REVIEW: Methods applied to UK kelp monitoring and implications for wild harvesting

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A review for The Crown Estate
1.0 EXECUTIVE SUMMARY

Kelp forests are an important feature of the British coastline, covering approximately 19,000 km$^2$. Levels of biodiversity living in this habitat-forming biomass rival that of tropical rainforests. Kelp also has commercial uses in pharmaceuticals, food, and fertiliser, amongst others: studies cite kelp-based ecosystems to be worth billions of pounds. The northeast Atlantic is an important biogeographic zone for kelp, and the UK in particular contains 50% of known kelp species in this region.

There is increasing interest in wild-harvesting of kelp in Britain, illustrated by a growing number of seaweed and sea-containing products, sought after for their nutritious ‘superfood’ properties. Whilst commercial aquaculture operations are currently absent from Britain, research and development into establishing an industry are currently ongoing, particularly in Scotland and Ireland.

Evidence suggests that the distribution and abundance of kelp in Britain is changing, driven by variations in sea-surface temperatures enhanced by climate change. Yet, complex relationships exist between causal factors, justifying the need for a large-scale monitoring effort, particularly of commercially-important species. Monitoring kelp poses many challenges, growing in difficult-to-access areas with often poor visibility and testing weather. This review will explore the research and methods that have been applied to monitoring this important oceanic flora in Britain.

In the past, quantitative research on kelp has been patchy and irregular. In a global review of ecological studies on kelp, only 7 out of 402 papers were from Britain. A number of data-recording projects have been set up to improve the disparity of data, including Citizen Science projects recruiting the public to go out and identify seaweeds. Occurrence records are often contributed to species distribution models, estimating suitable kelp habitat through associations with environmental variables.

Remote sensing is also being explored for aquatic vegetation, offering a large-scale, holistic approach that is cost-effective and saves time. Whilst both satellite and aerial imaging have shown to be effective, signals can be lost in murky water, and images do not account for changing tides. New avenues are being explored in acoustic monitoring, particularly multi-beam sonar, which are proving successful. However, these have only been tested on an ad-hoc basis, and a standardised rapid assessment technique for monitoring kelp has yet to be developed.

Given monitoring difficulties, kelp remains understudied in the northeast Atlantic, with great implications for the conservation and management of species that are both ecologically and commercially important. With an increase in wild-harvesting, coupled with ongoing climate change, it is vital that novel approaches are used to monitor the wild stocks of the British Isles.
2.0 INTRODUCTION

Kelp (Order: Laminariales) are large brown seaweeds typified by a long stipe and broad fronds. They are iconic in Britain, with seven prominent species covering 19,000 km² of coastline (Yesson et al. 2015c). See Bartsch et al. (2008) for a comprehensive review of kelp ecology and taxonomy.

2.1 The importance of kelp

The great abundance of this coastal biomass provides many uses, ecological and commercial. Forming habitats for many species in the intertidal and subtidal zones of marine ecosystems, kelp have considerable ecological importance (Araújo et al. 2016). Traditionally, alginates (carbohydrates) from kelp were used for kelp ash and a source of iodine. Small-scale commercial harvesting of wild kelp is conducted in Northern Ireland and Scotland. In parts of England, there is a growing interest in kelp as a superfood and in artisanal products, by small-scale organisations. Table 1 details the ecological and economic benefits that can be derived from kelp.

Table 1 Kelp provides both ecological and economic benefits

<table>
<thead>
<tr>
<th>Ecological</th>
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<tbody>
<tr>
<td>• Some kelp genera are known to grow as fast as half a metre per day, leading to a dense surface canopy and a forest-like structure. Through this habitat-forming surface area, kelp forests are noted as the most productive habitats on earth and underpin the ecology of the northeast Atlantic coast, with ~ 1800 species of flora and fauna recorded in one ecosystem (Birkett et al. 1998; Brodie et al. 2014; Smale et al. 2013).</td>
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<td>• Kelp washed up on the shores after storm damage ('kelp wrack') is of great importance to birds, insects, and other coastal wildlife (Burton 2012).</td>
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<td>• In particular, the UK is an important biogeographic zone for seaweeds, supporting up to 50% of those documented in the North Atlantic (Yesson et al. 2015c).</td>
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<table>
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<tr>
<th>Commercial</th>
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<tr>
<td>• Studies cite kelp-based ecosystems to be worth billions of pounds (Smale et al. 2013). In the NE Atlantic, lobsters depend on kelp habitat; the European lobster fishery is worth £30 million to the UK alone (Smale et al. 2013). Other commercially important seafoods use kelp as a nursery, including Atlantic cod, European seabass, and crabs (Birkett et al. 1998; Smale et al. 2013).</td>
<td></td>
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<td>• Kelp-derived alginates can be used for thickening in foods such as jelly and ice cream, and cosmetics including make-up and shampoo. In 2010, scientists found alginate can prevent fat absorption, and a recent surge in ‘health food’ related uses of kelp has been anecdotally reported.</td>
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<td>• Leisure and recreational activities around kelp (snorkelling, diving, kayaking) are estimated to be worth over £11 billion annually, as well as non-monetary benefits like human health and wellbeing (Smale et al. 2013).</td>
<td></td>
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<td>• Open-ocean kelp farms could serve as a renewable energy source, offering an alternative to controversial biofuels (Araújo et al. 2016). Kelp also buffers wave action and prevents erosion, adding structure to the shoreline and alleviating flood damage (Yesson et al. 2015c; Smale et al. 2013).</td>
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2.2 The distribution of UK kelp

The seven kelp species found in Britain ( ) are distributed bioregionally, each dependent on specific environmental niche requirements (Williamson et al. 2015), details found in Table. Undaria pinnatifida (Wakame) is a non-indigenous species escaped from a kelp farm in France, spreading north with warming waters (Araujo et al. 2016; Birkett et al. 1998; Heiser et al. 2014).

2.3 Changes in kelp distribution and abundance

A number of biotic, abiotic, and anthropogenic factors affect seaweed distributions. Importantly, climate change, wild-harvesting, over-fishing and invasive species have been cited as having the greatest spatio-temporal impact on UK kelp.

2.3.1 Climate change

Climate change causes oceanic acidification and warming, exceeding the physiological thresholds at which kelp typically survives: resulting stress can lead to reduced productivity and mortality (Smale et al. 2013; Wernberg et al. 2016).
contributes significantly to primary productivity and carbon sequestration, and thus declines could elicit a loop of positive feedback (Smale et al. 2013).

Studies report both shifts and declines in suitable habitat for kelp (Bush et al. 2013; Brodie et al. 2014; Moy & Christie 2012; Smale et al. 2013), alongside anecdotal evidence for declines without any reliable repeated measurements (Araújo et al. 2016; van Rein et al. 2011). Attempts were made to use existing kelp survey data to measure spatio-temporal changes in seaweed abundance alongside the changing climate (Yesson et al. 2015b). The resulting patterns were based on life history traits in kelp, supporting predictions by Brodie et al. (2014) that some kelp species decline whilst others thrive at high CO2 levels. Forecasts into the future predict climate warming will lead to increasingly poleward distributions as species in the South fail to tolerate conditions. Although structural and functional replacements could occur, substitutes may be unable to support the same biodiversity (Brodie et al. 2014).

In 2016, a 100 km kelp range contraction was documented resulting from extreme marine heat waves and increasing frequency of El Niño events (Wernberg et al. 2016). Increased storminess as a result of climate warming may affect the resilience of coastal flora through repeated erosive wave action (Brodie et al. 2014). It is apparent therefore that temperature must be studied alongside indirect factors like turbidity, current, and El Niño events in order to elicit trends in kelp distributions (Steneck et al. 2002).
**Figure 1** Seven UK kelp species image identification and kelp habitat

**Kelp species and habitat**

1. *Laminaria digitata*[^1]
2. *Laminaria ochroleuca*[^2]
3. *Undaria pinnatifida*[^3]
4. *Alaria esculenta*[^4]
5. *Laminaria hyperborea*[^5]
7. *Saccorhiza polyschides*[^7]
8. Kelp Habitat[^8]

[^2]: Image sourced from NutraWiki [https://nutrawiki.org/laminaria-ochroleuca/](https://nutrawiki.org/laminaria-ochroleuca/)
[^4]: Image sourced from Norwegian Seaweeds [http://seaweeds.uib.no/?art=136](http://seaweeds.uib.no/?art=136)
[^5]: Image sourced from The Seaweed Site [http://www.seaweed.ie/descriptions/Laminaria_hyperborea.php](http://www.seaweed.ie/descriptions/Laminaria_hyperborea.php)
[^8]: Image taken in Stackpole, Pembrokeshire. 16th May 2016
Table 2 Approximate distribution of seven UK kelp species
[Adapted from Table 1 and Figure 2 in Smale et al. (2013), Table 1 in Yesson et al. (2015b); Table 3 in Birkett et al. (1998). Reported changes in distribution numbered by quantity of studies on that kelp]

<table>
<thead>
<tr>
<th>Kelp species</th>
<th>Common name</th>
<th>Documented distribution</th>
<th>Depth range (m)</th>
<th>Reported changes in distribution</th>
<th>Predicted range change in response to future environment</th>
<th>UK distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Laminaria digitata</em></td>
<td>Oarweed, Horsetail kelp, Sea Girdle, Sea Wand, Red Ware</td>
<td>Arctic - France</td>
<td>0 - 15</td>
<td>2 Decrease</td>
<td>Decrease</td>
<td>Common around UK coastline and Ireland, absent for southeast UK, and no further south than France</td>
</tr>
<tr>
<td><em>Laminaria hyperborea</em></td>
<td>Forest Kelp, Northern Kelp, Tangle Weed, Cuvie, Cuvey, Redware</td>
<td>Arctic - Portugal</td>
<td>0 - 30</td>
<td>2 Decrease 1 No change</td>
<td>Decrease</td>
<td>Common around UK coastline and Ireland, absent for southeast UK</td>
</tr>
<tr>
<td><em>Laminaria ochroleuca</em></td>
<td>Golden Kelp</td>
<td>UK – Morocco</td>
<td>0 – 30</td>
<td>1 Increase</td>
<td>Increase</td>
<td>Absent around UK and Ireland, found in sporadic distribution in southwest UK</td>
</tr>
<tr>
<td><em>Saccharina latissima</em></td>
<td>Sugar Kelp. (Previously <em>Laminara saccharina</em>)</td>
<td>Arctic – France</td>
<td>0 – 30</td>
<td>8 Decrease</td>
<td>Decrease</td>
<td>Common around UK coastline and Ireland, absent for small parts of southeast UK</td>
</tr>
<tr>
<td><em>Alaria esculenta</em></td>
<td>Dabberlocks, Bladderlocks, Winged Kelp</td>
<td>Arctic – France</td>
<td>0 – 35</td>
<td>3 Decrease</td>
<td>Decrease</td>
<td>Common around UK coastline and Ireland, absent in large parts of southeast UK</td>
</tr>
<tr>
<td><em>Saccorhiza polyschides</em></td>
<td>Furbelows, Furbelowed Hangers, Bulbous Rooted Tangle</td>
<td>Norway – Morocco</td>
<td>0 – 35</td>
<td>1 Decrease</td>
<td>Increase</td>
<td>Common around UK coastline and Ireland, absent for much of UK East coast as well as Scotland</td>
</tr>
<tr>
<td><em>Undaria pinnatifida</em></td>
<td>Wakame</td>
<td>Global non-indigenous species</td>
<td>0 – 15</td>
<td>-</td>
<td>Increase</td>
<td>Absent around UK and Ireland, found in sporadic distribution on South UK coastline</td>
</tr>
</tbody>
</table>
2.3.4 Wild harvesting

Worldwide, there is a growing interest in kelp for both aquaculture and wild harvesting, up 5.7% every year (Araújo et al. 2016; Bush et al. 2013; NetAlgae 2012). There are no commercial seaweed aquaculture operations in the UK presently, but research and development for this is currently underway (Dunningham & Atack 2012); small-scale harvesters operate in Scotland and Ireland, and small amounts are collected in southwest England. In 2003, the FAO commented that most of the European seaweed industry was in fact based on wild harvesting, with up to ~390,000 tonnes taken in one year (FAO 2003).

Techniques with which specific UK kelp are exploited were demonstrated in a NetAlgae report (2012): *Alaria esculenta, Laminaria digitata, L. hyperborea,* and *Saccharina latissima* by manual shore-gatherers; *Undaria pinnatifida* is not harvested, and *L. ochroleuca* and *Saccorhiza polyschides* are not mentioned. Shore-gathering equipment includes knives, rakes, pitchforks, and nets, from both the shore and on boats. Whilst the report mentions manual harvest is limited to domestic use (NetAlgae 2012), evidence since publication suggests otherwise, with an increase in seaweed and seaweed-containing food in the UK (Bouga and Combet 2015). All kelp are edible, with *Saccharina latissima* and *A. esculenta* the most palatable; these kelp are sought after by Scottish and Irish health food companies to be marketed as ‘sea vegetables’.

Limited wild harvest could be sustainable if properly managed, including fallow periods in rotation and seasonal closures (Smale et al. 2003; FAO 2003). Indeed, some organisations follow such measures (http://cornishseaweed.co.uk/). In the UK, harvesters require a lease from the Crown Estate or private landlord. Harvesting is exempt in areas classified under Natura 2000: in the UK there are 203 sites classed as partially or fully marine (data available from www.eea.europa.eu). There is question as to whether these sites will persist after the UK exits the EU. Natural England does not issue specific licenses, but authored a rough Code Of Conduct (see Bailey & Owen 2014 for species-specific details). The Aquaculture Stewardship Council (ASC) and the Marine Stewardship Council (MSC) are collaborating to develop a sustainable certification scheme for seaweed harvest; this ‘Seaweed Standard’ strives to ensure ‘environmentally friendly and socially responsible use of seaweed resources’, earmarked for completion in late 2017.

Despite kelp fast growth rate, regenerating the associated biodiverse assemblages may take significantly longer (Smale et al. 2013). In Europe, harvesting standards require 3-4 years between harvests, whilst studies in
Norway contend that recovery can take over 10 years when harvesting fully mature kelp (Birkett et al. 1998). Evidence suggests that kelp forests can recover from perturbations, with most species maturing in 1-6 years, and associated communities taking 7-10 years (Smale et al. 2013; Steneck et al. 2002). However, the likelihood of 10 years without repeated disturbance is low, given the increase in documented stressors, both natural and anthropogenic, dependent on the biotope in question (Steneck et al. 2002).

### 2.3.2 Overfishing

The regulation of kelp forest ecosystems by certain keystone species is well documented (Steneck et al. 2002); for example, hunting of sea otters in California for fur led to an increase in urchins, decline in Giant Kelp forest, and decimation of the biodiversity associated with these ecosystems, resulting in a barren urchin landscape. In the NE Atlantic, overfishing of commercial species such as cod in Norway and Sweden has similar knock-on effects, as apex predators controlling herbivores (Moy & Christie 2012; Steneck et al. 2002).

### 2.3.5 Invasive species

Loss of native species can open up niches for invasive species to thrive, assisted by the development of artificial marine structures (Brodie et al. 2014). For example, offshore renewable energy capture offers bare substrata free of competitors to facilitate invasion corridors across oceans, assisted by polar shipping routes as well as through natural dispersal. *U. pinnatifida* demonstrates this, crossing into Plymouth Sound from France assisted by boat (Heiser et al. 2014). Oceanic warming also accelerates the movement of invasive species through an increase in niche availability (Brodie et al. 2014).

### 2.4 Summary: the state of kelp in Britain

Human-derived stressors have been impacting coastal marine ecosystem structures for over 150 years (Smale et al. 2013). Wild harvesting, exacerbated by ongoing climate change, is likely to be impacting kelp. Yet, essential knowledge is still lacking on kelp distribution and abundance, impeding monitoring activities of this important oceanic flora (Brodie et al. in review; Williamson et al. 2012). An ideal approach would consist of standardised, repeatable, and systematic surveying of the British coastline, which is logistically complex, time-consuming, and expensive (Araújo et al. 2016; Yesson et al. 2015c). Given the difficulties in accessing seaweed-dominated areas in the subtidal and littoral shores, remote sensing offers an efficient and effective
method to begin to tackle this task (Pauly & DeClerk 2010). The rest of this review will focus on past remote sensing research on kelp in Britain.
3.0 MONITORING AND REMOTE SENSING OF UK KELP

There are many ways to monitor kelp, from direct sampling to remote sensing, and successful effective methods have evolved with technology over time. These developments are largely driven by the need to overcome the difficult conditions that often characterise kelp habitat: in the remote subtidal zone where there can be dangerous currents and testing weather.

3.1 Historical surveys

Seaweeds have been physically documented in the UK for over 250 years (Yesson et al. 2015b). Since WWII, quantitative research on UK kelp forests has been on-going, following demand from the Ministry of Supply to produce camouflage textiles and other goods from kelp-derived alginates (Smale et al. 2013). In the 1950s, an estimate of Scotland’s kelp biomass was made using aerial photography and quadrat sampling, calculated to be over 10 million tonnes across 8000 km² (Smale et al. 2013). Except for variations on a pioneering classification of abundance method, initiated by Crisp and Southward (1958) (ACFOR - Abundant, Common, Frequent, Occasional, Rare), there has been no continued systematic pattern. In the 1970s, much work on *Laminaria* sp. was published from the Isle of Man, but there has been little interest in kelp since (Smale et al. 2013): in a global review of ecological studies on kelp, only 7 out of 402 papers were from the UK, and few were focused on the subtidal rocky shore where kelp is most often found.

Smale et al. (2013) documented seaweed surveys between 1970 and 2000, yet only to a regional scale and with no planned strategy to continue monitoring at a national level. Regardless of the known diversity and occasional surveying of kelp, there remains an incomplete picture (Araújo et al. 2016), despite noted decline in some large brown seaweeds (Yesson et al. 2015b). The patchiness of kelp, caused in part by the multitude of impacting anthropogenic and natural factors, enhances the difficulty of setting up monitoring efforts (Birkett et al. 1998).

To date there exists no direct assessment of the distribution of UK kelp: at a time when the environment is rapidly changing, it is imperative that reliable and spatially explicit biological records exist (Pauly & DeClerk 2010).
3.2 Data-recording projects

A number of data-recording projects have been set up to improve the disparity of kelp data in the United Kingdom. Data portals exist to provide publically-available global occurrence records free-of-charge. The National Biodiversity Network (NBN Gateway) (https://data.nbn.org.uk/) collates many of these, whilst (www.algaebase.org) is focused on taxonomic information; and The Ocean Biogeographic Information System (OBIS) (http://iobis.org/) contained over 22,000 occurrence records available for the Laminaria genus alone (Pauly & De Clerck 2010). Data-recording projects often submit data to these portals, from which scientists can draw patterns and conclusions.

3.2.3 Seasearch

Seasearch (www.seasearch.org.uk) is a UK volunteer project actively recruiting divers to submit information about what they see during dives. These semi-quantitative surveys along subtidal rocky shores often include kelp, with an overarching aim to record patterns in marine biodiversity in the near-shore zone (Smale et al. 2013). The organisation runs courses for members to learn skills such as seaweed identification. Records are submitted to the NBN Gateway.

3.2.4 The Big Seaweed Search

In 2009, the UK Natural History Museum (NHM) in collaboration with the Marine Conservation Society (MCS) launched the Big Seaweed Search (http://www.nhm.ac.uk/take-part/citizen-science/big-seaweed-search.html), to investigate how invasive species and climate change affect UK seaweeds, whilst encouraging the public to document seaweed species they find on the shore. Thousands of observations have been collected, including three species of kelp, cited as indicative of notable changes in the ocean. The project is on-going, with occurrence records submitted to the NBN Gateway for open source use.

3.2.5 Capturing Our Coast

In 2015, Capturing Our Coast (www.capturingourcoast.co.uk/) (COC) was launched in 2010. Elaborating on the Big Sea Survey, with a focus on northeast England, COC aims to recruit and train ~5000 citizen scientists to record coastal habitat change. One focus (‘Race To Recovery’), looks at rocky shores, and the impact of climate change increasing storminess; this is known to affect kelp recovery time (Brodie et al. 2014) more than other factors in some regions (Bekkby & Moy 2011).
3.2.5 MarClim Project

The MarClim project, run by the Marine Biological Association (www.mba.ac.uk/marclim/) was set up to investigate how climate change affected marine organisms in the UK, with a focus on intertidal species such as kelp (Araújo et al. 2016). However, as the data do not include subtidal samples, it is difficult to infer trends in actual kelp abundance or distribution over time.

3.2.6 Floating Forests

Floating Forests (https://www.floatingforests.org/) is a citizen science initiative to study Giant Kelp (Macrocystis pyrifera) over a long-term period between 1984 to the present, where the public identify then label aerial images containing kelp. These remotely sensed (Landsat) images are often obscured by cloud, are targeted only to one kelp species, and do not account for tidal fluctuations.

3.2.7 Summary of data recording projects

Citizen Science offers new avenues to increase the proficiency with which data are collected and contributes to science. Moreover, it serves to communicate the conservation agenda, enhancing understanding and education about biodiversity (Steneck et al. 2002). However, there ultimately remains a persistent need for more effective monitoring in the subtidal zones where kelp occurs.

3.3 Species distribution modelling (SDM)

These occurrence records can be correlated with environmental variables to generate predicted suitable habitat and distribution estimates for kelp (Pauly & DeClerk 2010; Yesson et al. 2015c). Depth, irradiance, water clarity, and sea surface temperature acting as a proxy for water column temperature are all relevant determinants (Birkett et al. 1998; Pauly & DeClerk 2010). Given the lack of data available for kelp, SDM offers a useful indirect method for estimating distributions (Yesson et al. 2015c).

This method is limited in what can be achieved with predictions. Firstly, studies in the same region conflict in the factors most influencing kelp distributions (Méleder et al. 2010; Gorman et al. 2012). Secondly, models based on limited records that vary in reliability lead to less reliable predictions (Cavanaugh et al. 2010). It is also difficult to include factors known to influence kelp distributions such as invasive species or wild harvesting. The ability for such models to
accurately predict suitable habitat is also limited by the need to manually validate and tune models by region (Williamson et al. 2015).

### 3.4 Remote sensing technologies

Remote sensing allows assessments of areas that are difficult to access, such as rocky sub-tidal zones where kelp often occurs, and where harvesting is often targeted (Silva et al. 2008). These indirect methods are advantageous for expansive coverage, cost-effectiveness, time-saving, and quantitative analyses (Casal et al. 2011). Disadvantages exist too; in GIS format, remote sensing data can have excessive sizes, which are time consuming to process. They can also be complicated by other variables (i.e. cloud cover), find it difficult to reach certain depths, and contain much noise.

#### 3.4.1 Satellite imaging

Modern satellites can provide high-resolution data, with multi-spectral sensors and infrared bands, useful for vegetation surveys (Pauly & DeClerk 2010). For example, where studies are in clear tropical water, seagrass can be detected with a spectroradiometer, displaying differences between clean and fouled leaves (Fyfe 2003). Spectral signals also differ dependent on stress, suggesting that satellite imaging is useful to determine kelp disease or desiccation (Fyfe 2003; Silva et al. 2008); however, murky UK waters are likely to prevent this kind of analysis. Casal et al. (2011) successfully used multispectral satellite images to detect European kelp biomass, verified with physical dives; the study is however at coarse resolution and cannot differentiate Laminariales with other seaweeds. Cavanaugh et al. (2010) commented that in general, species-specific differences exist in canopy structure of kelp, alongside variations in responses to tides and currents, and therefore any satellite mapping methodology should be developed specifically for the target species. Brodie et al. (unpublished manuscript) adds that depths at which kelp is found can cause problems with detection, exacerbated by tides. Overall, satellite images are useful, but are often not targeted at coastal regions, and do not account for tides during data acquisition (Holmes 2015; Yesson et al. 2015a).

#### 3.4.2 Aerial imaging

Light aircrafts and drones can gather aerial images, at higher resolution than satellite images, desirable for quantitative analyses. Programmes are in place for coastal monitoring of the UK, with freely accessible, tidally-coordinated aerial imagery available from the Channel Coast Observatory (CCO).
Brodie et al. (*in review*) successfully used data from the CCO to map macroalgal abundance in Thanet, Kent. In a study testing the capacity of aerial versus satellite images to detect seaweed habitat, data from CCO, Bing Maps aerial images, RapidEye satellite images, and Landsat (8) satellite images were compared, with the CCO providing the highest resolution (0.1m), tide-specific, best estimates of habitat extent (Yesson et al. 2015a). Aerial images are in general of greater resolution (sub-metre) than satellite imagery. However, in Alaska, Stekoll et al. (2006) use multi-spectral imaging to estimate kelp biomass suitable for harvest, and encountered difficulties with tides. Aerial surveys are also affected by bad weather. Moreover, UK murky waters, alongside the occasional deep growing depths of kelp (Bartsch et al. 2008), can obscure detection ability.

### 3.4.3 Lidar (Light Detection and Ranging)

Lidar derives structural information using a high-frequency light pulse and interpreting differences between return times of each beam (Holman & Haller 2013). Resultant 3D datasets have been used to effectively detect aquatic vegetation (Silva et al. 2008). However, it is recommended that LiDAR heights are properly calibrated and validated with ground-truthing (Silva et al. 2008). Brown and Blondel (2008) argue that light penetration into the seawater is limited. Lacking the capacity to record in multiple spectral bands is important when considering submerged vegetation (Silva et al. 2008). Multispectral videography can be used to estimate plant coverage (Sprenkle et al. 2004), but challenges still remain, namely isolating the submerged plant signal from interference in the water column.

### 3.4.4 Sonar (Sound Navigation and Ranging)

Sonar acoustic monitoring offers an alternative, processing backscatter from an echosounder to give a visual output from which it is possible to determine the composition of the seabed and visualise three-dimensional submerged vegetation (Silva et al. 2008; McGonigle et al. 2011). Both single-beam and multi-beam sonar is used, with the former emitting one beam and a receiving transducer processing the time it takes for the signal to return (backscatter), discriminating between different parts of the returning echo, and visualising the results on a sonogram. Single-beam sonar, such as the RoxAnn brand processor, has been used to map the marine benthos in Scotland (Downie 1999), to detect kelp in Germany (Bartsch et al. 2008), and to generate a variable of subtidal rock to use in SDM for kelp in France (Gorman et al. 2012). All data still requires ground-truthing validation, such as video or grab-samples (Humhorstad et al. 2004; Ehrhold et al. 2006).
Multi-beam, more expensive and with greater data volume, can produce comprehensive seabed maps. Preferred by fisherman for the ability to detect shoals of fish, multi-beam echosounders (MBES) have evolved greatly in the last 30 years, as have methods for analysing backscatter (Brown and Blondel 2008). MBES has been used to estimate kelp biomass (Williamson et al. 2012), to map seagrass (Komatsu et al. 2003; Pauly & De Clerck 2010), to monitor seabed habitat with a sidescan sonar (Ehrhold et al. 2006), and to monitor varying marine biotopes in Northern Ireland, concluding that the success of the seabed classification is dependent on the type of acoustic system used and the target biotope (van Rein et al. 2011). It has not yet been used in the UK to monitor kelp distributions, except in Northern Ireland (van Rein et al. 2011). This study concludes that kelp monitoring can be successful with MBES acoustic techniques, ground-truthed with video or dive surveys. Ground-truthing is integral to automated habitat recognition (Casal et al. 2011; Ehrhold et al. 2006; Gorman et al. 2012; Downie 1999; Williamson et al. 2012).

Pauly & De Clerck (2010) recommend that ecologically critical seaweed habitats can be most effectively mapped with remote sensing methods, due to difficult accessibility. The UK Hydrography Office (UKHO) (now ADMIRALITY Maritime Products & Services), stores sonar multibeam data, surveyed for the entire coastline. When interrogated, this can be used to determine the location of kelp (McGonigle et al. 2011), accessing novel methods unmatched by other alternatives (Silva et al. 2008).
4.0 CONCLUSION AND RECOMMENDATIONS

A multitude of drivers are attributed to declines in kelp distribution and abundance. The northeast Atlantic is of particular concern, with kelp at the edge of their range, and the region experiencing warming rates above the global average. Certainly, harvesting of wild seaweed is an emerging activity that needs to be carefully monitored. Yet, without detailed baseline knowledge of the abundance and distribution of kelp, any plans for sustainable management are prohibited, and there consequently persists a need for novel monitoring technologies to inform the conservation of this important oceanic flora.

Although occurrence records are available for kelp, collected by both casual public observations and active citizen science collections, these are variable in quality and abundance per species. SDM attempts to compensate for a lack of records, predicting distributions and suitable habitat to direct future explorations. This method is not without limitations, offering remote sensing the opportunity to provide the greatest coverage with the least effort and cost. Whilst satellite and aerial imaging have been effective in many studies, new avenues are being explored in acoustic monitoring, particularly MBES sonar, and are proving effective. However, these have been tested on an ad-hoc basis, and a standardised rapid assessment technique for monitoring kelp has yet to be developed. Such a method could be used for ground-truthing publically-available multi-beam data available for the UK (UKHO), in conjunction with genetic information on population composition, to monitor ecologically and commercially important species threatened by climate change and wild-harvesting.

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