OSPAR COMMISSION

Background document on kelp forest habitat

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Background document on kelp forest habitat

OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. The Contracting Parties are Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Convention OSPAR

La Convention pour la protection du milieu marin de l´Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d´Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. Les Parties contractantes sont l´Allemagne, la Belgique, le Danemark, l´Espagne, la Finlande, la France, l´Irlande, l´Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume- Uni de Grande Bretagne et d´Irlande du Nord, la Suède, la Suisse et l´Union européenne

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Contents

Executive Summary

This Background Document on Kelp Forest habitat has been developed by OSPAR following the inclusion of this species on the OSPAR List of threatened and/or declining species and habitats (OSPAR Agreement 2008-6). The inclusion of the feature on the list was supported by an analysis against the Texel-Faial criteria (OSPAR Agreement 2019-03), as presented in the case report (publication 358/2008). This Background Document provides proposals for action and includes measures that could be taken to improve the conservation status of the species. In agreeing to the publication of this document the OSPAR Contracting Parties have indicated the need to further review these proposals. However, the publication of this background document does not imply any formal endorsement of these proposals by the OSPAR Commission. On the basis of the further review of these proposals, OSPAR will continue its work to ensure the protection of Kelp Forest habitat, where necessary in cooperation with other competent organisations. This background document may be updated to reflect further developments or additional information that become available on the status of the species.

Récapitulatif

Le présent document de fond sur Les forêts de varechs a été élaboré par OSPAR après l'inclusion de cette espèce dans la Liste OSPAR des espèces et habitats ménacés et/ou en déclin (Accord OSPAR 2008-6). L'inclusion de l'espèce à été soutenue par une analyse par rapport aux critères Texel-Faial (Accord OSPAR 2019-03), qui se trouve dans le rapport de cas (publication 358/2008). Ce document fournit des proposition d'actions et des mesures qui pourraient être prises dans le but d'améliorer l'état de conservation de l'espèce. En se mettant d'accord sur la publication de ce document, les Parties Contractantes OSPAR ont indiqué la nécessité de réviser de nouveau ces propositions. La publication de ce document ne signifie pas, par conséquence, que la Commission OSPAR adopte elle-même et à titre formel ces propositions. Après la nouvelle révision de ces propositions, OSPAR poursuivra ses travaux dans le but d'assurer la protection de Les forêts de varechs, le cas échéant avec la coopération d'autres organisations compétentes. Ce document de fond pourra être mis à jour pour tenir compte de nouvelles avancées ou des informations nouvelles qui deviendront disponibles concernant le statut de l'éspèce.

a) Threat and link to human activities

Table 1: Listed habitats dominating features (from Case Report OSPAR Publication 787/2021)

Region II	Region III	Region IV
- ***Alaria esculenta*** dominated forest: Probability of significant decline - Potentially threatened - ***Laminaria digitata*** dominated forest: Probability of significant decline - Potentially threatened - ***Saccharina latissima*** dominated forest: Significantly declined - Currently threatened	- ***Alaria esculenta*** dominated forest: Probability of significant decline in the French EEZ - Potentially threatened - ***Laminaria digitata*** dominated forest: Probability of significant decline in the French EEZ - Potentially threatened	- ***Laminaria digitata*** dominated forest: Significantly declined - Currently threatened - ***Laminaria hyperborea*** dominated forest: Severely declined - Currently threatened - ***Laminaria ochroleuca*** dominated forest: Severely declined - Currently threatened - ***Saccharina latissima*** dominated forest: Significantly declined - Currently threatened - ***Saccorhiza polyschides*** dominated forest: Significantly declined - Currently threatened

The potential synergistic or cumulative effects on Kelp Forests of several pressures interacting at the same place and time are still unknown, but exposition to multiple stressors will surely undermine the resistance and resilience of Kelp Forests contributing to their decline (Strain et al. 2015, Araújo et al. 2016). An increasing body of literature demonstrates the transitions from diverse and complex Kelp Forests to simple turf algae mediated by human activities through geographically disparate abiotic (e.g. warming and eutrophication) and biotic (e.g. herbivory and epiphytism) drivers of Kelp Forests loss (Table 2). The mechanistic understanding of each individual pressure and impacts is detailed in Table 2 below.

Table 2: Summary of the main threats and impacts to Kelp Forests[1]

<table>
<tr><th>Type of pressure[2]</th><th>Region II</th><th>Region III (French EEZ only)</th><th>Region IV</th></tr>
<tr><td rowspan="2">Changes in suspended solids (water clarity)</td><td colspan="3"> Cause of threat/human activities[3]: <u>Mariculture (intensive in Region II), Dredging for navigational purposes, Dumping of wastes or other matter (as well as deposits of dredged materials), Land reclamation - Coastal defence; Agriculture [MSFD], Forestry [MSFD], Industrial uses [MSFD], Urban uses [MSFD].</u> General pressure/threat: Distribution of Kelp Forests is strongly linked to turbidity (see turbidity proxies: phytoplankton and suspended material concentrations linked with kelp abundance) (Burrows 2012). The resulting lower light availability for Kelp Forests affect (i) growth, (ii) photosynthetic activity and (iii) kelp density (Spilmont et al. 2009, Jasper & Hill 2015). Given kelps are photophilic algae, turbidity then (iv) reduces depth distribution of Kelp Forests (Birkett et al. 1998) and hence their total surface cover (Eriksson et al. 2002). Conversely, an important increase in water clarity is likely to impact Kelp Forests because of high light stress and resulting photodamages (Díez et al. 2012). Compared to the growing conditions of S. latissima (sheltered conditions) and to a lesser extent L. digitata forests (from wave-exposed to more sheltered conditions), A. esculenta forests are growing in high wave-exposed environment and are therefore less exposed to high turbidity stress. </td></tr>
<tr><td> Level of threat: - High for S. latissima forests - Medium for L. digitata and A. esculenta forests The increase of coastal waters darkening or “browning” in Norway is an important threat to S. latissima forests (Gundersen et al. 2014). In southeast Norway, higher turbidity led to a severe reduction of S. latissima depth distribution (Rueness & Fredriksen 1991, Moy & Christie 2012). On the coast of France (south of Region II), the increase in turbidity likely due to high river discharge, dredging </td><td> Level of threat: Medium Northern and western Brittany waters (France) are usually clear, except for sheltered and very sheltered areas (e.g. rias, estuaries, bays) where turbidity is higher (Derrien-Courtel et al. 2013). L. digitata inhabits exposed sites but can also support more sheltered conditions given water turbidity is low (Raybaud et al. 2013). The increase in turbidity has been reported as one of the potential factors explaining the loss of L. digitata forests in Normandy (south of the region II, border </td><td> Level of threat: Low On the Spanish Basque coast (southeast Bay of Biscay), a decrease in water turbidity has been reported, likely due to lower rain resulting in a decrease in land run-off. A substantial increase in light availability may be a stress factor for some kelp species as observed for other macroalgae (Díez et al. 2012, Quintano et al. 2015). </td></tr>
</table>

[1] [1] Additionnal information on threat in OSPAR region V is provided in Appendix 3

[2] Pressures list from the OSPAR JAMPS 2014-2023 (OSPAR Agreement 2014-02, Table II), completed with additional climate change related pressures from Garrard & Tyler-Walters, 2020.

[3] Human activities listed from the OSPAR JAMP 2014-2023 (OSPAR Agreement 2014-02, Table I), completed with the MFSD list of uses and human activities affecting the marine environment (EU 2017/845, Annex III, Table 2b). Mariculture comprises any type of aquaculture including kelp culture. Climate change is also included as a cause of threat and encapsulates all human activities leading to the different aspects of climate change.

Type of pressure[2]	Region II	Region III (French EEZ only)	Region IV
	activities and climate-driven modifications in wind regime is highly suspected to be one of the main stressors affecting *L. digitata* forests. In highly turbid environments, suspension feeders such as mussels can develop extensively (into banks) and outcompete Kelp Forests (Cosson 1999, F. Gevaert pers. comm.). In region II around the Island of Helgoland, an increase in water clarity led to an amelioration of *L. hyperborea* depth distribution (Pehlke & Bartsch 2008).	with region III) (Cosson 1999). The connectivity of *L. digitata* populations in French region III is impacted by habitat discontinuity (i.e. long sandy beaches) and leads to Kelp Forests isolation (Billot et al. 2003, Valero et al. 2011), making them more prone to additional stress such as increasing turbidity.	
Siltation rate changes (incl. smothering)	**Cause of threat/human activities**: Mariculture (intensive in Region II), Dredging for navigational purposes, Dumping of wastes or other matter (as well as deposits of dredged materials), Land reclamation - Coastal defence; Agriculture [MSFD], Forestry [MSFD], Industrial uses [MSFD], Urban uses [MSFD]. **General pressure/threat**: Operations that lead to an increase in siltation in rocky habitats (e.g. dredging activity, land run-off, coastal defence) have detrimental effects on Kelp Forests (Birkett et al. 1998). Siltation can (i) reduce kelp recruitment by covering the substrate and preventing attachment of spores, (ii) affect growth and development of germlings by smothering and scouring, and (iii) in extreme case reduce photosynthesis activity of adults by smothering (Birkett et al. 1998, Pedersen & Snoeijs 2001, Isæus et al. 2004, Roleda & Dethleff 2011), likely to cause decline in kelp populations. All Kelp Forests growing in sheltered conditions (such as rias, fjords and bays) can be subject to a relatively high siltation stress, particularly if changes in land runoff and water movement regime are occurring. *A. esculenta* forests are growing in high wave-exposed environment and are therefore less exposed to high siltation stress. However, scouring by particles in the water column can have a high impact due to strong hydrodynamism (Birkett et al. 1998).		
	Level of threat: - **High** for *S. latissima* forests - **Medium** for *L. digitata*, *A. esculenta* forests In Norway, an intense increase in area covered by silt caused significant reduction of	**Level of threat: Medium** *No documented regional specificities, general evaluation of threat applies*	**Level of threat: Medium** *No documented regional specificities, general evaluation of threat applies*

Type of pressure[2]	Region II	Region III (French EEZ only)	Region IV
	bare rocks in some sites (e.g. Moy et al. 2008). The effect of siltation on *S. latissima* forests is magnified by the shift toward turf algae that intensely trap sediment and limit kelp recovery (Moy & Christie 2012, Christie et al. 2019). In the south of Region II (border of region III), on the French coast, siltation and smothering are reported as possible factors explaining the loss of *L. digitata* forests (Cosson 1999, Gevaert pers. comm.). The change in sedimentation, enhanced by the extension of mussel banks, limits the recruitment of *L. digitata* and can increase the competition with the invasive macroalgae *Sargassum muticum* (Cosson 1999).		
Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion	**Cause of threat/human activities:** Fisheries, Placement of cables and pipelines, Sand and gravel extraction, Dredging for navigational purposes, Installations and structures, Placement of cables and pipelines, Tourism and recreational activities (Trampling). **Level of threat: Low** Alteration of substrate by dredging gears (targeting specifically Kelp Forests or other species) or for installation of human infrastructures (e.g. cables) can remove patches of kelps, fragment Kelp Forests and alter structure of the seabed and thus the habitat. This pressure is very unlikely for hard rock but is possible in extreme cases or within boulder fields. Species found in lower intertidal shores (i.e. *L. digitata*, *S. latissima*) can be subject to trampling pressure. No impact assessment has been reported yet but trampling on prostrate blades and young recruits could potentially damage kelp individuals (Tyler-Walters & Arnold 2008).		
Nutrient enrichment &	**Cause of threat/human activities**: Mariculture (intensive in Region II), Dumping of wastes or other matter (as well as deposits of dredged materials); Agriculture [MSFD], Forestry [MSFD], Industrial uses [MSFD], Urban uses [MSFD].		

Type of pressure[2]	Region II	Region III (French EEZ only)	Region IV
Organic enrichment	**General pressure/threat**: A minimum level of nutrient is necessary for kelp growth but high level of enrichment can seriously alter kelp development (e.g. Eriksson et al. 2002, reviewed in Filbee-Dexter & Wernberg 2018). The process impacting Kelp Forests are usually driven by two mechanisms: (i) the over-development of kelp epiphytes and (ii) an increase in water turbidity due to phytoplankton bloom (see 'Changes in suspended solids' section). All these sets of pressures and impacts of high nutrient enrichment can be encapsulated in the term "Eutrophication". Eutrophication affects Kelp Forests primarily in moderately wave-exposed to sheltered environment (i.e. archipelagos, rias, fjords and bays) and its effect is usually reduced in exposed sites (Norderhaug et al. 2015). *A. esculenta* forests are growing in high wave-exposed environment where the turnover of seawater is higher and the nutrients continuously renewed and are therefore less exposed to over-enrichment stress.		
	Level of threat: - **High** for *S. latissima* forests - **Medium** for *L. digitata* forests - **Low** for *A. esculenta* forests Excessive nutrient enrichment, often induced by fish farming, sewage discharge and agricultural nutrient run-off (Birkett et al. 1998, Skarbøvik et al. 2017), is responsible for nearshore coastal eutrophication in region II (Cloern 2001). Chronic eutrophication has been identified as one of the main drivers (in combination with climate change) for the replacement of *S. latissima* forests by filamentous turf algae (Pedersen & Snoeijs 2001, Eriksson et al. 2002, Moy & Christie 2012). The excess in nutrients favoured the growth of filamentous species, including kelp epiphytes, whose heavy fouling can cause kelp mortality (Andersen et al. 2011). *S. latissima* inhabiting sheltered	**Level of threat: Low** Nutrient enrichment leading to eutrophication is reported as relatively low in Region III.	**Level of threat: Medium** In the north-western part of the Iberian Peninsula the opposite situation occurs because of a reduction in nutrient availability. The change in wind regime weakens the summer upwelling (Sydeman et al. 2014) and the decrease in land run-off leads to an increase in summer seawater stratification and reduction in nutrient availability. Observations and models suggested that low upwelling and poor nutrient conditions are impacting kelp growth and recruitment (Fernández 2011, Assis et al. 2017, Franco et al. 2018).

<table>
<tr><th>Type of pressure[2]</th><th>Region II</th><th>Region III (French EEZ only)</th><th>Region IV</th></tr>
<tr><td></td><td>environments is particularly impacted by nutrient enrichment.</td><td></td><td></td></tr>
<tr><td rowspan="2">Synthetic compound contamination (incl. pesticides, antifoulant, pharmaceuticals)</td><td colspan="3">Cause of threat/human activities: <u>Mariculture (intensive in Region II), Dumping of wastes or other matter (as well as deposits of dredged materials); Agriculture [MSFD], Forestry [MSFD], Industrial uses [MSFD], Urban uses [MSFD].</u>
General pressure/threat: Kelp Forests are subject to contaminations from terrestrial run-off and coastal activities in the coastal fringe. Herbicides used in both agricultural and non-agricultural situations are reported as very toxic to macroalgae (Cole et al. 1999). Therapeutant used in fish farming can be harmful to wild kelp populations (e.g. hydrogen peroxide against sea lice infections with salmon) (Haugland et al. 2019).</td></tr>
<tr><td>Level of threat:
- Medium for S. latissima forests
- Low for L. digitata, A. esculenta forests
Juveniles of S. latissima growing near fish farms are highly sensitive to chemicals (Haugland et al. 2019).</td><td>Level of threat: Medium
No documented regional specificities, general evaluation of threat applies</td><td>Level of threat: Medium
Pollution has been reported as a highly relevant pressure acting on Kelp Forests reduction in the southern Iberian Peninsula (Araújo et al. 2016).</td></tr>
<tr><td rowspan="2">Transition elements and organo-metal (e.g. TBT contamination)</td><td colspan="3">Cause of threat/human activities: <u>Mariculture (intensive in Region II); Industrial uses [MSFD], Urban uses [MSFD].</u>
General pressure/threat: Metals (such as copper, zinc, mercury, nickel, cadmium) are likely to cause sub-lethal effects on kelp species depending on their concentration in seawater (Tyler-Walters 2008). Accumulation of metals along the food chain can also alter predator survival with possible top-down effect on Kelp Forests (Birkett et al. 1998). Copper is used in fish farming as antifouling coatings on the nets to limit algal growth (Skarbøvik et al. 2017), leading to high discharge and accumulation below the cages (Simpson et al. 2013). Copper pollution is known to impact growth and ontogenic development of S. latissima (Thompson & Burrows 1984, Brinkhuis & Chung 1986). L. digitata and A. esculenta inhabiting respectively wave exposed and highly exposed areas, will be less affected given the preference of fish farms for more sheltered environments.</td></tr>
<tr><td>Level of threat:
- Medium for S. latissima forests
- Low for L. digitata and A. esculenta forests
Copper discharges from intensive fish farming can impact wild populations of S. latissima in the vicinity.</td><td>Level of threat: Low
No documented regional specificities, general evaluation of threat applies</td><td>Level of threat: Medium
Pollution impacting Kelp Forests has been reported in the southern Iberian Peninsula (Araújo et al. 2016).</td></tr>
</table>

Type of pressure[2]	Region II	Region III (French EEZ only)	Region IV
Hydrocarbon and PAH contamination	**Cause of threat/human activities**: Exploration for and exploitation of oil and gas and placement and decommissioning of structures for the exploitation of oil and gas, Maritime transportation. **Level of threat: Low to Medium** Accidental oil spill and chronic hydrocarbon discharge can have toxic effects on Kelp Forests. Kelp species are little susceptible to direct smothering by oil because of the presence of mucilaginous coating (O'Brien & Dixon 1976) but the emulsion of hydrocarbon within seawater can be algicidal and reduce photosynthesis, with higher impact on recruits (Birkett et al. 1998). A chronic low level of pollution can also reduce growth rate of *L. digitata* in the second and third year of growth, but the plants completely recover after an oil-free season (Bokn 1985). Sublittoral fringe and lower intertidal populations of *A. esculenta* and *L. digitata* would be more exposed to oil contamination than subtidal populations. The impact of dispersed oil is uncertain because most studies were conducted on the first-generation dispersants (Lewis & Pryor 2013). Even if the direct impact on kelps is potentially relatively low and depends on concentration levels, the associated faunal and algal community may be seriously damaged by hydrocarbon pollution (Birkett et al. 1998).		
Hydrological process: Water flow changes, emergence regime changes, wave exposure changes	**Cause of threat/human activities**: Land reclamation / Coastal defence, Sand and gravel extraction - Exploration and exploitation of deep sea mineral resources, including deep sea mining, Dredging for navigational purposes, Mariculture (intensive in region II), Installations and structures – offshore wind farms and other marine energy developments, Construction or placement of artificial reefs. **Level of threat: Low** Any alteration of hydrological process (flow rate, emergence regime, wave exposure) can affect Kelp Forests and lead to changes of depositional and erosional patterns (Birkett et al. 1998).		
Introduction or spread of non-indigenous species (NIS)	**Cause of threat/human activities**: Maritime transportation, Mariculture (intensive in region II), Climate change **General pressure/threat**: Competition for substratum, light and nutrients with invasive macroalgal species, such as *Sargassum muticum*, *Undaria pinnatifida*, *Asparagopsis armata*, *Codium fragile* and *Rugulopteryx okamureae* is a threat to native kelp species (Rueness 1989, Jasper & Hill 2015, Casado-Amezúa et al. 2016, 2019, García-Gómez et al. 2020). However, the impact of invasive species may be highly variable and site-specific, and such species can be considered sometimes as *passengers* of change rather than *driver* of decline (Epstein & Smale 2018). *A. esculenta* forests inhabit more exposed sites and no competitions with macroalgal invasive species has been reported so far. Tropical populations of herbivorous fishes have been increasingly reported moving north into the southern OSPAR regions (Franco et al. 2020) with likely associated damages to Kelp Forests similar to other temperate reef systems (Bennett et al. 2015, Vergés et al. 2016, Zarco-Perello et al. 2017).		
	Level of threat: - **High** for *L. digitata* and *S. latissima* forests - **Low** for *A. esculenta* forests	**Level of threat:** - **Medium** for *L. digitata* forests - **Low** for *A. esculenta* forests	**Level of threat: High** Region IV and particularly the Galician Rías region on the north-western Iberian Peninsula are considered

Type of pressure[2]	Region II	Region III (French EEZ only)	Region IV
	S. muticum has replaced many Kelp Forests in the south-west of the Region II in France (Cosson 1999). In Denmark, *S. muticum* invasion was followed by a decrease in abundance of *S. latissima* (Stæhr et al. 2000). The competition is mainly for space and light (Stæhr et al. 2000). Once established, *S. muticum* is known to modify hydrodynamics and could lead to an increase in water turbidity and siltation affecting native kelp species (Cosson 1999).	The threat posed by NIS is poorly documented in region III but, according to documented impacts in region IV, it may be amplified in the future for Kelp Forests of region III.	as a hotspot for NIS introduction (Bárbara 2008). Tropical populations of herbivorous fishes are reported to have moved into temperate areas of Portugal and NW Spain due to seawater warming (Franco et al. 2020) and are very likely to damage Kelp Forests (Tuya et al. 2012, Franco et al. 2015, 2017).
Removal of target species	**Cause of threat/human activities:** Fisheries **General pressure/threat**: Removal of target species can have two kinds of impact on Kelp Forests: (i) direct impacts when kelp species are commercially harvested, i.e. reduction in Kelp Forests; and (ii) indirect impacts when other species are targeted, i.e. overfishing of key predators such as crabs, cods and other predator fishes that can cause different trophic cascades leading to a reduction in kelp populations. Typically, overfishing of urchin' predators can result in an outbreak of urchin populations and intense grazing pressure on Kelp Forests (Steneck et al. 2002, Ling et al. 2009, 2015). Different gears exist for harvesting kelps and the recovery of Kelp Forests will depend on the gear used (Marine Scotland 2016).		
	Level of threat: High Overfishing of piscivorous fishes (such as cods) can result in an increase of small fishes predation on mesograzers, that control the development of epiphytes on *S. latissima* (Moy & Christie 2012). In some cases, overfishing can therefore lead to "pseudo-eutrophication" effect with the overgrown of filamentous algae (e.g. Moksnes et al. 2008, Eriksson et al. 2009). Near the northern limit of Region II, grazing pressure by sea urchins	**Level of threat:** - **High** for *L. digitata* forests - **Medium** for *A. esculenta* forests *L. digitata* wild populations have been commercially harvested in France since the beginning of the 19th. A shift in kelp species composition from *L. digitata* to *S. polyschides* can occur after harvesting (Engelen et al. 2011). This replacement could become durable with increasing seawater temperature pressure as observed in the north of	**Level of threat: Medium** The harvesting of kelp species increased in NW Iberia in recent years (*L. hyperborea*, *L. ochroleuca*, *S. latissima*, *S. polyschides*) but its intensity and impacts have not been properly assessed (Garcia-Tasende & Peteiro 2015, Casado-Amezúa et al. 2019). Given the climatic refuge area for Kelp Forests and ongoing decline in NW Spain and Portugal, this activity is likely to have a strong impact (Casado-Amezúa et al. 2019). Harvesting is an additive factor

Type of pressure[2]	Region II	Region III (French EEZ only)	Region IV
	led to phase shift from Kelp Forests to "simple barrens" (Hagen 1983, Norderhaug & Christie 2009). Fishing of urchin' predators (e.g. edible crab *Cancer Pagurus*, cod *Gadus morhua*) was recognized as an important threat to Kelp Forests (Fagerli et al. 2014).	region IV (Southern Brittany, border of region III) where a gradual replacement has been reported (S. Derrien-Courtel pers. com., Arzel 1998, Engelen et al. 2011). Concurrent habitat fragmentation and intensive harvesting can exacerbate Kelp Forests decline initiated by climate change (Raybaud et al. 2013), therefore leading to a loss of rare genetic diversity and local adaptations for resilience (Robuchon et al. 2014, King et al. 2019, 2020a). It should be noted that *L. hyperborea* (considered as "not declining" in region III but in strong regression in France) is harvested by bottom trawling. The two *Laminaria* fisheries are tightly linked (same vessel but different harvesting gears/timing) and a reduction of *L. digitata* harvesting could lead to activity report on *L. hyperborea*. Direct harvesting of *A. esculenta* is rare but it has recently received commercial interest in UK for food provision as "Sea Vegetables" or "Atlantic Wakame Kelp" (Stamp & Tyler-Walters 2015). No studies report the presence of harvesting in the French EEZ but care should be taken for potential future harvesting activities in trailing edge populations.	limiting the resilience of population to climate change pressure (Borja et al. 2013, Mineur et al. 2015) In the north of Region IV (border region III - south Brittany), *L. digitata* and *L. hyperborea* are commercially harvested. Although kelp harvesting is regulated in France to ensure regrowth of kelp stock and technical adaptations are made to limit mitigate impact on associated communities, there are still a lack of knowledge on Kelp Forests resilience after harvesting. In others regions, full recovery of the whole community is still not reached several years following disturbance (Rinde et al. 1992, Christie et al. 1998, Steen et al. 2016).

<table>
<tr><th>Type of pressure[2]</th><th>Region II</th><th>Region III (French EEZ only)</th><th>Region IV</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Genetic modification and translocation of indigenous species,
Introduction of microbial pathogens</td><td colspan="3">Cause of threat/human activities: <u>Mariculture (kelp culture only).</u>
Level of threat: Low to Medium
The growing interest in kelp aquaculture and the potential areas to develop this activity (Thomas et al. 2019, Broch et al. 2019) could be a threat for natural Kelp Forests if the development of culture is not properly managed. Facilitation of kelp disease, alteration of population genetics and wider alterations to the local physiochemical environment form the potential threats of kelp culture development (Campbell et al. 2019).</td></tr>
<tr><td rowspan="2">Climate Change (Global warming &
Marine heatwaves)</td><td colspan="3">Cause of threat/human activities : <u>Climate change.</u>
General pressure/threat: Gradual increase in air/seawater temperature is considered as a major threat to Kelp Forests (lethal effect and sublethal effect: limited growth, reproduction and recruitment), not only at their southernmost range edge. Increase in air temperatures will also have indirect effects by affecting rain regime and subsequent land run-off. The changes in land run-off can have differing effects depending on OSPAR regions (lower in the south and higher in the north of the OSPAR regions) and lead to nutrient depleted-waters or nutrient-enriched waters (eutrophication) with both detrimental effects on kelps forests (Moy et al. 2008, Fernández 2011, Norderhaug et al. 2015, Assis et al. 2017) (see Nutrient enrichment & Organic enrichment section). Sudden and extreme increases in seawater temperature (marine heatwaves) are increasing in intensity and frequency and can also threaten Kelp Forests. In other regions (e.g. South West Australia), heatwaves led to a complete regime shift from temperate Kelp Forests to habitats dominated by tropical and subtropical species (Wernberg et al. 2013, 2016).</td></tr>
<tr><td>Level of threat: High
In the south of Region II, A. esculenta has shown severe decline in the English Channel during a warm period in the 1950s (Southward et al. 1995). Climate models predict population losses from south-western England (Mieszkowska et al. 2005). A. esculenta does not recruit over 15 °C and the interaction with L. digitata changes along temperature gradient indicating that global warming may also change kelp species interactions (Zacher et al. 2019).
In Helgoland, L. digitata populations showed a decrease in reproduction</td><td>Level of threat: High
The level of threat of increasing seawater temperature is particularly high in region III where both listed species (A. esculenta, L. digitata) are closed to their southernmost distribution limits. Projected habitat models are all indicating severe regional decline or extinction of both species (Mieszkowska et al. 2005, Müller et al. 2009, Raybaud et al. 2013, Araújo et al. 2016, Assis et al. 2018) (Annex 1).
However, some Kelp Forests may persist like in the Iroise Sea where the Ushant tidal front</td><td>Level of threat: High
L. digitata distribution in Region IV is restricted to southern Brittany. Populations already show signs of maladaptive response and decline in genetic diversity (Oppliger et al. 2014). Seawater temperature models predict that these populations, subjected to strong stratification of water during summer, are at risk of extinction due to increasing temperature (Raybaud et al. 2013, Assis et al. 2018).
In southern Brittany, L. hyperborea seems to be gradually replaced by Saccorhiza polyschides</td></tr>
</table>

Type of pressure[2]	Region II	Region III (French EEZ only)	Region IV
	due to higher temperature and uppermost stands died during a severe summer heat stress regenerating the year after (Bartsch et al. 2013). In general, *L. digitata* needs cold winter and spring for successful reproduction, thereby winter or spring heatwaves may in future especially be detrimental (Martins et al. 2017, 2020, Liesner et al. 2020b). In south-western Norway, long periods of high summer temperature together with chronic eutrophication are most probably the causes of *S. latissima* forest shifts to turf filamentous algae habitat (Moy & Christie 2012, Norderhaug et al. 2015). Furthermore, changes in rain regime and higher subsequent land run-off in Norway can also lead to eutrophicated conditions (Norderhaug et al. 2015). However, in the north of region II, seawater warming limits sea urchins' pressure through two mechanisms: increasing of seawater temperature limits directly sea urchins recruitment (Rinde et al. 2014) and indirectly through the northwards spread of sea urchins-predatory crabs (Fagerli et al. 2014) favouring therefore Kelp Forests regrowth from previous overgrazing events.	contributes to maintain cool water during summer by preventing warm-water intrusion in northern Brittany (Le Boyer et al. 2009, Davoult et al. 2011). This phenomenon might explain that northern *L. digitata* populations in France are currently less affected by temperature than southern populations (Davoult et al. 2011) but they could be highly impacted in future if the Ushant front reduces. Populations of *L. digitata* in Brittany and south-west England have lower genetic diversity than northern populations but have developed advantageous adaptation for climate changes, showing a better resistance to thermal stress. A decline of these populations will result in the loss of evolved adaptation for resilience (King et al. 2019, 2020a). See section below "Evaluation of climate change impacts on Kelp Forests distribution using SDM" for up-to-date Kelp Forests projected distributions.	(S. Derrien pers. com., Engelen et al. 2011). The Iberian Peninsula is one of the most affected areas by climate change in the Atlantic coast of Europe (Belkin 2009). The species *L. hyperborea*, *L. ochroleuca*, *S. latissima*, *S. polyschides* have undergone range contractions and/or decline in abundance in recent decades in response to seawater warming along the Iberian Peninsula (Casado-Amezúa et al. 2019). Warming is more pronounced in the eastern Cantabrian Sea (+ 0.26°C per decade, Goikoetxea et al. 2009) compared to other regions (+ 0.15°C per decade, Gómez-Gesteira et al. 2011). *L. hyperborea* and *S. latissima* are now restricted to the north-west of the Iberian Peninsula in the Upper and Lower Rias region (Casado-Amezúa et al. 2019). The warm-temperate kelp, *L. ochroleuca* and *S. polyschides*, are also found in the southern Portugal and in the Strait of Gibraltar. The northwest region of the Iberian Peninsula represents a refuge area for these species that persist in this area due to the presence of a cold-water upwelling (Lima et al. 2007). However, the summer upwelling in

Type of pressure[2]	Region II	Region III (French EEZ only)	Region IV
	See section below "Evaluation of climate change impacts on Kelp Forests distribution using Species Distribution Models (SDM)" for up-to-date Kelp Forests projected distributions.		northern Portugal has been observed to be weaker due to a decrease in favourable winds (Lemos & Pires 2004, Sydeman et al. 2014). This can cause an increase in summer seawater temperature and a decrease of nutrient availability with additive effect on kelp performance (Franco et al. 2018). In addition to local extinction and decline in abundance, the four species have shown a shift into deeper and colder waters with smaller individuals (Martínez et al. 2015, Casado-Amezúa et al. 2019). The increase in temperature can also increase the grazing rate of herbivorous species with higher impact on Kelp Forests (Vergés et al. 2016). The long periods of consecutive summer days with a temperature higher than 20-22°C, which corresponds to survival kelp limits, have increased and have detrimental effect on Kelp Forests (Fernández 2011). Important heatwaves with maximal temperature of 26.5°C and 25.5°C have been experienced in 2003 and 2006 and affected photosynthesis, growth and individual survival of kelp species (Casado-Amezúa et al. 2019).

Type of pressure[2]	Region II	Region III (French EEZ only)	Region IV
			See section below "Evaluation of climate change impacts on Kelp Forests distribution using SDM" for up-to-date Kelp Forests projected distributions.
Storms and waves	**Cause of threat/human activities**: Climate change. **Level of threat: Medium** An increase in the frequency and intensity of storms caused by climate change is observed and predicted in Europe (Lozano et al. 2004). Severe storms increase breakage and dislodgment of kelp individuals (Filbee-Dexter & Scheibling 2012, de Bettignies et al. 2013), induce mortality (Smale & Vance 2016), may decrease complexity of kelp food web (Byrnes et al. 2011) and can increase turbidity due to sediment resuspension (Birkett et al. 1998). Kelp species inhabiting exposed area are more likely to be impacted by storm pressure.		
Sea-level rise	**Cause of threat/human activities**: Climate change. **Level of threat: Medium** The rise of sea-level could lead to an upward migration of upper sublittoral species adapted to shallower water (e.g. *A. esculenta* and *L. digitata*) and in some cases, where no adequate substratum is available, to a reduction of Kelp Forests' extent.		

Prediction of climate change impacts on Kelp Forests distribution using Species Distribution Models (RCPs IPCC climatic scenarios for 2090-2100)

Authors: Sandra Hernández, Ana García, Brezo Martínez.

Institution: Universidad Rey Juan Carlos, Spain.

PROJECTIONS. For methodology and maps, see Appendix 1. Projections showed a contraction of the southern distributional limits of all kelp-forests forming species considered, mainly driven by winter and summer ocean warming, matching to recent evidence of decline in southern Europe (e.g. Casado-Amezúa et al. 2019) and worldwide (e.g. Wernberg et al. 2016). Such projections were increasingly drastic from the RPC2.6 IPCC scenario where hardly any changes were seen, until the RCP8.5 IPCC scenario where the distributional changes were very evident. These projections agree with the previous ones done under the RCP8.5 using similar ecological niche modelling approaches for these species (Assis et al. 2017). Potential refugee areas of benign climatic conditions were projected in the northern coast of the British Islands and Northern Norway. In contrast to the predictions of contraction by physical stress, the colonization of new areas depends on the species been able to disperse and establish in a new community, and thus is largely related to biotic factors not included in SDMs. Thus, projected expansions northwards remain uncertain, whereas contractions are more likely to occur as the climate surpass the species physiological tolerance, as is currently occurring (e.g. SDMs in Martínez et al. 2018).

The distributional changes projected for each species are explained below according to the models based on the intermediate climate change scenarios (RCP4.5 and RCP6.0), which according to the latest studios are the most probable that occur in the future (see Hausfather and Peters 2020):

• *Alaria esculenta* (Figure A1. A) was projected to disappear from France, southern Ireland and UK, and from some stretches of coast along Iceland (summer and winter warming). The model suggested present-day less favourable conditions in Denmark, Sweden, North Iceland and northern Norway, that may be biased by less presence records in those areas compared to those along the British Islands. Projections suggested persistence along South Iceland, the northern half of the British Islands and Ireland, and most of the coast of Norway, but lower probability of persistence in the south coast facing the North Sea.

• *Laminaria digitata* (Figure A1. B) was projected to disappear from France with the only exception of Brittany, and some parts of the southern coast of the British Islands. As in *A. esculenta*, the model suggested present-day less favourable conditions in Denmark, North Iceland, and northern Norway, that may be biased by less presence records in those areas compared to those along the British Islands. Persistence and expansion of this species was projected in Norway, Sweden, South Iceland, most of UK, and Ireland.

• *L. hyperborea* (Figure A1. C) was projected to disappear from Portugal, Spain, most part of the French coast, and from some parts of the south-coast of the UK due to the summer and winter warming. The model suggested present-day unfavourable conditions in Germany, Denmark, North Iceland and North Norway, that may be biased by less presence records such areas. Uncolonized areas of potential suitable habitat would appear in northern Norway, which may represent a refugee area, if species dispersal and biotic interactions with the recipient communities allow the species establishment. Ireland, South Iceland and UK would be continuing presenting suitable areas where this species could persist.

• *L. ochroleuca* (Figure A1. D) was projected to disappear from Morocco, Azores Islands and South Spain, and to expand northwards along the whole Ireland and to northern unoccupied locations of British Islands and France if promoted by biotic conditions. As occurred with the previous species, the present-day model did not consider as favourable parts of the current distribution due to the less presence of records there. This was the case of the Canary Islands where this species only present one record for modelling.

• *Saccharina latissima* (Figure A1. E) was projected to disappear from Portugal, Spain, most part of the French coast, some areas from the southern coast of the United Kingdom, Germany, Denmark and Sweden. This was related by the SDM to summer and winter warming in the south, plus salinity changes as approaching to the Baltic Sea. Potential refugee areas were suggested in UK, Ireland, Norway and South Iceland.

• *Saccorhiza polyschides* (Figure A1. F) was projected to disappear from Morocco and southern coasts of Portugal and Spain by means of summer and winter warming in these areas. The model suggested present-day less favourable conditions in Norway where this species is currently present, that may be biased by less presence records in that country. Projections suggested persistence along most of the coast of Portugal, North Spain, France, Belgium, Netherlands, UK, Ireland and some parts of the southern coast of Norway and Iceland.

b) Existing management measures

Kelp Forests habitats are included in several local, national and regional conservation plans including European directives implementation and Marine Protected Areas management. Such listings serve to highlight the conservation needs of the habitat, but successful protection depends on specific actions that follow. Current management is mostly focused on the direct exploitation of kelps (Meland & Rebours 2012).

Legislation and legal protection

The ecological importance of Kelp Forests is such that it is nowadays protected by the European legislation:

- **Bern Convention**:
  - Recommendation No. 152 (2011) of the Standing Committee, adopted on 2 December 2011, on Marine Biodiversity and Climate Change.

Laminaria species are listed under paragraph 20 *“Accelerate the preparation and implementation of species-specific conservation plans focusing on Bern Convention marine features that may be most vulnerable to climate change, such as species that are known to depend on climate-sensitive habitats, or which already face an elevated risk of local extinction. The following lists are not comprehensive but focus on some species/groups already identified as potentially threatened according to existing knowledge*”.

Kelp Forests are cited under paragraph 21 “*Take conservation measures to protect and restore habitats expected to be most affected by climate change, including in overseas territories, such as lowland coastal areas, beaches, seagrasses, Kelp Forests, mangroves, reefs etc. Focus efforts on species not covered by the Bern Convention but protected under other national or international agreements*”.

- Appendix I - Strictly protected flora species, status in force since 4 March 2000. *Laminaria ochroleuca* is listed in the Mediterranean.

- **Habitats Directive** : **Annex 1** (Directive 92/43/EEC)

Kelp Forests as defined in the Case Report may be included in the following habitat types of Community interest:

- 1170 Reefs
- 1130 Estuaries
- 1150 Coastal lagoons
- 1160 Large shallow inlets and bays

The provisions of the Habitats Directive thus protect Kelp Forests in designated Natura 2000 sites. The conservation status of the 1170 Reefs habitat type in the Marine Atlantic biogeographic region was assessed as *Unfavourable - Bad* (U2) due to several Member states reporting Unfavourable – Bad (U2) for both parameters *Structure and Functions* and *Future Prospects* (EEA, 2019).

- **Links with the Water Framework Directive & Marine Strategy Framework Directive**

Kelp Forests forming species are often considered in the implementation of the **Water Framework Directive** (WFD; Directive 2000/60/EC) as *Biological Quality Element* (*Macroalgae*) to evaluate the biological quality of coastal waters through a dedicated monitoring network. There is a strong link with the secondary criteria D5C7 (*Macrophyte communities*) of the Descriptor 5 (Human-induced eutrophication) of the **Marine Strategy Framework Directive** (MSFD; Directive 2008/56/EC) to evaluate the Good Environmental Status (GES). Kelp Forests can also be considered for the MSFD-GES assessment of *Infralittoral rock and biogenic reef* (listed as MSFD benthic broad habitat types) relating to Descriptor 1 (*Biodiversity*) and 6 (*Sea-floor integrity*). More specifically Kelp Forests can be monitored for the primary Descriptors D6C4 (*extent of loss of the habitat type resulting from anthropogenic pressure*) and D6C5 (*extent of adverse effects from anthropogenic pressure on the condition of the habitat type*).

- **At the regional level, Kelp Forests are listed in**:

- the North-East Atlantic Red List under different habitat types (codes: A3.11, A3.12, A3.15, A3.21, A3.22, A3.31, A3.32) but they are all identified as *Data Deficient*.

- the HELCOM Red List of Baltic Sea biotopes and habitats under “Baltic photic shell gravel dominated by kelp” (code AA.E1C4) as *Near Threatened*.

- the HELCOM Red List of Baltic Sea biotope complexes under “Reefs” (code: 1170) as *Vulnerable*.

- **At the national level Kelp Forests are listed in**:

In Norway:

- the Norwegian Red List for Habitat (2018) under “*S. latissima* forest in the North Sea south and Skagerrak region” as *Endangered*.

In Spain:

- Scientific experts proposed to include the species *L. hyperborea*, *L. ochroleuca*, *S. latissima* and *S. polyschides* in the National Catálogo Español de Especies Amenazadas (CEA) and in the Listado de Especies Silvestres en Régimen de Protección Especial (LESPE) with the status *Endangered* (Casado-Amezúa et al. 2016).

- **Legislation and legal protection**

They exist for kelp harvesting activity and for indirect pressures such as fisheries, aggregate extraction, coastal development, shipping, pollution from agriculture, nutrient run-off and marine aquaculture activities (see dedicated sections below).

Communication and Awareness Raising

Actions such as outreach programs, public exhibitions, video reports are used to inform the general public and are mainly developed in MPAs. For example in France, the Iroise Marine Natural Park (PNMI listed as OSPAR MPA) built a traveling exhibition for the general public to present the richness and ecosystems services of Kelp Forests under the *VALMER* project (Vanhoutte-Brunier et al. 2016).

Citizen science projects can allow to increase awareness and improve knowledge on Kelp Forests. For example in Europe, the projects *Big Seaweed Search* (UK, Natural History Museum and the Marine Conservation Society, www.bigseaweedsearch.org) and *Coastwatch Europe Seaweed* (Ireland, http://coastwatch.org/europe/seaweed/) involved citizen to understand changes in distribution of seaweeds including kelp species. In the USA, the citizen science project *Floating Forest* (https://blog.floatingforests.org) allows to analyse thousands of images of Kelp Forests mapping to understand changes in kelp cover and environmental drivers.

Monitoring and Assessment

Monitoring and assessment programs relative to Kelp Forests habitats are mainly associated with state indicators related to European directives (WFD, HD, MSFD), MPAs management and regulation of Kelp Forests harvesting. At the European scale, the Biodiversity Knowledge programme (under EUFP7) gathered distribution data and expert knowledge to assess the status, trends and drivers of Kelp Forests across Europe (Araújo et al. 2016), and was the cornerstone of the present document.

In Norway, only *L. hyperborea* and *S. latissima* have been mapped and monitored. The largest *L. hyperborea* forests have been mapped and identified as part of the National program for mapping of biodiversity - coast (Bekkby et al. 2013). There is no particular monitoring, with the exception of monitoring associated with *L. hyperborea* harvesting (e.g. Steen et al. 2019, Steen 2019, 2020). *S. latissima* forests have only been sporadically mapped by the National program. However, this species dominated forests have been monitored as part of the coastal monitoring program (e.g. Fagerli et al. 2018, Kaurin et al. 2018). The development of spatial model of kelp distribution and its comparison with actual distribution is used to assess kelp disappearance (e.g. Bekkby & Moy 2011).

In the UK, monitoring and assessment of Kelp Forests have been carried out mainly in MPAs (e.g. Lundy SAC, Scilly Island SAC; Axelsson et al. 2014, Vance & Ellis 2016). The MarClim project and the Centre for Environmental Data and Recording (CEDaR) collected data on kelp distribution. In 2020, the MarClim Project intended to include monitoring and assessment of changes of Kelp Forests habitats due to climate change. Metrics have been proposed to assess the condition of kelp habitats (Burrows et al. 2014) which would be used for the assessment of Good Environmental Status (GES) for the UK Marine Strategy, however, further work is currently ongoing (started 2019) to test and refine these metrics to create an operational kelp indicator. Northern Ireland has planned to start mapping Kelp Forests, including citizen science projects.

In France, Kelp Forests are followed under monitoring programs and a sites network along the Atlantic French coast (REBENT-Bretagne, implementation of WFD and MSFD). A quality index of subtidal macroalgae has been developed to assess the ecological status of coastal water : Quality Index of Subtidal Macroalgae (QISubMac, Le Gal & Derrien-Courtel 2015). This indicator is based on several metrics including (mostly related to *L. hyperborea*): depth extension, composition and density of Kelp Forests, composition of associated species (diversity, opportunistic and sensitive species), size of kelp stipe and stipe epiphytes assessment. Additionally, the NATURALG project (de Bettignies et al. in prep.) is merging indicators knowledge from REBENT, WFD and MSFD to propose integrated indicators and pragmatic monitoring methods of Kelp Forests status for the conservation needs of MPAs manager (focus on Natura 2000 sites).

In Germany, regular quantitative monitoring of Kelp Forests takes place for the WFD assessment and for the HELCOM-monitoring program in the Baltic Sea (Wiltshire et al. 2010, Araújo et al. 2016, Kuhlenkamp et al. 2020).

In Spain, several monitoring programs exist under the MSFD in the Spanish Atlantic coast (MSFD, Law 41/2010). In particular, the HB program (Benthic habitats) with several subprograms (rocky subtidal, benthic protected species and human interactions) including Kelp Forests. Monitoring programs derived from the application of the MSFD are complemented with those derived by the WFD. An indicator for the assessment of macroalgae for the WFD, the *Quality of Rocky Bottoms index*, has also been developed (CFR; Guinda et al. 2014).

Other monitoring initiatives are being carried out by Spanish scientific institutions:

- Kelp Forests monitoring in Illas Atlánticas National Park (NW Iberian Peninsula) (BIOCOST group, University of La Coruña, https://cica.udc.gal/en/groups/biologia-costera).

- monitoring of benthic communities in the Basque Country coasts (Bay of Biscay) since 1999 and periodical monitoring of *S. polyschides* around the Iberian coasts (Marine Benthos Research Group, University of Basque Country, https://www.ehu.eus/en/web/bentos/home).

- monitoring of intertidal and subtidal macroalgae in Cantabria (Bay of Biscay) since 2005 to assess their ecological status according to WFD (https://ihcantabria.com/en/).

Spanish scientific experts proposed a standardized protocol of monitoring within a sites network along the Spanish coastline to assess changes in community and conservation status of seaweeds including 4 Kelp Forest-forming species (*L. hyperborea*, *L. ochroleuca*, *S. latissima* and *S. polyschides*). The protocol consists in annual determination of species cover using quadrats and coupling results with abiotic variables (temperature, light, nutrient, waves) (Casado-Amezúa et al. 2016).

In Portugal, few monitoring programs exist since 2010 including transects with video images in the northern region. The project *Sea Forester* (https://ihcantabria.com/en/) will include monitoring program and citizen science to map existing Kelp Forests.

Marine Protected Areas

Kelp Forests occur in many Marine Protected Areas (MPAs) although sites are rarely designated specifically for this habitat, but rather designated for broader scale habitats that can include Kelp Forests (e.g. Habitats Directive's Annex I habitat types in Natura 2000 sites). Thus, very few management measures specifically target the conservation of Kelp Forests in MPAs.

In Norway, several MPAs of different kinds such as national parks and reserves include Kelp Forests and many of these sites are also designated as OSPAR MPAs. Harvesting of kelp is restricted to some parts of Norway and is prohibited in the reserves along the coast and in reference areas. 15 of 36 suggested areas, have been protected under the Nature management Act and several of these contain Kelp Forests. There is an ongoing work on white paper for the protection of marine areas. Local areas with Kelp Forests may also be given protection through The Planning and Building act.

In the UK, 77 MPAs are known to include Kelp Forests habitats. These sites are also part of the UK OSPAR MPA network. UK Kelp Forests are protected as a component of Annex I Habitats that are designated within the UK Special Area of Conservation network. Furthermore, Kelp Forests are a designated feature within Marine Conservation Zones (MCZs) under the Marine and Coastal Access Act 2009 in England and Northern Ireland, and within Nature Conservation MPAs in Scotland (where kelp beds are listed as a Priority Marine Feature) under the Marine (Scotland) Act 2010. The habitat is also protected as a component of the lower part of 'Intertidal Rock' in Sites of Special Scientific Interest (SSSIs) in England, Wales and Scotland and in Areas of Special Scientific Interest (ASSIs) in Northern Ireland. Northern Ireland (NI) is currently considering the addition of this habitat to the Priority Marine Feature list for the NI inshore region. Work is ongoing to implement the management measures considered necessary to achieve the conservation objectives of the UK MPA network and to put in place monitoring programmes to detect the measures effectiveness over time.

In France, several MPAs of different kinds (e.g., Marine Natural Park, Natura 2000 sites, Marine Reserves) include kelps forests. Many of these sites are also designated as OSPAR MPAs (http://mpa.ospar.org/home_ospar). The Iroise Natural Marine Park (part of the OSPAR MPA network) has developed numerous projects to ameliorate knowledge of Kelp Forests, including mapping, regulations of harvesting and pressure-impact studies (see Research and Knowledge generation section).

In Spain, the creation of MPAs is identified by experts as the main effort required for Kelp Forests conservation (Araújo et al. 2016). The designation of a new MPA in the Northwest region of Spain (Galicia) is in discussion in 2020, with a special focus on the conservation of macroalgae and the creation of climatic refugees' area.

In Germany, Kelp Forests in the North Sea occur in the Marine Protected Area at the reef around Helgoland, 60 km off the Wadden Sea coast, but there is no specific program targeting Kelp Forests conservation (Araújo et al. 2016).

Pressures from Human Activities

Management on direct exploitation

Kelp Forests are harvested for industrial purposes along the west coast of Norway, the French Channel coast and west Britany, along some parts of the UK coast (west of Scotland) and Ireland. It is also exploited at smaller scale in Portugal and Spain.

Existing regulations depend on the country, the species targeted, the harvesting technique, and usually involve different tools : licenses or harvesting authorisations, quotas by harvesting zone, individual quotas by boat, harvesting size and fallow periods (Meland & Rebours 2012).

In the UK, kelp harvesting (targeting *A. esculenta*, *L. digitata*, *L. hyperborea*, *S. latissima* and *S. polyschides*) and management vary. In Northern Ireland, mechanical harvesting of kelp would be licensable activity, but no application has been received yet in 2020. In Scotland, a provision in The Scottish Crown Estate Act passed by the Scottish Parliament (21 November 2018, section 15) has made it illegal to mechanically harvest whole kelp plants (if removal would inhibit the regrowth of the individual plant) for commercial purposes. In England, harvesting is not banned outright but, is regulated by the Inshore Fisheries Conservation Authorities (IFCAs). In MPAs, harvesting requires permission by Natural England. Generally, only hand gathering (no mechanical collection) is allowed and both commercial and non-commercial harvesters are required to follow a seaweed harvesting code of conduct. In Wales, there have not been any request yet, in 2020, for large scale/mechanical harvesting of kelp.

In Norway, *L. hyperborea* has been harvested by trawl for alginate extraction since the 1970s, with annual landings of around 150,000 tons. The Norwegian kelp harvesting regulation includes licenses, harvesting authorisations and sector-based management. The kelp management plans are evaluated every fifth year. The coastline where *L. hyperborea* harvesting takes place (between Rogaland to Trøndelag counties on the west coast of Norway) is divided into sectors one nautical mile wide in the north-south direction. The sectors (denoted by a unique number and a letter (A-E indicating harvesting period)) are open to kelp harvesting every fifth year (following a four-year fallow period) in a rotational cycle and arranged in a manner that prevents neighbouring sectors from being harvested in subsequent years. Kelp harvesting is not allowed below 20 meters depth and is also prohibited in the reserves and reference areas along the coast. The harvesting sectors and reference areas are annually monitored by the Institute of Marine Research. Advice regarding the scheduled forthcoming harvest is provided for the management (Directorate of Fisheries) based on the observed restoration status of the kelp assemblages in each sector (Steen 2019, 2020).

In Sweden, commercial harvesting of macroalgae is forbidden in MPAs.

In France, *L. digitata* (from 40,000 to 60,000 tons per year) and *L. hyperborea* (from 20,000 to 30,000 tons per year) forests are commercially and mechanically harvested in Brittany. The principal areas of exploitation are located along the North Finistère and within the Molène Archipelago in the Iroise Marine Natural Park (PNMI, an OSPAR MPA), which include the largest Kelp Forests field in Europe. The regulation of kelp harvesting is defined in a specific commission composed of kelp harvesters, government services, scientists and seaweed processing industry representatives. Decisions are validated by the public authorities. The PNMI in which the major part of the exploitation takes place, has mapped Kelp Forests, evaluated the exploitable biomass stock and tracked fishing effort. Harvesting is regulated by licences limiting the number of vessels that all have to be equipped with a Vessel Monitoring System. *L. digitata* harvesting management includes seasonal restrictions (6 months per year), daily biomass quotas, the assignment of specific restricted collection zone to each vessel and a limited annual harvesting stock to each collection zone. *L. hyperborea* harvesting regulations also include a rotational set-asides with 1/3 of the area that can be exploited for a year and then lied fallow for the following 2 years to allow for stock recovery. The harvesting is organised in mapped grid in which a maximal exploitable stock is determined. Furthermore, some areas are closed to *L. hyperborea* exploitation for conservation purpose (biodiversity, habitat protection, sensitive species) and cohabitation between fishing professions.

In Spain, kelp harvesting is increasing, particularly in Galicia (NW Iberian Peninsula) with 113 tons harvested in 2013. In the Galician coasts, Law 11/2008 of Galician Fisheries establishes the framework for algae collection within Galician waters. The preparation of management plans is regulated by Decree 153/2019 (in force in all those aspects that do not contradict Law 11/2008).

Management plans for seaweeds collection, are established pluriannual (every three years). This plan constitutes the set of rules and guidelines that will govern the harvesting of seaweeds, establishing also which seaweeds are allowed to be harvested. In 2020, the Fisheries Department of the Autonomous Government of Galicia has approved a research project that aims to evaluate the effectiveness of the current management plans for seaweed harvesting in order to adapt the model to a new paradigm base on the seaweed's biology and through an ecosystem approach. For now, although there are extraction programs, these do not contain specific plans adapted to the situation of the natural populations, and particular biological characteristics of each species (Garcia-Tasende & Peteiro 2015).

Management on indirect pressure

The decline of water quality is a major stressor for Kelp Forests habitats. For EU Member States more general measures on water quality management are specified under the EU Water Framework Directive (EC/2000/60) which tackle problems relative to eutrophication, pollution, industry and agriculture run-off, to achieve *Good status* for coastal waters.

Water quality management legislation is also in place in the UK including: the Water Environment (Water Framework Directive) Regulations 2017 in England and Wales, the Water Environment (Water Framework Directive) Regulations (Northern Ireland) 2017 in Northern Ireland and the Water Environment and Water Services (Scotland) Act 2003.

Other management measures protecting benthic habitats such as Kelp Forests may include fisheries byelaws and regulations to manage demersal fishing activities, licensing of activities (such as aggregate extraction, aquaculture, renewable developments, oil and gas activities, coastal development, shipping, etc), decrease the effluent of nutrients, management of pollution from agricultural, energy production, industrial, residential, recreational and marine aquaculture activities.

Research and Knowledge generation

Many research projects have been conducted on the decline of Kelp Forests in Europe and worldwide (e.g. Krumhansl et al. 2016, Filbee-Dexter & Wernberg 2018, Wernberg et al. 2019, Casado-Amezúa et al. 2019 and references therein).

Additionally, national research projects have been developed in association with kelp harvesters to improve knowledge on harvesting impacts and improve management of harvested Kelp Forests. Such projects include:

- mapping of distribution and biomass of harvested species to help spatial planning (e.g. Bajjouk et al. 2015, van Son et al., 2020).

- assessment of kelp harvesting impact on kelp biomass, the associated biodiversity and the functioning of trophic food webs (e.g., HYPERIMP, SLAMIR and SEPALG projects; (Davoult et al. 2011, Christie et al. 2014, Steen et al. 2016).

- assessment of acoustic signature of kelp harvester vessels to study the impact on marine mammals (Clorennec & Le Provost 2016).

- assessment of ecosystem services provide by Kelp Forests (e.g., VALMER - INTERREG IV, Vanhoutte-Brunier et al. 2016, Norderhaug et al. 2020).

Other knowledge generation projects include, amongst others, genetic monitoring to detect changes in population size and connectivity (e.g. Valero et al. 2011, Robuchon et al. 2014, King et al. 2020), spatial models of distribution (e.g. Bekkby & Moy 2011), the impact of climate changes and other pressures (e.g. Voerman et al. 2013, Norderhaug et al. 2015), the plasticity of kelp species along distribution gradients (e.g. EU-project MARFOR: Monteiro et al. 2019, Liesner et al. 2020a b, King et al. 2020b) and predicting models of the effects of climate changes (e.g. Assis et al. 2017, Martínez et al. 2018).

In Ireland, research programs are starting in 2020. The research project (*KelpRes*) aims to better understand Kelp Forests' ecology including : surveys, ecology, genetic diversity, resilience, assessment and monitoring of Kelp Forests distribution and "health" (Schoenrock et al. 2020b a).

Research programs conducted on Kelp Forests recovery are numerous and innovative restoration methods are currently under development (for restoration recommendations see Bekkby et al. 2020). Kelp Forests restoration can be based on the improvement of local environmental conditions, such as the level of sediment and nutrients (bottom-up control; e.g. Strain et al. 2015). Other strategies involve the control of urchin population by the creation of MPAs that increase urchin predator populations (Leleu et al. 2012), the direct reintroduction of predators (e.g. Ling et al. 2015) or the removal or killing of urchins (e.g. Sunnset et al. 2010, Sanderson et al. 2016). More active restoration measures have been used to restore local forest loss such as the construction of artificial reefs (e.g. in the USA: Reed et al. 2006), the transplantation of adult or juvenile kelps from a donor site (e.g. in Japan: Unno & Hasegawa 2010; Australia, *Operation Crayweed*) or the out-planting of lab-cultured kelps (e.g. in Norway: '*Green gravels'* Fredriksen et al. 2020). Different *ex-situ* conservation actions (germplasm banks) are under development in Spain.

Several international projects are ongoing in 2020 to increase knowledge on kelp distribution and develop restoration programs. For example, the project *Marine Forests* (https://marineforests), supported by scientists and volunteer citizens, aims to build and maintain an open-source database of seaweeds distribution, including Kelp Forests. The project *Sea Forester* (http://seaforester.org) supports monitoring, Kelp Forests restoration projects and database development of restoration programs in Europe (Portugal) and internationally (e.g. *Green Gravel* project, Australia).

The current high loss rate of entire Kelp Forests and predicted threats from climate warming have recently fostered innovative research into using emerging genetic technologies (e.g. transplantation of stress-tolerant strains), and associated guidelines and decision tools for Kelp Forests restoration (Wood et al. 2019, Layton et al. 2020, Coleman et al. 2020, Eger et al. 2020). These methods have rarely been adapted in the field and have never been tested on Kelp Forests yet, so there is great uncertainty about their effectiveness and the potential risks posed by the transplantation of genetically different organisms. However, the dramatic loss of Kelp Forests for entire areas, such as in the northern Iberian Peninsula, and the difficulty to manage the major threat of climate change in a short and effective delay, leads to a point where such measures should be discussed.

c) Management needs and actions to be taken by OSPAR

Background considerations

The most important actions to prevent Kelp Forests loss are:

a) Protection of the known and likely occurrences (potential adequate areas) of Kelp Forests from further degradation.
b) Control and treatment of urban, agriculture, industrial and mariculture sewage to reduce the loading with nutrients, organic matter and chemicals.
c) Regulation of land use to reduce nutrient runoff and siltation due to soil erosion.
d) Regulation of land reclamation, coastal construction, dredging and dumping activities close to Kelp Forests which can affect hydrological process and sediment deposition.
e) Regulation of CO_2 emission to address the effects of climate change
f) Regulation of damaging activities on seabed and kelp species.
g) Regulation of key predator fisheries such as crabs and cods, whose reduction of populations can cause trophic cascades leading to a reduction in Kelp Forests.
h) Development of Kelp Forests restoration programs where Kelp Forests locally are disappearing or disappeared.
i) Development of research project on climatic refuge areas.
j) Monitoring of Kelp Forests distribution and knowledge acquisition on their ecology to better understand local and global impacts and long-term survival factors.

General Recommendations for measures and activities

Active local management of Kelp Forests should be encouraged as evidence shows that local factors play a dominant role in driving Kelp Forests dynamics and their region-specific responses to stressors (Krumhansl et al. 2016, Filbee-Dexter & Wernberg 2018). Furthermore, local and regional stressors are more amenable to management and conservation actions than global stressors (Strain et al. 2015) and the reduction of local pressures is essential to improve the resilience of Kelp Forests.

Pressures induced by climate change such as global warming, increase of marine heatwaves, increase of storms magnitude and frequency are major stressors for Kelp Forests. Management measures to reduce these impacts should include the reduction of CO_2 emission and the development of active restoration projects to increase Kelp Forests resilience. The most important regional pressures include the alteration of water quality (i.e. decrease of water clarity, nutrient and organic enrichment, pollution), increase in siltation rate and introduction of non-indigenous species. Management measures should further regulate the human activities leading to an alteration of Kelp Forests habitats.

Another management measure may be to further regulate commercial harvesting of kelps to ensure the sustainability of natural resources. Measures could include developing alternative “less damaging” methods of harvesting, establishing (longer) fallow periods, limiting harvesting in vulnerable areas, long-term management plans, and controlling substrate removal or physical damage to the habitat, for instance through comprehensive environmental impact assessments (Marine Scotland, 2016). When measures fall outside the remit of OSPAR, OSPAR can communicate an opinion on its concern about these habitats and their biological communities to the relevant bodies. OSPAR could also introduce any relevant supporting measures that fall within its own remit if such measures exist.

Studies have demonstrated that well managed MPAs with high level of protection can be effective at protecting existing Kelp Forests and may also allow for their recovery following impacts (Halpern & Warner 2002). Management programs could be designated under both national and international levels and measures could directly or indirectly benefit Kelp Forests (Table 3). As Kelp Forests are covered by the EU Habitats Directive and therefore covered in the Natura 2000 sites network across most of the OSPAR area, priority management action could be focused on assessing the ecological coherence of the existing MPAs network for Kelp Forests habitats at the regional level (see EU guidelines for network- and site-criteria for an ecologically coherent network under the HD). If significant gaps are identified management plans could include the designation of new MPAs. As Kelp Forests are mostly included in existing MPAs under broader habitat definition (e.g. "reefs" under the HD) and are rarely specifically targeted by management measures, the implementation of management plans adapted for the conservation and restoration of Kelp Forests should be set up where this habitat is degraded or receding northwards and/or when key threats are identified. This holds also for areas where Kelp Forests disappeared but were known to occur. When management plan and measures exist, the OSPAR Commission should assess their efficiency in protecting Kelp Forests. Given the high level of pressure and threat from seawater warming, a safeguarding strategy of Kelp Forests located in *climatic refuge areas* should be prioritized and such localities included in priority within the MPAs network.

Table 3: Competent authorities and their role in the management of Kelp Forests in the OSPAR Maritime Area.

Activities	Legal Basis	Relevant authority
Improvement of management in existing MPAs, Designation of MPAs (national MPAs, Natura 2000 sites, OSPAR MPAs)	National legislation or national legislation in conjunction with the EU Habitat and Birds Directives OSPAR	National ministries/agencies European Community OSPAR MOP
Protection, surveillance and monitoring of MPAs for the habitat	National legislation or national legislation in conjunction with the EU Habitat and Birds Directives	National authorities, provincial authorities, national park administration
Fishing (Territorial waters, EEZ or equivalent)	National legislation or for EU Member States the CFP UN FAO Code of Conduct for Responsible Fisheries, and FAO Compliance Agreement	National ministries/agencies European Community, or the Commission in case of emergency measures FAO
Kelp harvesting	National legislation or for EU Member States the CFP	National ministries/agencies European Community, or the Commission in case of emergency measures
Nutrient reduction	National legislation or national legislation in conjunction with the EU Nitrates Urban Wastewater Directive and the WFD OSPAR: nutrient reduction programmes	European Community OSPAR MOP
Pollution	National legislation	National ministries/agencies

	OSPAR	OSPAR MOP
Mineral, petroleum, gas and oil extraction (Legal continental shelf)	UNCLOS	National ministries/agencies under the UNCLOS legal basis
Protection, communication, research	OSPAR	Other Organisations OSPAR MOP
Climate change	UNFCCC	UNFCCC COP OSPAR MOP

Possible recommendations for further measures and activities

Legislation and legal protection

- Enforce the legislation for the protection of the known and likely occurrences of Kelp Forests from further degradation.
- Include *A. esculenta*, *L. digitata*, *L. hyperborea*, *L. ochroleuca*, *S. latissima* and *S. polyschides* forests in the national and European red lists of ecosystems where decline is recognized.
- Explore and extend the use of other policy instruments for the protection of Kelp Forests notably Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), and ocean and coastal planning.

Marine Protected Areas

- Integrate Kelp Forests protection into national and regional MPAs networks, including under the EU Habitats Directive, ensuring adequate representation of Kelp Forests habitats and species.
- Improve and enforce existing management systems where Kelp Forests occur in existing MPAs, to ensure adequate habitat protection.
- Develop relevant and targeted management measures for the specific protection of Kelp Forests.
- Protect areas which have a potential for Kelp Forests recovery and/or which can act as climatic refuge areas.

Pressures from human activities

- Improve and speed-up nutrient reduction (nitrogen and phosphorus compounds) in accordance with EU Directives.
- Limit activities which decrease water transparency and increase siltation rate (e.g. land runoff, coastal reclamation, dredging activity) close to Kelp Forests.
- Dedicate more resources to the study of the impacts of harvesting and mariculture on Kelp Forests functioning and biodiversity, including the risks posed by the spread of NIS and kelp disease.
- Develop a regional approach to reducing the interaction of fishing gear with Kelp Forests in cooperation with fisheries management bodies and ensure the sustainability of such natural resources.
- Improve regulation of fisheries of predators of kelp grazers to avoid the risk of trophic cascade deleterious to Kelp Forests.
- Develop guidelines for responsible and sustainable management of Kelp Forests and associated biota.

Communication and awareness raising

- Raise awareness of the importance of Kelp Forests and their sensitivity to climate change and regional pressures to national authorities and general public.
- Improve the knowledge transfer and communication between local, national and international works on Kelp Forests.
- Improve the coordination of management approaches at the international level.
- Improve international, national and regional exchange of scientific data.

Research and knowledge generation

- Investigate the current and future occurrence and status of Kelp Forests through field surveys and predictive modelling.
- Improve information on population dynamics and genetic diversity (all regions), resilience, ecological status and functionality of Kelp Forests, including their ecosystems services (e.g. coastal protection, carbon storage, nursery ground for commercially valuable species).
- Identify the effect of individual and cumulative pressures, e. g. climate change, on Kelp Forests and assess the cumulative impacts of multiple stressors at local and regional scales.
- Support research on recovery and active restoration of Kelp Forests. These projects could include *in-situ* seeding and transplantation methodologies (e.g. selection of stress-tolerant strains), artificial reef deployment if habitat is destroyed and *ex-situ* conservation methods (e.g. seed banks and cultures).

Monitoring and assessment

- Develop a long-term monitoring and assessment programs within the entire OSPAR geographical range and shared between Contracting Parties with quantitative datasets to address the knowledge gaps in Kelp Forests distribution (including mapping and modelling), ecological state and surrounding abiotic factors.

Proposals for actions and measures / Role of OSPAR

It is proposed that the OSPAR Commission should:

a) Inform the European Commission of OSPAR work to ensure that ongoing work is linked with the Habitat Directive (Natura 2000), Water Framework Directive and the Marine Strategy Framework Directive to avoid duplication of work;
b) Regularly assess the effectiveness of management plans in place in the OSPAR MPA network regarding Kelp Forests conservation and adapt its recommendation to competent authorities and/or Contracting Parties accordingly;
c) Agree arrangements, in conjunction with other authorities, for the coordinated implementation of the monitoring and assessment system for Kelp Forests for the OSPAR area, which co-ordinate activities at the national level for data collation, monitoring and management and build on work undertaken under existing mechanism such as biodiversity plan and Natura 2000;
d) Where management activities are outside the remit of OSPAR, request and advise the relevant authorities of desired conservation actions;
e) Develop and adopt guidelines for the protection and management of Kelp Forests.

It is proposed that OSPAR recommend that Contracting Parties should:

a) Introduce legislation to protect Kelp Forests;

b) Designate areas which are important for Kelp Forests as protected areas with management plans that ensure the protection of Kelp Forests under the OSPAR's Marine Protected Area (MPA) program as well as within Natura 2000;
c) Intensify efforts to reduce discharges and emissions of nutrients and hazardous substances to Kelp Forests into the marine environment in accordance with relevant European Community legislation;
d) Implement the monitoring and assessment system, in order to complete knowledge base and provide indicator for the state and recovery of the habitat;
e) Whenever applicable, seek ways and means to broaden the knowledge base on the occurrence of threats to Kelp Forests by gathering additional knowledge from sources such as national planning authorities, environmental impact assessments and post-development monitoring, research institutes, fisheries research, local sea-fisheries committees, commercial and recreational fisheries, Non-governmental organisations (NGOs) and the general public;
f) Map of distribution and abundance of Kelp Forests for conservation measures purposes;
g) Promote harvesting reserves and other spatial management tools in Kelp Forests;
h) Address and minimise adverse impacts on Kelp Forests arising from human activities such as dredging, dumping of wastes and kelp harvesting in waters under its national jurisdiction;
i) Ensure by appropriate management that any introduction of invasive and/or non-indigenous macroalgae species is avoided through marine aquaculture and marine transportation;
j) Raise awareness for the importance and maintenance of good ecological conditions of Kelp Forests among relevant management authorities and actors, including industry sectors and the general public;

It is proposed that OSPAR should establish a mechanism by which Contracting Parties report back on the implementation of the above recommendations and the implementation of the monitoring and assessment strategy so that progress can be evaluated in conjunction with the future assessment of habitat status.

d) Brief summary of the proposed monitoring system (see appendix 2)

Various monitoring programs of Kelp Forests exist in Europe but there is still deficiency in information on Kelp Forests distribution and ecological status, and there is a need of coordination and data exchange. The proposed monitoring system is based on three complementary approaches: (i) long-term monitoring of Kelp Forests distribution and biomass stock, (ii) identification of the main pressures and effectiveness of management measures to reduce them and (iii) fine-scale assessment of kelp populations, individuals and associated biota.

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f) Contacts

Marie La Rivière

UMS Patrimoine Naturel

36 rue Geoffroy Saint-Hilaire 75005 Paris

France

mlariviere@mnhn.fr

g) Overview of contribution made by Contracting Parties

Contracting Party	Feature occurs in CP's maritime area	Contribution made to the assessment (e.g. data/information provided)	Names of contributors to the drafting of the document
Belgium	N		
Denmark	Y		
European Commission			
France	Y	Y	Florian de Bettignies, Thibaut de Bettignies, Alice Boiffin, Laureline Gauthier, Marie La Rivière
Germany	Y	Y	Miriam Mueller, Thorsten Werner,

			Janos Hennicke, Inka Bartsch
Iceland	Y		
Ireland	Y	Y	Oliver Ó Cadhla
Netherlands	N		
Norway	Y	Y	Trine Bekkby, Hartvig Christie, Frithjof Moy, Kjell Magnus Norderhaug, Henning Steen, Mats Walday
Observers	-	Y	Nicolas Fournier (Oceana), Morven Robertson (Blue Marine Foundation)
Portugal	Y	Y	Ester Serrão, Isabel Sousa Pinto
Spain	Y	Y	Pilar Casado de Amezúa, Ana García, Sandra Hernández, Brezo Martinez
Sweden	Y	Y	Christina Halling, Maria Kilnäs
United Kingdom	Y	Y	Hugh Edwards, Katie Gillham, Marion Harrald, Nova Mieszkowska, Pippa Moore, Megan Parry, Kirsten Ramsay, Trudy Russell, Dan Smale and Margaret Street

Appendix 1: Prediction of climate change impacts on Kelp Forests distribution using Species Distribution Models (RCPs IPCC climatic scenarios for 2090-2100)

Authors: Sandra Hernández, Ana García, Brezo Martínez.
Institution: Universidad Rey Juan Carlos, Spain

Methods

List of independent predictors

The raster of the environmental conditions known to influence the geographic distribution of macroalgae were gathered from two different sources: Bio-ORACLE (http://www.bio-oracle.org/), from Uv. of Ghent (Belgium); and OCLE (http://ocle.ihcantabria.com/), from Uv. of Cantabria (Spain). From the long list of available variables, we included only those with *a priori* knowledge of their importance in the geographical distribution of macroalgae (reviewed in Lüning 1990), and which pairwise Pearson correlations were less than 0.85, to avoid excessive autocorrelation between pairs of predictors (see Elith et al. 2010). We excluded data on ocean pixels not contiguous with land areas because they are outside potential seabed habitat for kelps and pixels not corresponded with the study area, the European Atlantic Ocean. The final environmental layers included a total of 465,687 pixels distributed throughout the European Atlantic coast from the Canary Islands in the south to the White Sea in the north with a resolution of 5 arcmin (~9.2 km). The only exception was the resolution of the layers used to model one of the studied species, *Laminaria ochroleuca*, because this species presents its northern limit of distribution in the south of UK, so a smaller extension to minimize the area of absence of the model for training was applied with a total of 191,100 pixels between the Canary Islands at South to the North Sea.

Biogeographic models rank first the **maximal and minimal sea surface temperatures** (SSTs), (reviewed by Lüning 1990). With exceptions, upper survival thresholds have been associated to the southern distribution of many European macroalgae, and lower lethal thermal conditions to the northern distribution limits (i.e. August and February isotherms, respectively). Therefore, we included as predictors the mean long term (2000-2014) of the averaged surface temperatures of the warmest and coldest month each year (SSTMax and SSTMin, respectively) as extracted from Bio-ORACLE II. For SSTMax, for example, this corresponds to the average of the 15 values of the August or July mean sea surface temperatures (the warmest in each year). We omitted other variables showing temperature ranges, and mean annual values, which do not represent relevant physiological thresholds.

Low **salinity**, as for example inside the Baltic Sea, represent a strong physiological stress for most seaweed (Lobban and Harrison 1994). This causes the absence of many intertidal and subtidal seaweed along this area, which is defined as a stand-alone ecoregion with unique environmental conditions (Spalding et al. 2007). Besides, low salinity may restrict the presence of stenohaline species in river plumes, or to the inner part of large embayment with freshwater inputs. We thus include the long-term average (2000-2014) of the mean salinity values of the lowest months each year from Bio-ORACLE II (SALINITYMin).

Waviness is the most important physical disturbance in rocky shores, tearing and/or dislodging macroalgae (de Bettignies et al. 2013). As there is not a dominant latitudinal gradient, but regional and local variation, biogeographic models have not related waviness to the distribution limits of macroalgae. However, sheltered locations, as for example the embayment of Galicia in the NO corner of the Iberian Peninsula, or the numerous fjords in the Norwegian coast, are important refuges for subtidal and intertidal macroalgae assemblages. Therefore, we included the average of the significant wave height (m) of the 16 maximal monthly means of each year (from 2000 to 2015) as extracted from OCLE database (WAVESMax).

The **concentration of macronutrients**, mostly Nitrogen, may be transiently lower than the demand of the macroalgae, sometimes resulting in a seasonal limitation at the end of the summer (e.g. Martínez and Rico 2002). Therefore, this variable has not been related to distributional limits, nor to the absence of seaweeds in large geographic areas or entire provinces and is thus of limited biogeographic meaning. However, it may favour physiological performance in summer in regions subjected to river runoff release, to upwelling events, or other localized inputs, increasing algal productivity (Martínez and Rico 2008). The same occurs with the phosphate content that rivers discharge into their mouths, which limited the species distributions as it was mentioned in this document since it is a proxy for eutrophication or contamination. We thus included the long-term averages (2000-2014) of the means of the months with the lowest inorganic nitrogen (nitrate + nitrite) concentration each year (NITROGENMin) and with the highest inorganic phosphate concentration each year (FOSFATEMax), as defined in Bio-ORACLE II. However, despite being included in the models, the resolution of that macronutrients layers is not the most adequate to capture the local or regional effects that they produce (Martínez and Rico 2008).

Aside from the importance of **light** limitation in periods of total darkness in polar areas not included in this study, overall, light radiation has not been related to the distribution limits of seaweed in biogeographic studies. Nevertheless, a well-illuminated and clear water column has been identified as an important factor promoting deep Kelp Forests at marginal areas (Ramos et al. 2016). We thus included the long term averaged of the monthly incoming Photosynthetic Active Radiation reaching sea surface of the brightest month of each year (PARMax), the maximal and minimal Diffuse Attenuation Coefficients of the water column (ATENUAMax and ATENUAMin), from Bio-ORACLE version I. We preferred data from the previous version (1997-2009) over those in the version II because it does not show negative values, making the potential interpretation of results more straightforward.

Table A1. Information about the considered environmental variables

Variable	Source	Time	Dominant pattern
1 SSTMax	Bio-ORACLE II	2000-2014	Latitudinal pattern increasing south. Colder regional temperatures in the Iberian and Saharan upwellings. Correlated with SSTMin.
2 SSTMin	Bio-ORACLE II	2000-2014	Latitudinal pattern increasing south. Correlated with SSTMax.
3 SALINITYMin	Bio-ORACLE II	2000-2014	Overall little variation but lower values in the White Sea and in the water mass between Denmark and Sweden, as approaching to the Baltic Sea.
4 WAVESMax	OCLE	2000-2015	Regional variation due to the orientation and rugosity of the coastline, protection by masses of

			land, and the enclosure by the continent. Also shows the shelter inside large embayments.
5 NITROGENMin	Bio-ORACLE II	2000-2014	Overall little variation but high values in the White Sea.
6 FOSFATEMax	Bio-ORACLE II	2000-2014	Lower values in the south and some regional variations.
7 PARMax	Bio-ORACLE I	1997-2009	Latitudinal pattern increasing south, with some regional variation.
8 ATENUAMax	Bio-ORACLE I	1997-2009	Regional variation. Higher values, i.e. high turbidity, around the White and North Seas and inner parts of UK and Norway.
9 ATENUAMin	Bio-ORACLE I	1997-2009	Regional variation. Higher values, i.e. high turbidity, around the White and North Seas.

Target species and presence records

We targeted six laminarian species representing the most dominant kelps forming the subtidal forest at rocky shores around the Atlantic European coastline, namely *Alaria esculenta*, *Laminaria digitata*, *L. hyperborea*, *L. ochroleuca*, *Saccorhiza polyschides*, *Saccharina latissima*. Occurrences were gathered from the Global Biodiversity Information Facility (GBIF, http://www.gbif.org/), the Ocean Biogeographic Information System (OBIS, http://www.iobis.org/mapper/), from the sampling data available to the various scientific collaborators of this report and from the database of the paper published by Assis et al. (2020). We did not consider records and literature older than 1950 as often appear positioned in erroneous locations, as for example on land or too far from the coastline.

Species distribution modelling

Species Distribution Models (thereafter SDMs) were developed using Maximum Entropy Modelling (MaxEnt v3.4.1, https://biodiversityinformatics.amnh.org/open_source/maxent/), a statistical approach that contrasts the actual spatial pattern of the presences, with a random pattern of background points of maximal entropy (i.e. close to uniform), but restricted to occur within the same environmental range of occurrence of the target species (Phillips et al. 2017). We allowed lines, quadratic terms, and hinge features in the regressions relating the occurrence records with the environmental gradients. The importance of each individual environmental variable in the distribution of the species was investigated by means of the percent gain contribution coefficient, the permutation importance score, and the Jackknife (“leave one out”) test, as performed by MaxEnt. Model performance was evaluated using the area under the curve (AUC) of a receiver operating characteristic (ROC) plot. Such metric was calculated for the whole dataset, and for datasets obtained using internal (data-splitting) validation performing 10 iterations (avoiding the potential bias associated to the randomization) of a 70-30 partitioning procedure, i.e. 70% points for model training and 30% for testing (Fielding and Bell 1997; Guisan and Zimmermann 2000). AUC values are indicative of the discrimination power: 1-0.9 good, 0.9-0.8 fair, 0.8-0.7 poor, 0.7-0.6 fail, following Swets (1988).

Predictions

Projections of the realized climatic niche for each species were done by applying the final model equation of the SDMs under the present to the future climate change scenarios RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 for the year 2090-2100 (from the Intergovernmental Panel on Climate Change-IPCC), as provided by Bio-ORACLE II. Despite having modelled the 4 scenarios proposed by the IPCC in its latest Assessment Report (IPCC 2014), recent studies have suggested that the most likely scenarios are the intermediate ones, RCP4.5 and RCP6.0 (Hausfather and Peters 2020), and for this reason, the results and discussion were focused on these two scenarios.

Results

The **Minimal SST** (SSTMin) and **Maximal SST** (SSTMax) were strongly related to the geographic distribution pattern of all kelps studied (Table A2). The SSTMin returned the highest percent gain contribution to the MaxEnt models (from 80.1 to 33.5 when all predictors included) except in *S. latissima* model which was ranked as the second most important variable behind the SSTMax, in agreement with the ranking by the permutation importance scores, and by the jackknife test (not shown). **Minimal salinity** (SalinityMin) was ranked third and returned importance values somewhat around 15 in *L. digitata* and *S*. *latissima* (values not shown) and thus included in the final model in those species (Table A2). WAVESMax, NITROGENMin, FOSFATEMax, ATENUAMax and ATENUAMin were found minimally related to the latitudinal distribution of kelps, i.e. estimations of variable importance lower than 15, and thus omitted as axes of the projections of the realized niche of the final models (Table A2).

The present projections based on the final models were shown in the Figure A1 at the upper right corner to compare the model reliability with current distribution data for each species (shown in the upper left corner of the Figure A1). All models projected well the current distribution based on the equate entropy of thresholded and original distributions (Morales and Fernández 2020; Liu et al. 2013).

We projected the equations from such final SDMs (Table A2) by using environmental layers projected for 2090-2100. SSTMin and SSTMax were considered in all the models, and SALINITYMin was added in the models for *S. latissima* and *L. digitata* (Figure A1).

Table A2. Final SDMs

MaxEnt SCORES	SSTMin Perc. Contrb.	SSTMin Permu. Import.	SSTMax Perc. Contrb.	SSTMax Permu. Import.	SALINITYMin Perc. Contrb.	SALINITYMin Permu. Import.	Nº cells with presences	Threshold for presence[a]	AUC[b]
Species									
A. esculenta	64.2	62.3	35.8	37.7	-	-	774	0.191	0.820
L. digitata	61.4	60.2	28.7	26.1	10	13.8	1195	0.166	0.797
L. hyperborea	68.9	67.3	31.1	32.7	-	-	1246	0.177	0.805
L. ochroleuca	66	72	34	28	-	-	180	0.202	0.892
S. latissima	42.2	51.6	43.8	31.9	13.9	16.5	1356	0.178	0.790
S. polyschides	86.4	74.8	13.6	25.2	-	-	723	0.097	0.872

MaxEnt SCORES	SSTMin Perc. Contrb.	SSTMin Permu. Import.	SSTMax Perc. Contrb.	SSTMax Permu. Import.	SALINITYMin Perc. Contrb.	SALINITYMin Permu. Import.	PARMax Perc. Contrb.	PARMax Permu. Import.	Nº cells with presences	Threshold for presence[a]	AUC[b]
Species											
A. esculenta	63.6	66.9	36.4	33.1	-	-	-	-	801	0.164	0.827
L. digitata	65.4	66.7	23.3	21.9	11.3	11.4	-	-	1199	0.155	0.799
L. hyperborea	66.6	68.7	33.4	31.3	-	-	-	-	1480	0.150	0.802
L. ochroleuca	59.1	68.3	-	-	-	-	40.9	31.7	170	0.170	0.911
S. latissima	46.3	56.6	43.7	29.8	10	13.6	-	-	1460	0.196	0.771
S. polyschides	92.5	74.4	7.5	25.6	-	-	-	-	849	0.111	0.871

Perc. Contrb. Percent Gain Contribution values of the variables in the final model estimated with MaxEnt.

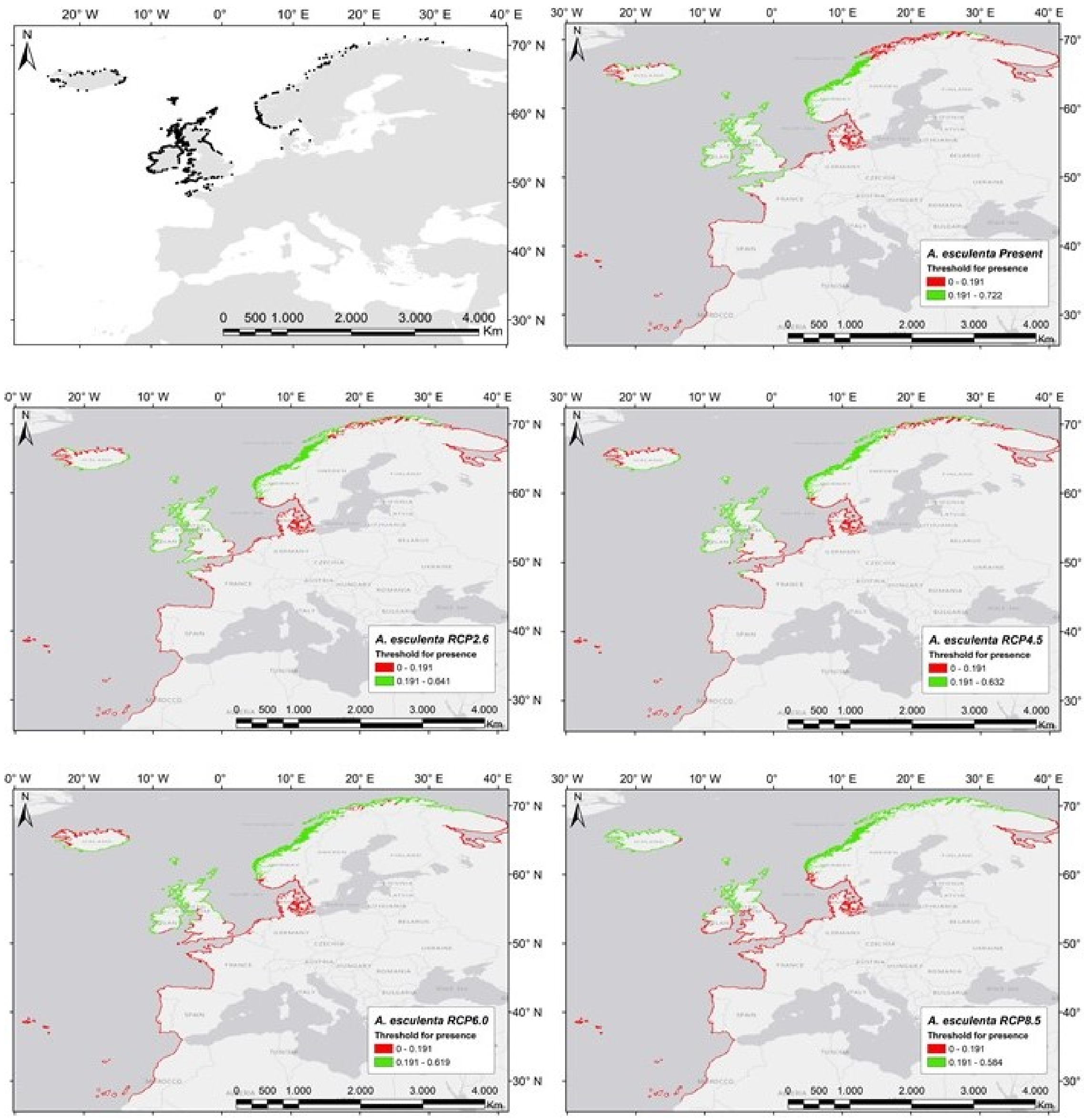
Permu. Import.: Permutation Importance scores of the variables estimated with MaxEnt**.**

[a] **Equate entropy of thresholded and original distributions**, habitat suitability values higher than the threshold are indicative of a projected presence.

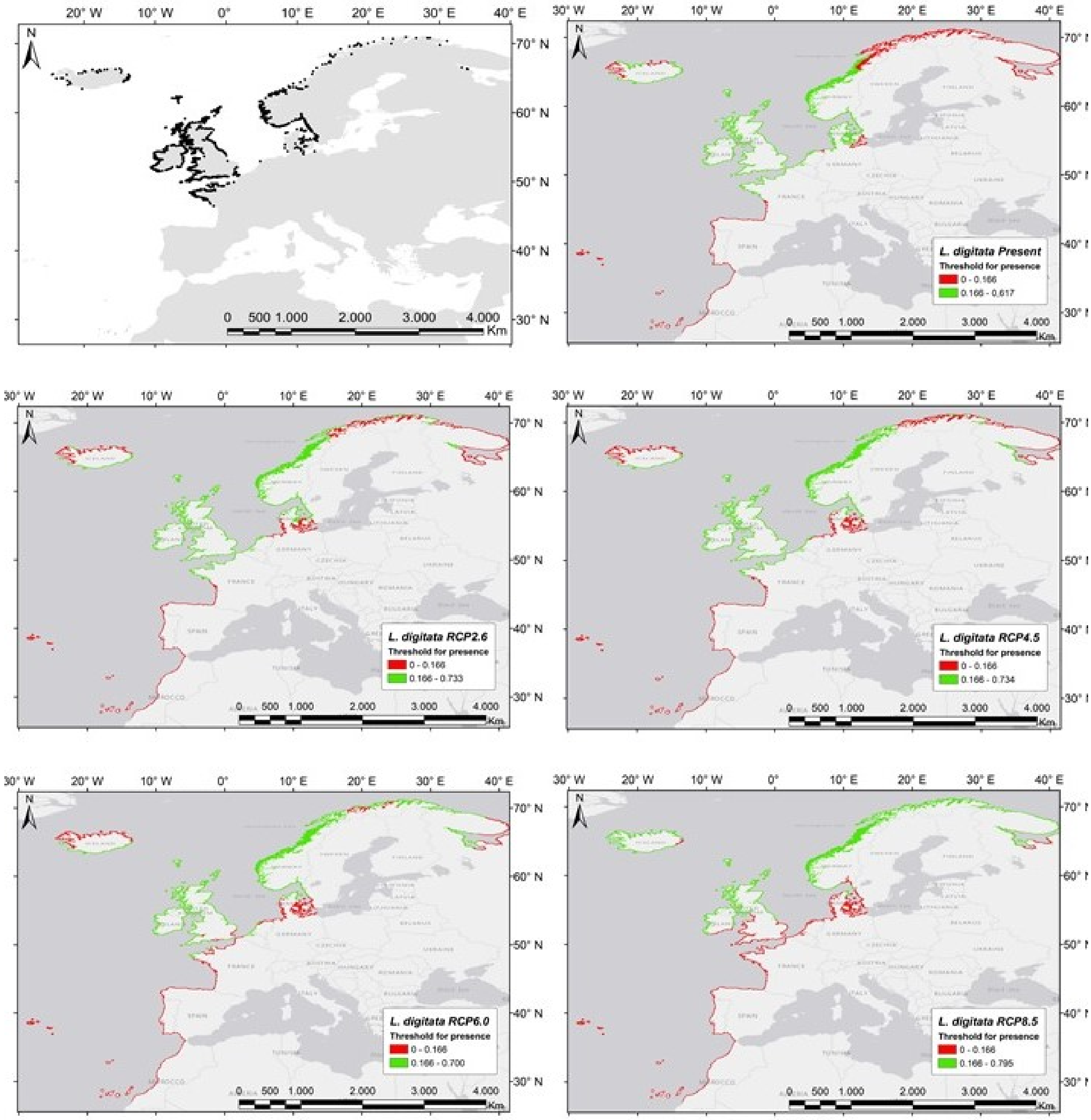
[b] Area under the curve (AUC) of a receiver operating characteristic (ROC) plot: 1-0.9 good, 0.9- 0.8 fair, 0.8-0.7 poor, 0.7-0.6 fail, following Sweets (1988).

Figure A1. Projections of Kelp Forests distribution based on habitat suitability from species distribution models at present time (upper right corner) and at RCPs IPCC climatic scenarios 2090-2100 (middle and bottom). Present distribution records are shown in the upper left corner of the figure. **A**. *Alaria esculenta*, **B**. *Laminaria digitata*, **C**. *L. hyperborea*, **D**. *L. ochroleuca*, **E**. *Saccharina latissima* and **F**. *Saccorhiza polyschides*.

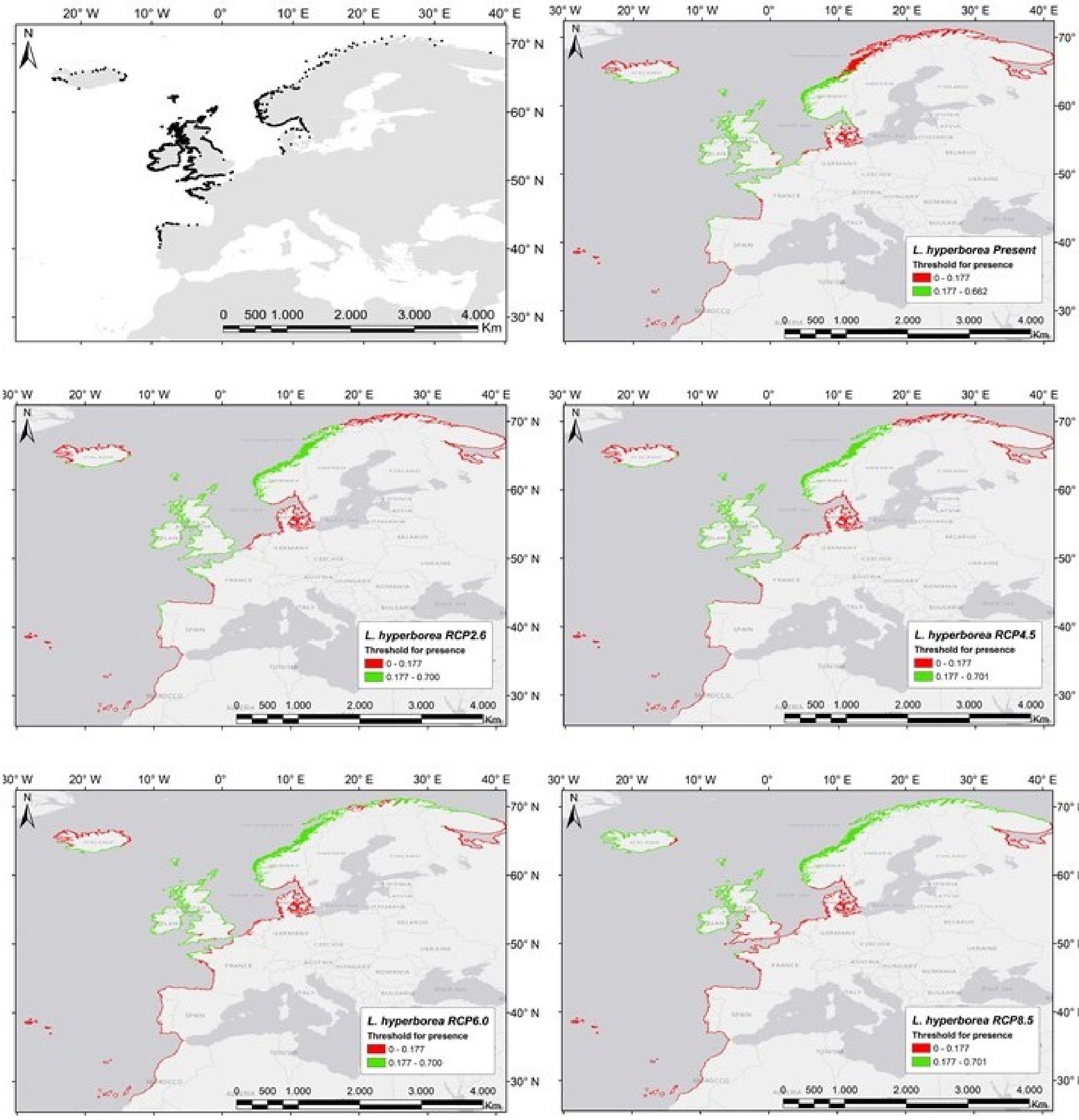
A Alaria esculenta



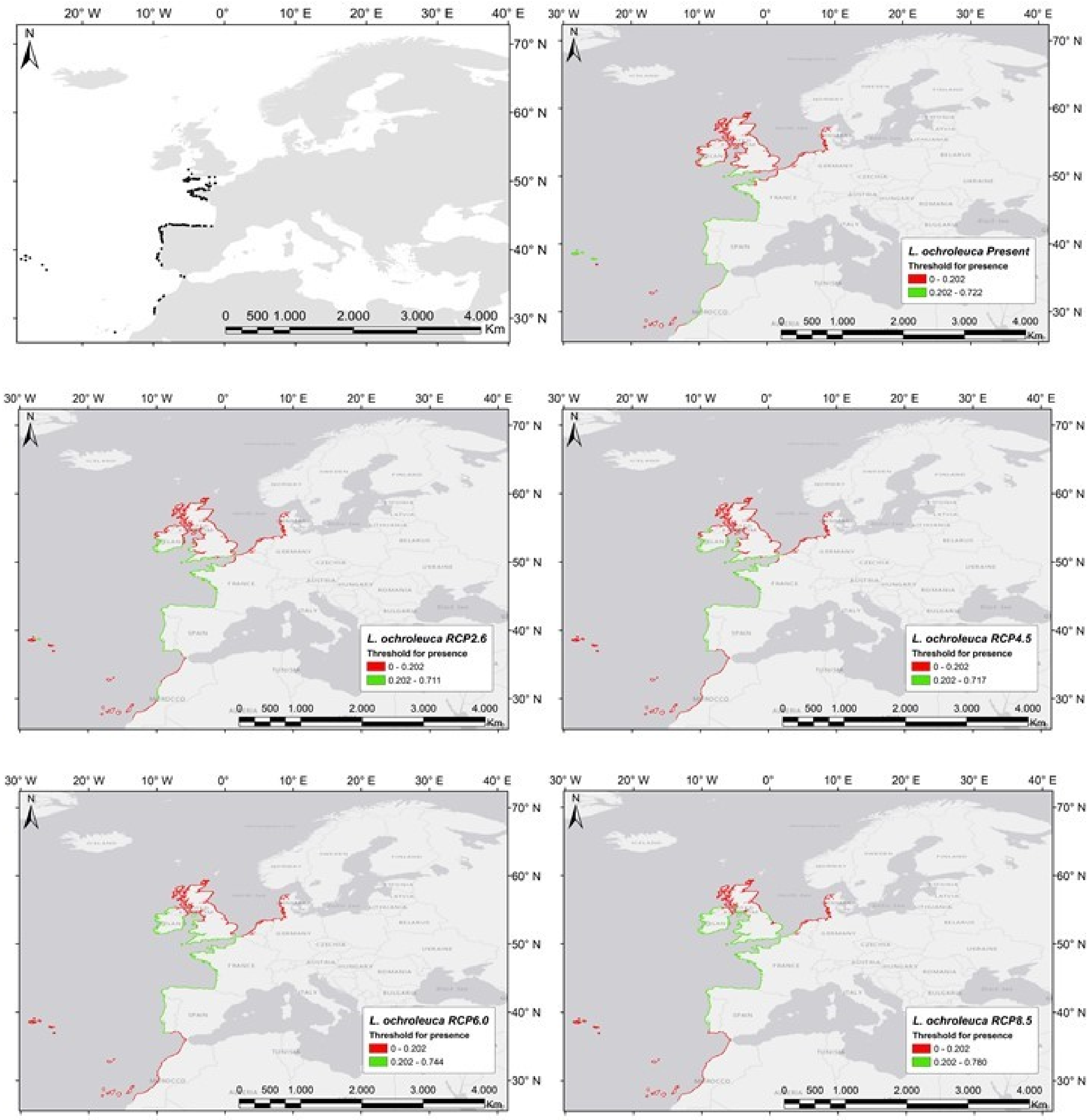
B Laminaria digitata



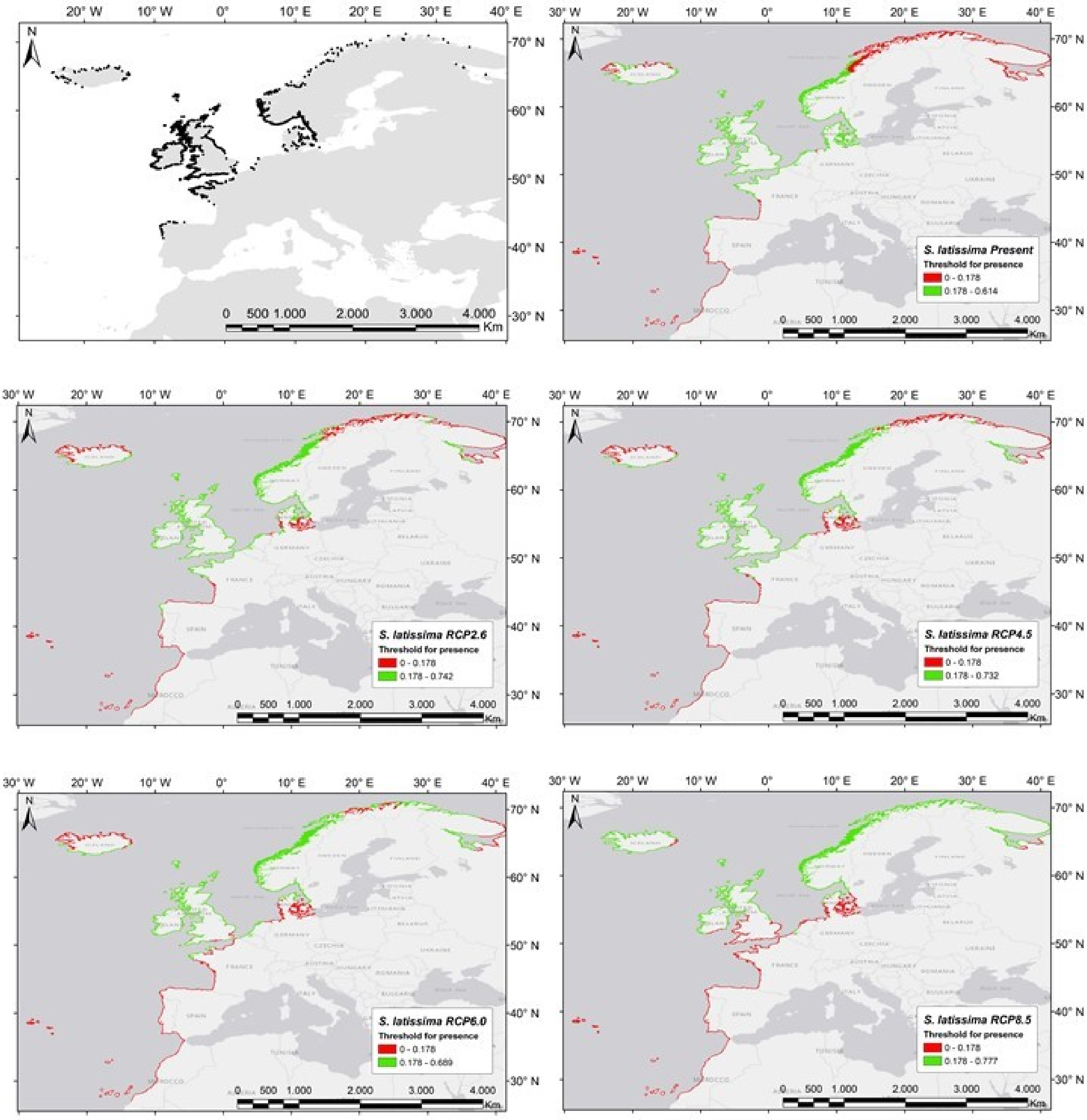
C Laminaria hyperborea



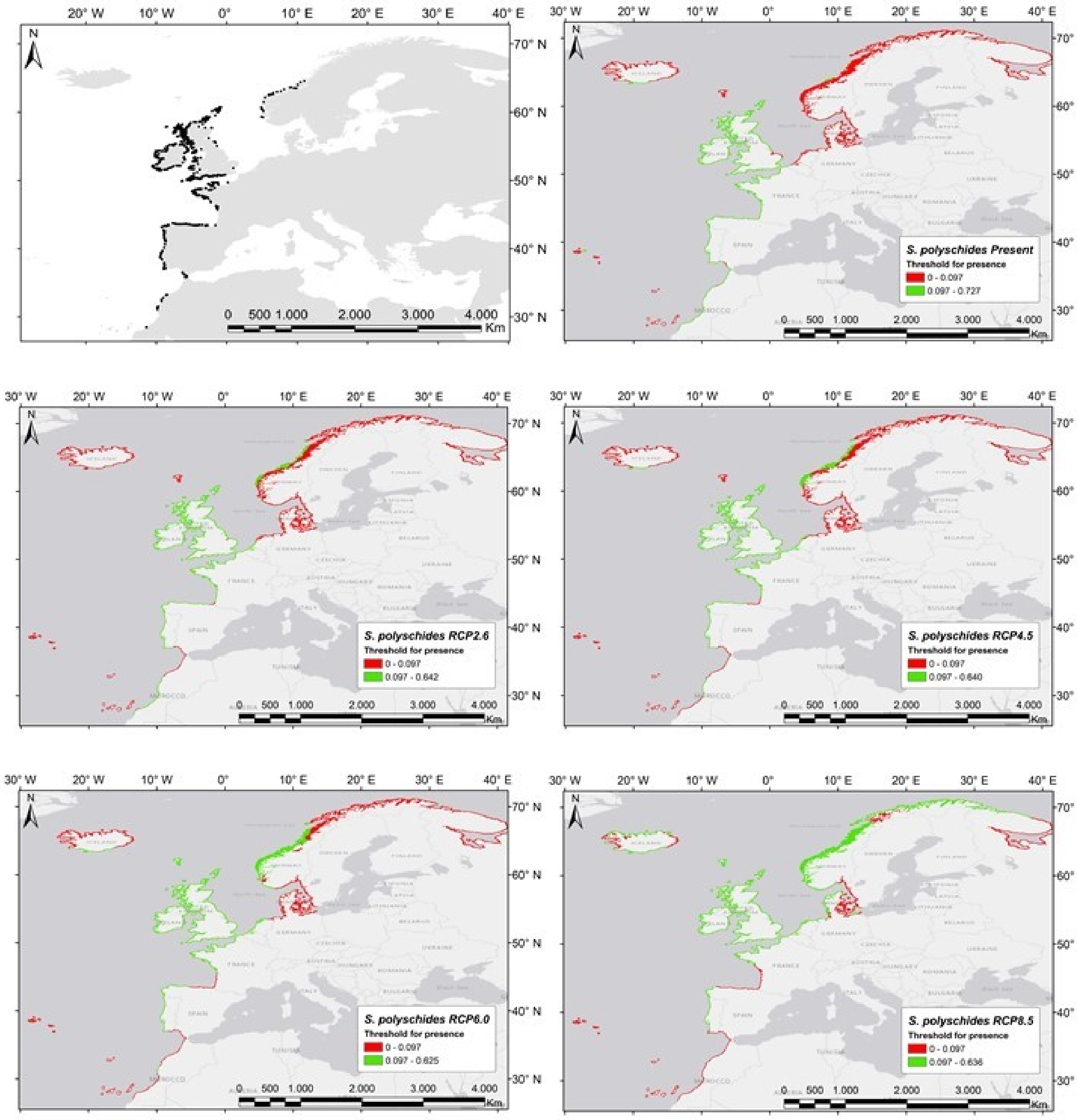
D Laminaria ochroleuca



E *Saccharina latissima*



F Saccorhiza polyschides



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Appendix 2: Detailed description of the proposed monitoring and assessment strategy

Rationale for the proposed monitoring

Drastic losses of Kelp Forests in the southern part of the OSPAR area and significant declines at several locations have already occurred and changes in habitat distribution are rapid. Multiple stressors including global changes and regional stressors are threatening Kelp Forests. Monitoring programs exists (Table B1) but there is a lack of large-scale consistent monitoring of Kelp Forests distribution and ecological status, and a need of coordination between programs. The proposed monitoring and assessment strategy is composed of three complementary approaches to (i) define the distribution and biomass of Kelp Forests, (ii) precise the threats and pressures and (iii) assess their ecological status.

Different approaches:

1. Distribution and biomass of Kelp Forests

Fine-scale and regular monitoring of Kelp Forests distribution is necessary to better evaluate areas of decline and identify areas that need further protection. Biomass stock gives also information on the status of Kelp Forests. When data are difficult to collect, estimations by predictive modelling can fill this knowledge gap and provide a complementary approach. It also allows to predict future distribution according to changes in environmental parameters (e.g. increase of temperature, change in turbidity). The distribution and biomass monitoring could be based on:

- Direct *in-situ* surveys
- Remote sensing programs (acoustic, imagery)
- Citizen science projects (presence/absence)
- Predictive modelling (SDMs) based on occurrence data and environmental parameters to compensate lack of records and predict change in distribution.

2. Pressures monitoring

Kelp Forests are subject to multiple threats. Monitoring of environmental parameters (e.g. seawater temperature, nutrient concentration, water clarity, siltation rate) and human activities (e.g. fisheries, aquaculture, dredging, land activity conducting to material run-off, …) is necessary to better manage Kelp Forests and identify management actions.

3. Monitoring of ecological status of Kelp Forests with associated biota

In-situ monitoring can go a step ahead kelp distribution and biomass evaluation through further measurement at different biological scales (community, population, individual) and for different biological components (kelp species, associated biota). These can include measurements on kelp populations, genetic diversity and connectivity, physiological and phenological responses and metrics on community structure for the associated biota. It is necessary to establish a network of stations with an increased effort on range edge populations and climatic refuges areas in which monitoring is carried with consistent methodology and long-term effort for data comparison.

Use of existing monitoring programmes

Currently, different local monitoring programs exist for Kelp Forests (Table B1) but there is no clear coordination at the EU level and no harmonisation in monitoring methodologies. Where monitoring programs exist, they often contain few sites and there is a lack of long term and continuous datasets to fully assess the distribution, temporal trends and ecological status of Kelp Forests in Europe.

The European Environment Agency (EEA) works at the moment with two types of actions: Increasing efficiency of monitoring by simplifying, streamlining and making comparable existing marine monitoring data and Convergence of assessments by leading work towards the development of a common set of pan-European marine indicators to be complemented regionally, in order to support the implementation of the European Marine Strategy (EMS) and proposed Marine Strategy Directive's (MSD) as well as to further develop its own pan-European marine assessments (Anon, 2006).

OSPAR Common Procedure - Macrophytes including macro-algae shifts from long-lived to short-lived nuisance species. Angiosperms and macroalgae are not used as indicators at the regional sea level but OSPAR does some monitoring in the context of its eutrophication assessment under the Eutrophication Monitoring Programme (OSPAR agreement 2005-4) as part of the Coordinated Environmental Monitoring Programme (CEMP). The parameters measured are biomass, species composition, coverage and depth distribution. Annual monitoring of biomass and species composition of macrophytes (including macroalgae and angiosperms) are carried in (potential) problem areas relating to eutrophication (applied as an assessment parameter). In OSPAR, where the parameter is monitored only for eutrophication problem areas and potential eutrophication problem areas; there are currently limited data available reported by Contracting Parties. National information is made available in the context of eutrophication assessments (2003, 2008 and 2017).

Table B1: Kelp Forests monitoring or observation programs within OSPAR area (in 2020, extracted from Duffy et al., 2019)

Observing Network	Group of Macrophytes	Spatial scales	Size of Reporting Unit (m)	Replicates per unit	Observing Frequency	Intertidal/ shallow	Measures of Macroalgae	Taxonomic Specificity
Denmark	Macroalgae and seagrass	National	From shallow to deep, variable length	> 100	Every year/2nd year	Subtidal	Cover	Species level for some, functional groups for others
France - Brittany (REBENT monitoring)	Kelps and other macroalgae	Statewide	Subtidal: 1 transect per site between 50 and 100m long, with 0.25m x 0.25m quadrats (10 per bathymetry). Intertidal: 3 replicates of 3 quadrats (33cmx33cm) per community and per site.	27 sites in subtidal and 12 sites in intertidal	Every 3 years since 2004	Both	Subtidal: flora and fauna biodiversity and abundance, colonization of the stipes of *L. hyperborea*, size and state of perennial kelps in quadrats. Intertidal: flora biodiversity, cover and size (in quadrats).	Species level, all taxa
France - Brittany (Roscoff Observatory)	Kelps	Statewide	Transect parallel to the coast (20m)	5	Every 5 years since 1997	Both	Genetic diversity / same sites each 5 years	Samples only a subset of species
France - Brittany (Roscoff Observatory)	Kelps	Local	10 permanent frame (1 m²). All individuals > 5 cm. tagged.	1	4 times a year (seasonal) since 2013	Subtidal	Demographic parameters: density, recruitment / mortality, size structure, individual stipe and lamina growth, age.	Samples only a subset of species
France - Chanel and Atlantic coast, (WFD, MSFD)	Kelps and other macroalgae	Regional	Subtidal: 1 transect per site between 50 and 100m long, with 0.25m x 0.25m quadrats (10 per bathymetry). Intertidal: 3 replicates of 3 quadrats (33cmx33cm) per	45 sites in subtidal and 38 sites in intertidal	Intertidal: every 3 years since 2007 Subtidal: every 3 years since 2010	Both	Subtidal: flora and fauna biodiversity and abundance, colonization of the stipes of *L. hyperborea*, size and state of perennial kelps in quadrats. Intertidal: flora biodiversity (and fauna for the WFD), cover and size (in quadrats).	Species level, all taxa
Germany - North Sea, Helgoland (WFD)	All macroalgae	Local	Area approx. 100 x 100 m	140 georeferenced points	twice per year (winter, summer), continuous since 2005	Intertidal	Percentage cover of all species; derived parameters integrated in Helgoland Phytobenthic Index: opportunists, green algal cover, *Fucus* cover, species richness	Species level, all taxa

Observing Network	Group of Macrophytes	Spatial scales	Size of Reporting Unit (m)	Replicates per unit	Observing Frequency	Intertidal/ shallow	Measures of Macroalgae	Taxonomic Specificity
Germany - North Sea, Helgoland (WFD)	Kelps plus all macroscopic macroalgae	Local	120 - 240 m, 3 replicate transects between -4 and -13 m	1; second site since 2016	Minimum: 3 x in 6 years; since 2007	Subtidal	Depth limit of kelp and five red algae, percentage cover of, relative frequency of understorey	Species level, all taxa
Greenland - Young Sund	Kelps	Local	1 collection at 10 m depth	1	Annual	Subtidal	Growth	Species level for some, functional groups for others
Iceland - West coast Breidifjordur	Kelps	Local	Acoustic survey, 500 m between survey lines, photo and video at irregular intervals		Variable	Subtidal	Density, kelp species composition	Species level for Laminarians
Norway - Barents Sea, North Sea, Norwegian Sea, Skagerrak (ECOCOAST)	Macroalgae and seagrass	Regional	Transect (deep, max 30m, to shallow) of subtidal zone or vertical belt of the supralittoral zone (8-15 m)	2 pr region	3 years cycle	Both	Depth limit, index and/ or species distribution	Species level 9 selected species
Norway - Norwegian Program for Mapping of Marine Habitats	Kelps	Regional	*S. latissima*, *L. hyperborea, zostera marina*		Variable	Subtidal	Density, canopy cover, depth, epiphytes	
Norway - Skagerrak	*S. latissima*	Local	Spatial predictive modelling				Distribution	
Norway – Rogaland-Trøndelag, harvesting surveys	*L. hyperborea*	Local	Videotransects (100-150 m long)	Variable	Yearly	Subtidal	Underwater video in harvesting areas and reference areas (closed for kelp harvesting)	Species level for Laminariales
Norway - Nordland county, harvesting survey	*L. hyperborea*	local	Videotransects (100-150 m long). Kelp collection at points	Variable	Yearly	Subtidal	Underwater video Kelp collection: morphology, age, growth, epiphytes	Species level for Laminariales
Portugal, NW Spain Iberian Peninsula	Kelps, associated	Regional	(n=5) 25 x 4 m (kelp counts) per site. 1m² (n=5) quadrats	25 reefs within the 5 regions	Annual (summer)	Subtidal	Density, biomass	Species level for some, functional

Observing Network	Group of Macrophytes	Spatial scales	Size of Reporting Unit (m)	Replicates per unit	Observing Frequency	Intertidal/ shallow	Measures of Macroalgae	Taxonomic Specificity
	macroalgae and fishes							groups for others
Spain - Basque Country (WFD)	Macroalgae and seagrass	Statewide	Transect length depending on the intertidal length	12 estuaries and 35 coastal transects	3 years cycle, since 2002	Intertidal	Cover (%)	Species level, all taxa
Spain - Coastal Monitoring Network of Cantabria (WFD)	Macroalgae	Regional	Transects 25 m	7	3 years cycles but with some gaps	Both	Cover (%)	Samples only a subset of species
Spain - North coast, Asturias	Fucoids and other macroalgae	Regional	Random quadrats (50 x 50 cm)	20 sites	twice a year	Intertidal	Cover (%), species richness	Species level, all taxa
Spain - North coast, Asturias	Kelps	Regional	Transects 500-600 m long	12	Once a year (summer)	Subtidal	Cover (%), density	Species level, all taxa
Spain - North coast, Asturias	Kelps	Regional	random quadrats (50 x 50 cm)	1 site for quantitative estimation, 20 for presence/absence	Twice a year (spring and autumn)	Intertidal	Density, biomass and recruitment	Species level, all taxa
Spain - North-West coast, Iberian Peninsula	Macroalgae	Bioregional	random quadrats (50 x 50 cm)	about 10	Variable	Intertidal	Cover (%)	Samples only a subset of species
Sweden -national monitoring of phytobenthic communities	All macroalgae	Bioregional	Variable	At least 8	Annual	Subtidal	Canopy Cover, density & biomass of invertebrates	
U.K., Northern France (MarClim)	Kelps and other macroalgae	Regional	n/a - SACFOR and % cover measures		Annual	Intertidal	Abundance of key species	Species level, all taxa

Synergies with monitoring of other species / habitats and environmental parameters

The parameters related to water quality and eutrophication such as nutrient concentration, light clarity, sedimentation rate and suspended organic particles are important drivers for Kelp Forests. These variables therefore constitute variables to measure in connection with Kelp Forests monitoring programmes. These parameters are measured in the Eutrophication Monitoring Programme (OSPAR agreement 2005-4) and the Eutrophication Assessment of the WFD (2000/60/EC, Guidance Document No. 23) but should be extended.

OSPAR established a set of biodiversity common indicators to assess the status of biodiversity. The Benthic Habitat indicators can be used for Kelp Forests assessment: BH1 (*Typical species composition*, in OSPAR Region IV), BH2 (*Condition of Benthic Habitat Communities*, in OSPAR Region II, III and IV) and BH3 (*Extent of Physical Damage to Predominant and Special Habitats*, in OSPAR Region II, III and IV).

Proposed assessment criteria

Table B2: Suggested parameters, metrics and proposed methods for basic and enhanced monitoring programs.

Parameters and metrics	Proposed techniques	Basic vs Enhanced monitoring
Spatial distribution and biomass of Kelp Forests - Presence / absence (biomass if possible) - Cover	**Remote sensing** - Satellite and aerial imagery, LiDAR, multispectral sensors (clear water, low depth) - Acoustic monitoring (multibeam sound navigation and ranging SONAR) - Underwater imagery with AUVs **Predictive modelling** **Direct ground surveys** **Citizen science**	**Basic monitoring**
Kelp populations - Density of Kelp species - Depth limit of Kelp Forests - Kelp size class distribution - Kelp recruits' density	**Direct *in-situ* surveys** - Transects - Quadrats	**Basic monitoring**
Kelp population (cont.) - Genetic diversity - Genetic connectivity	- Random collection	**Enhanced monitoring**
Kelp individual - Epiphytes load	**Direct *in-situ* surveys** - Individual measurement	**Enhanced monitoring**

- Kelp morphology and frond state		
Associated biota - Diversity - Presence and abundance of filamentous algae (turf) - Presence and abundance of sensitive/key associated species - Presence and abundance of NIS species	**Direct *in-situ* surveys** - Transects - Quadrats	**Enhanced monitoring**
Pressure drivers - Temperature - Nutrient concentration - Water transparency - Siltation rate	**Satellite imagery, water samples and sensor deployments**	**Basic monitoring**
Activities linked to pressure	**?**	**Basic monitoring**

Additional details on monitoring methods

Two complementary networks should be established to monitor Kelp Forests with (1) a broad scale survey to assess Kelp Forests distribution and biomass and (2) a series of sentinel sites survey to assess the state of Kelp Forests.

Assess Kelp Forests distribution and biomass stock (Basic monitoring - broad scale survey)

To assess the Kelp Forests distribution and biomass stock, a broad scale survey is necessary. This survey should aim to cover as much of the coastline in area with poor knowledge or with old data. The distribution of Kelp Forests can be determined using rapid ground surveys, remote sensing emerging techniques and species distribution models (SDMs) (Burrows et al. 2014). A conceptual framework helps to choose the most appropriate remote sensing method (Figure A2 from Bennion et al. 2019). The ground surveys to monitor distribution of Kelp Forests should use SACFOR estimates of abundance as the minimum level of data collection.

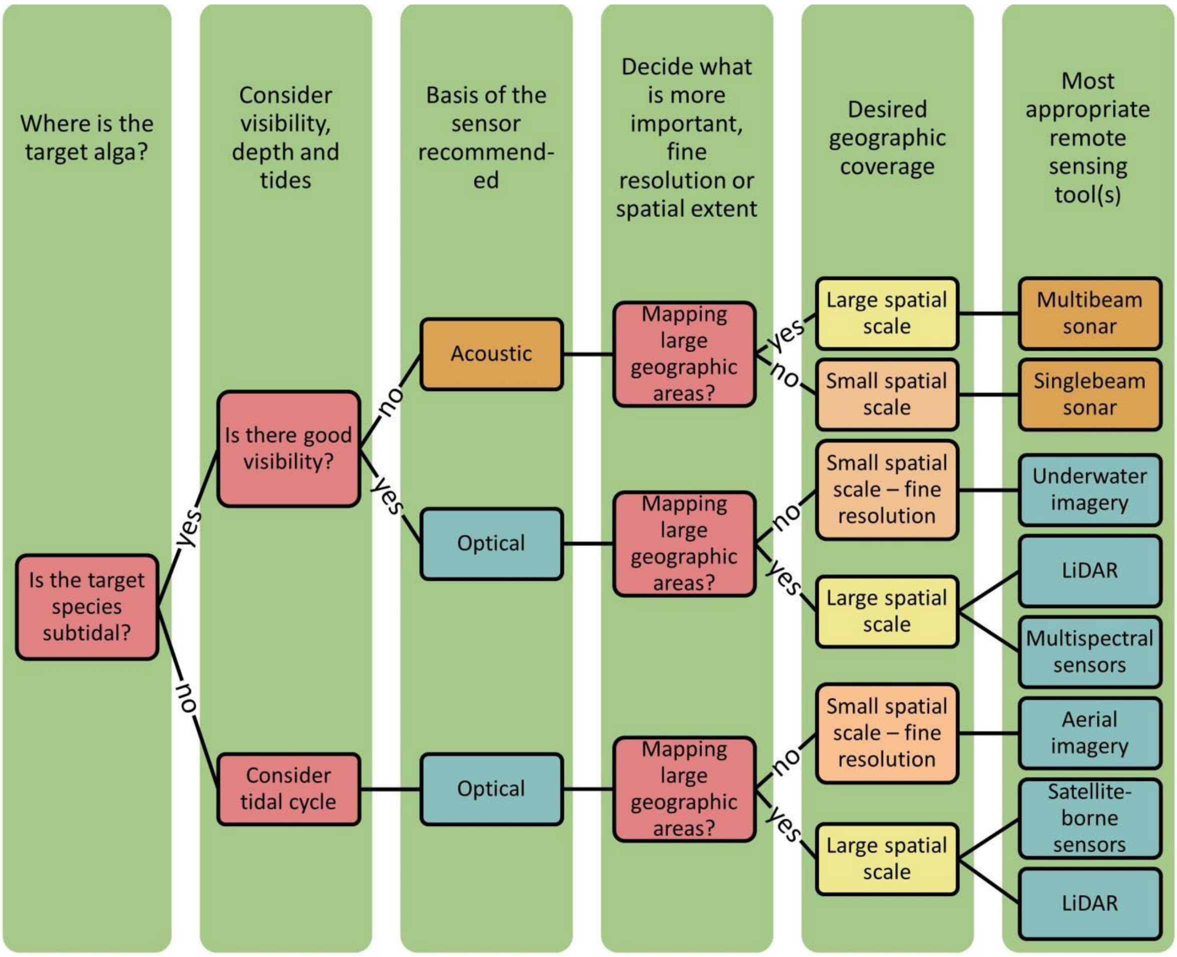

Fig. B1 ‘Remote sensing of macroalgae decision tree’ provided to aid the selection of appropriate remote sensing tools for mapping submerged and intertidal macroalgae. The detection of submerged algae will likely be best achieved using a combination of acoustic and optical techniques as acoustic sensors are ineffective in water <2 m (From Bennion et al., 2018).

Kelp population

For the status of Kelp Forests populations, more quantitative methods can be used but required more time and resources. The depth limit of kelp belts is an important indicator of water quality. Random belt transects might be preferred to quadrats given areas with low kelp numbers where quadrats is not ideal. Within each transect divers should record kelp species, density and size of kelps (size class distribution, recruits’ density). Samples of kelp can be taken to measure genetic diversity and connectivity.

Kelp individual

Within the transects, random collection of adults can be done to assess epiphytes cover (biomass, epifauna and epiphyte species) and morphology (frond width and stipe length) that give information on Kelp Forests maturity and physiological stress.

Associated biota

Rapid Assessment Surveys (RAS, using SACFOR scale) methodology might be prefer rather than quadrats or transects to measure all metrics recommended while covering a larger area. The RAS should include algal and faunal diversity, presence and abundance of filamentous algae (turf), sensible/key associated species (e.g. Gorgonian species), presence and density of invasive species.

Pressures- Temperature

- Nutrient concentration
- Water transparency
- Siltation rate
- Human pressures

Selection of monitoring locations

The broad scale survey to cover Kelp Forests distribution has to be conducted for most of the coastline with rocky substratum with a focus on range edge distributions, kelp declining areas and areas with a lack of data. It should be conducted at least every 6 years.

The regular sentinel sites survey to assess population status, physiological stress and associated flora and fauna should be conducted regularly (annually) within sentinel sites. Burrows et al. (2014) recommend for UK a split in 6 different bioregions. Three hub locations would be selected per region with three to four sentinel sites surveyed per location, representative of local biogeographic conditions. The same methodology could be applied for each contracting party of OSPAR holding Kelp Forests, with specific national effort depending on national situation (range edge and declining populations, extent of Kelp Forests distribution).

Timing and Frequency of monitoring

Developing a monitoring programme which would specify the timing and frequency could be developed as a collective action.

Data collection and reporting

Data recorded from the samplings should include date, time, site or transect description, quadrat size, number of replicates, GPS location, tide condition and water depth.

Appendix 3: Threats on Kelp Forests habitats in OSPAR region V

Judging from the existing studies, climate change seems to be the main threat to the Azores kelp stands.

While benefitting from some buffering from natural and anthropogenic surface stressors, the mesophotic niche occupied by the Azores kelps remains nonetheless vulnerable to climate change. Projections by Assis et al. (2017) estimate that the thermal niche of L. ochroleuca in the archipelago should decline between 23% and 85% depending on the emission scenario retained (RCP 2.6 or RCP 8.5, respectively). We underline that the niche may be constricted simultaneously from above and below. Warmer, more stratified and nutrient-depleted ocean surface conditions (Capotondi et al. 2012) are expected to reduce the niche from the surface downwards (see e.g. Voerman et al. 2013 for L. ochroleuca range reduction on the Iberian shores). On the other hand, enhanced precipitation (Santos et al. 2004; Hernández et al. 2016) may result in increased siltation of island shelves and an attenuation of PAR levels that would diminish the kelps' niche from the lower depth limit upwards.

As far as direct exploitation goes, the situation seems to be the following

Although the Formigas kelp population is already enclosed within a marine protected areas this is not the case with the kelp occurrences located in the vicinity of inhabited islands. Their relative accessibility and limited regulation make them susceptible to deliberate collection, especially where the kelp upper range is within reach of conventional SCUBA diving. Although seaweed harvesting using this practice is presently limited to depths above 10 m, this commercial activity is regaining momentum throughout the Azores and has been traditionally important around certain islands. Expanding existing MPAs to cover the most important kelp stands would better safeguard their integrity and associated ecosystem services.

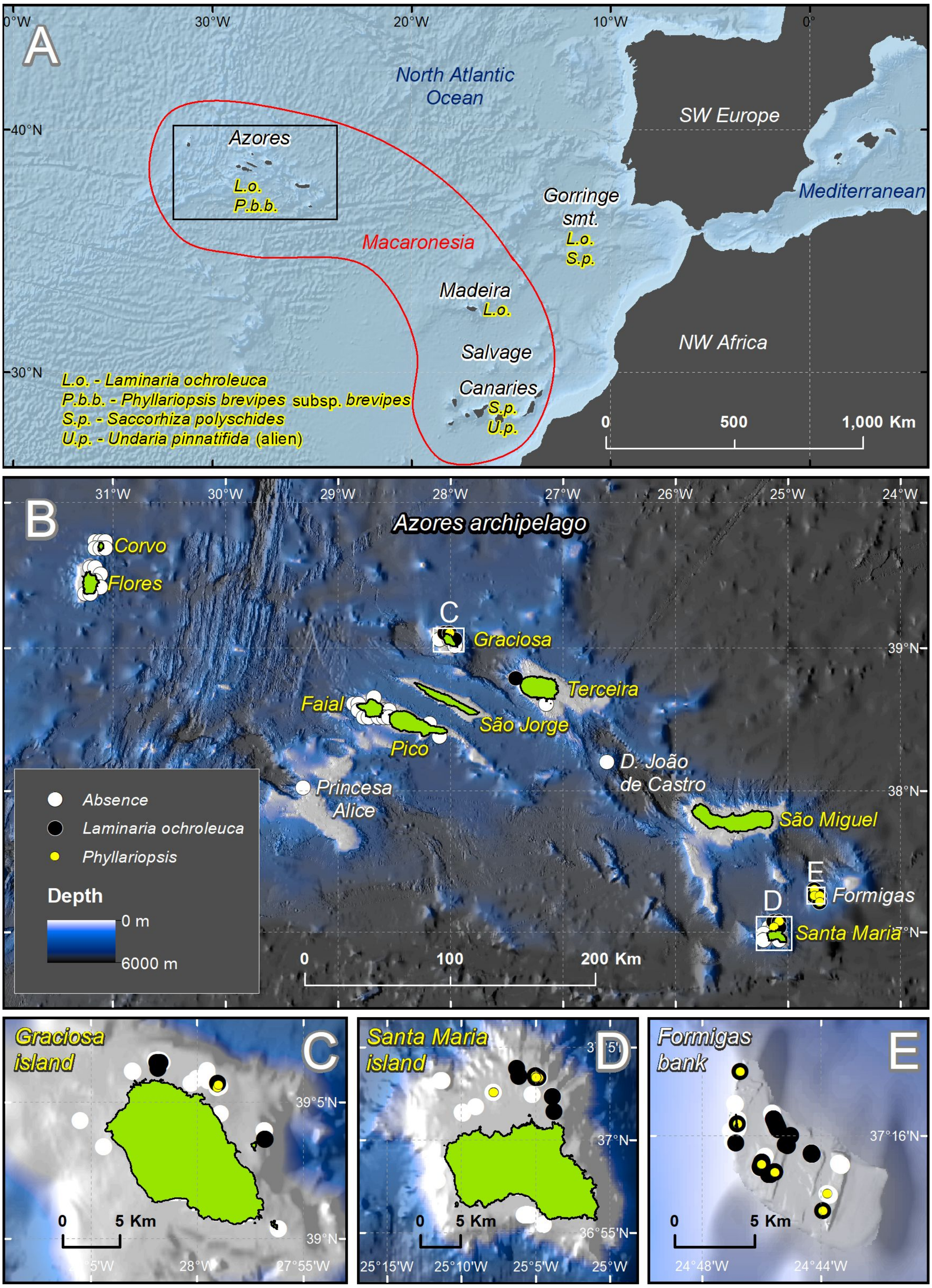

Figure A3-1 : Distribution map from Tempera et al. 2020

Tempera, F., E. Atchoi, A.L. Sinde-Mano & D. Milla-Figueras. 2020. Kelp occurrences in the Azores (NE Atlantic). EMODNET Biology dataset. https://doi.org/10.14284/423.

OSPAR Secretariat
The Aspect
12 Finsbury Square
London
EC2A 1AS
United Kingdom

t: +44 (0)20 7430 5200
f: +44 (0)20 7242 3737
e: secretariat@ospar.org
www.ospar.org

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