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Grazed, mixed *Laminaria hyperborea* and *Saccharina latissima* on sheltered infralittoral rock

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

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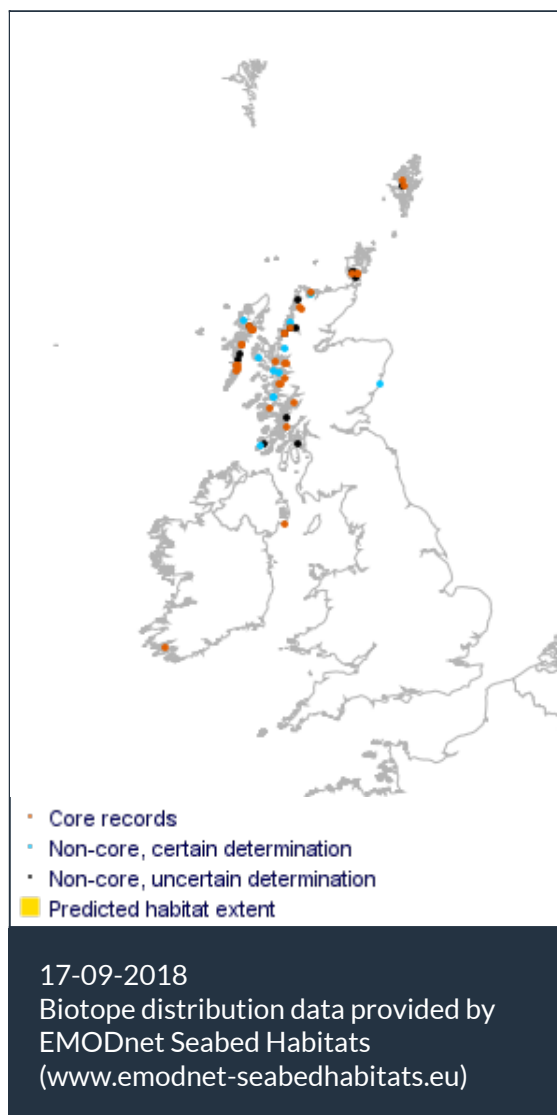
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Researched by Thomas Stamp Refereed by Admin

Summary

☰ UK and Ireland classification

EUNIS 2008	A3.3123	Grazed, mixed <i>Laminaria hyperborea</i> and <i>Laminaria saccharina</i> on sheltered infralittoral rock
JNCC 2015	IR.LIR.K.LhypSlat.Gz	Grazed, mixed <i>Laminaria hyperborea</i> and <i>Saccharina latissima</i> on sheltered infralittoral rock
JNCC 2004	IR.LIR.K.LhypLsac.Gz	Grazed, mixed <i>Laminaria hyperborea</i> and <i>Laminaria saccharina</i> on sheltered infralittoral rock
1997 Biotope		

🔍 Description

Silted infralittoral rock with mixed *Laminaria hyperborea* and *Saccharina latissima* kelp forest, intensively grazed by the echinoderm *Echinus esculentus* and the gastropods *Gibbula cineraria* and *Calliostoma zizyphinum*. Although both kelp species can occur in equal abundance

(Common), *Laminaria hyperborea* usually dominates. The grazing-resistant brown seaweed *Desmarestia aculeata* and *Cutleria multifida* may be present. A similar variety of red seaweeds to those found in the ungrazed kelp forest (LhypSlat.Ft) may occur beneath the kelp canopy, but in much lower abundance. As grazing intensity increases the seaweed cover decreases, and some sites are reduced to the bare appearance of encrusting brown and coralline algae beneath the kelp canopy. The *Laminaria hyperborea* stipes generally support more seaweeds than the rock beneath, including *Cryptopleura ramosa*, *Delesseria sanguinea*, *Phycodrys rubens* and *Bonnemaisonia hamifera*. The stipes may also support sometimes dense ascidians *Clavelina lepadiformis* and *Ciona intestinalis* and the echinoderm *Antedon bifida*. The kelp fronds are often densely covered by the hydroid *Obelia geniculata*. At the most intensively grazed sites even the kelp stipes are bare. Although the rock appears bare, between boulders and in crevices there are often the brittlestar *Ophiothrix fragilis* and the crabs *Necora puber* and *Pagurus bernhardus*. The tube-building *Spirobranchus triqueter* and bryozoan crusts are commonly found on any vertical surfaces.

↓ Depth range

-

Additional information

-

✓ Listed By

- none -

Further information sources

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Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

IR.LIR.K.LhypSlat plus sub-biotopes are characterized by mixed canopies of *Laminaria hyperborea* with *Saccharina latissima* (syn. *Laminaria saccharina*). IR.LIR.K.LhypSlat is predominantly found in Scottish sea lochs, however is also found at sheltered locations around the UK. Although both species can occur in equal abundance (common) *Laminaria hyperborea* usually dominates the biotope. Underneath the kelp canopy and on kelp stipes there is a community of red seaweeds which includes; *Delesseria sanguinea*, *Plocamium cartilagineum*, *Cryptopleura ramosa* and *Callophyllis laciniata*. *Echinus esculentus* also defines IR.LIR.K.LhypSlat.Gz, in which intensive grazing diminishes the understory community.

In wave exposed locations other laminarian kelps (e.g. *Laminaria hyperborea*) can out-compete *Saccharina latissima* or form mixed canopies as in IR.LIR.K.LhypSlat. IR.LIR.K.LhypSlat is typically recorded in sheltered sea lochs of Scotland, however is also recorded in other sheltered locations around the UK. IR.LIR.K.LhypSlat represents an intermediate biotope between a suite of exposed-moderately wave exposed *Laminaria hyperborea* dominated biotopes and the *Saccharina latissima* dominated IR.LIR.K.Slat biotopes found predominantly from sheltered-ultra wave sheltered environments (Connor *et al.*, 2004). Observations from Norwegian fjords have also recorded IR.LIR.K.LhypSlat forming a thin band above IR.LIR.K.Slat (Svendsen & Kain, 1971).

Kelp beds increase the three dimensional complexity of unvegetated rock (Norderhaug, 2004, Norderhaug *et al.*, 2007, Norderhaug & Christie, 2011, Gorman *et al.*, 2012; Moy & Christie, 2012; Smale *et al.*, 2013), support high local diversity, abundance and biomass of epibenthic species (Smale *et al.*, 2013), and serve as nursery grounds for a number of commercial important species, e.g. Atlantic cod and pollock (Rinde *et al.*, 1992).

In undertaking this assessment of sensitivity, account is taken of knowledge of the biology of all characterizing species in the biotope. There is an abundance of literature for regeneration of mono-specific *Laminaria hyperborea* beds, however at the time of writing there is limited research for the recovery of mixed kelp canopies. For this sensitivity assessment *Echinus esculentus*, *Laminaria hyperborea* and *Saccharina latissima* are the primary foci of research, however it is recognized that the understory red seaweed communities also define the biotope. Examples of important species groups are mentioned where appropriate.

Resilience and recovery rates of habitat

Saccharina latissima is a perennial kelp characteristic of wave sheltered sites of the North East Atlantic, distributed from northern Portugal to Spitzbergen, Svalbard (Birkett *et al.*, 1998; Conor *et al.*, 2004; Bekby & Moy, 2011; Moy & Christie, 2012). *Saccharina latissima* is capable of reaching maturity within 15-20 months (Sjøtun, 1993) and has a life expectancy of 2-4 years (Parke, 1948). Maximum growth has been recorded in late winter early spring, in late summer and autumn growth rates slow (Parke, 1948; Lüning, 1979; Birkett *et al.*, 1998). The overall length of the sporophyte may not change during the growth season due to marginal (distal) erosion of the blade, but extension growth of the blade has been measured at 1.1 cm/day, with total length addition of over 2.25m of tissue per year (Birkett *et al.*, 1998). *Saccharina latissima* has a heteromorphic life strategy. Vast numbers of zoospores are released from sori located centrally on the blade between autumn and winter. Zoospores settle onto rock substrata and develop into dioecious gametophytes (Kain, 1979) which, following fertilization, germinate into juvenile sporophytes from

winter-spring. Kelp 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 following disturbance can be influenced by the proximity of mature kelp beds producing viable zoospores to the disturbed area (Kain, 1979; Fredriksen *et al.*, 1995).

The temperature isotherm of 19-20°C has been reported as limiting *Saccharina lattisma* growth (Müller *et al.*, 2009). Gametophytes can develop in $\leq 23^\circ\text{C}$ (Lüning, 1990). However, Bolton & Lüning (1982) reported an experimental optimal temperature of 10-15°C for growth of the *Saccharina latissima* sporophyte. Growth was inhibited by 50-70% at 20°C and, all experimental specimens completely disintegrated after 7 days at 23°C. In the field *Saccharina latissima* has however shown significant regional variation in its acclimation response to changing environmental conditions. For example, Gerard & Dubois (1988) observed sporophytes of *Saccharina latissima* which were regularly exposed to $\geq 20^\circ\text{C}$ could tolerate these high temperatures, whereas sporophytes from other populations which rarely experience $\geq 17^\circ\text{C}$ 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 2002 a large scale decline of *Saccharina latissima* was discovered on the Norwegian coast (Moy & Christie, 2012). A subsequent large survey was undertaken between 2004-2009 of 660 sites covering 34,000km of south and west Norway to assess the decline of *Saccharina latissima* abundance and distribution (Moy & Christie, 2012). The survey indicated an 83% reduction of *Saccharina latissima* forests across the south Norwegian region of Skagerrak. The west Norwegian coast was less affected, but *Saccharina latissima* was either absent or very sparse at 38% of sites where it was expected to be abundant. At all sites where *Saccharina latissima* was sparse a community of ephemeral macro-algae species was dominant and persisted throughout the study period (2004-2009). Bekby & Moy (2011) modelled the regional decline which indicated a decline of 50.7% of *Saccharina latissima* from Skagerrak, Norway. Approximately 50% of Europe's *Saccharina latissima* is found in Norway (Moy *et al.*, 2006), therefore, despite large discrepancies between the two estimates of *Saccharina latissima* decline (50.7-83%) the results indicated a significant decline in *Saccharina latissima* across the region. Moy & Christie (2012) suggested the ephemeral filamentous macroalgae communities represented a stable state shift that had persisted throughout the study period (2004-2009). Although no measurements were made, they suggested that the decline was due to low tidal movement and wave action in the worst affected areas combined with the impacts of dense human populations and increased land run-off. Multiple stressors such as eutrophication, increasing regional temperature, increased siltation and overfishing may also be acting synergistically to cause the observed habitat shift.

Kelp biotopes are partially reliant on low (or no) populations of sea urchins, primarily the species; *Echinus esculentus*, *Paracentrotus lividus* and *Strongylocentrotus droebachiensis*, which graze directly on macroalgae, epiphytes and the understory community. Multiple authors (Steneck *et al.*, 2002; Steneck *et al.*, 2004; Rinde & Sjøtum, 2005; Norderhaug & Christie, 2009; Smale *et al.*, 2013) have reported dense aggregations of sea urchins to be a principal threat to kelp biotopes of the North Atlantic. In northern Norway intense urchin grazing create expansive areas known as 'urchin barrens', in which a shift can occur from kelp dominated biotopes to those characterized by coralline encrusting algae, with a resultant reduction in biodiversity (Lienaaas & Christie, 1996; Steneck *et al.*, 2002, Norderhaug & Christie, 2009). Lienaaas & Christie (1996) removed *Strongylocentrotus droebachiensis* from 'urchin barrens' and observed a succession effect. The substratum was colonized initially by filamentous algae and, after a couple of weeks, these were out-competed by *Saccharina latissima*. However after 2-4 years, *Laminaria hyperborea* dominated

the community. These results demonstrate that *Saccharina latissima* will re-establish quickly in optimal conditions; however in moderately wave exposed conditions will be out-competed by *Laminaria hyperborea*.

Reports of large scale urchin barrens within the North East Atlantic are generally limited to regions of the North Norwegian and Russian Coast (Rinde & Sjøtun, 2005, Nourderhaug & Christie, 2009). Within the UK urchin grazed biotopes (IR.MIR.KR.Lhyp.GzFt/Pk, IR.HIR.KFaR.LhypPar, IR.LIR.K.LhypSlat.Gz & IR.LIR.K.Slat.Gz) are generally localised to a few regions in North Scotland and Ireland (Smale *et al.*, 2013; Stenneck *et al.*, 2002; Norderhaug & Christie 2009; Connor *et al.*, 2004). IR.MIR.KR.Lhyp.GzFt/Pk, IR.HIR.KFaR.LhypPar, IR.LIR.K.LhypSlat.Gz & IR.LIR.K.Slat.Gz are characterized by a canopy forming kelp, however, urchin grazing decreases the abundance and diversity of understory species. In the isle of Man Jones & Kain (1967) observed low *Echinus esculentus* grazing pressure can control the lower limit of *Laminaria hyperborea* in the and remove *Laminaria hyperborea* sporelings and juveniles. Urchin abundances in 'urchin barrens' have been reported as high as 100 individuals/m² (Lang & Mann, 1978). Kain (1967) reported urchin abundances of 1-4/m² within experimental plots of the Isle of Man. Therefore while 'urchin barrens' are not presently a large scale issue within the UK, relatively low urchin grazing has been found to control the depth distribution of *Laminaria hyperborea*, negatively impact on *Laminaria hyperborea* recruitment and reduce the understory community abundance and diversity.

In favourable conditions *Laminaria hyperborea* can recover following disturbance events reaching comparable plant densities and size to pristine *Laminaria hyperborea* beds within 2-6 years (Kain, 1979; Birkett *et al.*, 1998; Christie *et al.*, 1998). Holdfast communities may recover in 6 years (Birkett *et al.*, 1998). Full epiphytic community and stipe habitat complexity regeneration requires over 6 years to recover (possibly 10 years). These recovery rates were based on discrete kelp harvesting events and recurrent disturbance occurring frequently within 2-6 years of the initial disturbance is likely to lengthen recovery time (Birkett *et al.*, 1998, Burrows *et al.*, 2014). 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 however within 2 years of clearance the blocks were dominated by *Laminaria hyperborea*.

Laminaria hyperborea has a heteromorphic life strategy, A vast number of zoospores (mobile asexual spores) are released into the water column between October-April (Kain & Jones, 1964). Zoospores settle onto rock substrata and develop into dioecious gametophytes (Kain, 1979) which, following fertilization, develop into sporophytes and mature within 1-6 years (Kain, 1979; Fredriksen *et al.*, 1995; Christie *et al.*, 1998). *Laminaria hyperborea* zoospores have a recorded dispersal range of approximately 200m (Fredriksen *et al.*, 1995). However, zoospore dispersal is greatly influenced by water movements, and zoospore density and the rate of successful fertilization decreases exponentially with distance from the parental source (Fredriksen *et al.*, 1995). Hence, recruitment following disturbance can be influenced by the proximity of mature kelp beds producing viable zoospores to the disturbed area (Kain, 1979, Fredriksen *et al.*, 1995).

Other factors that are likely to influence the recovery of kelp biotopes is competitive interactions with the Invasive Non Indigenous Species (INIS) *Undaria pinnatifida* (Smale *et al.*, 2013; Brodie *et al.*, 2014; Heiser 2014). *Undaria pinnatifida* has received a large amount of research attention as an INIS which could out-compete UK kelp habitats (see Farrell & Fletcher, 2006; Thompson & Schiel, 2012, Brodie *et al.*, 2014; Hieser *et al.*, 2014). *Undaria pinnatifida* was first recorded in Plymouth Sound, UK in 2003 (NBN, 2015) subsequent surveys in 2011 have reported that *Undaria pinnatifida* is widespread throughout Plymouth Sound, colonizing rocky reef habitats. Where *Undaria*

pinnatifida is present there was a significant decrease in the abundance of other *Laminaria* species, including *Laminaria hyperborea* (Heiser *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 of the substratum was partially due to an annual *Undaria pinnatifida* die back, which as noted by Heiser *et al.* (2014) did not occur in Plymouth sound, UK. It is unknown whether *Undaria pinnatifida* will out-compete native macro-algae in the UK. However from 2003-2011 *Undaria pinnatifida* had spread throughout Plymouth sound, UK, becoming a visually dominant species at some locations within summer months (Hieser *et al.*, 2014). At the time of writing there is limited evidence available to assess the ecological impacts of *Undaria pinnatifida* on *Laminaria hyperborea* associated communities. *Undaria pinnatifida* was successfully eradicated on a sunken ship in Clatham Islands, New Zealand, by applying a heat treatment of 70°C (see Wotton *et al.*, 2004) however numerous other eradication attempts have failed, and as noted by Farrell & Fletcher (2006) once established *Undaria pinadifida* resists most attempts of long-term removal. Kelp biotopes are unlikely to fully recover until *Undaria pinnatifida* is fully removed from the habitat, which as stated above is unlikely to occur.

Echinus esculentus is a sea urchin found within Northeast Atlantic, recorded from Murmansk Coast, Russia to Portugal (Hansson, 1998). *Echinus esculentus*, along with other urchins, is an important algal grazer in the North East Atlantic. (Connor *et al.*, 2004). *Echinus esculentus* is estimated to have a lifespan of 8-16 years (Nichols, 1979; Gage, 1992) and reach sexual maturity within 1-3 years (Tyler-Walters, 2008). Maximum spawning occurs in spring although individuals may spawn over a protracted period throughout the year. Gonad weight is at it's maximum in February/March in English Channel (Comely & Ansell, 1989) but decreases during spawning in spring and then increases again through summer and winter until the next spawning season. Spawning occurs just before the seasonal rise in temperature in temperate zones but is probably not triggered by rising temperature (Bishop, 1985). *Echinus esculentus* is a broadcast spawner, with a complex larval life history which includes a blastula, gastrula and a characteristic 4 armed echinopluteus stage that forms an important component of the zooplankton. MacBride (1914) observed planktonic larval development could take 45-60 days in captivity. Recruitment is sporadic or variable depending on locality, e.g. Millport populations showed annual recruitment, whereas few recruits were found in Plymouth populations during Nichols studies between 1980-1981 (Nichols, 1984). Bishop & Earll (1984) suggested that the population of *Echinus esculentus* at St Abbs had a high density and recruited regularly whereas the Skomer population was sparse, ageing and had probably not successfully recruited larvae in the previous 6 years (Bishop & Earll, 1984). Comely & Ansell (1988) noted that the largest number of *Echinus esculentus* occurred below the kelp forest.

Echinus esculentus is a mobile species (Tyler-Walters, 2008) and could therefore migrate and re-populate an area quickly if removed. For example, Lewis & Nichols (1979) found that adults were able to colonize an artificial reef in small numbers within 3 months and the population steadily grew over the following year. If completely removed from a site and local populations are naturally sparse then recruitment may be dependent on larval supply which can be highly variable. As suggested by Bishop & Earll (1984) the Skomer, Wales *Echinus esculentus* population had most likely not successfully recruited for 6 years which would suggest the mature population would be highly sensitive to removal and may not return for several years. On 19th November 2002 the *Prestige* oil tanker spilled 63 000t of fuel 130 nautical miles off Galicia, Spain. High wave exposure and strong weather systems increased mixing of the oil to "some" depth within the water column, causing sensitive faunal communities to be effected. Preceding and for nine years following the oil spill, the biological community of Guéthary, France was monitored. Following the oil spill taxonomic richness decreased significantly from 57 recorded species to 41, which included the

loss of *Echinus esculentus* from the site. 2-3 years after the oil spill taxonomic richness had increased to pre-spill levels and *Echinus esculentus* had returned (Castège *et al.*, 2014).

Resilience assessment. Of the 2 kelp species (*Laminaria hyperborea* and *Saccharina latissima*) that characterize IR.LIR.K.LhypSlat plus associated sub-biotopes, *Laminaria hyperborea* is the slowest to recover following disturbance. *Laminaria hyperborea* can regenerate from disturbance within a period of 1-6 years, and the associated community within 7-10 years. *Saccharina latissima* has reportedly a rapid recovery rate or re-generation time, following clearance of *Strongylocentrotus droebachiensis* from 'urchin Barrens' *Saccharina latissima* was a rapid colonizer appearing after a few weeks, and can reach maturity within 15-20 months (Birkett *et al.*, 1998). *Echinus esculentus* can reportedly reach sexual maturity within 1-2 years (Tyler-Walters, 2008), however as highlighted by Bishop & Earll (1984) and Castège *et al.*, (2014) recovery may take 2-6 years (possibly more if local recruitment is poor). Due to comparatively slow growth rates resilience estimates are largely based on *Laminaria hyperborea*, however the recovery of *Saccharina latissima* and the understory red seaweed is accounted for where relevant. Resilience has therefore been assessed as 'Medium'.

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

Kain (1964) stated that *Laminaria hyperborea* sporophyte growth and reproduction could occur within a temperature range of 0-20°C. Upper and lower lethal temperatures have been estimated at between 1-2°C above or below the extremes of this range (Birkett *et al.*, 1988). Above 17°C *Laminaria hyperborea* gamete survival is reduced (Kain, 1964 & 1971) and gametogenesis is inhibited at 21°C (Dieck, 1992). It is therefore likely that *Laminaria hyperborea* recruitment will be impaired at a sustained temperature increase of above 17°C. Sporophytes however can tolerate slightly higher temperatures of 20°C. Temperature tolerances for *Laminaria hyperborea* are also seasonally variable and temperature changes are less tolerated in winter months than summer months (Birkett *et al.*, 1998).

The temperature isotherm of 19-20°C has been reported as limiting *Saccharina latissima* growth (Müller *et al.*, 2009). Gametophytes can develop in ≤23°C (Lüning, 1990). Optimal temperature for *Saccharina latissima* sporophyte growth was 10-15°C (Bolton & Lüning, 1982), while reported growth was inhibited by 50-70% at 20°C and all experimental specimens completely disintegrated after 7 days at 23°C. In the field, *Saccharina latissima* has however shown significant regional variation in its acclimation response to changing environmental conditions. For example Gerard & Dubois (1988) found *Saccharina latissima* sporophytes which were regularly exposed to ≥20°C could tolerate these high 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 *Saccharina latissima* to a change in temperatures is likely to be locally variable.

Andersen *et al.* (2011) transplanted *Saccharina latissima* in the Skagerrak region, Norway and from 2006-2009. There was annual variation however high mortality occurred from August-November within each year of the experiment. In 2008 of the original 17 sporophytes 6 survived from March-September (approx. 65% mortality rate). All surviving sporophytes were heavily fouled by epiphytic organisms (estimated cover of 80 & 100%). Between 1960-2009, sea surface

temperatures in the region have regularly exceeded 20°C and so has the duration which temperatures remain above 20°C. High sea temperatures has been linked to slow growth of *Saccharina latissima* which is likely to decrease the photosynthetic ability of, and increase the vulnerability of *Saccharina latissima* to epiphytic loading, bacterial and viral attacks (Anderson *et al.*, 2011). These factors combined with establishment of annual filamentous algae in Skegerrak, Norway are likely to prevent the establishment of self sustaining populations in the area (Anderson *et al.*, 2011; Moy & Christie, 2012).

Bishop (1985) suggested that *Echinus esculentus* cannot tolerate high temperatures for prolonged periods due to increased respiration rate and resultant metabolic stress. Ursin (1960) reported *Echinus esculentus* occurred at temperatures between 0-18°C in Limfjord, Denmark. Bishop (1985) noted that gametogenesis occurred at 11-19°C however, continued exposure to 19°C disrupted gametogenesis. Embryos and larvae developed abnormally after 24hr exposure to 15°C but normally at 4, 7 and 11°C (Tyler & Young, 1998).

IR.LIR.K.LhypSlat is distributed throughout the UK (Connor *et al.*, 2004). Northern to southern Sea Surface Temperature (SST) ranges from 8-16°C in summer and 6-13°C in winter (Beszczynska-Möller & Dye, 2013).

Sensitivity assessment. A 2°C increase for one year may approach the upper temperature threshold of *Echinus esculentus*, impair *Laminaria hyperborea* recruitment processes and *Saccharina latissima* sporophyte growth. A 5°C increase for one month combined with high UK summer temperatures is likely to affect *Laminaria hyperborea* sporophyte growth. *Saccharina latissima* populations that are not acclimated to >20°C may incur mass mortality within 3 weeks of exposure. Resistance has been assessed as 'None', to reflect the potential mass mortality effect of sudden temperature increases on *Saccharina latissima*, and 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

Kain (1964) stated that *Laminaria hyperborea* sporophyte growth and reproduction could occur within a temperature range of 0-20°C. Upper and lower lethal temperatures have been estimated at between 1-2°C above or below the extremes of these ranges (Birkett *et al.*, 1988). *Saccharina latissima* has a lower temperature threshold for sporophyte growth at 0°C (Lüning, 1990). Subtidal red algae can survive at temperatures between -2 °C and 18-23 °C (Lüning, 1990; Kain & Norton, 1990).

Echinus esculentus has been recorded from the Murmansk Coast, Russia (Hansson, 1998). Due to the high latitude at which *Echinus esculentus* can occur it is unlikely to be affected at the pressure benchmark.

Sensitivity assessment. *Echinus esculentus*, *Laminaria hyperborea* and *Saccharina latissima* have northern distributions (Birkett *et al.*, 1998; Hansson, 1998). An acute or long-term decrease in temperature within the UK, at the benchmark level, is not likely to have any dramatic effect on biotope structure. Resistance has been assessed as 'High', resilience as 'High' and sensitivity as 'Not sensitive'.

Salinity increase (local)**Low**

Q: High A: High C: High

Medium

Q: High A: Low C: High

Medium

Q: High 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 and growth rates are likely to be affected by periodic salinity stress. Birkett *et al.* (1998) suggested that long-term increases in salinity may affect *Laminaria hyperborea* growth and may result in loss of affected kelp, and therefore loss of the biotope.

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 affect of long-term salinity changes (>5 days) or salinity >60 PSU on *Saccharina latissima*' photosynthetic ability was not tested. 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 and quicker.

Echinoderms are generally stenohaline and possess no osmoregulatory organ (Booolootian, 1966). Therefore an increase in salinity may cause *Echinus esculentus* mortality.

Sensitivity assessment. The evidence suggests that *Saccharina latissima* can tolerate exposure to hypersaline conditions of $\geq 40\%$. However, optimal salinities for *Laminaria hyperborea* growth are assumed to be 30-35 psu. An increase in salinity may cause *Echinus esculentus* mortality. Resistance has been assessed as 'Low', resilience as 'Medium'. The sensitivity of this biotope to an increase in salinity has been assessed as 'Medium'.

Salinity decrease (local)**Low**

Q: High A: High C: High

Medium

Q: High A: Low C: High

Medium

Q: High 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 and growth rates are likely to be affected by periodic salinity stress. Birkett *et al.*, (1998) suggest that long-term changes in salinity may result in loss of affected kelp. Hopkin & Kain (1978) tested *Laminaria hyperborea* sporophyte growth at various low salinity treatments. The results showed that *Laminaria hyperborea* sporophytes could grow 'normally' at 19 psu, growth was reduced at 16 psu and did not grow at 7 psu.

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 affect of long-term salinity changes (>5 days) or salinity >60

PSU on *Saccharina latissima*' photosynthetic ability was not tested. 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 and quicker.

Echinoderms are generally unable to tolerate low salinity (stenohaline) and possess no osmoregulatory organ (Boolootian, 1966). At low salinity urchins gain weight, and the epidermis loses its pigment as patches are destroyed; prolonged exposure is fatal. However, within *Echinus esculentus* there is some evidence to suggest intracellular regulation of osmotic pressure due to increased amino acid concentrations. Furthermore as highlighted the Marine Nature Conservation Review (MNCR) records of 23rd Oct 2014 show *Echinus esculentus* is found within a number of variable and reduced salinity biotopes, e.g. IR.LIR.KVS.SlatPsaVS.

Sensitivity assessment. A decrease in one MNCR salinity scale from 'Full Salinity' (30-40psu) to 'Reduced Salinity' (18-30 psu) may result in a decrease of *Laminaria hyperborea* sporophyte. Resistance has been assessed as '**Low**' and resilience as '**Medium**'. Therefore, sensitivity of this biotope to a decrease in salinity has been assessed as '**Medium**'.

Water flow (tidal current) changes (local)

High

Q: Medium A: High C: High

High

Q: Medium A: High C: High

Not sensitive

Q: Medium A: High C: High

Peteiro & Freire (2013) measured *Saccharina latissima* growth from 2 sites, the first had maximal water velocities of 0.3m/sec and the second 0.1m/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) found *Saccharina latissima* productivity is reduced in moderately strong tidal streams (≤ 1 m/sec) when compared to weak tidal streams (< 0.5 m/sec). Despite the results published in Gerard & Mann (1979) *Saccharina latissima* can characterize or be a dominant in the tide swept biotopes IR.MIR.KT.XKTX & IR.MIR.KT.SlatT, which have been recorded from very strong (> 3 m/sec) to moderately strong tidal streams (≤ 1 m/sec) (Connor *et al.*, 2004), indicating *Saccharina latissima* can tolerate greater tidal streams than < 1 m/sec.

Kregting *et al.* (2013) measured *Laminaria hyperborea* blade growth and stipe elongation from an exposed and a sheltered site in Strangford Lough, Ireland, from March 2009-April 2010. Maximal significant wave height (Hm0) was 3.67 & 2m at the exposed and sheltered sites, and maximal water velocity (Velrms) was 0.6 & 0.3m/s at the exposed and sheltered sites respectively. Despite the differences in wave exposure and water velocity there was no significant difference in *Laminaria hyperborea* growth between the exposed and sheltered sites. Therefore water flow was found to have no significant effect on *Laminaria hyperborea* growth at the observed range of water velocities.

Echinus esculentus occurred in kelp beds on the west coast of Scotland in currents of about 0.5 m/sec. Outside the beds specimens were occasionally seen being rolled by the current (Comely & Ansell, 1988), which may have been up to 1.4 m/sec. Urchins are removed from the stipe of kelps by wave and current action. *Echinus esculentus* are also displaced by storm action. After disturbance *Echinus esculentus* migrates up the shore, an adaptation to being washed to deeper water by wave action (Lewis & Nichols, 1979). Therefore, increased water flow may remove the population from the affected area; probably to deeper water although individuals would probably

not be killed in the process and could recolonize the area quickly.

Sensitivity assessment. IR.LIR.K.LhypSlat plus sub-biotopes are classed as low energy biotopes, found predominantly in weak tidal streams (<0.5 m/sec). Large scale changes tidal velocities (~>1 m/sec) may increase the predominance of tide swept biotopes (e.g. IR.MIR.KR.LhypT/X, IR.MIR.KT.XKTX or IR.MIR.KT.SlatT) and replace IR.LIR.K.LhypSlat. However, the available evidence suggests that a change in flow velocities of between 0.1-0.2 m/sec would have little effect. Resistance has been assessed as '**High**', resilience as '**High**'. Sensitivity has been assessed as '**Not Sensitive**' at the benchmark level..

Emergence regime changes

Low

Q: Low A: NR C: NR

Medium

Q: High A: Low C: High

Medium

Q: Low A: NR C: NR

IR.LIR.K.LhypSlat plus associated sub-biotopes are recorded predominantly in the sublittoral. An increase in emergence will result in an increased risk of desiccation and mortality of the dominant kelp species (*Laminaria hyperborea* & *Saccharina latissima*) in shallow examples of the biotope. Removal of canopy forming kelps has also been shown to increase desiccation and mortality of the understory macro-algae (Hawkins & Harkin, 1985). Several mobile species such as sea urchins, brittle stars and feather stars are likely to move away. However, 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. Resilience has been assessed as '**Low**'. Resistance as '**Medium**'. The sensitivity of this biotope to a change in emergence is considered as '**Medium**'.

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

IR.LIR.K.LhypSlat represents an intermediate biotope between a suite of exposed-moderately wave exposed *Laminaria hyperborea* dominated biotopes and the *Saccharina latissima* characterized IR.LIR.K.Slat biotopes found in very wave sheltered environments (Connor *et al.*, 2004). Large changes in local wave height may affect the proportion/dominance of *Laminaria hyperborea* and *Saccharina latissima* and change the biotope structure. Changes in local wave height also have the potential to increase urchin dislodgement from IR.LIR.K.LhypSlat.Gz, and potentially decrease urchin grazing.

Kregting *et al.* (2013) measured *Laminaria hyperborea* blade growth and stipe elongation from an exposed and a sheltered site in Strangford Lough, Ireland from March 2009-April 2010. Wave exposure was found to be between 1.1. to 1.6 times greater between the exposed and sheltered sites. Maximal significant wave height (Hm0) was 3.67 & 2m at the exposed and sheltered sites. Maximal water velocity (Velrms) was 0.6 & 0.3m/s at the exposed and sheltered sites. Despite the differences in wave exposure and water velocity there was no significant difference in *Laminaria hyperborea* growth between the exposed and sheltered site.

However, Pederson *et al.* (2012) observed *Laminaria hyperborea* biomass, productivity and density increased with greater wave exposure. At low wave exposure *Laminaria hyperborea* canopy forming plants were smaller, had lower densities and had higher mortality rates. At low wave exposure, high epiphytic loading on *Laminaria hyperborea* was suggested to impair photosynthesis, nutrient uptake, and increase the drag of the host *Laminaria hyperborea* during extreme storm

events. The morphology of kelp stipe and blades vary in different water flows and wave exposures water flow. In wave exposed areas, for example, *Laminaria hyperborea* develops a long and flexible stipe and this is probably a functional adaptation to strong water movement (Sjøtun *et al.*, 1998). In addition, the lamina becomes narrower and thinner in strong currents (Sjøtun & Fredriksen, 1995).

Saccharina latissima is rarely found at wave exposed sites (Birkett *et al.*, 1998). *Saccharina latissima*, if present, develops a short thick stipe and a short, narrow and tightly wrinkled blade (Birkett *et al.*, 1998).

Echinus esculentus occurred in kelp beds on the west coast of Scotland in currents of about 0.5 m/sec. Outside the beds specimens were occasionally seen being rolled by the current (Comely & Ansell, 1988), which may have been up to 1.4 m/sec. Urchins are removed from the stipe of kelps by wave and current action. *Echinus esculentus* are also displaced by storm action. After disturbance *Echinus esculentus* migrates up the shore, an adaptation to being washed to deeper water by wave action (Lewis & Nichols, 1979). Keith Hiscock (pers. comm.) reported *Echinus esculentus* occurred in significant numbers as shallow as 15m below low water at the extremely wave exposed site of Rockall, Scotland. Therefore, localised increases in wave height may remove the population from the affected area; probably to deeper water although individuals would probably not be killed in the process and could recolonize the area quickly.

Sensitivity assessment. Wave exposure is one of the principal defining features of kelp biotopes, and changes in wave exposure are likely to alter the relative abundance of the kelp species, grazing and understory community, and hence, the biotope. However a change in near shore significant wave height of 3-5% is unlikely to have any significant effect. Resistance has been assessed as 'High', resilience as 'High' and sensitivity 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 *Laminaria hyperborea* 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). *Echinus esculentus* recruitment is likely to be impaired by heavy metal contamination due to the intolerance of its larvae. *Echinus esculentus* are long-lived and poor recruitment may not reduce grazing pressure in the short-term. 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.

Sporophytes of *Saccharina latissima* have a low intolerance to heavy metals, but the early life stages

are more intolerant. The effects of copper, zinc and mercury on *Saccharina latissima* have been investigated by Thompson & Burrows (1984). They observed that the growth of sporophytes 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. Little is known about the effects of heavy metals on echinoderms. Bryan (1984) reported that early work had shown that echinoderm larvae were intolerant of heavy metals, e.g. the intolerance of larvae of *Paracentrotus lividus* to copper (Cu) had been used to develop a water quality assessment. Kinne (1984) reported developmental disturbances in *Echinus esculentus* exposed to waters containing 25 µg / l of copper (Cu). Sea-urchins, especially the eggs and larvae, are used for toxicity testing and environmental monitoring (reviewed by Dinnel et al. 1988). Taken together with the findings of Gomez & Miguez-Rodriguez (1999) above it is likely that echinoderms are intolerant of heavy metal contamination.

Little is known about the effects of heavy metals on echinoderms. Bryan (1984) reported that early work had shown that echinoderm larvae were sensitive to heavy metals contamination, for example Migliaccio *et al.* (2014) reported exposure of *Paracentrotus lividis* larvae to increased levels of cadmium and manganese caused abnormal larval development and skeletal malformations. Kinne (1984) reported developmental disturbances in *Echinus esculentus* exposed to waters containing 25 µg / l of copper (Cu).

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.

Laminaria hyperborea and *Saccharina latissima* fronds, being predominantly subtidal, would not come into contact with freshly released oil but only to sinking emulsified oil and oil adsorbed onto particles (Birkett *et al.*, 1998). The mucilaginous slime layer coating of laminariales 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 kelp forests. Similarly, surveys of subtidal communities at a number sites between 1-22.5m below chart datum, including *Laminaria hyperborea* communities, showed no noticeable impacts of the Sea Empress oil spill and clean up (Rostron & Bunker, 1997). An assessment of holdfast fauna in *Laminaria* showed that although species richness and diversity decreased with increasing proximity to the Sea Empress oil spill, overall the holdfasts contained a reasonably rich and diverse fauna, even though oil was present in most samples (Sommerfield & Warwick, 1999). Laboratory studies of the effects of oil and dispersants on several red algae species, including *Delesseria sanguinea* (Grandy 1984; cited in Holt *et al.*, 1995) concluded that they were all sensitive to oil/ dispersant mixtures, with little differences between adults, sporelings, diploid or haploid life stages. Holt *et al.* (1995) concluded that *Delesseria sanguinea* is probably generally sensitive of chemical contamination. Loss of red algae is likely to reduce the species richness and diversity of IR.LIR.K.LhypSlat.

Echinus esculentus is subtidal and unlikely to be directly exposed to oil spills. However, as with the 'Prestige' oil spill rough seas can cause mixing with the oil and the seawater, and therefore sub-tidal habitats can be affected by the oil spill. Castège *et al.*, (2014) recorded the recovery of rocky shore communities following the *Prestige* oil spill which impacted the French Atlantic coast. Rough weather at the time of the spill increased mixing between the oil and seawater, causing sub-tidal communities/habitats to be affected. The urchin *Echinus esculentus* was reported absent after the

oil spill however returned after 2-5 years. Large numbers of dead *Echinus esculentus* were found between 5.5 and 14.5 m in the vicinity of Sennen cove, presumably due to a combination of wave exposure and heavy spraying of dispersants following the 'Torrey canyon' oil spill (Smith 1968). Smith (1968) also demonstrated that 0.5 -1ppm of the detergent BP1002 resulted in developmental abnormalities in its echinopluteus larvae. *Echinus esculentus* populations in the vicinity of an oil terminal in A Coruna Bay, Spain, showed developmental abnormalities in the skeleton. The tissues contained high levels of aliphatic hydrocarbons, naphthalenes, pesticides and heavy metals (Zn, Hg, Cd, Pb, and Cu) (Gomez & Miguez-Rodriguez 1999).

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.

Although *Laminaria hyperborea* sporelings and gametophytes are intolerant of atrazine (and probably other herbicides) overall they may be relatively tolerant of synthetic chemicals (Holt *et al.*, 1995; Johansson, 2009). *Laminaria hyperborea* survived within >55m from the acidified halogenated effluent discharge polluting Amlwch Bay, Anglesey, albeit at low density. These specimens were greater than 5 years of age, suggesting that spores and/or early stages were more intolerant (Hoare & Hiscock, 1974). *Patella pellucida* was excluded from Amlwch Bay by the pollution and the species richness of the holdfast fauna decreased with proximity to the effluent discharge; amphipods were particularly intolerant although polychaetes were the least affected (Hoare & Hiscock, 1974). The richness of epifauna/flora decreased near the source of the effluent and epiphytes were absent from *Laminaria hyperborea* stipes within Amlwch Bay. The red alga *Phyllophora membranifolia* was also tolerant of the effluent in Amlwch Bay.

Smith (1968) also noted that epiphytic and benthic red algae were intolerant of dispersant or oil contamination due to 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. *Delesseria sanguinea* was probably to most intolerant since it was damaged at depths of 6m (Smith, 1968). Holt *et al.*, (1995) suggested that *Delesseria sanguinea* is probably generally sensitive of chemical contamination. Although *Laminaria hyperborea* may be relatively insensitive to synthetic chemical pollution, evidence suggests that grazing gastropods, amphipods and red algae are sensitive. Loss of red algae is likely to reduce the species richness and diversity of the biotope and the understory may become dominated by encrusting corallines; however, red algae are likely to recover relatively quickly.

Large numbers of dead *Echinus esculentus* were found between 5.5 and 14.5 m in the vicinity of Sennen, presumably due to a combination of wave exposure and heavy spraying of dispersants in that area following the Torrey Canyon oil spill (Smith 1968). Smith (1968) also demonstrated that 0.5 -1ppm of the detergent BP1002 resulted in developmental abnormalities in echinopluteus larvae of *Echinus esculentus*. *Echinus esculentus* populations in the vicinity of an oil terminal in A

Coruna Bay, Spain, showed developmental abnormalities in the skeleton. The tissues contained high levels of aliphatic hydrocarbons, naphthalenes, pesticides and heavy metals (Zn, Hg, Cd, Pb, and Cu) (Gomez & Miguez-Rodriguez 1999).

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: Low C: Low

High

Q: High A: Low C: High

Not sensitive

Q: Medium A: Low C: Low

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).

In general, respiration in most marine invertebrates do not appear to be significantly affected until extremely low concentrations are reached. For many benthic invertebrates this concentration is about 2 ml l⁻¹, or even less (Herreid, 1980; Rosenberg *et al.*, 1991; Diaz & Rosenberg, 1995).

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

This biotope is considered to be '**Not sensitive**' at the pressure benchmark that assumes compliance with good status as defined by the WFD.

Conolly & Drew (1985) found *Saccharina latissima* sporophytes had relatively higher growth rates when in close proximity to a sewage outlet in St Andrews, UK when compared to other sites along the east coast of Scotland. At St Andrews nitrate levels were 20.22µM, which represents an approx 25% increase when compared to other comparable 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 Salmon farms, where elevated ammonium can be readily absorbed. 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 occurred. 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 however could also be time dependant.

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 macro-algal 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).

Holt *et al.* (1995) suggest that *Laminaria hyperborea* may be tolerant of organic enrichment since healthy populations are found at ends of sub littoral untreated sewage outfalls in the Isle of Man. Increased nutrient levels e.g. from sewage outfalls, has been associated with increases in abundance, primary biomass and *Laminaria hyperborea* stipe production but with concomitant decreases in species numbers and diversity (Fletcher, 1996). Increases in ephemeral and opportunistic algae are associated with reduced numbers of perennial macrophytes (Fletcher, 1996). Increased nutrients may also result in phytoplankton blooms that increase turbidity.

It was suggested by Comely & Ansell (1988) that *Echinus esculentus* could absorb dissolved organic material for the purposes of nutrition. Nutrient enrichment may encourage the growth of ephemeral and epiphytic algae and therefore increase sea-urchin food availability. Lawrence (1975) reported that sea urchins had persisted over 13 years on barren grounds near sewage outfalls, presumably feeding on dissolved organic material, detritus, plankton and microalgae, although individuals died at an early age.

Organic enrichment

Medium

Q: High A: High C: High

High

Q: High A: High C: High

Low

Q: High A: High C: High

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Sensitivity assessment. Although nutrients may not affect kelps directly, indirect effects such as turbidity may significantly affect photosynthesis. Furthermore organic enrichment may denude the associated community. Resistance has therefore been assessed as '**Medium**', resilience as '**High**'. Sensitivity has been assessed as '**Low**'.

A Physical Pressures

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

All marine habitats and benthic species are considered to have a resistance of '**None**' to this pressure and to be unable to recover from a permanent loss of habitat (resilience is '**Very Low**'). Sensitivity within the direct spatial footprint of this pressure is therefore '**High**'. Although no specific evidence is described confidence in this assessment is '**High**', due to the incontrovertible nature of this pressure.

Physical change (to another seabed type)	None Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High
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If rock substrata were replaced with sedimentary substrata this would represent a fundamental change in habitat type, which kelp species would not be able to tolerate (Birkett *et al.*, 1998). 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 sedimentary or soft rock substrata to hard

rock or artificial substrata or vice-versa is assessed as 'High'.

Physical change (to another sediment type)

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant

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 substratum (rock) biotopes.

Abrasion/disturbance of the surface of the substratum or seabed

Low

Q: High A: High C: High

Medium

Q: High A: High C: High

Medium

Q: High A: High C: High

Low level disturbances (e.g. solitary anchors and scallop dredges) are unlikely to cause harm to the biotope as a whole, due to the impact's small footprint. Commercial *Laminaria hyperborea* trawling occurs in Norway. Please refer to resilience section for more detail however trawling typically removes all large canopy forming sporophytes (Christie *et al.*, 1998). *Saccharina latissima* is commercially cultivated, however typically sporophytes are matured on ropes (Handå *et al.* 2013) and not directly extracted from the seabed. Thus evidence to assess the resistance of *Saccharina latissima* to in/direct harvesting or abrasion is limited.

Christie *et al.* (1998) observed *Laminaria hyperborea* habitat regeneration following commercial *Laminaria hyperborea* trawling in south Norway. Within the study area trawling removed all large canopy-forming adult *Laminaria hyperborea*, however sub-canopy recruits were unaffected. Within 2-6 years of harvesting a new canopy had formed 1m off the seabed. The associated holdfast communities recovered in 6 years however the epiphytic stipe community did not fully recover within the same time period. Christie *et al.*, (1998) suggested that kelp habitats were relatively resistant to direct disturbance of *Laminaria hyperborea* canopy.

Species with fragile tests, such as *Echinus esculentus* were reported to suffer badly as a result of scallop or queen scallop dredging (Bradshaw *et al.*, 2000; Hall-Spencer & Moore, 2000). Kaiser *et al.* (2000) reported that *Echinus esculentus* were less abundant in areas subject to high trawling disturbance in the Irish Sea. Jenkins *et al.* (2001) conducted experimental scallop trawling in the North Irish sea and recorded the damage caused to several conspicuous megafauna species, both when caught as bi-catch and when left on the seabed. The authors predicted 16.4% of *Echinus esculentus* were crushed/dead, 29.3% would have >50% spine loss/minor cracks, 1.1% would have <50% spine loss and the remaining 53.3% would be in good condition. Sea urchins can rapidly regenerate spines, e.g. *Psammechinus miliaris* were found to re-grow all spines within a period of 2 months (Hobson, 1930). The trawling examples mentioned above were conducted on sedimentary habitats and thus the evidence is not directly relevant to the rock based biotopes- CR.MCR.EcCr.FaAlCr.Adig, CR.MCR.EcCr.FaAlCr.Pom & CR.MCR.EcCr.FaAlCr.Sec, however does indicate the likely effects of abrasion on *Echinus esculentus*.

Sensitivity assessment. Abrasion by passing trawls or harvesting of macroalgae is likely remove a

large proportion of the kelp biomass and cause high *Echinus esculentus* mortality. Resistance has been assessed as 'Low', resilience as 'Medium', and sensitivity as 'Medium'.

Penetration or disturbance of the substratum subsurface	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Not Relevant to hard substratum (rock) biotopes

Changes in suspended solids (water clarity)	None	Medium	Medium
	Q: High A: High C: High	Q: High A: High C: High	Q: High A: High C: High

Moore (1977) suggested that *Echinus esculentus* was unaffected by turbid conditions. *Echinus esculentus* is an important grazer of red macro-algae within CR.MCR.EcCr. Increased turbidity and resultant reduced light penetration is likely to negatively affect algal growth. However, *Echinus esculentus* can feed on alternative prey, detritus or dissolved organic material (Lawrence, 1975, Comely & Ansell, 1988). Suspended Particle Matter (SPM) concentration has a linear relationship with sub surface light attenuation (Kd) (Devlin *et al.*, 2008). An increase in SPM results in a decrease in sub-surface light attenuation. Light availability and water turbidity are principal factors in determining depth range at which kelp can be found (Birkett *et al.*, 1998). 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 6-7m 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.* 1998).

Laminaria spp. 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). An increase in water turbidity will likely affect the photosynthetic ability of *Laminaria hyperborea* and *Saccharina latissima*, decrease kelp abundance and density and increase the dominance of kelp park biotopes in shallow water (see sub biotope- IR.LIR.K.LhypSlat.Pk). Kain (1964) suggested that early *Laminaria hyperborea* gametophyte development could occur in the absence of light. Furthermore observations from south Norway found that a pool of *Laminaria hyperborea* recruits could persist growing beneath *Laminaria hyperborea* canopies for several years, indicating sporophytes growth can occur in light limited environments (Christie *et al.*, 1998).

Sensitivity Assessment. An increase in water clarity from clear to intermediate (10-100mg/l) represent a change in light attenuation of ca 0.67-6.7 Kd/m, and is likely to result in a greater than 50% reduction in photosynthesis of *Laminaria* spp. Therefore the dominant kelp species will probably suffer a severe decline and resistance to this pressure is assessed as 'None'. Resilience is probably to this pressure is defined as 'Medium' at the benchmark. Hence, this biotope is regarded as having a sensitivity of 'Medium' to this pressure.

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

Smothering by sediment e.g. 5 cm material during a discrete event, is unlikely to damage *Laminaria hyperborea* or *Saccharina latissima* sporophytes but may affect holdfast fauna, gametophyte survival, interfere with zoospore settlement and therefore recruitment processes (Moy & Christie, 2012). Given the short life expectancy of *Saccharina latissima* (2-4 years-(Parke, 1948)), IR.LIR.K.LhypSlat is likely to be dependent on annual *Saccharina latissima* recruitment (Moy & Christie, 2012). Given the microscopic size of the gametophyte, 5 cm of sediment could be expected to significantly inhibit growth. However, laboratory studies showed that kelp gametophytes can survive in darkness for between 6-16 months at 8°C and would probably survive smothering by a discrete event. Once returned to normal conditions the gametophytes resumed growth or maturation within 1 month (Dieck, 1993). Intolerance to this factor is likely to be higher during the peak periods of sporulation and/or spore settlement.

Comely & Ansell (1988) recorded large *Echinus esculentus* from kelp beds on the west coast of Scotland in which the substratum was seasonally covered with "high levels" of silt. This suggests that *Echinus esculentus* is unlikely to be killed by smothering, however, smaller specimens and juveniles may be less resistant. A layer of sediment may interfere with larval settlement. If retained within the host biotope for extended periods a layer of 5cm of the sediment may negatively affect successive recruitment events.

If inundation is long lasting then the understory flora may be adversely affected. If clearance of deposited sediment occurs rapidly then understory communities are expected to recover quickly. In moderately exposed examples of IR.LIR.K.LhypSlat, deposited sediment is unlikely to remain for more than a few tidal cycles (due to water flow or wave action). In wave sheltered examples of IR.LIR.K.LhypSlat, sediment could remain and recovery rate would be related to sediment retention but will probably be dissipated within a year.

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

Smothering and siltation rate changes (heavy)

Medium

Q: Low A: NR C: NR

Medium

Q: High A: Low C: High

Medium

Q: Low A: Low C: Low

Smothering by sediment e.g. 5 cm material during a discrete event, is unlikely to damage *Laminaria hyperborea* or *Saccharina latissima* sporophytes but may affect holdfast fauna, gametophyte survival, interfere with zoospore settlement and therefore recruitment processes (Moy & Christie, 2012). Given the short life expectancy of *Saccharina latissima* (2-4 years-(Parke, 1948)), IR.LIR.K.LhypSlat is likely to be dependent on annual recruitment (Moy & Christie, 2012). Given the microscopic size of the gametophyte, 30cm of sediment could be expected to significantly inhibit growth. However, laboratory studies showed that gametophytes can survive in darkness for between 6-16 months at 8°C and would probably survive smothering by a discrete event. Once returned to normal conditions the gametophytes resumed growth or maturation within 1 month (Dieck, 1993). Intolerance to this factor is likely to be higher during the peak periods of sporulation and/or spore settlement.

Comely & Ansell (1988) recorded large *Echinus esculentus* from kelp beds on the west coast of Scotland in which the substratum was seasonally covered with "high levels" of silt. This suggests that *Echinus esculentus* is unlikely to be killed by smothering, however, smaller specimens and juveniles may be less resistant. A layer of sediment may interfere with larval settlement. If retained within the host biotope for extended periods a layer of 5cm of the sediment may negatively affect successive recruitment events.

If inundation is long lasting then the understory flora may be adversely affected. If clearance of deposited sediment occurs rapidly then understory communities are expected to recover quickly. In moderately exposed examples of IR.LIR.K.LhypSlat, deposited sediment is unlikely to remain for more than a few tidal cycles (due to water flow or wave action). In wave sheltered examples of IR.LIR.K.LhypSlat sediment could remain and recovery rate would be related to sediment retention, which may take a few years to dissipate.

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

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
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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
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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
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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: NR C: NR
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There is no evidence to suggest that anthropogenic light sources would affect *Laminaria hyperborea* or habitats. 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 laminarian abundance from forest to park type biotopes.

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
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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
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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

Saccharina latissima has shown significant regional acclimation to environmental conditions. Gerard & Dubois (1988) found *Saccharina latissima* sporophytes which were regularly exposed to $\geq 20^{\circ}\text{C}$ could tolerate these high temperatures, whereas sporophytes from other populations which rarely experience $\geq 17^{\circ}\text{C}$ showed 100% mortality after 3 weeks of exposure to 20°C . It is therefore possible that transplanted eco-types of *Saccharina latissima* may react differently to environmental conditions that differ from those of their origin. However, there is little evidence for translocation of *Saccharina latissima* over significant geographic distances. Nor is there any evidence regarding the genetic modification or effects of translocation of native kelp populations.

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* are likely to be worst affected and out-competed by *Undaria pinnatifida*. Where present *Undaria pinnatifida* has also corresponded to a decline *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) did not occur in Plymouth sound, UK. It is unknown whether *Undaria pinnatifida* will out-compete native macroalgae in the UK. However, from 2003-2011 *Undaria pinnatifida* had spread throughout Plymouth sound, UK, becoming a visually dominant species at some locations within summer months (Hieser *et al.*, 2014).

Undaria pinnatifida was successfully eradicated on a sunken ship in Clatham Islands, New Zealand, by applying a heat treatment of 70°C (see Wotton *et al.*, 2004) however numerous other

eradication attempts have failed, and as noted by Fletcher & Farrell, (1999) once established *Undaria pinadifida* 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 'None', and resilience 'Very Low'. The sensitivity of this biotope to INIS is assessed as 'High'.

Introduction of microbial pathogens

Medium

Q: Medium A: High C: Medium

High

Q: Low A: NR C: NR

Low

Q: Low A: NR C: NR

Laminaria hyperborea and *Saccharina latissima* may be infected by the microscopic brown alga *Streblonema aecidioides*. 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 (Peters & Scaffelke, 1996). Infection can reduce growth rates of host algae. *Echinus esculentus* is susceptible to 'Bald-sea-urchin disease', which causes lesions, loss of spines, tube feet, pedicellariae, destruction of the upper layer of skeletal tissue and death. It is thought to be caused by the bacteria *Vibrio anguillarum* and *Aeromonas salmonicida*. Bald sea-urchin disease was recorded from *Echinus esculentus* on the Brittany Coast. Although associated with mass mortalities of *Strongylocentrotus franciscanus* in California and *Paracentrotus lividus* in the French Mediterranean it is not known if the disease induces mass mortality (Bower 1996). No evidence of mass mortalities of *Echinus esculentus* associated with disease have been recorded in Britain and Ireland.

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

Removal of target species

Low

Q: High A: High C: High

Medium

Q: High A: High C: High

Medium

Q: High A: High C: High

Incidental/accidental removal of *Laminaria hyperborea* and *Saccharina latissima* is likely to cause similar effects to that of direct harvesting; as such the same evidence has been used for both pressure assessments. There has been recent commercial interest in *Saccharina latissima* as a consumable called 'sea vegetable' (Birkett *et al.*, 1998). *Laminaria hyperborea* is also extracted on a commercial scale in southern Norway, primarily for alginates (Werner & Kraan, 2004).

Commercial *Laminaria hyperborea* trawling occurs in Norway. Please refer to resilience section for more detail however trawling typically removes all large canopy forming sporophytes but sub-canopy sporophytes and understory community remain intact (Christie *et al.*, 1998). *Saccharina latissima* is commercially cultivated, however typically sporophytes are matured on ropes (Handå *et al.* 2013) and not directly extracted from the seabed. Thus evidence to assess the resistance of *Saccharina latissima* to in/direct harvesting or abrasion is limited.

The collection of *Echinus esculentus* for the curio trade was studied by Nichols (1984). He concluded that the majority of divers collected only large specimens that are seen quickly and often missed individuals covered by seaweed or under rocks, especially if small. As a result, a significant proportion of the population remains.

Sensitivity assessment. Commercial extraction removes all large canopy forming kelps (*Laminaria hyperborea*), but sub-canopy sporophytes and understory community remain intact. *Saccharina*

latissima can reportedly recover from disturbance and dominate the substrate within a couple of weeks, however *Laminaria hyperborea* may take up 2-6 years to fully recover, and the associated understory community 7-10 years. Resistance has been assessed as '**Low**', resilience as '**Medium**' and 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

There has been recent commercial interest in *Saccharina latissima* as a consumable called 'sea vegetables' (Birkett *et al.*, 1998). *Laminaria hyperborea* is also extracted on a commercial scale in southern Norway, primarily for alagnate (Werner & Kraan, 2004).

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An intermediate intolerance has been suggested to reflect the possibility that either of these two species may experience some loss.

Sensitivity assessment. Commercial extraction removes all large canopy forming kelps (*Laminaria hyperborea*), but sub-canopy sporophytes and understory community remain intact. *Saccharina latissima* can reportedly recover from disturbance and dominate the substrate within a couple of weeks, however *Laminaria hyperborea* may take up 2-6 years to fully recover, and the associated understory community 7-10 years. Resistance has been assessed as '**None**', Resilience as '**Medium**'. Sensitivity has been assessed as '**Medium**'.

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