would expose the understory fauna and flora to increased desiccation. Experimental macroalgal canopy removal experiments conducted in the Isle of Man (Hawkings & Harkin, 1985) found that following the removal of the macroalgal canopy the understory encrusting red algae became bleached and died within a week. *Mytilus edulis* settlement has also been found significantly higher in close proximity to *Alaria esculenta* and is thought to increase beneath *Alaria esculenta* canopies (Bégin *et al.*, 2004). Therefore, any loss of *Alaria esculenta*, as a result of commercial extraction, may dramatically affect the understory community.

Traditionally *Laminaria digitata* was added to agricultural lands as fertilizers; now *Laminaria* species are used in a range of different products, with its alginates used in the cosmetic, pharmaceutical and agri-food industries (Kervarec *et al.*, 1999; McHugh, 2003). *Laminaria digitata* is harvested with a 'Scoubidou' (a curved iron hook which is mechanically operated) in France. This device is considered to be selective- only harvesting individuals older than 2 years (Arzel, 2002). France reportedly harvests 75,000t kelp, mainly consisting of *Laminaria digitata* annually (FAO, 2007). The loss of *Laminaria digitata* would represent a significant change to IR.HIR.KFaR.Ala.Ldig.

*Corallina officinalis* is collected for medical purposes; the fronds are dried and converted to hydroxyapatite and used as bone forming material (Ewers *et al.*, 1987). It is also sold as a powder for use in the cosmetic industry. Moderate trampling on articulated coralline algal turf in the New Zealand intertidal (Brown & Taylor, 1999; Schiel & Taylor, 1999) resulted in reduced turf height, declines in turf densities, and loss of crustose bases in some case probably due to loss of the canopy algae and resultant desiccation. Calcification is thought to be an adaptation to grazing and sediment scour (Littler & Kauker 1984). *Corallina officinalis* produces spores over a protracted period and can colonize artificial substratum within one week in the intertidal (Harlin & Lindbergh 1977; Littler & Kauker 1984). The crustose base enables *Corallina officinalis* to survive the loss of fronds.

**Sensitivity assessment.** There is little evidence for the effects of commercial harvesting of *Alaria esculenta*. If it is assumed that all canopy-forming kelp are removed then resistance would be assessed as '**None**', resilience would be assessed as '**Medium**'. Sensitivity has been assessed as '**Medium**'. Within IR.HIR.KFaR.AlaAnCrSp and IR.HIR.KFaR.Ala.Myt, monospecific canopies of *Alaria esculenta* are expected to recover quicker than mixed canopies of *Laminaria digitata* (as in IR.HIR.KFaR.Ala.Ldig) Sensitivity of the latter would be assessed as follows; resistance '**None**', resilience as '**High**', Sensitivity as '**Medium**'.

## Bibliography

- Azel, P., 2002. La laminaire digitée. *Les nouvelles de l'Ifremer*, **33** (4).
- Azel, P., 1998. *Les laminaires sur les côtes bretonnes. Évolution de l'exploitation et de la flottille de pêche, état actuel et perspectives*. Plouzané, France: Ifremer.
- Baardseth, E., 1956. The growth rings in *Alaria stipes*. In *Proceedings of the International Seaweed Symposium, 2, Trondheim* (eds T. Braarud & N.A. Sorensen) pp. 153-157. London: Pergamon Press.
- Bamber, R.N. & Irving, P.W., 1993. The *Corallina* run-offs of Bridgewater Bay. *Porcupine Newsletter*, **5**, 190-197.
- Bartsch, I., Vogt, J., Pehlke, C. & Hanelt, D., 2013. Prevailing sea surface temperatures inhibit summer reproduction of the kelp *Laminaria digitata* at Helgoland (North Sea). *Journal of Phycology*, **49** (6), 1061-1073.
- Bégin, C., Johnson, L.E. & Himmelman, J.H., 2004. Macroalgal canopies: distribution and diversity of associated invertebrates and effects on the recruitment and growth of mussels. *Marine Ecology Progress Series*, **271** (1), 121-132.
- 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>
- 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 CO<sub>2</sub> world. *Ecology and Evolution*, **4** (13), 2787-2798.
- Brown, P.J. & Taylor, R.B., 1999. Effects of trampling by humans on animals inhabiting coralline algal turf in the rocky intertidal. *Journal of Experimental Marine Biology and Ecology*, **235**, 45-53.
- 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.
- Chapman, A.R.O., 1981. Stability of sea urchin dominated barren grounds following destructive grazing of kelp in St. Margaret's Bay, Eastern Canada. *Marine Biology*, **62**, 307-311.
- 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](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.*
- Cosse, A., Potin, P. & Leblanc, C., 2009. Patterns of gene expression induced by oligoguluronates reveal conserved and environment-specific molecular defence responses in the brown alga *Laminaria digitata*. *New Phytologist*, **182** (1), 239-250.
- Crisp, D.J. & Mwaiseje, B., 1989. Diversity in intertidal communities with special reference to the *Corallina officinalis* community. *Scientia Marina*, **53**, 365-372.
- Crump, R.G., Morley, H.S., & Williams, A.D., 1999. West Angle Bay, a case study. Littoral monitoring of permanent quadrats before and after the *Sea Empress* oil spill. *Field Studies*, **9**, 497-511.
- 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.
- Dommasnes, A., 1968. Variation in the meiofauna of *Corallina officinalis* with wave exposure. *Sarsia*, **34**, 117-124.
- Eckman, J.E. & Duggins, D.O., 1991. Life and death beneath macrophyte canopies: effects of understory kelps on growth rates and survival of marine, benthic suspension feeders. *Oecologia*, **87**, 473-487.
- Eckman, J.E., 1983. Hydrodynamic processes affecting benthic recruitment. *Limnology & Oceanography*, **28** (2), 241-257.
- 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.
- 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.
- Ewers, R., Kasperk, C. & Simmons, B., 1987. Biologisches Knochenimplantat aus Meeresalgen. *Zahnaerztliche Praxis*, **38**, 318-320.
- FAO, 2007. *Aquaculture production: values 1984-2005. FISHSTAT Plus - Universal software for fishery statistical time series [online or CD-ROM]*. Fishery Information, Data and Statistics Unit. Food and Agriculture Organization of the United Nations, Rome, Italy.
- 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., 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].
- 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., 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.
- 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.
- Grahame, J., & Hanna, F.S., 1989. Factors affecting the distribution of the epiphytic fauna of *Corallina officinalis* (L.) on an exposed rocky shore. *Ophelia*, **30**, 113-129.
- Grandy, N., 1984. *The effects of oil and dispersants on subtidal red algae*. Ph.D. Thesis. University of Liverpool.
- Guiry, M.D. & Blunden, G., 1991. *Seaweed Resources in Europe: Uses and Potential*. Chichester: John Wiley & Sons.
- 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.
- Harkin, E., 1981. Fluctuations in epiphyte biomass following *Laminaria hyperborea* canopy removal. In *Proceedings of the X<sup>th</sup> International Seaweed Symposium, Gøteborg, 11-15 August 1980* (ed. T. Levring), pp.303-308. Berlin: Walter de Gruyter.
- Harlin, M.M., & Lindbergh, J.M., 1977. Selection of substrata by seaweed: optimal surface relief. *Marine Biology*, **40**, 33-40.
- 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. & Hartnoll, R.G., 1985. Factors determining the upper limits of intertidal canopy-forming algae. *Marine Ecology Progress Series*, **20**, 265-271.
- 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.
- Hill, T., 1993. *Algal zonation in the sublittoral fringe: the importance of competition*. Ph.D. Thesis., University of Liverpool, Liverpool, UK.
- 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)].
- Hiscock, K., 1983. Water movement. In *Sublittoral ecology. The ecology of shallow sublittoral benthos* (ed. R. Earll & D.G. Erwin), pp. 58-96. Oxford: Clarendon Press.
- 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.
- Hull, S., 1997. Seasonal changes in diversity and abundance of ostracodes on four species of intertidal algae with differing structural complexity. *Marine Ecology Progress Series*, **161**, 71-82.
- 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>
- 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.
- Kervarec, F., Arzel, P. & Guyader, O., 1999. Fisher Behaviour and Economic Interactions Between Fisheries: Examining Seaweed and Scallop Fisheries of the Brest District (Western Brittany, France). *The XIth Annual Conference of the European Association of Fisheries Economists. 6th-10th April 1999, Dublin*, pp.
- Kindig, A.C., & Littler, M.M., 1980. Growth and primary productivity of marine macrophytes exposed to domestic sewage effluents. *Marine Environmental Research*, **3**, 81-100.
- Kinne, O. (ed.), 1971a. *Marine Ecology: A Comprehensive, Integrated Treatise on Life in Oceans and Coastal Waters. Vol. 1 Environmental Factors, Part 2*. Chichester: John Wiley & Sons.
- 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.
- 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., Sjøtun, 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.
- Lewis, J.R., 1964. *The Ecology of Rocky Shores*. London: English Universities Press.
- Littler, M.M., & Kauker, B.J., 1984. Heterotrichy and survival strategies in the red alga *Corallina officinalis* L. *Botanica Marina*, **27**, 37-44.
- 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.
- 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.
- McHugh, D.J., 2003. *A guide to the seaweed industry*: Food and Agriculture Organization of the United Nations Rome.
- 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.
- Munda, I.M. & Luning, K., 1977. Growth performance of *Alaria esculenta* off Helgoland. *Helgolander Wissenschaftliche Meeresuntersuchungen*, **29**, 311-314.
- 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., 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.
- 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
- Pérez, R., 1971. Écologie, croissance et régénération, teneurs en acide alginique de *Laminaria digitata* sur les cotes de la Manche. *Revue des Travaux de l'Institut des Pêches Maritimes*, **35**, 287-346.
- 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.
- 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.

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.

Seapy, R.R. & Littler, M.M., 1982. Population and Species Diversity Fluctuations in a Rocky Intertidal Community Relative to Severe Aerial Exposure and Sediment Burial. *Marine Biology*, **71**, 87-96.

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.

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*.

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.

Sundene, O., 1962. The implications of transplant and culture experiments on the growth and distribution of *Alaria esculenta*. *Nytt Magasin for Botanik*, **9**, 155-174.

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.

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.