SEAWEED FARMING FEASIBILITY STUDY FOR ARGYLL & BUTE

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EXECUTIVE SUMMARY

This report has been commissioned by Argyll and Bute to determine the feasibility and opportunities for establishing a seaweed cultivation industry in the region and the markets potential growers could access. It does not cover the wild harvesting of seaweeds. As highlighted in the Argyll and Bute Rural Deal and the MAXIMAR Science and Innovation Audit, seaweed represents a new growth industry in the region. Seaweed cultivation as an industry in Scotland is nascent, with only one company commercially cultivating seaweed (New Wave Foods Ltd.), but others are establishing themselves in the rest of the UK (Islander Kelp Ltd, Dorset Seaweeds and the Cornish Seaweed Company). The major driver for seaweed cultivation in Scotland and Europe in the last 20 years has been for bioremediation of aquaculture and marine biomass for bioenergy production. Interest in production is now focused on food and higher value products markets. In order for the industry to move forward in Argyll and Bute and for the economics to start to sift there needs to be innovation. This is the same as any developing industry. Essentially the report describes the process of setting up and running a seaweed farming business in Argyll and Bute from conception, cultivation, processing to selling products to consumers. For each stage of the process the following descriptions have been taken into account:

- Required activities and resources
- Available resources in Argyll and Bute
- Stakeholders
- Estimated costs
- Estimated timelines
- Other factors

In more depth the report details:

a. The current state of the global seaweed industry before focusing on opportunities in Scotland. Scottish waters support the cultivation of kelp species (*Laminaria sp., Alaria esculenta* and *Saccharina latissima*), and the steps required to successfully cultivate these species are relatively well known. There are a variety of end markets, such as human food, alginate production and additives for animal feed to name a few. It is likely that kelp species are the most suitable species for cultivation during the initiation of the seaweed industry in the Argyll and Bute region. But there may be opportunities for tank cultivation, when combined with renewable energy supplies to reduce the costs of production, for species difficult to line cultivate that have a higher end value.

b. The process of setting up a seaweed farm is detailed, covering the full cultivation cycle from hatchery to out planting on a farm, to monitoring, harvesting and post-processing of raw material. Various different designs of cultivation structures are presented, including adapted mussel longlines, individual longlines, grid-based systems and offshore cultivation rigs. The suitability of particular types of cultivation structure are influenced by the several variables, such as the scale of the farm, the local environmental conditions and the types of harvesting methods planned.

c. The consenting and policy regime for seaweed cultivation in Scotland is discussed, providing a practical guide on the two types of lease required (a seabed lease from Crown Estate Scotland and a license from Marine Scotland). The current Scottish Government Policy on Seaweed Cultivation is examined, with each policy dissected so that individuals can better understand the context of the policy and what consideration need to be made when developing a cultivation site.

d. The potential environmental impacts of seaweed cultivation are summarised to provide a context for how farm sites may affect the surrounding marine environment. Due to the emergent nature of the industry, there is a lack of evidence on the potential impacts of cultivation sites. The level of environmental impacts will be dependent on the scale of the cultivation sites, with larger sites more likely to require more due diligence in terms of environmental monitoring.

e. As highlighted in the report the suitability of a particular location for seaweed cultivation is dictated by numerous factors, which can be separated into three broad groupings:

    I. Local environmental conditions e.g. temperature, light climate, waves salinity, nutrient concentrations, depth;
    II. Existing uses and socio-economic context (e.g. fishing, boat traffic, protected areas);
    III. Operational considerations (e.g. landing point, onshore facilities. These will be assessed in a later section).

f. A modelling exercise was undertaken, examining the first set of constraints, to produce a map of potentially suitable areas for the establishment of seaweed farms in the Argyll and Bute region. This showed that large areas of the Argyll and Bute region are potentially suitable for establishing seaweed farms. The upper Firth of Lorn, west Mull, east Colonsay, large parts of the Sound of Jura and to the east of Gigha emerge as candidate locations on the west coast. In the Clyde Sea and Clyde sea lochs, large stretches of the Kintyre coast and Loch Fyne appear as potentially suitable locations, as does the coastal area around Bute. However, the potential influence of increased nutrients, and increased phytoplankton levels on light availability may limit the usefulness of the eastern areas compared with the west coast. Whether the positive influence of higher nutrient levels will outweigh the negative influences of reduced light on production from seaweed farms is an open question, and likely deserving of some limited growth trials.

g. Beyond the environmental constraints on seaweed farm location, developers should seek to understand the socio-economic barriers that might constrain establishment of farms in particular locations. The report explains the concept of social licence, the benefits for the emergent seaweed industry in working towards social license for its activities. Social license can empower communities to seek benefits from industries that have social and environmental costs and provides a framework for industries to go beyond legal compliance with environmental and social regulations. These costs can include the use of space, environmental and visual degradation, and disruptions to normal social life. Social license can provide a useful framework for the seaweed industry to manage the social risk of opposition to expansion, by developing communication and best practice strategies, and for communities and other users of the marine environment to negotiate beyond compliance behaviour from the industry. In terms of how seaweed cultivation can develop in a sustainable manner, three prevailing narratives have emerged for the Argyll and Bute region:

- Environmental sustainability as a priority;
- Global market focus supported by domestically-owned companies;
- Community benefits and local jobs as a priority.

h. An assessment of the business feasibility of seaweed cultivation in Argyll and Bute has been undertaken, describing the emergent industry and exploring routes for its development. The assessment has adopted a market system approach to identify the business models best suited for development in the region aligned to level of investment and return. This draws upon insights from consultation with both new and established actors along the seaweed value chain, together with learning from wild harvesting and comparator industries. Three key roles within the industry have been identified:

- Producer organisations, who cultivate the seaweed crop;
- Intermediary organisations, who provide services to support the producers and to serve as a link to the market;
- End market/ off-taker.

i. The feasibility of these roles has been assessed and illustrated with case studies specific for the Argyll and Bute region. The first case study uses South West Mull and Iona Development (SWMID) as an example of a community led producer organization. The second examines a number of companies capable of providing various services in an intermediary function. The third case study uses Davidson's Animal Feed as an example of an end market (that of seaweed as a feed supplement for livestock). These case studies detail the activities that each type of organization will undertake, the resources currently available to them within the region, the stakeholders for the type of operation, estimated costs and timelines for their activities, and other factors pertinent to the success of their operations. Each case study also includes general comments for consideration beyond the case study organization.

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Acronyms & Abbreviations

ABC	Argyll & Bute Council
ASC	Aquaculture Stewardship Council
ASLEE	Algal Solutions for Local Energy Economy
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
DTAS	Development Trusts Association of Scotland
dw	Dry Weight
ECA	European Communities Act
EIA	Environmental Impact Assessment
FAO	Food and Agriculture Organisation of the United Nations
HIE	Highlands and Islands Enterprises
IET	Islay Energy Trust
IMTA	Integrated Multi-Trophic Aquaculture
INNS	Invasive Non-Native Species
KTP	Knowledge Transfer Partnership
MCAA	Marine and Coastal Access Act
MP	Microplastics
MPA	Marine Protected Area
MSC	Marine Stewardship Council
MS-LOT	Marine Scotland Licensing Operations Team
NAFC	NAFC Marine Centre UHI
NGO	Non-Governmental Organisations
NMP	National Marine Plan
NMPi	National Marine Plan interactive
NNS	Non Native Species
OM	Organic Matter
PAR	Photosynthetically Active Radiation
POM	Particulate Organic Matter
ROV	Remotely Operated Vehicle
SAIC	Scottish Aquaculture Innovation Centre
SAMS	Scottish Association for Marine Science
SCPS	Seaweed Cultivation Policy Statement
SEA	Strategic Environmental Assessment
SEARS	Scottish Environment and Rural Services
SNH	Scottish Natural Heritage
SRSL	SAMS Research Services Ltd.
SSC	Scottish Salon Company
SSIA	Scottish Seaweed Industry Association
SSMG	Scottish Shellfish Marketing Group
SWMID	South West Mull & Iona Development

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1. INTRODUCTION

1.1 Project Background

The Food and Agriculture Organisation of the United Nations (FAO) estimates the global value of seaweed farming at 4.5 billion dollars, most of which happens in Southeast Asia. In Scotland, seaweed farming is an emergent industry and in anticipation of future growth, the Scottish Government recently published its Seaweed Cultivation Policy Statement. Given its abundant natural resources and strategic position on the west coast of Scotland, Argyll and Bute has the potential to become a hub for seaweed farming in Scotland and perhaps Europe.

Although the first trails for seaweed cultivation occurred in Scotland in 2004, this was only at an experimental scale, and there are a number of unknown elements that are currently a barrier to the realisation of that vision. Private investors do not have a clear picture of what is involved in setting up a seaweed farm: the different stages, timelines, resources, and factors for viability. At the same time, the public sector does not have a clear picture of the key infrastructure and support that may be required to grow this industry. As a result, private and public investor confidence is low, despite several enthusiastic businesses. In order to address some of these unknowns, ABC commissioned SAMS Research Services Ltd. (SRSL) in November 2018 to undertake a feasibility and guidance study for seaweed farming in Argyll and Bute to encourage the development of seaweed farming in the region.

The desired outcomes for the feasibility study are threefold. Firstly, to provide sufficient information to enable investors to make informed, confident decisions about investing in, setting up and running seaweed farming businesses in Argyll and Bute. Secondly, to inform the public sector about potential investment in suitable infrastructure and support for the growth of the seaweed farming industry in Argyll and Bute. Finally, to enable local communities to investigate the potential of seaweed farming to contribute to community-led development in their local area.

To achieve these outcomes, the following report has been produced. It contains a summary of the seaweed cultivation sector to provide background to frame the possibilities for the establishment of the industry within Argyll and Bute. The process of setting up a seaweed farm is detailed, from the stages of conception, to farm design, species selection, consenting, cultivation and harvesting, including discussion of social license, and environmental considerations. Information has been provided on site selection criteria for favourable seaweed farming sites within the Argyll and Bute area. Economic feasibility assessments have been made for a variety of different seaweed farm types, with discussion of how variables such as the end market will alter the cost structure and approach to cultivation. Case studies have been included to demonstrate viable scenarios for seaweed cultivation within the Argyll and Bute area. Finally, recommendations have been made for the key areas to be considered to aid the establishment of Argyll and Bute as seaweed farming hub.

1.2 Document Structure

This document has been structured so that specific areas of information are collated within discrete chapters, the intention being that readers can focus on the sections that are most relevant their needs.

Section 2 contains a review of the seaweed industry, covering areas such as what is seaweed cultivation, what types of species can be grown, the cultivation cycle from hatchery to farm and harvesting, end products and processing, and a summary of global, European and UK markets.

Section 3 summarises the Scottish consenting and policy regime concerning seaweed cultivation, and details the steps that any developer will need to undertake with regards to consenting.

Section 4 examines the environmental constraints that govern selection of sites for seaweed cultivation. It includes a mapping exercise to identify potentially suitable areas within the Argyll and Bute region, and summarises other constraints that need to be considered when selecting locations to establish seaweed farms.

The environmental impacts associated with seaweed farming are detailed within Section 5. These are dependent on the location and scale of cultivation, but should be considered at an early stage when establishing a seaweed farm.

Social licence is discussed in Section 6, which defines the concept and explains how it is relevant for seaweed cultivation, and how engaging with community groups can be a key factor in the success of the sector.

Section 7 contains the business feasibly assessment, describing the emergent industry and exploring routes for its development. Case studies that illustrate issues of commercial feasibility are presented, along with indicative costings for setting up and running a commercial seaweed farm. Areas for investment are discussed, including opportunities for economic development, employment and training, and achieving community benefit and buy-in.

2. REVIEW OF THE SEAWEED INDUSTRY

2.1 What is Seaweed Cultivation?

2.1.1 What are Seaweeds?

Marine macroalgae or seaweeds are photosynthetic organisms found in the sub- and intertidal around the world, while not strictly part of the Plantae kingdom they are functionally very similar and also known as marine plants. Seaweed are divided into three groups based on their photosynthetic pigments: brown seaweeds (Phaeophyta), red seaweeds (Rhodophyta) and green seaweeds (Chlorophyta). Only green seaweed are related to land plants. Brown and red seaweeds evolved separately and use different light frequencies to grow. Brown seaweed are the largest and most abundant seaweeds within British waters; kelp (Family: Laminariales) form large subtidal forests and wracks cover large parts of the intertidal shoreline. Seaweed are important ecosystem engineers through the provision of habitats for other species, coastal protection and as a sink for blue carbon (Tang *et al*., 2011; Krumhansl & Scheibling 2012; Smale *et al*., 2013; Bouma *et al*., 2014; Duarte *et al*., 2017). Wrack is the only seaweed currently harvested on a large scale from the wild in Scotland. Over the last decade, kelp has increasingly been the focus of research to develop cultivation methods in Scotland (e.g. SAMS, NAFC Marine Centre and FAI Aquaculture Ltd.) and across the world).

Kelp species are suitable for cultivation at sea, they have the potential for high biomass production and are commercially of interest for human food, biofuel production and the extraction of valuable chemicals and bioactives. Red and green seaweed are also of commercial interest for a variety of uses and can be grown at sea or in tanks on land.

2.1.2 Global Production of Seaweed

Seaweed has been utilised for centuries as a source of food and fertiliser due to its high contents of macro- and micronutrients. More recently, many industrial applications have been developed from seaweed including use as a thickening agent, energy production and bioactive chemicals. Seaweed is cultivated in 50 countries with the majority of seaweed produced in Asia. In 2012, Asian countries produced 95% of the global production (Capuzzo & Mckie, 2016). Global production for aquatic plants (dominated by seaweed) grew in output volume from 13.5 Mt in 1995 to just over 30 Mt in 2016 (FAO, 2018; see Figure 1). The global seaweed market is estimated to be worth €8.1 billion per year (Barbier *et al*., 2019).

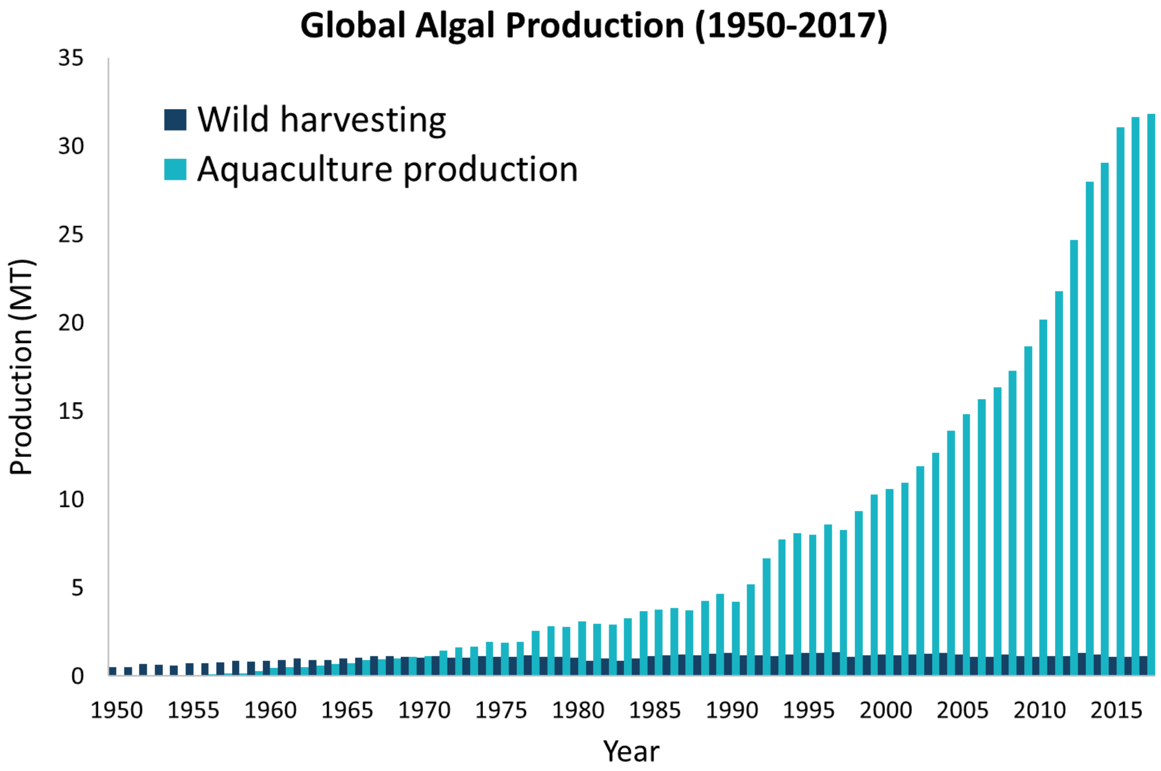


Figure 1. *Global production of cultivated and wild harvested algae between 1950 and 2017 (from FAO 2018).*

2.1.2.1 European and UK Production of Seaweed

By 2050, the suggested value of the kelp industry is predicted to hit a turnover of 4×10^9 Euro per year in Norway alone, with a production of 2×10^7 t per year through cultivation of mainly kelp species (Broch *et al*., 2019). At a global level seaweed cultivation has been suggested to lie between 10^9 to 10^{11} t dry weight (dw) (Lehahn *et al.,* 2016). In Europe, commercial production of seaweed is, at current, predominantly from wild harvesting of brown seaweeds across Norway, France, Ireland and the United Kingdom.

Seaweed cultivation has been the focus of research for over a decade with the aim to create knowledge to support the development of the marine economy. To meet the increase in demand there will have to be a considerable increase in commercial cultivation. Seaweed farms on a pilot and small scale have been set up across Europe at research organisations and increasingly by commercial companies or start-ups. It is difficult to get consistent data about seaweed production, FAO provides volume estimates but these may be over- or underestimated for European production (Barbier *et al*., 2019). Main species of interest for seaweed cultivation on a large scale are *Saccharina latissima* and *Alaria esculenta,* but other species have also been grown in trials and include *Laminaria digitata*, *Sacchoriza polyschides*, *Laminaria hyperborea*, *Ulva* spp., *Palmaria palmata* and *Osmundea pinnatifida* (Kerrison *et al*., 2016; Barbier *et al.,* 2019).

Currently in the UK there are a small number of commercial growers in Scotland, Northern Ireland and the South Coast of England. There has also been the establishment of industry organisation in both Scotland, Scottish Seaweed Industry Association (SSIA) and in Wales, Seaweed Forum Wales. The largest European producer of seaweed in 2013 was C'Weed based in Brittany, France, the company cultivates *L. digitata* and *A. esculenta* and harvests nori and dulse (Organic Monitor, 2014).

2.1.2.2 Scottish Seaweed Production

The first seaweed cultivation trails took place in Scotland in 2004, with both *S. latissimi* and *P. palmata,* investigating their potential as a form of bioremediation at the Calbha salmon farm sites operated by Loch Duart on the North West Coast (Sanderson *et al*., 2012). At this stage there were also questions being asked about the end use of the produced biomass. At the time, with the environment of increasing oil prices, the potential of using the biomass for bioenergy production, both in the form of biogas and bioethanol, was investigated (Hughes *et al*., 2012). Initial cultivation trails relied heavily on Kuralon string which is used exclusively for seaweed production in China. As this had to be imported through a single supplier in Europe, it was difficult to get hold off and was expensive. Coupled to the fact that the line to be seeded was manually wrapped onto a frame. Moving forward 15 years, the range of textiles used for seeding line has now expanded (Kerrison *et al*., 2017) and line is being mechanically wound onto pipes for seeding, saving both time and money. Cultivation at small scale in Scotland has taken place as far south as Loch Fyne and as far north as Lewis and Shetland, with SAMS establishing their first trail site based on a mussel cultivation system in the Sound of Kerrera in 2012 and a grid system based at Port a Bhuiltin in 2014. It must be noted that the use of, and the diversification of, unused aquaculture infrastructure and sites in Scotland represents a way of reducing initial set up costs, again sifting the economics of production.

As already stated, the major driver for seaweed cultivation in Scotland and Europe in the last 20 years has been for bioremediation of aquaculture and marine biomass for bioenergy production. Interest now focuses on the food and higher value products markets. In order for the industry to move forward in Argyll and Bute and for the economics to start to shift there needs to be innovation. This is the same as any developing industry. But there are still new opportunities coming through from aquaculture, which in terms of quantities of seaweed needed may initially dwarf supply to other markets. For example, Mowi is currently trailing using kelp lines in their fish cages to provide a more natural environment for clearer fish (https://mowiscotland.co.uk/wp-content/uploads/2019/04/may-news-2019-optimised.pdf) and Integrated Multi-Trophic Aquaculture (IMTA), including the use of seaweed in this context, is still of interest both at home and internationally.

2.2 Species Selection

Seaweed are a diverse group of organisms with different growth rates and life cycles dependent on the species and environmental conditions. In general, most seaweeds are able to reproduce through sexual and asexual reproduction. In sexual reproduction new individuals are formed from two different individuals through the fertilisation of an egg. Many seaweeds can also reproduce vegetatively, either through the release of vegetative spores or through growth of fragmented blades.

2.2.1 Kelps (*Saccharina latissima, Alaria esculenta, Laminaria digitata*)

The group most widely known for cultivation are the kelps. The cultivation method for this group was developed in China in the 1950s, for the species *Saccharina japonica* and *Undaria pinnatifida*. In 2017 the industrial cultivation of these two species totalled 12.5 Mt, more than a third of global seaweed production, and 10-fold more than all seaweed gathering from the wild (FAO, 2018). These methods have since been adapted for the cultivation of European kelps. Cultivation has been shown to be successful in *L. digitata, A. esculenta* and *S. latissima*. Each of these species have different properties making them suitable for different markets.

2.2.1.1 Saccharina latissima; Common names: Sugar kelp, sea-belt

Sugar kelp is a fast growing species widely distributed across Europe (Portugal to Norway) and the West Atlantic coast (Greenland to New Jersey). It has been the focus of many collaborative research projects and is currently the most cultivated European seaweed (Figure 2). Commercial cultivation is known in Norway, Denmark, the Netherlands, France, Germany, Portugal, Spain, Ireland, Scotland and the Faroes Islands. It has value as a food due to its sweet taste from a high mannitol content. It can also taste metallic, whilst older material can be bitter. It is related to the East Asian cultivated species *S. japonica* (Kombu), and so is marketed as Sweet or Royal Kombu. It may have future value for chemical extraction/conversion, but this end market has yet to be commercially realised.

Figure 2. Saccharina latissima. *A) Collected from coastal Argyll; B) Cultivated on a longline system at Kerrera seaweed farm, Argyll (SAMS operated)*

2.2.1.2 *Alaria esculenta; Common names: Dabberlocks, Winged kelp*

A. esculenta is another fast growing species. It is naturally found in exposed locations, but will grow well in sheltered sites when cultivated (Figure 3). It is sensitive to high summer temperatures, with a southern limit to its distribution in Brittany. This southern boundary of distribution is expected to move northwards under future climate change scenarios. *A. esculenta* is cultivated in Ireland, Scotland, Norway and the Faroe Islands. The more limited distribution of the species means there is good potential for export to European markets. Its frond has a fresh grassy taste, similar to the East Asia cultivated species *U. pinnatifida* (Wakame), and so is sometimes marketed as Atlantic Wakame. The sporophyll bladelets near the holdfast and its central midrib are tougher and have a stronger flavour.

Figure 3. Alaria esculenta. *A) Collected from coastal Argyll; B) Cultivated on a dropper system at Kerrera seaweed farm, Argyll (SAMS operated)*

2.2.1.3 *Laminaria digitata; Common names: Oarweed, Sea tangle*

This species is the typical kelp bed species seen exposed at low tide. It has a similar geographical distribution to *S. latissima* but has slower growth (Figure 4A). The species is characterised by an extremely high iodine content, which can be reduced by boiling/blanching. There currently appears to be less demand for the cultivation of this species, as it can be naturally harvested. Despite this, *L. digitata* cultivation is currently being undertaken by Islander Kelp Ltd., in Northern Ireland, and it has previously been harvested in Scotland for its alginate content.

The closely related species *L. hyperborea* does not currently have a value for food (Figure 4B). It is very slow growing and has value as a source of high quality alginate. Both species are also of interest for the extraction of microcrystalline cellulose for various industries including printer ink and biodegradable polymer film.

Figure 4. *A)* Laminaria digitata *growing attached to rocks in coastal Argyll; B) The similar species* Laminaria hyperborea*.*

2.2.2 Other Species that may be Relevant in the Future

There is interest to cultivate other European seaweeds, although further research is required to make their cultivation reliable. These species hold potential as future target species for cultivation.

2.2.2.1 ***Porphyra/Pyropia*** **spp.**

This group encompasses a number of species that are found intertidally as thin membranous sheets that range from red to dark purple in colour. They have a complex lifecycle, requiring an expensive hatchery process, but are cultivated in East Asia to produce high value nori sheets (Figure 5A). Despite the low biomass yield, over 2.5 Mt were produced in 2017. Cultivation of this species may be possible in Europe and trials are underway in Norway, Ireland, Portugal and Scotland (Figure 5B).

Figure 5. Porphyra *spp***.** *A) An example of cultivation in Wando, S Korea. B) Natural settlement at the Kerrera seaweed farm, Argyll; growing as biofouling on the farm structure (SAMS operated)*

2.2.2.2 *Palmaria palmata*

Also known as dulse and dilisk, this red intertidal species is highly valued for food due to its umami flavour. It is currently wild harvested across its distribution range, particularly in Ireland and Scotland. Cultivation has been trialled since the 1980s (Figure 6), but there are still problems with the control of the lifecycle making it unreliable. Research is underway in this area due to the market demand. There is currently a developing relationship between SAMS and SRUC investigating the domestication of this particular species.

Figure 6. Palmaria palmata *cultivated in an integrated aquaculture system in Scotland (see Sanderson, 2006).*

2.2.2.3 *Ulva* spp.

This seaweed can be various shades of green, with a number of species that can be hard to distinguish (Figure 7). It forms a thin sheet that fragments easily, and so it is not suitable for open water cultivation, except possibly in very sheltered sites. *Ulva* can grow very quickly in high nutrient conditions resulting in green tides. Tank cultivation is currently underway in southern Europe and Israel.

Figure 7. Ulva *spp. collected from the shore in coastal Scotland.*

2.2.2.4 *Osmundea pinnatifida*

This small red seaweed grows slowly in the low intertidal (Figure 8). It has a strong garlic-like flavour and so has value as a condiment. It may also contain other bioactives with pharmaceutical/nutraceutical applications. Cultivation is currently not possibly on seeded line but is under development. Tank cultivation has been investigated at SAMS as part of a PhD studentship funded by IBioIC and HIE. This method of cultivation seems to offer the best solution for cultivating this particular species.

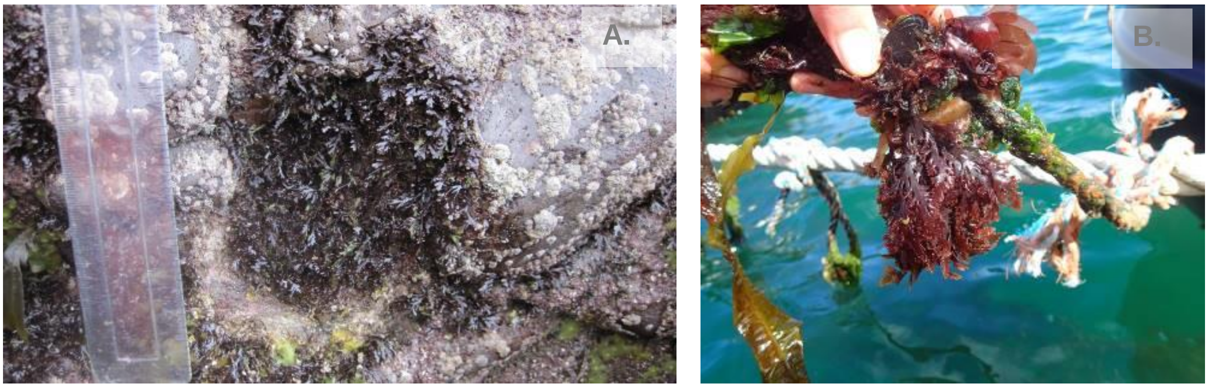


Figure 8. Osmundea pinnatifida. *A) Growth on an intertidal rockface, Argyll; B) Growing as biofouling after natural settlement on the Kerrera seaweed farm, Argyll (SAMS operated).*

2.3 Cultivation Methods

2.3.1 Collection and Maintenance of Reproductive Material

Cultivation begins with the collection of fertile wild seaweed to provide a seeding stock. For kelp species, collection is timed to coincide with spring low tides, when most seaweeds are either exposed at the surface or are in very shallow water. Other species that are found higher in the intertidal are available for collection more often.

The reproductive peak of many cultivated seaweed species occurs from autumn through to early spring, when nutrient concentrations are high and temperature and light are lower. This provides a suitable environment for the sensitive juveniles to begin to develop. In some species such as *L. digitata* and *L. hyperborea*, their reproductive peak is during summer/autumn.

Seaweed distribution varies depending on the environmental and habitat requirements of each species. For example, it is unlikely to find *A. esculenta* in sheltered sandy bays as it is most common on exposed rockfaces. Online resources such as NBN Atlas Scotland (https://scotland.nbnatlas.org/), the Marine Life Information Network (https://www.marlin.ac.uk/) and Algaebase (www.algaebase.org), give information on individual species distribution and their site/growth requirements.

Many seaweed species have a low ability to disperse, and so exist as distinct populations separated by distance along coastlines, or within separate water bodies (e.g. lochs/fjords). There is a very poor understanding of the genetic population structure of seaweeds, and this is an area of research that needs to be addressed. This is very important to understand in the context of seaweed cultivation, as it is likely that farm grown seaweed (if collected from a distant location) will interbreed with the same wild species local to the farm. If interbreeding occurs it may lead to a loss of natural genetic diversity in the wild populations. Currently, there exists little restriction on the distance between the site where fertile material is collected and the end cultivation site where the seed stock is grown out.

In an attempt to mitigate potential damage to wild populations from interbreeding with cultivated stock, a condition has been set in Marine Licences that: state "*The licensee must utilise locally sourced stocks for seeding of the cultivation systems*" (Licence No.; 05292/17/0: Port a Bhuiltin, Lynn of Lorn). Yet, 'local' cannot be defined without understanding the genetic population structure. The recent PEGASUS report (Barbier *et al*., 2019) defines a local strain as:

"A cultivated strain or variety whose genetic background is similar to that of the natural population geographically close. The degree of similarity taken into account is directly dependent on the observed genetic diversity of the species in the considered area, compared to distant populations of the same species. It is a relative parameter ("more or less similar")."

To date, a number of population genetic surveys have been undertaken on *S. latissima,* including in Denmark (Nielsen *et al.*, 2016), Maine (USA) (Breton *et al.*, 2018), and the Irish Sea (Mooney *et al.*, 2018). In Scotland and the Irish Sea, populations from Stranraer and Troon showed relatively little differentiation (φ-st = 0.024) over >60 km distance (Mooney *et al.*, 2018). Guideline distances between collection populations and cultivation sites could be suggested based on general trends in existing studies, however, without localised genetic knowledge recommendations are difficult to make.

As well as genetic distance, environmental distance between collection and farm site should also be considered when selecting wild populations for cultivation material. Little research exists on local adaptation in seaweeds, however the wide geographical distribution of many species, their ability to colonise a wide range of environments, and the phenotypic diversity observed across those environments, suggests the strong influence of local adaptation in many species (Augyte *et al.*, 2018). As such selecting seedstock from a dissimilar environment to the farm location may prove detrimental to the growth of the out-planted crop in the new environment. Though determining environmental similarity can be difficult, a simple solution may be to sample from multiple locations within the agreed local limits for seedstock in order to encompass a greater genetic diversity and a wider range of environmental tolerances. Selecting a greater number of adult donors from multiple source populations may also offer further mitigating benefits by increasing the effective population size of the farmed crop and reducing the degenerate impact of a small hatchery source population on wild population effective size (Laikre *et al.*, 2010).

Kelps have a very high fecundity, and a single adult can release hundreds of millions of spores from their reproductive regions, which are known as sori. When seeding a farm it is recommended at least 5-10 sorus regions are collected to ensure a mixed genetic diversity in the crop. This could potentially seed 10-20 km of hatchery twine (see Section 2.6). If very few sori are used, this may cause inbreeding depression in the crop, leading to poor growth on the farm. In Australia, Sea Health Products Ltd. have been granted a licence to collect up to 30 individuals of their common kelp *(Ecklonia* radiata) per year, for the purpose of seeding trials, which seems a very reasonable allowance (Jo lane, pers. comms). Whilst collection of sorus is required, the small quantities required are highly unlikely to lead to any significant impact on the local population.

The sorus region of *Laminaria* spp*.* and *S. latissima* are located towards the distal end of the blade (Figure 9A). These areas can be removed whilst leaving the adult plant in place to regrow. In *A. esculenta* the sorus region is located on the sporophylls near the holdfast (Figure 9B), and similarly these can be removed while leaving the adult in place. Commercial collections should be carried out in accordance with requirement of a Crown Estate licence to ensure the practice is managed sustainably (https://www.thecrownestate.co.uk/en-gb/what-we-do/on-the-seabed/coastal/seaweed-harvesting/).

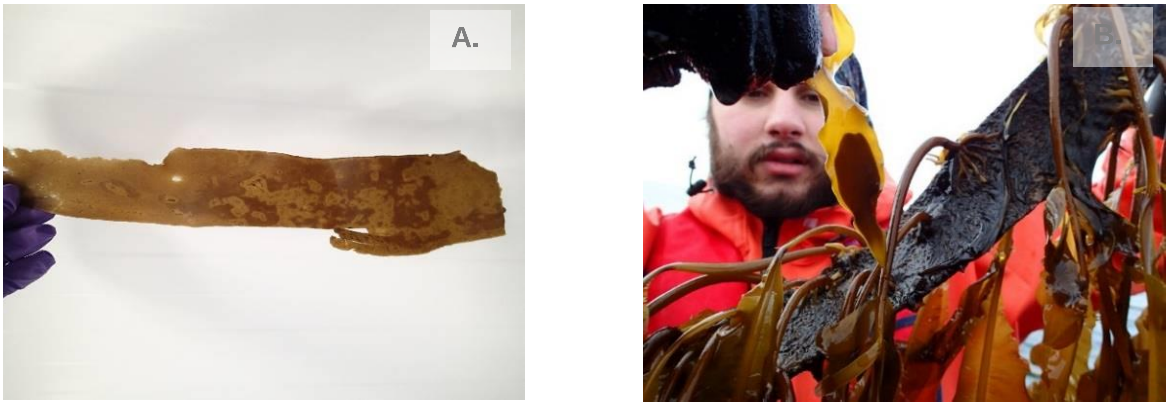


Figure 9. *Sorus material on kelps appears are slightly raised dark regions. On many species it is located on the frond, usually at the distal end. A) Sorus of* L. digitata*; B) The sorus of* A. esculenta *occurs on the sporophylls near the holdfast.*

The quantity of fertile material required for many other species is currently unknown. In the case of *P. palmata*, a larger quantity of individuals/ fertile material is necessary to generate enough seed. Based on Werner & Dring (2011), between 6.5-13.1 kg of fertile material per linear km seeded is required. In all species, care should be taken to leave a portion of the adult meristematic tissue (i.e. the growth area of the plant) in place to allow tissue regeneration, and to leave at least half of the wild population undisturbed to allow population recovery following collection. This is particularly true for species that have a small distribution area, such as *P. palmata*.

Guides exist for the preparation and extraction of spores from kelps (Werner & Dring, 2011; Flavin *et al.,* 2013; Rolin *et al.,* 2017). Generally, this involves a cleaning step (see Section 2.5) followed by slight drying overnight in a fridge. The following day, spores are released following re-immersion in seawater (Figure 10).

Figure 10. *Sorus material of* S. latissima *which was cleaned and desiccated overnight, then re-immersed in seawater. Within 15-30 minutes, spore release can be seen on the left, whereas it was unsuccessful on the right.*

2.4 Use of Kelp Seedbanks

Kelps have an independent microscopic lifestage called the gametophyte, which are capable of growing as filaments and can be maintained in vegetative culture (tom Dieck, 1993). Gametophyte cultures can act as seedstock for cultivation for many years and are available year-round, negating the need to annually search for and recollect fertile material from the wild. Independent gametophyte cultures for a particular species can be maintained for each location used for cultivation (Figure 11). It is not recommended to collect seed from the cultivated seaweed itself, as this will reduce the genetic diversity of the seedstock and may select for earlier reproductive maturity.

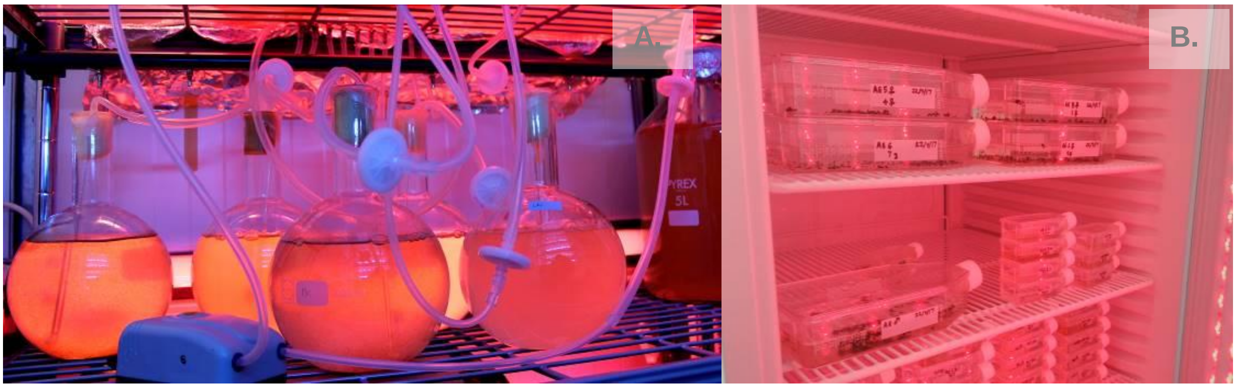


Figure 11. *Kelp gametophytes are maintained in a vegetative stage using red light. A) In a bubbling culture; B) In tissue culture flasks.*

In the future, commercial seedbanks for kelps may allow the long-term storage of cultures from all across Europe. These can act as a biological bank (biobank) to conserve the natural genetic diversity of seaweed populations, as well as supplying commercial kelp farmers. Such a biobank is currently being established at SAMS for *S. latissima* from across Europe under the H2020 funded project, Genialg. Biobanking may be assisted through the use of cryopreservation for the long-term (decadal) storage of gametophytes. Further study is needed to confirm that growth and fertility can recover following this treatment (Day, 2018), although initial trials are encouraging (Wouter Visch unpublished results). *Porphyra/Pyropia* spp. also have an independent filamentous lifestage called the conchocelis. Again this may be biobanked and cryopreserved, similar to kelp. Methods to biobank many other seaweed species (e.g. *P. palmata, Himanthalia elongata*) have not yet been developed, and so these species currently require collection of fertile material from the wild every year. An attempt at biobanking with *O. pinnatifida* was not successful.

2.5 Hatchery Phase

During the hatchery/nursery phase of cultivation, the seaweed seed (usually a microscopic stage), is reared under set light, temperature and nutrients conditions to maximise early growth and survival. The hatchery phase is usually 6-8 weeks, until the juveniles have grown up to 1 cm long. The culture is maintained as cleanly as possible to prevent the inclusion of grazing animals or overgrowth by space competitors such as other macroalgae (Figure 12).

2.5.1 Summary of the Process of Seeded Twine Production

Twine seeding is currently the most reliable method for seaweed cultivation (see Section 2.6). 1-2 mm twine is wound around plastic tubing (spools) in a single layer. The twine on the spools is then seeded with a microscopic phase of the seaweed (usually by spraying or dipping). The spools are then immersed into seawater tanks set up with appropriate lighting and supplied with gentle aeration. The tanks will either be supplied with flow-through seawater or be can static with regular refreshment (e.g. weekly). The water should always be filtered and UV sterilised to prevent the introduction of other organisms, which can impact on the success of the species being line seeded.

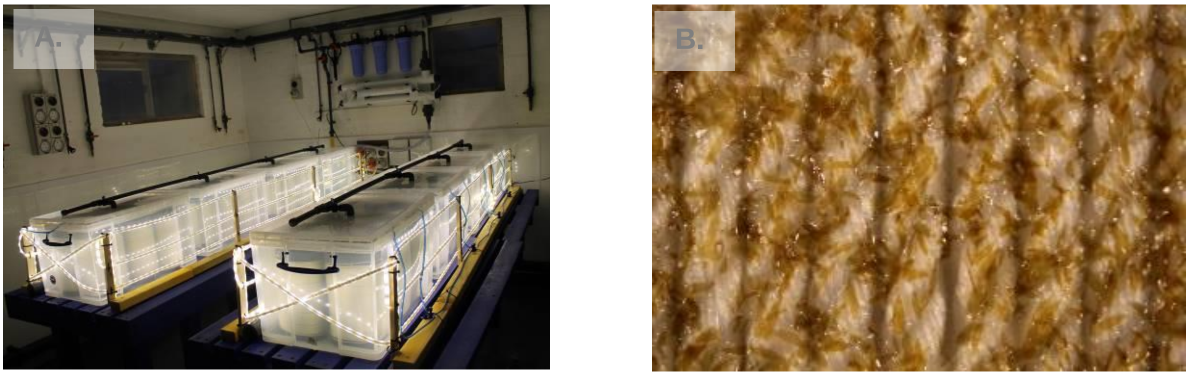


Figure 12. *Seeded twine production. A) Juvenile seaweeds are cultured in lit seawater tanks attached on 1-2 mm twine. B) After usually 6-8 weeks, the twine is covered with developing juveniles and is ready for outplanting.*

The addition of a typical algal growth medium such as F/2 or PES is recommended to accelerate the growth of the juvenile seaweed during this initial vulnerable stage. The chemical germanium dioxide is also recommended during the first seven to nine days of the hatchery to inhibit overgrowth by diatoms (microalgae). Open access guides exist that provide more detail on these hatchery methods (Edwards & Watson, 2011; Flavin *et al.*, 2013).

2.5.2 Hatchery Biosecurity

Hatcheries must ensure that appropriate practical biosecurity measures are in place to prevent the accidental movement and spread of invasive non-native species and/or disease. A biosecurity plan should be established to address these concerns.

2.5.2.1 Cleaning fertile tissue

Fertile seaweed tissue collected from the wild must be cleaned before spores are extracted. This will ensure that other organisms are not accidentally introduced into the culture. The first step involves the manual removal of all macroscopic biota (i.e. mobile animals, other seaweeds, encrusting bryozoan etc. that are visible to the naked eye; see Section 2.10), usually by cutting and repeatedly rubbing with tissue and sterile seawater. A second step may involve a chemical treatment such as dipping in dilute bleach, peroxide or iodine (Rød, 2012; Flavin *et al*., 2013). The selection of the chemical will depend on the tolerance of the particular species being cultured. Spores extracted from cleaned fertile material are then able to grow without competition from non-target species or grazing. This treatment does not make the material axenic (free of all microbes), as it is beneficial for the seaweed to retain its natural microbial associations.

2.5.2.2 Maintaining Hygiene in the Hatchery

All hatchery materials (including twine spools, tanks and bubbling tubes), should be cleaned before and after use. In stagnant culture, the water should be refreshed regularly and the tanks cleaned and all equipment sterilised. The use of multiple, spatially separate tanks, are recommended in case one becomes contaminated. To prevent tank cross-contamination, each tank should be covered and clean gloves worn when handling the spools. Waste water discharge from the hatchery should follow local regulations.

2.5.2.3 Hatcheries handling non-local Seaweed Populations

Biosecurity must be stricter when non-local (see Section 5.10) seaweed populations are cultured, or when seaweeds from multiple locations are all grown in the same hatchery. Firstly, each population must be cultured in isolated tanks and/or rooms and no equipment moved between tanks without first being sterilised. Secondly, all wastewater must be treated, for example either chemically, via UV light or heat, before being discharged as waste. These steps will prevent two potential outcomes:

1. The release of seaweed to a non-local/distant cultivation site leading to unknown ecological consequences (e.g. seaweed from Shetland being outplanted in the Firth of Clyde);
2. The cross-contamination of seaweed disease/contaminants between populations. Seaweed diseases/ culture contaminants are currently understudied and may be transported into the hatchery with the seedstock (either wild collected spores or gametophyte cultures). It is important that hatcheries do not facilitate disease transmission by preventing cross-contamination of tanks which are then outplanted all around the UK. Detection methods for diseases/contaminants are currently being researched at SAMS.

Figure 13 below provides a schematic diagram of the typical phases of kelp cultivation in Europe.

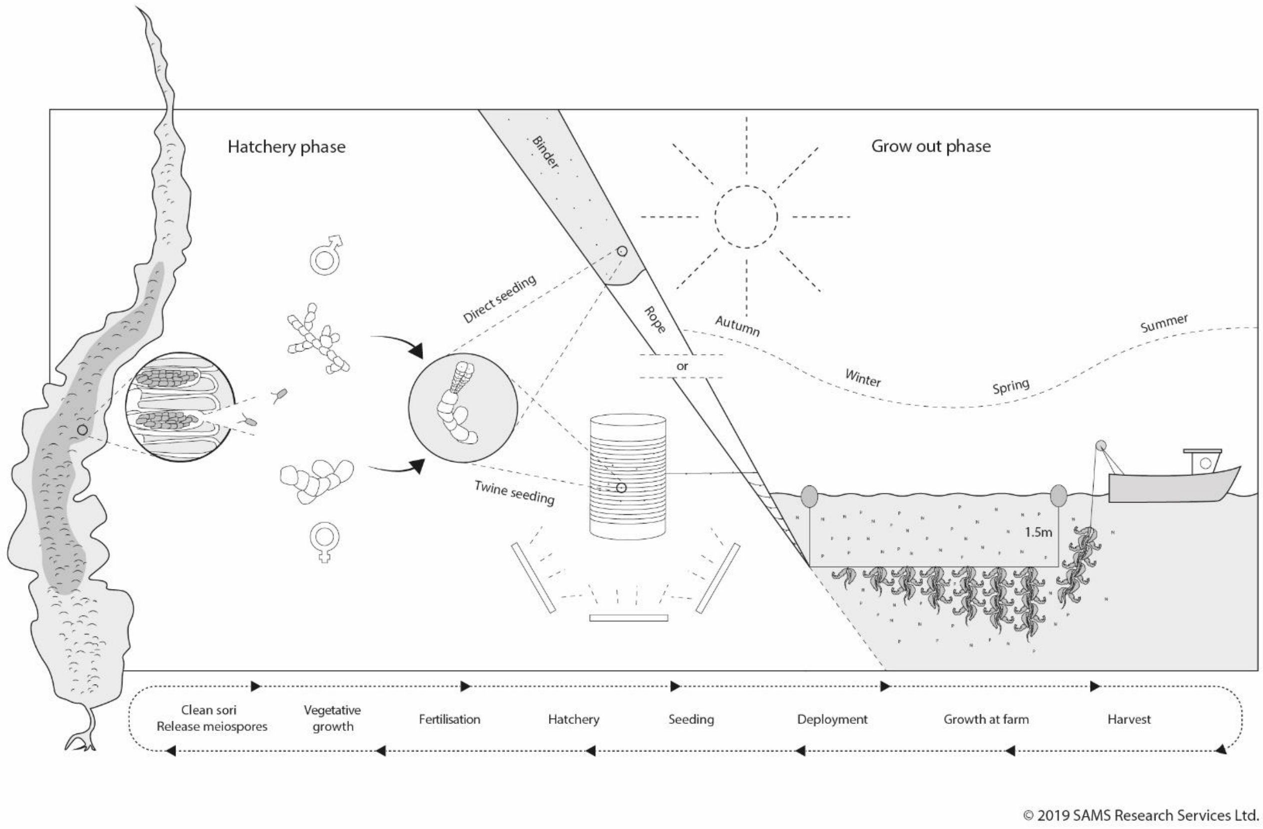


Figure 13. *Summary of typical kelp cultivation in Europe. Fertile kelp (sporophyte stage) with darkened areas of sporangial tissue are collected form the wild and cleaned. Meiospore release is stimulated, these germinate and grow into either male or female gametophytes. The male spermatia fertilise the female oogonium and a new juvenile sporophyte grows attached to the female. This culture is then seeded onto twine spools and allowed to grow for 6-8 wk in a hatchery with artificial lighting. The twine is then outplanted at a seaweed farm by helically wrapping it around a rope. An alternative seeding method is that the culture containing juvenile sporophytes is seeded directly onto a rope using the binder method without and extended hatchery phase. Using either method, rope are deployed in autumn suspended at 1.5 m depth. The seaweed grows by intercepting incident light and absorbing nutrients from the surrounding water. The harvesting time is in spring to early summer.*

2.6 Twine vs. Direct Seeding

Effective seeding of macroalgae requires an initial hatchery phase, which maximises the survival of early recruits by optimising the conditions for their growth from microscopic spores to macroscopic juveniles (see Section 2.5). Seeding of spores followed by direct out-planting in the sea without a hatchery phase gives very poor results (Kerrison *et al*., 2018).

There are currently two approaches to seeding; the established method using twine, and a new method called direct seeding.

2.6.1 Twine

In a typical seaweed (kelp) hatchery, juveniles are reared attached to twine on a spool for 6-8 weeks, until they are, generally, up to 1 cm long. Similar method have been used for dulse (*P. palmata*).

There are many variants of how this twine is then utilised:

1. **Rapid method (common in Europe).** The twine spools are threaded onto a carrier rope and helically unwound into the lay of the rope (Figure 14 A/B). This method allows fairly fast deployment. As the twine is coated in a dense population of juveniles, there is intense competition between the juveniles for space. Thus, a large proportion of the juveniles die. If successful, this method leads to 100% coverage of the rope. If problems arise during the hatchery phase, or the line is not deployed correctly, patchiness can occur. This method is most suitable for lengthy continuous longlines.
2. **Twine inserts.** The twine is cut into short sections (e.g. 10 cm), which are inserted (lazy spliced) into the carrier rope at regular intervals (e.g. 30 cm). By spacing out the twine, this reduces the space competition, giving each individual more space to grow to its maximum size. This method uses less twine, but is more labour intensive. It is often used in dropper systems.
3. **Individual juvenile inserts.** This is the dominant method used in Chile/China. Individual juveniles are picked from the twine and lazy spliced into the carrier rope at set distances (e.g. 30 cm). This method requires that the juveniles are grown to a large size in the hatchery (5-10 cm), and strongly selects for fast growth. It is the most economical use of the juveniles and, due to the spacing, allows each to grow to their maximum size without intraspecific competition. This method is extremely labour intensive and so is not expected to be feasible for European seaweed cultivation.

2.6.2 Direct/Binder Seeding

An alternative seeding method was developed during the EU FP7 project AT~SEA. The kelp juveniles are grown in tumble culture, detached from any surface, rather than on twine. These juveniles are then mixed with a Binder/Bioglue and applied directly onto the cultivation surface, which can then be immediately deployed into the sea (Figure 14C). This method has numerous advantages. The hatchery phase is cheaper, deployment is faster, and growth can occur on materials other than ropes (i.e. net or sheets; Kerrison *et al*., 2018). It is very suitable for sheltered locations, but it is currently unreliable in exposed sites or during periods of unsettled weather. Further research is underway to improve the formulation of the Binder/Bioglue through the UKRI BBSRC Bindweed project to allow deployment at any site and time.

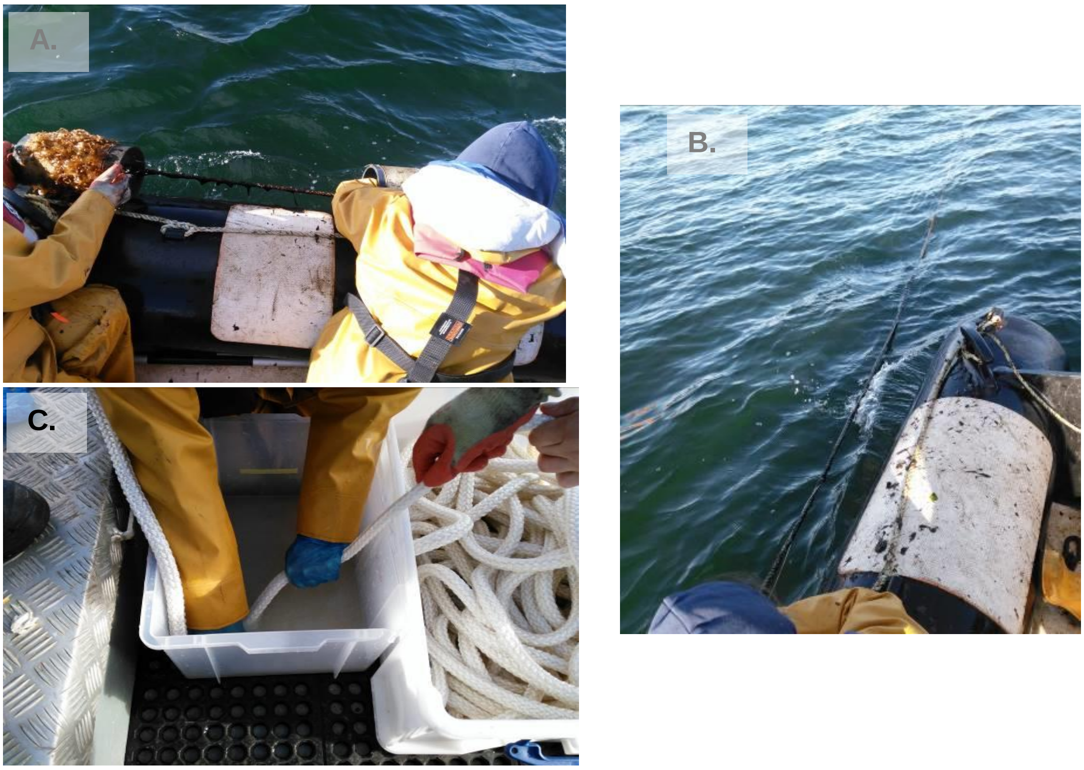


Figure 14. *A/B) Rapid twine seeding, where twine carrying juvenile seaweed is helically unwound from a spool onto a rope; C) Direct seeding, where the juvenile seaweed are loose in a solution mixed with a binder. These are then embedded or sprayed onto ropes, ribbons, nets or sheets.*

2.7 Outplanting and Harvesting Timings for Different Macroalgal Groups

Cultivation times are broadly similar across a range of seaweed species. In natural populations, many species are fertile over the winter-spring period, with developing young juveniles able to grow rapidly during spring. A high biomass is then achieved in the early summer (Figure 15B).

In the 1950s researchers in China developed the summer hatchery method. In this, juveniles are grown in cooled water in the late summer, and then are outplanted as soon as the water temperature decreases in autumn. This resulted in far higher yields at harvest time in summer. This method can also be applied to European kelp species.

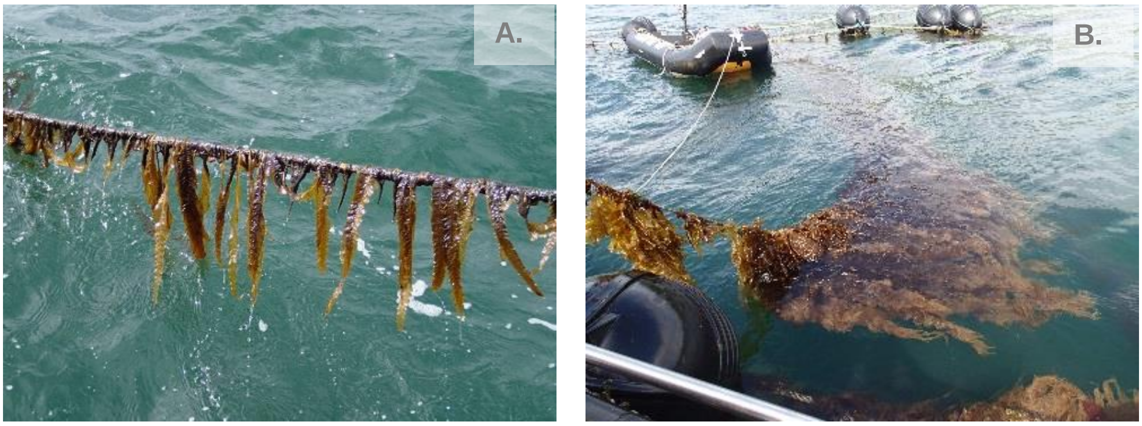
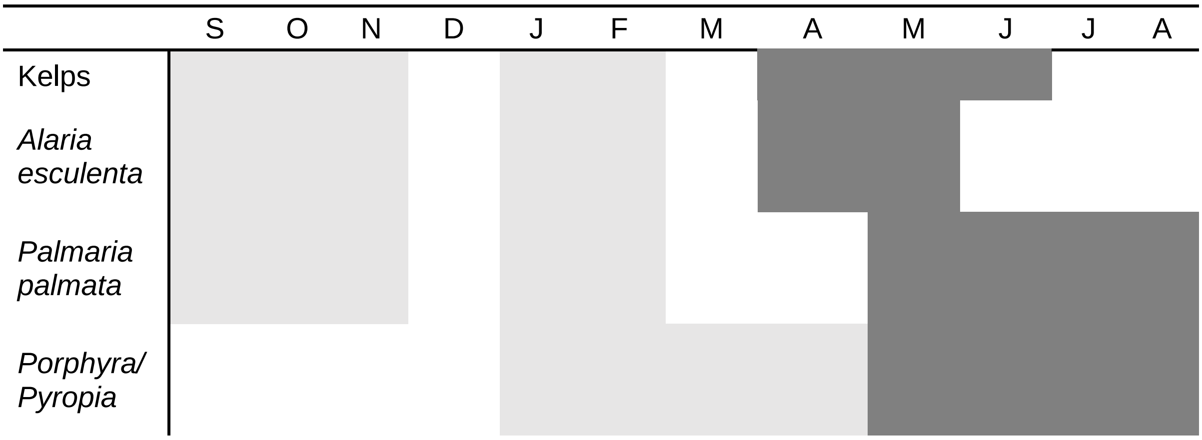


Figure 15. *A) Juvenile growth in January (up to 25 cm in length) after deployment in October; B) A cultivation line at harvest with 10-15 kg per m of linear rope.*

October out-planting of kelps in Scotland has been shown to give a higher yield compared to deployment in later months (Figure 15A). September may also give excellent results but has not been trialled. The latest month for deployment that can potentially give a reasonable harvest yield is February. December appears to be the worst month due to increased storminess and low light. But there is also the possibility that the geography of the site will both impact on the timing of deployment of the seeded and the overall productivity of the seaweed been cultivated. There will also be annual variation related to the impact a season's weather patterns has on deployment through to harvest. The timing of harvest again will be specie dependent but will also potentially be related to what market the biomass is ultimately destined for. In order of preference, the ideal deployment months are Oct>Nov>Jan>Feb. For other species (i.e. *P. palmata*) the deployment time in Scotland has not been studied, but is expected to be similar. The fine sheet-like *Porphyra/Pyropia* spp., grows to a harvestable size very quickly and so deployment for this species may be later in the year, possibly Jan-April. Table 1 summaries the seaweed cultivation calendar for Scotland.

Table 1. *Cultivation calendar of seaweed cultivation in Scotland. Light grey – deployment period. Dark grey – harvesting period.*



In most kelps the harvesting period is between April to June, with the exception of *A. esculenta,* which tends to degrade earlier and so may need to be harvested by the end of May (Table 1). It may be possible to harvest the red seaweed species including *P. palmata* and *Porphyra/Pyropia* spp., over the summer, although this needs to be tested

The timing of harvest will depend on four factors:

1. **The growth rate of the crop.** This will depend on both the out-planting time and method (e.g. longline, V droppers), as well as the environmental conditions over the cultivation cycle. The growth rate is very high over the spring-summer period. The total biomass yield continues to increase over this period and then may peak in midsummer. After this, the yield may decline due to nutrient limited conditions (see Section 2.9) and overgrowth by biofouling.
2. **The development of biofouling by other organisms.** Many invertebrate animals or other macroalgae will grow on the surface of cultivated seaweed. These may overgrow the frond, graze it away or cause it to fragment. This is an unavoidable natural process, increasing with the time cultivated material stays in the water. The timing and type of biofouling appears to be highly site specific and varies inter-annually. Monitoring of fouling is therefore very important for harvest timing. See Section 2.10 for a summary of the different types of fouling.
3. **The end use of the biomass.** For food applications, the seaweed frond needs to be as clean as possible with little or no biofouling organisms. This is particularly true when sold fresh or as the whole frond. Due to the nature of cultivating in the sea, it is (likely) impossible to prevent biofouling from developing or ensure the 100% removal of all contaminating material from the final product. Thus, harvesting a lower crop biomass, before biofouling becomes well established, will be favoured over harvesting later, when peak crop biomass is available, but biofouling is heavier. Careful monitoring of the onset of biofouling (intensity and organism type) is therefore very important for food end uses. As a generalisation for non-food applications, the most important factor determining the harvesting time will be yield achieved. Biofouling will have a lower impact on the quality of the bulk biomass harvested, and so a later harvest with higher bulk biomass, but also

higher % composition of fouling will likely be favoured. The allowable fouling will vary depend on the particular end use or processing method used.

4. **Seaweed chemical composition.** The chemical composition of seaweeds also varies seasonally (Schiener *et al.*, 2015). For example in kelps, the highest protein is achieved in autumn/winter, while highest carbohydrate content is seen in summer. Harvesting time may therefore vary depending on the end use (e.g. a particular target bioactive may peak in January). For food applications, the flavour profile of seaweed also varies seasonally, and so harvest time may need to be adjusted to a particular time of year.

2.8 Farm Design

The goal of the farm infrastructure is to keep the seaweed material in a stable position for the duration of the cultivation cycle (i.e. between deployment and harvest). The seaweed is generally held within 1-2 m of the surface, but sometimes to a maximum depth of about 5 m. The farm therefore requires a mooring to the substratum and a floatation system. The structure must be suitably engineered to tolerate storms and be located in sufficient depth of water to prevent it beaching. Many different forms of farm have been developed.

2.8.1 General Farm Requirements

Aquaculture sites in Scotland require a Crown Estate licence, a Marine Scotland Marine Licence and must include suitable site marking (see Wood *et al.,* 2017). Section 3 of this report summarises the consenting and policy regime for Scotland. The type of farm system used will depend on the volume of seaweed to be produced, the intended end-use of the biomass, and whether a manual or mechanised harvesting method will be used. Sections 2.8.2 to 2.8.5 summarise typical seaweed farm types.

2.8.2 Adapted Mussel Longlines

Double-header longlines can be an excellent structure for seaweed cultivation when only a small quantity of biomass is required (Figures 16 & 17). The components and methods to construct these structures are widely available, and mussel farmers can immediately re-purpose unused lines. The header lines at the surface allow the easy attachment of droppers. The moorings are usually drag embedment anchors, which must be tensioned.

There are some drawbacks to these systems. Firstly, they tend to have an excessive amount of buoyancy, as they are designed for growing heavy mussels. This can easily be remedied by reducing the number of floats to one every 10 m, as this should be sufficient for seaweed cultivation. Secondly, the surface lines and large floats attract heavy fouling.

Figure 16. *Mussel system used for seaweed cultivation in the Sound of Kerrera, Argyll (operated by SAMS).*

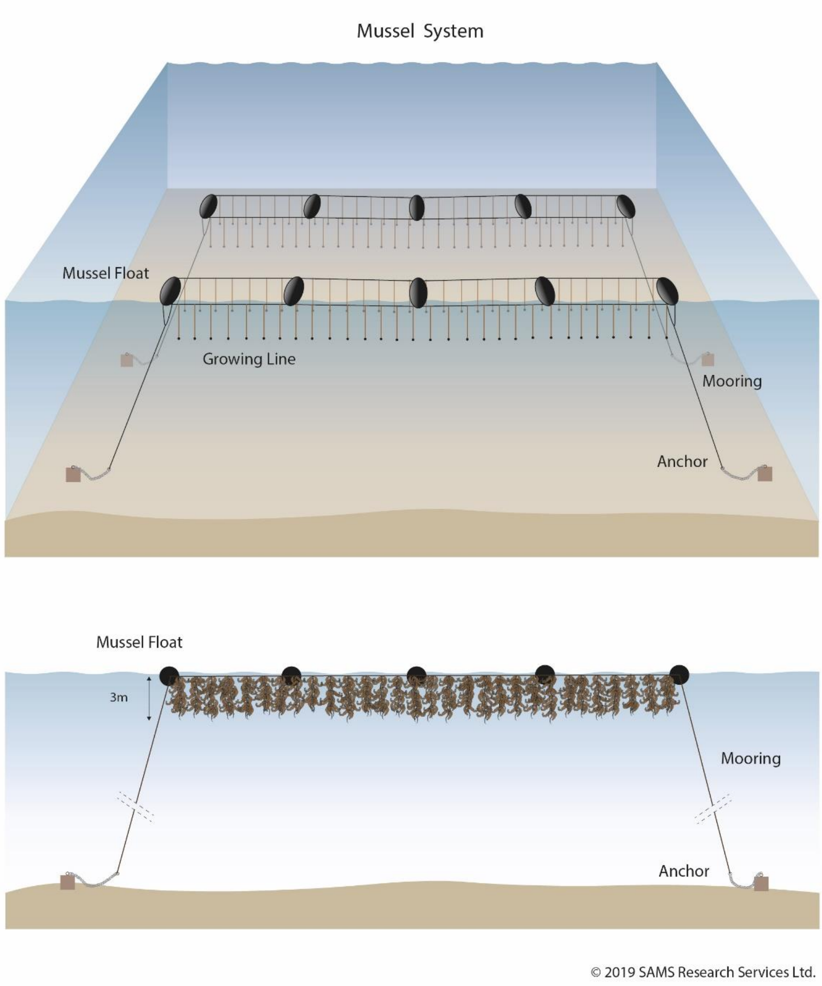


Figure 17. *Diagrammatic view of a pair of double-header rope mussel systems used for seaweed cultivation.*

2.8.3 Individual Longlines

Longline systems have a simple, cheap construction, generally with moorings every 100 m (Figures 18 & 19). The moorings themselves can be made from various available materials including concrete blocks or eco-anchors containing local stone. A guide to their construction is given by Edwards & Watson (2011). Longlines are excellent for most farms. The growing line (usually at 1.5 m depth) is loose, allowing it to be easily pulled to the surface for inspection. Approximately 10 m spacing is recommended between parallel longlines to prevent interaction during storms. This system is not economical at large scale due to the need for a large number of anchors.

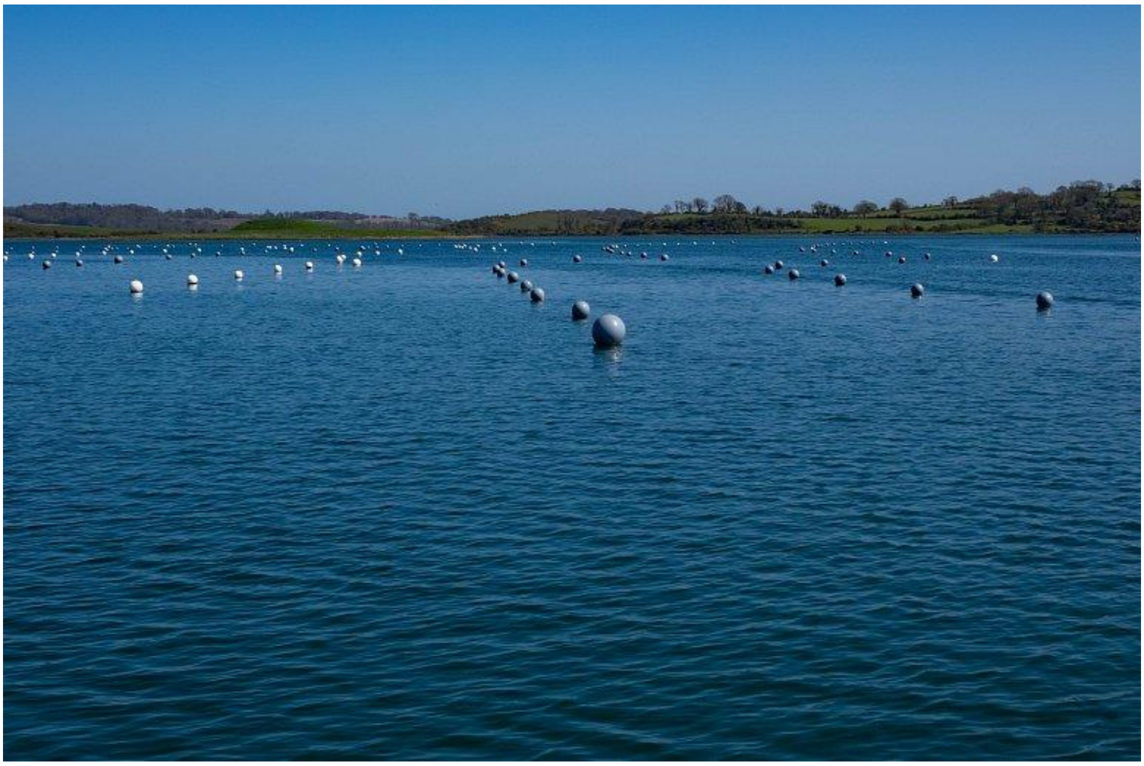


Figure 18. *Parallel longline systems in Strangford Lough, Northern Ireland (operated by Queen's University Belfast).*

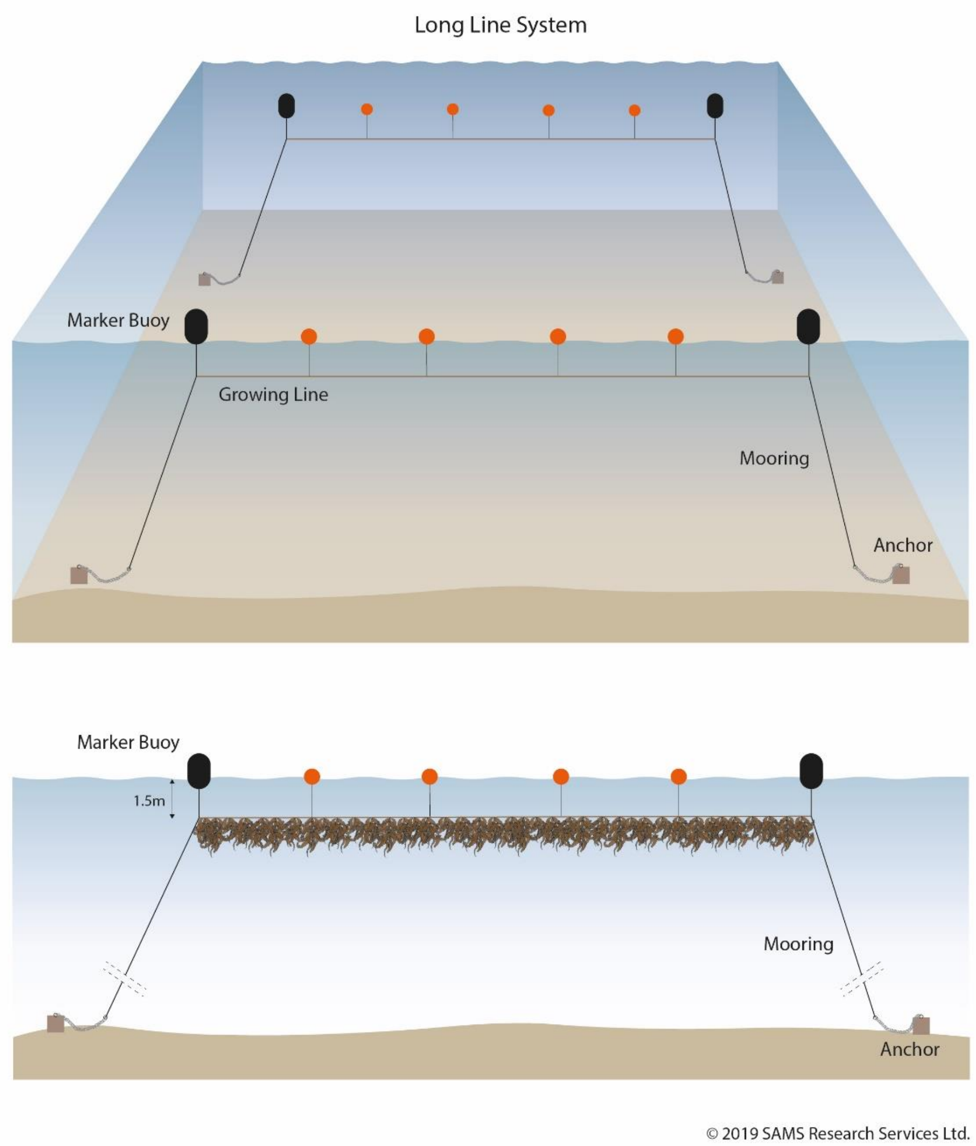


Figure 19. *Diagrammatic view of a pair of double-header rope mussel systems used for seaweed cultivation.*

2.8.4 Grid Based System

Grid based systems are likely to be most suitable where larger farms are needed and/or space is restricted (Figures 20 & 21). A sub-surface rope grid is positioned at a set depth below the surface (e.g. 3 m). This is anchored in all directions using embedment anchors or pilings. Surface buoyancy prevents the grid from sinking. Cultivation lines are then attached onto the grid at a set distance apart. Grids require less anchorage than longline systems, but a disadvantage is that due to the grid being tensioned below the water, it can be difficult to access the growing lines from the surface without a mechanical winch. The rigid nature of this system, resisting water movements, may increase component wear compared to more flexible systems e.g. individual longlines.

Figure 20. *100x100 m grid system used for seaweed cultivation at Port a Bhuiltin, Argyll (operated by SAMS).*

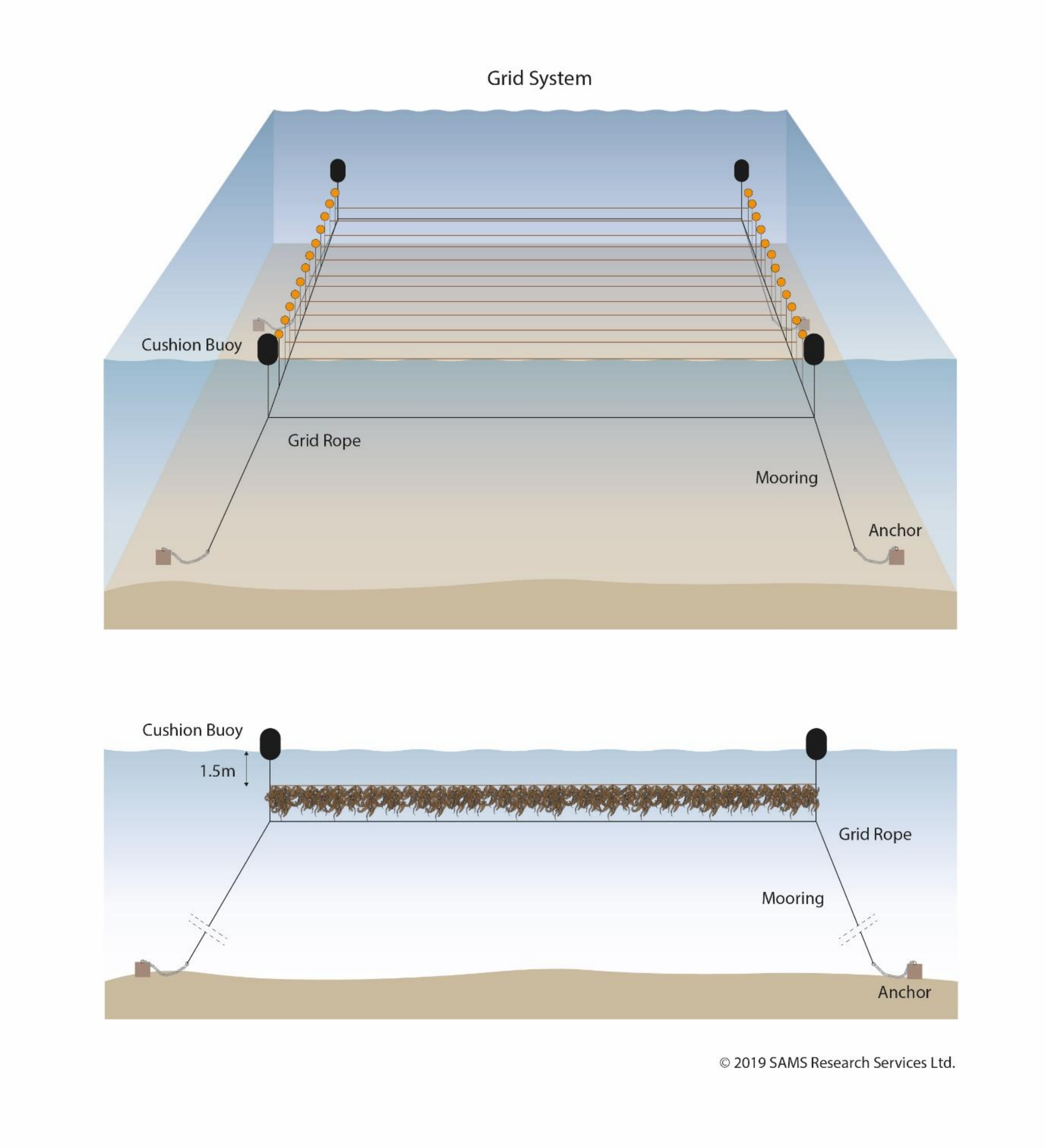


Figure 21. *Diagrammatic view of a grid based system used for seaweed cultivation.*

2.8.5 Offshore Cultivation Rig

This system was developed by OceanRainforest SpF for use in deep oceanic water (Figure 22). A sub-surface rope line is loosely moored over 1-2 km, with buoyed vertical ropes that rise to the surface that are used for cultivation. This unique system is only suited where a large sea surface is free for cultivation, as each parallel line must be 20-50 m apart to prevent rope interaction. The loose construction allows the structure to move far more freely with water currents than other systems.

Figure 22. *Riser growth lines of the OceanRainforest offshore cultivation rig in the Faroe Islands. Photo credit OceanRainforest SpF.*[1]

2.9 Inspections, Monitoring and Maintenance Operations

Once deployed, seaweed grows using light from the sun and by absorbing nutrients and dissolved gas from the surrounding water. No further direct intervention by the farmer is necessary (i.e. no fertilisation of the site is needed). Regular site inspections are still essential.

Site inspections are required under the conditions of the Marine Licence to ensure that navigation lighting and the farm infrastructure are maintained in good condition. If the site is deemed to pose a threat to marine traffic due to inadequate lighting, maintenance, drifting or wreck, the licensee is liable for expenses incurred. Criminal charges, such as negligence, or civil action may be pursued if this leads to injury or damage to property. It is recommended that the licensee has suitable insurance in place.

Other non-urgent but actionable observations (e.g. partially worn ropes/missing buoys) should be noted, so that time is allocated and suitable equipment can be brought during the next farm inspection to carry out the repair. It is likely that in the future remote sensing methods e.g. unmanned aerial vehicles (commonly known as drones) may be used to assist in these tasks.

[1] To view a schematic diagram see: https://www.yumpu.com/en/document/view/5993795/ocean-rainforest-algecenter-danmark

At regular intervals during the growth cycle, growth monitoring visits (see Section 2.9.1) should be used to determine the optimal harvesting time and allow a prediction of the harvesting yield. During these visits, inspections should be made of the accessible below surface infrastructure to:

- Identify and replace worn connections or wear points;
- Monitor for the presence of Invasive Non-Native Species (see Section 5.10);
- Remove biofouling where necessary (Figure 23; Section 2.12);
- Adjust buoyancy of the lines; a little buoyancy is necessary when out-planted, but more may need to be added during spring-summer.

It is good practice to also arrange yearly inspections of all moorings using either divers or a remotely operated vehicle (ROV). This will also allow other problems with the sub-surface infrastructure to be identified. It is recommended that a yearly service contract is negotiated with a suitable marine contractor if the farm operators are unable to conduct the activities themselves.

Figure 23. *Fouling on farm infrastructure by non-target species should be removed regularly to prevent it impacting on the growth of the crop.*

During all inspections, the appearance of invasive non-native species should be recorded and reported to the GB non-native species secretariat (http://www.nonnativespecies.org/index.cfm?sectionid=81).

In Scotland, the two most important to look out for are *Didemnum vexillum* (Dvex, the carpet sea squirt) and *Undaria pinnatifida* (Japanese Wakame kelp). Sightings must be reported immediately to the Scottish Environment and Rural Services (SEARS)[2].

2.9.1 Growth Monitoring to Predict Harvest

After out-planting in October, it is recommended that the site is inspected within 2-3 weeks, and/or following the next storm. This will allow early detection and corrections of problems and allow contingency planning in the case of catastrophic damage. Growth is slow in late autumn and winter due to low light levels, so early growth may not be detectable within this period.

[2] https://www2.gov.scot/Topics/marine/marine-environment/species/non-natives/ReportingNNS
08452 30 20 50 or info@sears.scotland.gov.uk. Please include a photo, the location and the date and abundance.

Growth monitoring visits are then typically carried out every 4-6 weeks. The growth rate accelerates during spring as light availability increases and nutrients levels are high (Figure 24A). As the harvest period is approached (see Section 2.7) monitoring should increase in frequency to once every 1-3 weeks. This will allow the harvestable biomass to be predicted allowing an accurate stock forecast and the organisation of appropriate logistics in preparation for harvest.

The extent of biofouling should also be recorded. Biofouling by other seaweeds and animals tends to become a problem during the late spring – early summer period (Figure 24B). The extent and type of biofouling varies with location and also inter-annually (see Section 2.11). Consistent monitoring is required to allow all cultivators to understand and predict its occurrence. Biofouling can rapidly spread through the crop within 2-3 weeks, degrading the quality of the biomass, particularly for food applications. Biofouling may be allowable for bioresource applications.

The optimal harvesting time is determined by the biomass accumulated (kg) and the level of biofouling. For bioresource applications, chemical analysis may also be employed as seaweed composition is known to vary fluctuate over a yearly cycle (Schiener *et al.,* 2015). The box below provides an example of a monitoring protocol for a seaweed farm whilst material is being cultivated[3].

Example monitoring protocol:

1. A 30 cm length of cultivation line is selected at a certain depth, typically 1-1.5 m;
2. The five largest blades are collected; frond length and maximum width are measured. The stipe length, stipe maximum diameter and fresh mass may also be recorded.
3. Counts/ estimates are made of the number of blades >5 cm within the 30 cm length.
4. Estimate fouling: (1) % coverage of hydroids, bryozoans and seaweeds (separately); (2) abundance of grazing snails; (3) abundance of all other animals together. Abundance ranked using SACFOR scale: super abundant, abundant, common, frequent, occasional and rare.
5. All the biomass stripped from the 30 cm section and bagged – to be weighed onshore.
6. Steps 1-5 replicated 3-5 times.
7. This process should be completed for each species cultivated. If cultivating using dropper lines you may wish to monitor at multiple depths, e.g. 1, 2, and 3 m.

[3] SACFOR – semi-quantitative categorical abundance scale for marine organisms. The quantity of specific organisms within a sample are categorised as **S**uperabundant, **A**bundant, **C**ommon, **F**requent, **O**ccasional or **R**are. See Connor & Hiscock (1996) for more details

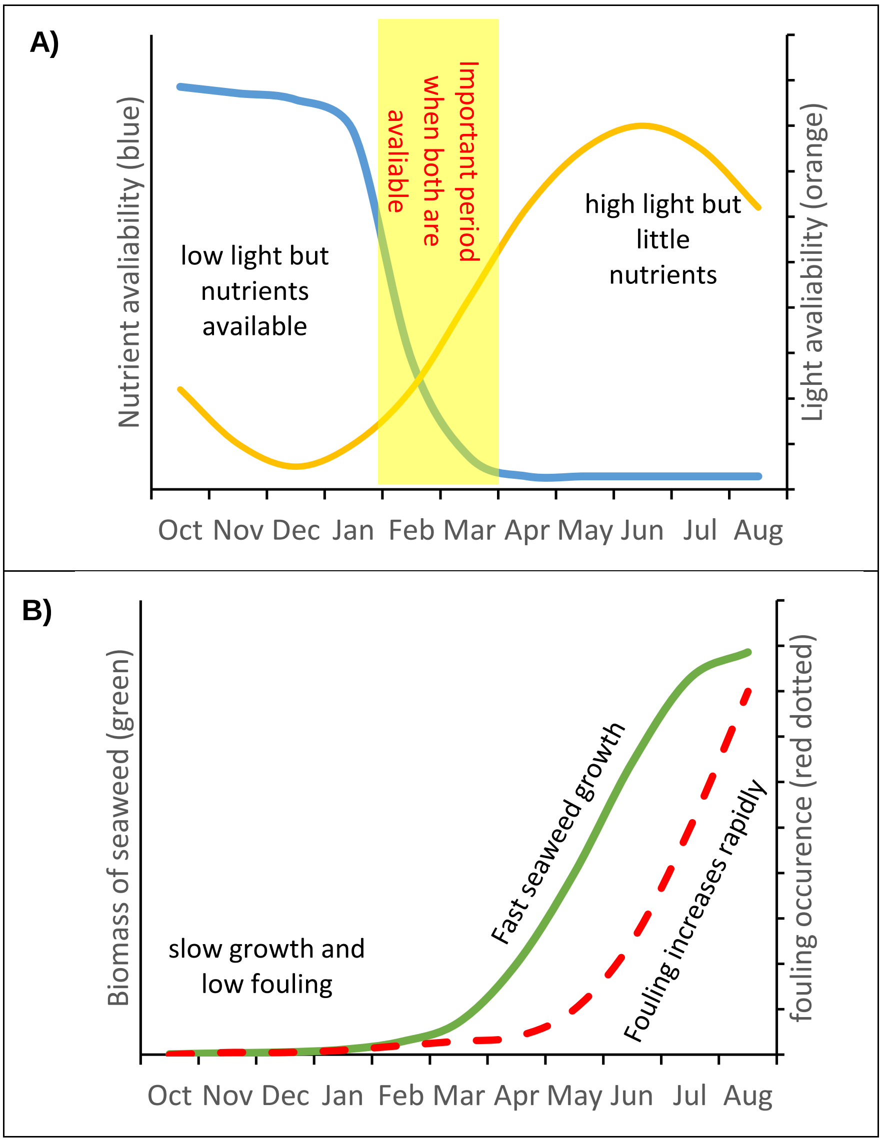


Figure 24. *An approximate representation of the seasonal changes relevant to seaweed harvesting. (A) The availability of light and nutrients over the cultivation cycle; (B) Typical seaweed biomass accumulation and the occurrence of biofouling.*

2.9.2 Monitoring Environmental Variables

Some monitoring of environmental conditions is recommended at the farm. Whilst the influence of the environmental conditions on seaweed growth is relatively well known, how the conditions influence biofouling may be more important. Environmental monitoring may assist in harvest yield/ fouling onset prediction over multiple years.

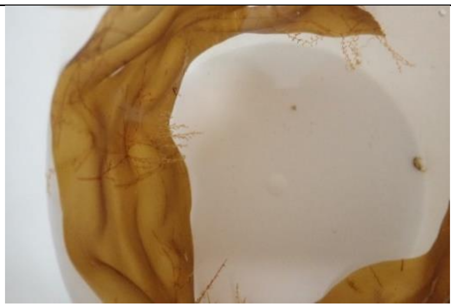
It is recommended that temperature and light at the cultivation depth (e.g. 1.5 m) are monitored and recorded. A cost-effective method is to use HOBO Pendant loggers (Onset Corp, USA), which can be set to log at 30 minute intervals and can be downloaded using an Android smart phone. In areas where salinity may be periodically low, an aquarium refractometer can be used during each sampling visit. Monitoring of the nutrient concentrations may also be desirable.

Aquarium test strips can give an instant measurement for nitrate, phosphate and ammonium. A more accurate measurement can be achieved using a handheld photometer. Projects such as the EU funded H2020 project IMPAQT (grant agreement number: 774109) are investigating the use of remote intelligent management systems to provide real time environmental monitoring data.

2.10 Common Biofouling on Cultivated Seaweed in Scotland

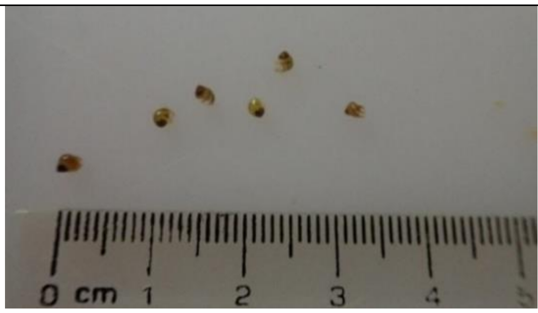
The surface of macroalgae provides a habitat for other species. These may be termed as biofouling if they degrade the quality of the seaweed. These include sessile organisms, such as other seaweeds and colonial animals, and also mobile animals including snails, amphipods and small fish. The most important species in Scotland are shown in Figure 25.

Filamentous brown algae.
These can cause mat-like growth on the ends of seaweed, which hold large quantities of water. They settle during winter and early spring so only cover the oldest material



Colonial hydroids
These animals appear as spider webs that spread diffusely over the frond surface with short (~1 cm) filaments that stick out from the surface. They appear during spring and facilitate the colonisation of other animals.

Colonial bryozoans
Another colonial organism, bryozoans also appear to settle most during the spring. The colonies totally cover the frond as they grow. By mid-summer they can smother the entire frond.



Lacuna vincta
These grazing snails settle from the plankton during the spring. 100s may cover each blade. The snails can then grow up to 1 cm long, causing extensive grazing damage in the summer.

Jassa falcata
The adults of this omnivorous amphipod form detrital tubes to brood their young which degrades the quality of the frond. This can become a problem in early to mid-summer.

Figure 25. *Groups of organisms which may cause biofouling problems on cultivated seaweed in Scotland.*

2.11 Tank Cultivation

Tanks on land can be used to grow some species of seaweed in a closed system. Smaller species that can grow in a tumble culture do best in this scenario for example *Ulva*, *Porphyra, Palmaria palmata* (Grote, 2016) and *Osmundea pinnatifida*, whereas larger species of kelp need more space and water flow. Land-based cultivation can be advantageous as it eliminates the need for operating at sea and it allows for more control of the system. Acadian Seaplants in Canada for example, successfully cultivate Irish moss, *Chondrus chrispus,* in fertilised land based tanks mainly for the Japanese food market (Neish *et al*., 2011). Elsewhere in the world, long term, large scale production of macroalgae in tanks has been reported in Chile, USA and Israel. Two systems can be deployed namely, seaweed cultivation only systems where exogenous nutrients are added, or integrated systems where seaweed cultivation is combined with aquaculture in polyculture systems, for example treating land-based salmon cultivation effluents (Buschmann *et al*., 1994).

Land based tank and pond cultivation can have several logistical and management benefits over cultivation of macroalgae at sea, including the ability to manage growth conditions more precisely and harvest material easily and more frequently. These systems also allow the production of seaweed species not suited to ocean farming and the cultivation of seaweed at higher production densities than in near shore farms. Reported yields for tank grown macroalgae have varied from 45 t dw/ha per year under natural conditions, to 74 t dw/ha per year under optimal growth conditions. The total amount of macroalgae grown in tanks and ponds for commercial purposes is unknown both globally, and in the UK, but is expected to be minimal compared to macroalgae cultivation at sea and wild harvesting.

2.12 Integrated Systems

The Integrated Multi-Trophic Aquaculture (IMTA) concept involves cultivating various species in a way that allows the uneaten food and wastes (e.g., nitrogen, phosphorus, etc.) associated with some species to be recaptured and be converted into inputs (fertilizers, food and energy) for the growth of the other species. “Multi-trophic” refers to the incorporation of species from different trophic or nutritional levels into the same system, while “integrated” refers to the more efficient cultivation of the different species in proximity of each other, connected by nutrient and energy transfer through water. The IMTA benefits are environmental sustainability through biomitigation, economic stability through product diversification and risk reduction, spatial optimisation by increasing productivity of a site, and social acceptability, through better management practices.

IMTA combines species that need supplemental feed such as fish, with “extractive” species. Extractive species use the organic and inorganic materials and by-products from the other species for their own growth. Extractive species can be primary producers (algae and plant species that transform inorganic nutrients into organic biomass) or secondary producers (those that use organic material from the water column or the seabed as food). The secondary producers can be either filter feeders (generally shellfish that sieve organic particles such as algae from the water column) or deposit feeders (organisms such as worms, sea urchins, sea cucumbers etc.

that feed on organic material on or within the sediment). Extractive species act as living filters. The natural ability of these species to recycle the nutrients (or wastes) that are present in and around fish farms can help growers improve the environmental performance of their sites (Sanderson *et al*., 2012). In addition, the extractive species have commercial value as marketable products, providing extra economic benefits.

The IMTA concept is sometimes used in a strict sense: having the different trophic levels integrated in one farm or business, at the same site. As identified in projects such as IDREEM, co-locating different trophic levels in very close proximity may not always result in optimal use of resources and increased productivity. Trophic links in aquatic ecosystems can extend over a large spatial scale. Depending on the local hydrodynamics and the biogeochemical processes involved, spatial separation may be even beneficial. E.g. as the transformation from fish waste into nutrients takes time and if there is a residual current, the best location for a seaweed farm to optimally utilise these nutrients may not be in the immediate vicinity of the fish farm, but further downstream. Conversely, cultivation of different species at the same site may occur, without a direct trophic link between the crops, due to the economic benefit of co-location and being able to use a production site in all seasons and for multiple products at the same site for example seaweed and shellfish. This type of co-location is perhaps a bit beyond the strict definition of IMTA, but still highly relevant for developing business cases for new forms of aquaculture.

However, IMTA has been only tested at very small scale in Europe. Even in countries that IMTA has been already practiced (mainly in Asian countries), management of large-scale IMTA areas remains difficult, principally due to limited knowledge of how the separate components in the IMTA ecosystem interact and function as a whole, as well as what is the impact on the environment and the broader community in regions that practice IMTA (Alexander & Hughes, 2017).

2.13 Bioremediation

Wastewater effluents can contain a range chemicals which can have an adverse effect on aquatic systems. The Water Framework Directive (Directive 2000/60/EC) has issued a variety of directives to improve water quality across Europe, which include the Nitrates Directive 1991 and the Dangerous Substances Directive 2006/11/EC. In order for macroalgae/seaweeds to grow, they need not only sunlight but also nutrients in the form of nitrogen and phosphorous. They are capable of removing nutrients, through the process of bioremediation, from wastewater and reduce pollution (Ross *et al*., 2018). The use of seaweeds for water treatment (in fish production, agricultural/ industrial effluents, waste water etc.) is well established (Sanderson, 2009; Park *et al.,* 2011). Attention in recent years has focused on using the algal biomass produced mainly for biofuels (Day *et al*., 2012; Dave *et al.,* 2013). Currently this is not economically viable but the economics and the sustainability of algal production could become viable by taking a whole systems approach (Atiken & Antizar-Ladislao, 2012). This for example includes the extraction of valuable compounds not utilized during biofuel production and the recovery of nutrients from the biomass for nutrient recycling/ waste recovery. The challenge is balancing production costs with the end product being produced (Sode *et al*., 2013).

2.14 Harvesting

The final stage of the seaweed cultivation cycle is the harvesting of the biomass from the farm site. There are two broad categories of harvesting techniques: manual harvesting and mechanical harvesting.

2.14.1 Manual Harvesting

Harvesting seaweed by hand is commonplace in seaweed farming, especially when production levels are low or labour is cheap. Hand harvesting seaweed normally involves cutting the seaweed off a rope, either through a single harvest or partially cutting the harvest multiple times in a year or over several years.

Harvesting by hand ensures higher accuracy and better quality seaweed, but is very labour intensive. Harvesting by hand may be preferable from a business point of view if the investment in equipment cannot be offset by the profits. However, in countries where labour costs are higher or production is to be scaled up, increasing efficiency or mechanising harvest may be preferable.

2.14.2 Mechanised Harvesting

Mechanised harvesting may improve harvesting efficiency and reduce labour effort and/or cost. For example, nori in Asia is harvested using mechanical harvesters, where the net is dragged over rotating blades. In Europe, seaweed farming is still in early stages of production, but already technologies are being developed. For example, the Dutch companies Royal IHC and Vuyk Engineering Rotterdam have developed concept for harvesting longlines where seaweed are cut off as the rope is pulled through a circular cutter or knife. The harvesting method will depend on the scale of the production, infrastructure available (such as boats, piers and lifting equipment) and the potential impact of mechanised cutting on the final product quality.

2.14.3 Knowledge Gaps

Harvesting is one of the bottlenecks of the production line in seaweed farming. Increasing harvesting efficiency is crucial to reduce costs and optimise harvesting times. Environmental factors can impact harvesting through inclement weather limiting harvesting days, onset of fouling and diseases as water temperatures increase, and environmental conditions influencing seaweed growth rates. In addition to developing better harvesting technologies, increased knowledge on optimal harvesting times can also improve production yields and quality.

2.15 Products and Processing

Seaweed is a hugely versatile crop that be used in a wide range of products from low to high value. There is a long established market for alginates extracted from seaweed, it has become one of the most useful and versatile polymers used across industries due to its gelling, thickening, emulsifying and stabilising properties (Peteiro, 2018). Seaweed as a food for humans has seen a rise due to its use in Asian cuisine and due to its nutritional qualities, consequently it is increasing in popularity as a food and health supplement. Similarly, there is increasing interest in the use of seaweed as a nutritional supplement in animal feeds.

Seaweed has been explored as a potential source of biomass for production of renewable energy, through the production of gases or liquid fuels. If seaweed is used for energy the cost price is much lower and large scale production needs to be in place. Integrating systems or supply chains through combination of bioremediation of waste effluents or biorefining of multiple products may be a way to extract more value from the crop and supply a range of industries. In addition to more efficient processing, marketing of products has the largest potential for increasing market value. Figure 26 shows a schematic diagram of the different products and associated production volumes.

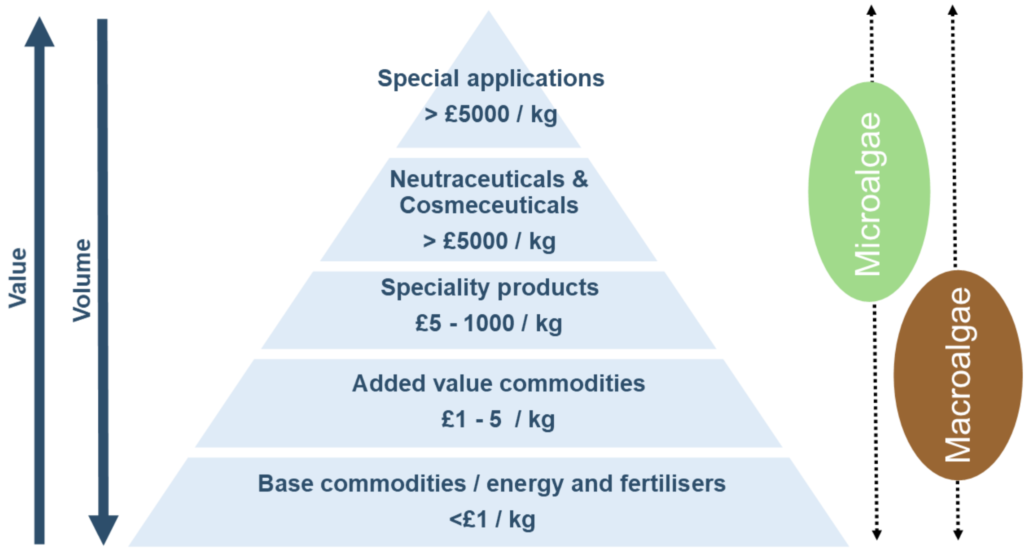


Figure 26. *Estimates of value of different products and the volume production required to meet demand for micro- and macroalgae (adapted from Schlarb-Ridley & Parker 2013).*

2.15.1 Edible Seaweed

2.15.1.1 Human Food

Use of seaweed in Asia is traditional so consumers are used to the taste, texture and colour. The markets in Europe and North America are less well-developed (see Section 2.16) but have become increasingly popular with the increase in Asian food restaurants and retail products. Blikra *et al*. (2019) suggest green seaweed are more palatable to humans due to their similarity to traditional vegetables. Brown seaweed like *S. latissima* and *A. esculenta* become green when heated, Blikra *et al*. (2019) therefore suggest heat treating these species at 95 degrees for 15 min to produce a green colour and ensure microbiological safety.

The human food market would desire high quality seaweed, and Scottish provenance can add value to any end product. There are opportunities for the production of more artisanal products with high value and potential for value-add into other products (e.g. agar, alginates and carrageenan).

2.15.1.2 Animal Feeds

The regulations covering animal feeds are harmonised across Europe and business manufacturing or selling feeds must be registered or approved and comply with specified standards (http://www.foodstandards.gov.scot/business-and-industry/industry-specific-advice/farming-and-primary-production/animal-feed#what%20animals%20eat). The addition of seaweeds to animal feeds is covered by EC Regulation 178/2002 and currently seaweeds are used as a supplement. This is in the form of usually one species, *Ascophyllum nodosum*, which has been harvested, dried and milled. For cattle the recommended daily feeding rates are set at 120/150 g per day, pigs 60/100 g per day and sheep 30/60 g. The seaweed is marketed as a way of boosting mineral content, improving health, fertility and overall productivity as well as potentially acting as a probiotic.

The market is now seeing a rise in seaweed blends, including companies such as Chase Organics and Ocean Harvest, and again claims are made linked to the probiotic effects of using macroalgae as an animal feed supplement. Using the search terms "macroalgae animal feeds" online, over 200 hits were generated. Review of the search engine hits show articles ranging from the physiological benefits of including seaweed supplementation for suppressing pre-slaughter stress (Kannan *et al*., 2007), through to natural feeding activities of Norwegian sheep (Novoa-Garrido *et al*., 2014). Perhaps one of best overall reviews is by Makkar *et al*. (2016). This highlighted, as has been previously seen, the long history of seaweed supplementation of animal feed diets, they point to the high mineral content which is contained within the ash of the seaweed which is 10-20% higher than terrestrial plant sources and is essential to support animal growth. The literature also confirmed that the choice of seaweeds for potential inclusion in animal feeds (Makkar *et al*., 2016; Tayyab *et al*., 2016). Tayyab *et al*. (2016) demonstrated that *Alaria, Laminaria*, and *Palmaria* were capable of supplying rumens with high amounts of rumen degradable protein, while *Ulva* could be used as a source of digestible bypass protein.

In aquaculture there is a very clear link for seaweed within feed, for example abalone using *Ulva* and *Fucus* sp for both feed and bioremediation (Lee 2004; Zhou *et. al.,* 2006; Amosu *et al*., 2016; Bansemer *et al*., 2016). Very little pre-processing is involved, keeping production costs down, with seaweed biomass usually either added as a feed either in the form of fresh or dried material (Carrier *et al*., 2017).

Although there is evidence of potential benefits for inclusion of seaweed as part of animal and/or aquaculture feeds, there is fairly limited quantification of these benefits, as well as potential adverse effects (Wells *et al*., 2017). There is also the potential impact that seasonality has on the overall chemical composition and many of the published studies currently only focus on wild harvested material (Schiener *et al*., 2015; Adamse *et al.,* 2017). There is still also a lack of understanding for a range of potentially useful species on the impacts of geographical location and the season/ time of harvest can have on the dietary value of seaweed.

If cultivated material is to successfully grow commercially within Scotland, a greater understanding of the links between chemical composition, site selection and timings of harvest is required, especially in terms of proteins and heavy metal contamination. Research from Australia has highlighted that bromoforms from the red macroalgae specie *Asparagopsis taxiformis* can reduce methane production by as much as 90% with just 2% inclusion in cattle (Vucko *et al*., 2017). But it should be noted that this was just in vitro testing and that there is currently no direct evidence of a reduction in methane production by dairy cows when feed this type of seaweed. Again, in this study a link to potential impacts of seasonality to the levels of the active compound, bromoform, has also been raised. Other studies have focused on the mineral content of the seaweed (Cabrita *et al.,* 2016). Calcium, phosphorous, magnesium, iron, iodine, zinc, copper, manganese, selenium, cobalt and bromine are all important macronutrients in animal feeds. However, this must be investigated in conjunction with the group of potential toxic trace elements that seaweeds can contain - cadmium, mercury, lead, aluminium and metalloid arsenic (Suttle, 2010). Although enzyme pretreatments can improve the lipid profile for some seaweeds, they also reduce the ash content. This preferentially contains nutritionally interesting macro/micronutrients. These studies are still fairly early stage and very reliant on those enzymes used for terrestrial biomass pre-treatment before ethanol fermentation (Schiener *et al*., 2015; Maehre *et al*., 2016).

2.15.1.3 Food Safety

Seaweed as human food is eaten both raw and cooked. While no seaweed produce human toxins, seaweed may contain environmental contaminants harmful to humans if grown near pollution sources. Seaweed can bioaccumulate toxic metals and care should be given to placement of farms near sources of metal pollution such as marinas, industrial pollution or certain geological features. Hijiki is a seaweed imported from Japan for human food, which is naturally high in inorganic arsenic which is toxic to humans; the levels of arsenic are deemed unsafe to eat by the Food Standards Agency in the UK (Rose *et al*., 2007).

Microorganisms are a common hazard in seafood; mussel farms in Scotland and the UK are therefore carefully monitored for toxic algae and microrganisms harmful to humans. Only a few studies have studied the risk posed by microorganisms from seaweed to humans, unlike mussels, seaweed do not filter feed and are therefore less likely to accumulate microorganisms. However, biofilms form on the surface of seaweed blades. Hendriksen & Lundsteen (2014) supposed levels of microorganisms on seaweed would not exceed levels found in ambient seawater, but highlighted research is needed to assess the risk of organisms such *as Eschericia* *coli* and *Vibrio* spp. on seaweed to human health. Blikra *et al*. (2019) sampled microbiological communities on brown seaweed *S. latissima* and *A. esculenta* in Norway, and encouragingly, found no enterococci, coliforms, pathogenic vibrios, or *Listeria monocytogenes*. *Bacillus* spp. were on found on the blades, they have been associated with food poisoning and their growth should therefore be controlled during processing (Blikra *et al*., 2019). Handling and processing blades needs to be designed to ensure raw blades are not contaminated by equipment or water sources. Microbiological growth can be controlled through preservation methods such as desiccation, heat treatments or freezing, Blikra *et al*. (2019) recommend 95˚C for 15 minutes as a way to reduce bacterial growth and not compromise colour and texture of product. While research so far indicates none or levels of human-pathogenic microbes are present on both raw and cooked seaweed, caution is advised to ensure food safety is maintained through handling, processing and storage.

Finally, seaweed are high in metals and iodine, which can cause adverse health effects if consumed in high amounts. The new EU recommendation 2018/464 on the monitoring of metals and iodine in seaweed, halophytes and products based on seaweed, lists species that should be monitored for levels of arsenic, cadmium, iodine, lead and mercury. Monitoring may already be in place for some products, especially human foods or animal feed in the supply chain, but the recommendation could lead to a broader framework for legislation or standards to regulate for. In general though, the risk to consumers' health is considered low at the current level of consumption of seaweed (Rose *et al*., 2007). Site selection for new seaweed farms within the UK should consider nearby pollution sources such as sewage outlets, marinas and industrial pollution. Strict coastal management and monitoring of seaweed for toxic metals and human pathogens can help ensure food safety standards are met and may fetch a higher premium from consumers.

2.15.2 Non-Edible Seaweed

Speciality nutraceutical and cosmeceutical products cover a wide range products and application areas. It can include everything from anti-oxidants, flavour ingredients through to their addition into cosmetics, personal care and food ingredients. These types of products are sold on the basis of their effect during use, and their value can depend on the application area. Some types of animal feed ingredients will also fall into this category particularly were the ingredient has a direct impact on the end product and its markets. For example, the pigment Astaxanthin is included in salmon feed to give the flesh its pink colouration. Products in this category have a price of £5 to £1,000 per kilogram with market volumes ranging from 1,000 t to 100,000 t. Naturally derived products may carry a premium over synthetic derived alternatives, especially where there are tangible performance benefits. For example a cyanobacterial pigment allo-phycocyanin commands a staggering price of up to €50/mg for use as an ultra-sensitive fluorescent tracer in protein labelling.

2.15.2.1 Base Commodities

These include energy and animal feed products with prices in the range of £1/kg. Energy products include liquid biofuels such a fatty acid methyl ester (biodiesel), ethanol and jet fuel, and biogas from Anaerobic Digestion (AD). The bioethanol price is currently around £450 per tonne and the base price for biogas is equivalent to natural gas (1.5-5 p/kWh over the last 2 years).

Prices for animal feed are between £50-1,100 per tonne, on a dry weight basis, with pricing dependent on nutritional value. In addition to providing saleable products included in this part of the value pyramid is the bioremediation of wastes, most notably carbon dioxide, organic waste and waste-water.

2.15.2.2 Hydrocolloids

Alginic acid/alginates constitute 20-30% of the total dry matter content of brown seaweeds. This is the only component of commercial importance to date. 16 t wet/fresh seaweed gives 1 tonne of alginate. The world market for alginates is roughly 30,000 t at an average of 6 - 10,000 US$ per tonne. Only 0.5 Mt of fresh brown seaweed would be required to meet this market. The world market for phycocolloids has so far grown at a few percent a year. In the long term, market saturation is a possibility (Reith *et al*., 2005). Macroalgae for hydrocolloids: The global hydrocolloids market was worth $3.30 billion in 2010, with the European market for Carageenan, a hydrocolloid extracted from red macroalgal species, worth $127.9 million ($10-12/kg) and the agar/alginate market, hydrocolloid extracted from brown macroalgae, worth $29.6 million ($20-23/kg). This is a well-established market and has not really grown in the last 50 years, but there is an increase potential in the use of macroalgal based hydrocolloids for health and value added functionalities for speciality applications including pharma. The Norwegian company AlgiPharma AS have taken the hydrocolloid alginate and alternated it to form what they call Oligo-G. This pharma-grade product is been formulated into several products aiming to treat microbial infections and respiratory diseases, and to treat and improve healing of infectious wounds and burns. The product has also just undergone stage 2 clinical trials with cystic fibrous (CF) patients, were it is used to disrupt bacterial lung infections. This should result in more effective treatment and has the potential to reduce the need for antibiotic treatment in CF patients.

2.15.2.3 Agar

This is a jelly-like substance extracted from two species of red macroalgae, *Gelidium* and *Gracilaria*. The algae are harvested either from the wild, or increasingly from cultivated seaweed farms. *Gracilaria* cultivation has been particularly successful in Chile, but both wild and cultivated material is available from Argentina, South Africa, Japan, Indonesia, Philippines, China and India. *Gelidium* is always in high demand so that natural resources are collected wherever possible, the principal countries being Spain, Portugal, Morocco, Japan, Republic of Korea, China, Chile and South Africa. Other minor sources of raw material for agar production include alternative algal species including: *Pterocladia* (a small alga similar to *Gelidium,* harvested in the Azores and New Zealand) and *Gelidiella* (India, Egypt and Madagascar). Agar is the main ingredient in desserts produced in Asia and also as a solid substrate for the cultivation of microorganisms. It can also be used as a laxative, an appetite suppressant, a vegetarian substitute for gelatin, a thickener for soups, in jams, ice cream and as a clarifying agent in brewing. About 55,000 t (dry weight) of macroalgae are extracted annually to produce 7,500 t of agar with a value of $132 million. Growth in the agar industry is only 1-2% a year and the development of new applications has been slow. There is high diversity in alginate function between seaweed species, environmental conditions and season (Peteiro, 2018).

2.15.2.4 Bioactives

Macroalgal products for use in personal care is an expanding market and there is potential for adding value. Especially if locally produced ranges include regionally sourced/grown material feeding into the organic, natural and "free from" markets. Products can range from simple dried seaweeds for home baths to high value spa and cosmetics ranges for example the Isa products from Lewis. Much of the evidence for the efficacy of these products is anecdotal and many products are still marketed on basis of traditional uses and "old wives" remedies. This has led market leaders to invest substantially in research and development to substantiate efficacy. This in turn then justifies the image these products have as high value products. Bioactive compounds range from sulphated polysaccharides, phlorotannins and diterpenes with everything from anti-inflammatory to anti-microbial activity (Gupta & Abu-Ghannam, 2011).

2.15.2.5 Bioenergy

In recent years there has been a great deal of interest surrounding the use of seaweeds, especially kelp, to create energy and fuels. Cultivating kelp is an attractive option as biomass production can expand at sea without competing with terrestrial crops. Seaweed can be converted into biogas through AD or into ethanol through sugar fermentation. However, current processes may not be well suited to the fermentation of seaweed to convert into biogas or ethanol. The development of new processes are needed, either through the addition of a conversion step to access the fermentable sugars or creating a new direct fermentation process by identifying adapted microorganisms. Seaweed can be used as a feedstock in conventional AD plants, but salt, water and chemical compound content needs to be carefully managed to not inhibit the fermentation process (Bruton *et al*., 2009).

Seaweed-based biofuels still face issues such as scalability and economic viability. Seaweed need to be produced at large-scale before biofuel production can start and the cost of cultivation and processing are currently too high to make production economically viable (Bruton *et al*., 2009). Seaweed as a feedstock would be a low-value product, consequently, the competitiveness of seaweed against other feedstocks (e.g. microalgae, wood and straw) needs to be considered (Bruton *et al*., 2009). Life cycle assessment of the production can help determine the economic viability of seaweed as a feedstock, or alternatively, the integration of multiple supply chains in a biorefinery could increase economic viability.

2.15.3 Biorefining

A biorefinery is a facility that integrates a chain of production for different fuels and products to extract a range of low and high value products. The biorefinery approach can help make a product viable to produce. Biorefining essentially optimises the processing of a biomass to improve the production economics and reducing waste produced (Figure 27). This feeds directly into the concepts of the bio and circular economies. In terms of seaweed biomass this would include the sustainable production of a range of natural commodities of commercial value could include biochemicals for the pharmaceutical, nutraceutical and cosmetics sectors, nutritional food and feed ingredients, polymers for biodegradable plastics and fabrics, and minerals as fertiliser. As seaweeds do not contain lignocellulose, they require different processing and conversion steps from those developed for land plants. They also contain recalcitrant sugars that are often sulphated, and a further challenge is the high intrinsic salt content of the biomass. Nonetheless, the significant levels of protein in some edible species have the potential to augment feed supplies in the UK and globally, whilst the high mineral content could contribute to closing the mineral fertilizer loop. However, there are major gaps in our knowledge of how to build a seaweed biorefinery industry. These encompass biological and engineering challenges, bioprocessing technologies, environmental implications, sustainability issues, and policy and legislation hurdles. It must be noted that for marine biomass to be considered as a serious contender in a biorefinery context, it will need to be cultivated rather than harvested from the wild (a kelp bed could collapse under high harvest pressure), and there is a need to develop downstream processing in order to reduce production costs.

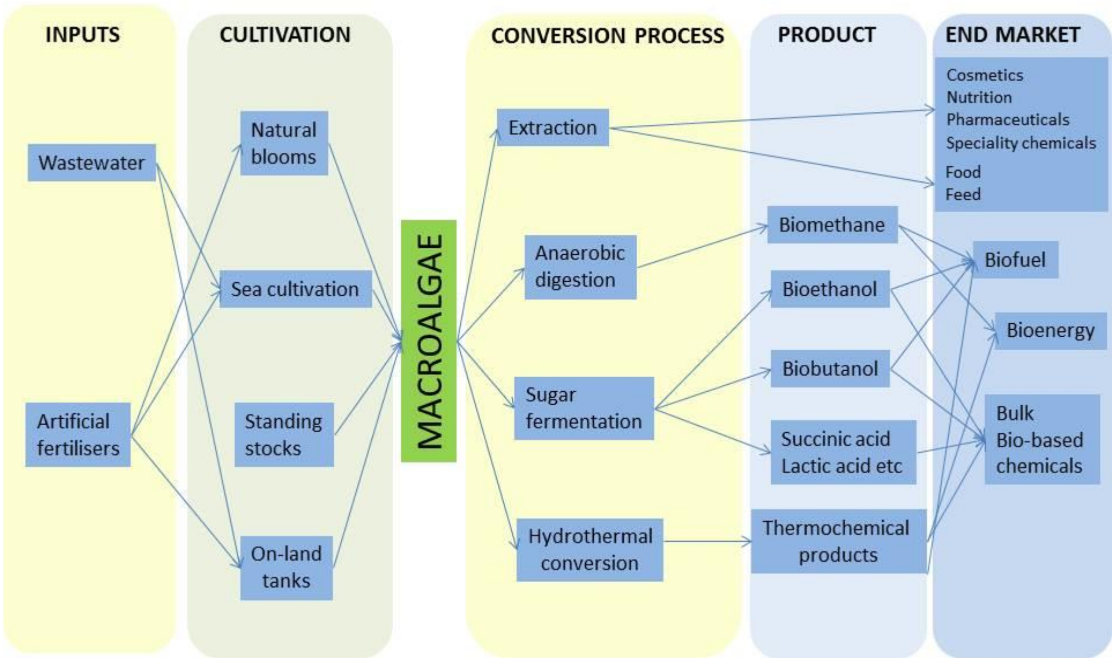


Figure 27. *Summary of the production chain in a biorefinery approach to production. Figure adapted from the Report for the Algal Bioenergy Special Interest Group: Research needs in ecosystem services to support algal biofuels, bioenergy and commodity chemical production in the UK, February 2012.*

2.15.4 Knowledge Industries

The development of seaweed industry in the UK and Europe creates a market for many support industries, such as research and development, advice and guidance, development of new technologies and culture methods for different species. Complementing technical research there is the need for a strong knowledge industry covering the whole process from growing/cultivation through to processing. This will also include market intelligence and the knowledge of how to commercialise any algal product or hardware (Schlarb-Ridley & Parker, 2013). The consultancy industry should have strong links to primary data producers taking the information/ knowledge they have translating it into a commercial context. Long-term survival of any industry demands minimizing environmental impacts and understanding this reduces risk enabling responsible management of resources. This has a clear link into Corporate Social Responsibility links to PR and branding, giving the consumer confidence. There is also a need for developing teaching tools, training programs from grass-roots level for learning about the industry but also working on policy advice and public perception to ensure that there is community buy-in and engagement. Creating both together can lead to retaining a skilled workforce building an interdisciplinary pool of expertise in this region. Within Argyll and Bute there has been a drive under the Rural Deal for the commercial underpinning of growing seaweed and shellfish industries, building on the academic expertise in the region and the commercial practise to develop a major industrial R&D innovation centre with a global client base

Within Scotland, all aquaculture production undergoes strict procedures for marine licencing to ensure production levels are within the capacity of the environment. While there are established monitoring tools and legislation surrounding fish and mussel farms in Scotland, seaweed farming legislation is still in its early stages (see Section 3). It is expected as the industry grows and commercial farm sites are set up that monitoring requirements may increase both to comply with legislation and monitor growth. Professional services may be offered by specialist consultancies. (Campbell *et al*., 2019)

2.16 Markets

2.16.1 UK Market

The UK market for seaweed has grown over the last decade as seaweed products have become increasingly available in retailers and restaurants. The UK is the biggest consumer of nori in Europe, accounting for 90% of the market in 2014 (Organic Monitor, 2014). Nori is imported from Asia and is not currently produced in Europe on a large scale. Seaweed has become popular through the rise of sushi restaurants, and in food retail, sushi sales have changed 95% in volume between 2008 and 2018 making it the biggest volume change in the seafood market segment (Seafish, 2018).

Seaweed is recognised as a superfood due to its health and nutritional benefits making it attractive for human food markets and as an additive in the animal food market. Consequently, retail penetration is high in specialist retailers such as organic food shops and health food retailers (Organic Monitor, 2014).

The UK market of locally grown seaweed has been a niche market often directly from producers or specialist retailers. However, large supermarkets are now stocking more seaweed products. Retailers stock both imported products such as nori sheets from Asia but products from UK-based companies are also making it onto the shelves. Commonly found products include seaweed salts from companies such as Mara Seaweed and The Cornish Seaweed Company, Waitrose is also offering its own brand of dried seaweeds. Seaweed is a popular add-in product to promote the product and add value.

More products are including seaweed as an ingredient, in particular in snack products or ready meals, for example, crisps and meals produced by the Scottish company Shore. Between 2011 and 2015 a third of new seaweed-based food and drinks products were in the snack category (Barbier *et al.,* 2019). Similarly, seaweed products are popular add-in's in the alcohol industry where locally harvested seaweed are used, they are especially popular in gin products where seaweed is added as a botanical in the distilling process but could also be added as an extract or garnish. Capuzzo & McKie (2016) found 27 UK-based companies producing seaweed-related products, of these 16 companies use seaweed harvested from the UK.

2.16.2 European Market

The European market, similar to the UK market, still relies mainly on the import of seaweed from Asian producers. Finding reliable estimates of European seaweed aquaculture production volumes can be difficult due to incomplete data records and uncertainty in the data gathered (Barbier *et al*., 2019). European production of seaweed is low, making up less than 1% of global production (FAO, 2018; Camia *et al*., 2018) and has historically relied on harvesting of wild seaweed (Barbier *et al*., 2019). As the European market for seaweed has grown the industry has increasingly looked towards seaweed farming as the solution to scale up production. In some countries, such as Ireland, France and Norway seaweed is still harvested on a large scale but increasingly pilot farms are being set up across Europe.

The market for sea vegetables within Europe was estimated to have a value of €24 million in 2013 (Organic Monitor, 2014). It is similar to the UK market with sales of seaweed mainly as a food or snack product in retailers or as an ingredient used by food processors, restaurants and caterers (Barbier *et al*., 2019). European countries do differ in their preferences for seaweed species, the UK is the largest consumer of nori (the most popular product across European market) but France has the highest consumption of dulse. Overall, France is the biggest consumer of seaweed (based on data from 2013) followed by the UK, Germany and Spain (Organic Monitor, 2014). In Ireland there is a small but established market for seaweed, especially for carageenan and dulse which are sold as food products, but other species are increasing popularity. The European market is small compared to Asian markets, but as interest grows and demand increases the European market is a potential growing market for UK producers to export products to.

2.16.3 Global Market

Seaweed is cultivated in 50 countries with the majority of seaweed produced in Asia. In 2012, Asian countries produced 95% of the global production of aquatic plants (Capuzzo & Mckie, 2016). Global production for aquatic plants (dominated by seaweed) grew in output volume from 13.5 Mt in 1995 to just over 30 Mt in 2016 (FAO, 2018). The main producers are China, Indonesia, Korea and the Philipines (FAO, 2018).

The global seaweed market is estimated to be worth €8.1 billion per year (Barbier *et al*., 2019). The seaweed aquaculture industry is the fastest growing aquaculture sector, growing by 10% each year (Barbier *et al*., 2019) and the global market for biotechnology is growing by 5 – 6% each year (Maximar, 2018). As seaweed continues to grow in popularity within Scotland, UK and European markets wild stocks are been continually placed under pressure and there is the opportunity to develop cultivation methods for high quality biomass. In terms of Europe the major driver has been in the cultivation brown seaweeds in particular *Saccharina latissimi* and *Alaria euslenta* for the food market. Red seaweeds potentially offer the most for export to Asian markets. Currently Japan is a major importer of nori and as already highlighted in Section 2.11 (Tank Cultivation) Acadian Seaplants already supply *Chrondus crispus* again into the Japanese market.

3. SEAWEED CONSENTING AND POLICY REGIME FOR SCOTLAND

3.1 Lease and Licence Requirement

In Scotland two permissions must be obtained before any development can be introduced in the marine environment. Due reflection should be taken on the amount of time it takes to apply for, and for all the relevant permissions to be granted, related to a seaweed cultivation site. The two permissions are a seabed lease from Crown Estate Scotland and a licence from Marine Scotland.

3.1.1 A Lease for the Seabed from Crown Estate Scotland

Crown Estate Scotland are custodians of the UK seabed out to the 12-nautical mile (NM) territorial sea limit. In some circumstances, the seabed may be owned by local landowners. A single Crown Estate Scotland application form exists for aquaculture developments. Due to the nascent state of the seaweed cultivation industry, the current application form and guidance document (version 9/3/2017) refers only to finfish and shellfish. This can be found at: https://www.crownestatescotland.com/maps-and-publications.

The application is free and Crown Estate Scotland encourage prospective applicants to contact them beforehand for informal discussion and to ensure that the site is available for lease. Contact details can be found at: https://www.crownestatescotland.com/what-we-do/marine/asset/aquaculture. The lease requires the applicant to provide details of the species to be cultured, cultivation equipment to be deployed and coordinates of the area to be leased. This area should be large enough to encompass and moorings and navigation lighting required. Additional supporting information includes a plan of the seabed to be licenced, a copy of the marine licence and all statutory consents (see Section 3.1.2 below), a brief outline of the business/production plan to ensure the business is feasible and a plan for decommissioning/removal of infrastructure a renunciation/termination of the lease. If a marine licence has not yet been granted, then a lease-option can be obtained. This provides a time-limited exclusive interest in an area of seabed for a three year duration, while a marine licence is obtained, preventing its assignment to another party.

Following the application, Crown Estate Scotland will advise on neighbouring activities which may impact on the development such as the location of nearby sewage outfalls. An annual fee is incurred for the lease duration, with the levy based on the type and amount of infrastructure installed (i.e. moorings, buoys and lines). In the case of the two experimental seaweed farms run by SAMS, a six year licence was issued. After this time, a resubmission is necessary for a new licence. Changes to any parameters of the site (e.g. spatial extent, equipment deployed, species under culture) will require a resubmission to Crown Estate.

3.1.2 A Licence from Marine Scotland

The Marine Scotland Licencing Operations Team (MS-LOT) provide marine licencing services. This regulator also provides enforcement within inshore waters (out to 12 NM) under the Marine (Scotland) Act 2010 and offshore regional water (12-200 NM) under the Marine and Coastal Access Act (MCAA) 2009. They recommend an informal discussion before applying.

A specific ‘Algal Farms Marine Licence Application’ exists. This requires a complete description of all equipment to be deployed, the date of installation, the area it covers, and the boundary co-ordinates of the site and position of all equipment such as longlines and navigation buoys. Information which must also be provided includes: a method statement for the works, any identified potential impacts this may have with mitigation steps to be carried out and how the development relates to Scotland’s National Marine Plan (NMP).

A one-time fee is charged at the time of application, levied against the deployment costs; infrastructure and labour. For a small-medium scale farm application before 1st April 2019, the charge is likely to be either £685 (infrastructure value >£5000 to ≤£50,000) or £2,285 (>£50,000 to ≤£2 million). Charges are revised for each financial year (https://www2.gov.scot/Topics/marine/Licensing/marine/feestructure). A marine licence is normally granted for 6 years.

Small scale farms with a footprint <10,000 m^2 /1 ha, Marine Scotland will open a 28 day consultation period with its Statutory Consultee. For the application of SAMS’ farms these included: Marine Scotland Science, Scottish National Heritage, The Northern Lighthouse Board, Crown Estate Scotland, The Royal Yachting Association Scotland, the local authority, the Maritime and Coastguard Agency, the UK Hydrographic Office and the Scottish Environmental Protection Agency. Other Consultees may include: The Scottish Environmental Protection Agency, Historic Scotland, The Royal Society for the Protection of Birds, the relevant District Salmon and Fishery Board and nearby Statutory Harbour. The Statutory Consultees may provide comments, to which the applicant must respond (e.g. requests for further information concerning the site or development) and/or will provide guidance (e.g. requirements on navigational lighting requirements from the Northern Lighthouse Board). If the licence is granted, before any infrastructure can be deployed, the applicant must issue: a public newspaper notice, circulate a Notice to Mariners and inform the Admiralty of the development. Determination of an application is 14 weeks, although it can take longer.

Where the farm footprint exceeds 10,000 m^2, Art.4(e) of the Marine Licensing (Pre-application Consultation) (Scotland) Regulations 2013 requires that the applicant carries out a 12 week consultation before the application is made. Under Art.6(2) of the aforementioned act, these must include: the Northern Lighthouse Board, the Maritime and Coastguard Agency, the Scottish Environmental Protection Agency, Scottish Natural Heritage and any delegate for the marine region such as the public authority. It is advisable that additional consultees (listed earlier) are also contacted to prevent the identification of ‘show stopping’ issues during the formal application process. A public pre-application consultation event must also be held. At least 6 weeks prior to the event all consultees under Art 6(2), must be invited to the event, and a public advert made in a local newspaper, providing them a method to respond with comments and inviting them to the

event. Following the event, the applicant must then complete a pre-consultation report following the guidance here:
https://www2.gov.scot/Topics/marine/Licensing/marine/guidance/preappconsult.

Once this report has been approved by MS-LOT, the application form is completed and the fee paid. The process then begins as for a farm with a footprint <1000 m^2 /1 ha with Marine Scotland carrying out a further 28 day consultation. MS-LOT will determine whether it is appropriate to undertake a full Habitats Regulations Assessment under The Conservation (Natural Habitats, & c.) Regulations 1994.

All Public authorities will give their decisions in accordance with the Scotland's NMP adopted in 2015, found here: http://www.gov.scot/Topics/marine/seamanagement/national. Within that document, Chapter 4 contains General Policies of particular relevance to seaweed cultivation.

3.2 Other Legal or Regulatory Requirements

Any seaweed cultivation business must also consider further applicable legislation, relevant to the business model and market. Currently, all existing UK seaweed cultivation businesses cater for the food market. Therefore, all relevant food safety, handling and labelling must be adhered to. This may include European Council Regulations which are directly applicable on all EU states under the European Communities Act 1972 (ECA). On 29th March 2019 the UK will withdraw from the EU (European Union Withdrawal Act 2018) by repealing of the ECA. On this date all existing EU-derived law, including Council regulations, will be incorporated into domestic law (Section 3 (1)).

Amendments to the Wildlife and Countryside Act 1981 under the Wildlife and Natural Environment (Scotland) Act 2011 makes it an offence for a person to plant or cause any plant species to grow outside its native range. This includes species of seaweed which can grow in the marine environment.

3.3 Scottish Governmental Policy on Seaweed Cultivation

The Scottish Government published a Seaweed Cultivation Policy Statement (SCPS) in 2017 following a stakeholder consultation process which started in 2013 (Marine Scotland, 2017). The policy statement recognises that seaweed cultivation, as a form of aquaculture, provides economic opportunities for fragile and rural communities in Scotland. The West Coast of Scotland was specifically identified as a suitable location for seaweed cultivation.

A Strategic Environmental Assessment (SEA) was conducted in 2012 to inform the consultation and the policy statement (Marine Scotland, 2012). The SEA considered climate change, biodiversity, population and human health, water, soil, geology and coastal processes, cultural heritage, landscapes and seascapes, and material assets. These material assets include improving water quality and reducing any adverse impacts of seaweed cultivation in the marine environment and on other users of the sea. Displacement of fishing activity and physical disturbance of fishing grounds, disturbance of fish stocks, navigation and safety of vessels were recognised as potential material considerations as was proximity to military activity. The SEA provides a comprehensive list of all of the strategies, programmes and laws which were taken into account when examining how seaweed might fit within the current regulatory regime for the marine environment (Figure 28).

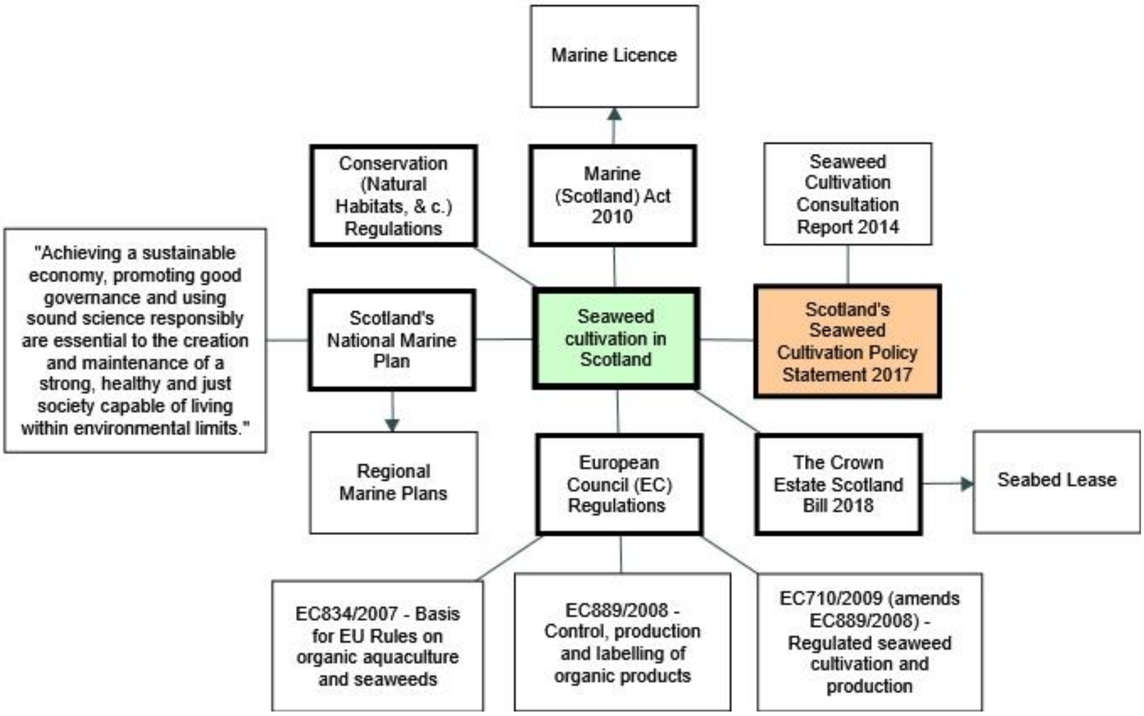


Figure 28. *Summary policy context for seaweed cultivation in Scotland.*

The SCPS sets out seven policies that determine the parameters of support for seaweed cultivation within Scottish waters out to 12 NM. Its purpose is to provide guidance to the industry and public bodies on the type of development which may be given approval.

Policy 1: In principle, the Scottish Government is supportive of small-medium farm seaweed cultivation, subject to regulatory consideration; the General Policies set out in Chapter 4 of Scotland's' National Marine Plan; and any other relevant policies within that Plan. Applications for such seaweed farms should demonstrate that mitigation measures have been considered to prevent adverse environmental impacts, and set out how these will be delivered.

The (SCPS) prescribes that all decisions made about seaweed aquaculture will be taken in accordance with Scotland's NMP and in particular the general principals set out in chapter four of the NMP. These general principals include: a predilection towards sustainable development; economic benefits; social benefits; co-existence; climate change mitigation and adaptation; the historic environment; landscape and seascape; coastal processes and flooding; natural heritage; invasive non-native species; marine litter; water quality and resource, noise; air quality, fairness;

engagement; sound evidence; adaptive management; and cumulative impacts. It also includes a principal for planning alignment between marine activities and the land-based components necessary to conduct the activity (Marine Scotland, 2017). This is of particular importance when considering the distance from the marine cultivation site, to suitable peer/ harbour infrastructure, to onshore processing or drying facilities, and the availability of suitable land (that fits within Town and Country Planning regulations and the Local Development Plan) for these shore-side activities. As such, these considerations should be included in the overall assessment of potential cultivation sites. They may be of particular importance to economic feasibility.

Policy 2: Only species native to the area where seaweed cultivation will take place should be cultivated, to minimise the risk from non-native species.

The policy is very broad and does not take into account changes of the genetic diversity of seaweeds across their native range. I.e. this policy would appear to allow the cultivation of *Saccharina latissima* collected from anywhere within its native range (from Norway, Portugal or Canada) within Scottish waters. SAMS considers that a more restrictive definition is required to safeguard our seaweed resource.

Current scientific evidence on the genetic diversity of seaweeds gives an incomplete picture, however some authors have concluded that seaweed populations can be considered genetically distinct at anywhere between 2-250 km, depending on species, analysis method and geographical location.

Seaweed used for cultivation needs to be sourced from a nearby local population to prevent possible environmental degradation, however, over restriction may limit the industries development. SAMS has a draft policy that advises seedstock should ideally be collected within 2 km of the cultivation site, and from a maximum distance of 50 km. Collection should always be within the same water body, i.e. not transplanting between adjacent lochs. We consider this seedstock distance policy to be good practice until further evidence is gathered; at this time the distance will be revised up or down. Seedstock may be transported to and from hatchery facilities that are not within these spatial limitations. However, a biosecurity assessment should be completed.

Policy 3: Where seaweed is grown for human consumption, cultivators should site farms away from sewage outfalls and other potential sources of pollution.

Scotland currently designated specific areas of the sea for harvesting of shellfish. This regime falls under the Water Environment (Shellfish Water Protected Areas: Environmental Objectives etc.) (Scotland) Regulations 2013 and the Scotland River Basin District (Quality of Shellfish Water Protected Areas) (Scotland) Directions 2015. It is the responsibility of the Scottish Environment Protection Agency to monitor and enforce these regulations. The aim of these regulations is to ensure the water from which the shellfish is harvested is clean enough to provide produce which is safe for human consumption (Scottish Government, 2019). As this is an already established regulation and monitoring regime that fits the requirements of policy 3 of the SCPS, consideration should be given as to whether it is efficient to situate seaweed cultivation sites within shellfish harvesting designated waters.

Policy 4: Equipment used in seaweed cultivation should be fit for purpose to withstand damage from adverse weather conditions.

Mooring and line systems should be developed with or by experts in the field and inspected according to equipment standards and industry recommendations. The marine sector within the Oban and Mull area, and wider Highlands Region is well positioned to provide these services as there are aquaculture and associated service companies which have experience of developing and building mooring systems to suit the parameters of particular sites and for varying purposes (see Table 2 for examples).

Table 2. *Companies offering services required for seaweed cultivation*

Name of Company	Location of Head Office	Indicative services
Inverlussa Marine Services	Craignure, Mull	Mooring system installation, inspection and removal
Kames Fish Farming	Loch Melfort	Mooring system design, installation, inspection and removal
North West Marine	Oban	Mooring grid installation, inspection, and removal
Gael Force Marine	Inverness	Moorings equipment supplier
Aquamoor	Dunstaffnage	Mooring system design, installation and removal

Policy 5: Other marine users and activities should be considered in the siting of farms.

The National Marine Plan interactive (NMPi) available on the Marine Scotland website provides data layers for marine activities undertaken by various industries including: inshore fishing, both static and mobile; leisure and tourism; shellfish harvesting; and aquaculture, both finfish and shellfish. Although this can be a useful tool in narrowing down what sites might be available, consultation with relevant and local marine user groups is essential to understanding the full extent of the use of that area, any impact that seaweed cultivation activities may have on that use, and therefore the level of acceptability of or support for changing the current status of the identified sites.

Although the current consenting regime for seaweed cultivation in Scotland does not go through the Town and Country Planning (Scotland) Act 1997 as all other aquaculture activities do, MS-LOT might require pre-licencing public consultation. Whether public consultation is needed for licencing to proceed can be established through direct enquiry to MS-LOT.

Evidence obtained through numerous studies and across subject areas (marine resource management, aquaculture, renewable energy, forestry, rural development) suggest that effective community engagement, whether mandatory or not, can benefit both the developer and the local community where the activity may take place (Mazur & Curtis, 2008; Devine-Wright, 2009; Hindmarsh, 2012; Geraint & Ferraro, 2016; Moffat *et al*., 2016). It allows a space for deliberation and addressing issues which might not have necessarily been brought up during the scoping and feasibility phase of planning for a development. Going one step further, incorporating local knowledge into development plans can prove valuable. Examples include identifying; valuable/ used fishing grounds, resources available in the local area such as suitable vessels, access to the foreshore through private land, and the expectations that the community has for the developers. This last point is important for gaining social license for the activity.

Social license includes managing expectations, fostering community buy-in, but also building a relationship where there is trust, openness and transparency, so that both the community and the developer feel they can rely on each other to act in a reasonable and responsible manner (Gunningham *et al*., 2004; Prno, 2013, Moffat & Zhang, 2014; Aguilar-Manjarrez *et al*., 2017). This is of particular importance for larger-scale non-local operators, but can also affect smaller-scale local operators. It becomes very obvious when an activity or organisation does not have social license as it often results in obstruction of the activity (e.g. cutting lines and moorings, objections, protests), degradation of reputation (e.g. campaigns), legal arguments, and in some cases, operators have had to cease their activities due to local opposition.

There are four readily identifiable forms of public engagement; informing, involving, consulting, and responding. Table 3 provides some examples of the methods that could be employed for each form. However, they are all relevant to the development and operation of most activities in the marine environment. MS-LOT is likely to require methods outlined in the ‘informing’ and ‘consulting’ side of the table. However, the methods outlined in the ‘involving’, ‘responding’ and ‘empowerment’ sections of the table are geared toward full community engagement and the development of social license for the activity. These are also the areas where community-owned and run operations can excel. Details specific to the Argyll and Bute region are further discussed in Sections 6 and 7.

Table 3. *Example methods for community engagement*

Informing	Involving	Empowering

Consulting	Responding
Public Exhibitions Questionnaires and Surveys One-to-one meetings Public meetings Request for written comments Interviews and focus groups (about community benefits)	Free phone line Monitored email address Timely responses to inquiries Providing information where required

Policy 6: Small-medium size farming is unlikely to be spatially limited, and may be located anywhere in Scotland, subject to agreement and appropriate local conditions.

Small-medium sized farms are classified as 0-50 x 200 m lines. These are the types of farms that are supported by the Scottish Government as they are likely to have limited environmental impacts on the marine environment. However, it was recognised by the SCPS that farms at a larger scale (30-100 x 200 m lines) are likely to have more impacts, both social, economic, and environmental. Benthic shading, spatial, navigational, visual, and coastal issues were identified by the SEA as requiring mitigation measures for larger farms. The lack of evidence relating to the environmental, social and economic interactions of seaweed cultivation in Scotland, means that the SCPS takes the precautionary approach. The current advice is that expansion beyond small-medium scale is unlikely within the immediate to near-term future due to technological, knowledge, and economic constraints. However, if such expansion were to take place, it is likely to require a monitoring and data collection regime to ensure that negative impacts are kept to within legal, spatial, and social parameters. This is currently problematic as these parameters are yet to be defined.

Policy 7: The Scottish Government is supportive of IMTA.

Integrated multi-trophic aquaculture (IMTA) is supported by the Scottish Government for its potential to mitigate negative environmental impacts and create efficient and effective use of space and environmental resources. However, any IMTA set-up is required to adhere to Policies 2-7 of the SCPS. Further, if the IMTA system is incorporated into or works with a finfish aquaculture system, operators are required to adhere to the *Technical Standard for Scottish Finfish Aquaculture (Marine Scotland 2015)* by 2020.

3.4 Non-Governmental Considerations

Consideration should be given to third-party labelling when exploring the feasibility of seaweed cultivation, including economic, environmental, and social aspects. The most well-known certifications for seaweed cultivation include the Soil Associations Organic certification (Soil Association, 2016), and the Aquaculture Stewardship Council and Marine Stewardship Council's (ASC-MSC) scheme for Seaweed (Algae) Standard (ASC-MSC 2017). Eco-labels in particular can draw an increased value for products certified under well-known schemes and shift the burden of proof for following environmental and social regulations onto the operator. However, they can also increase the cost of production and can limit the viability of sites due to certification constraints.

For example, the Soil Association may find it difficult to provide their *Organic* certification for IMTA-grown crops if the adjacent crops (e.g. salmon or trout) are not also certified under the same scheme or are run by different operators (Soil Association, 2016). The ASC-MSC standard includes the three pillars of sustainability in its principals (environmental, social, and economic) and requires operation for at least 12 months before certification (ASC-MSC 2017). The burden of documentation, monitoring and certification can be significant for small-medium operators.

4. SITE SELECTION

The suitability of a particular location for seaweed cultivation is dictated by numerous factors, which can be separated into three groupings:

1. Local environmental conditions e.g. temperature, light, waves salinity, nutrient concentrations, depth;
2. Current uses and socio-economic context e.g. fishing, boat traffic, protected areas; and
3. Operational considerations e.g. landing point, onshore facilities. These will be assessed in a later section.

Cultivation methods used to grow seaweed depend on a large number of considerations. However, similar environmental legislation and policies throughout Europe dictate similar principles common to cultivation practices employed. To make a meaningful assessment of the environmental risks of cultivation activities, certain assumptions have been made regarding the likely standard practices within a European context (Kraan, 2017; Marine Scotland, 2017). These assumptions are as follows:

- Farms will be sited in locations that minimise damage to sensitive environments;
- Reproductive material used to seed lines must be sourced in a way that maintains the genetic diversity of wild stocks;
- The cultivation of non-native species will not be permitted;
- Adequate biosecurity measures to control the spread of disease, parasites and non-native species must be in place;
- The use of fertiliser to encourage growth will not be permitted;
- Seaweed farms should be managed responsible to ensure that infrastructure deployed is well maintained and fit for purpose.

When discussing the likely consequence of environmental changes associated with seaweed cultivation it is assumed that these common principles have been followed when undertaking cultivation projects. However, it should be noted that variation from these assumptions is possible within other European countries currently developing policy governing seaweed cultivation practices. For example, the cultivation of non-native species (e.g. *Undaria pinnatifida*) at locations where this species has already become established.

4.1 Suitability of Inshore Areas in Argyll and Bute as Potential Sites for Seaweed Cultivation

Much is known of the suitability of inshore habitats for seaweed species. Based on the spatial association of abundance data from older diver surveys in the 1980s and 1990s with more recently developed environmental data layers, it has been possible to develop a quantitative understanding of the environmental requirements of the major species, including those being considered for cultivation. Models based on these associations have been used to estimate the size of wild stocks as possible sources of carbon sequestration (Burrows *et al.*, 2014) and for potential harvesting (Burrows *et al.*, 2018). Likely habitats for wild species are mostly determined by broad-scale patterns in environmental variables like light and temperature, combined with local-scale availability of suitable rocky seabed for attachment of plants at depths with sufficient light, whilst the species composition of seaweed communities are influenced by the wave conditions. These indications of suitability of habitat for wild species offer a broad guide to the best placement of seaweed growing areas around Argyll and Bute.

With the constraint of finding rocky seabed for plants removed for seaweed farms, the availability of suitable local conditions for farm operation, maintenance and installation of associated infrastructure is considered here as the primary guide to the suitability of inshore areas. These factors are in turn determined by local wave conditions and depth for anchoring.

4.1.1 The Geographical Context: Broad-Scale (5-100 km) Information from Satellite Data Products

Seaweeds have particular requirements for environmental conditions (light and temperature) that typically vary on broad geographical scales beyond the Argyll and Bute region. Studies of natural coastal communities of macroalgae show that waters rich in phytoplankton around Scotland tend to have reduced species diversity on rocky shores (Burrows *et al.*, 2008), and that kelp beds in such areas are restricted to shallower water (Burrows *et al.*, 2018). This suggests that, although nutrients may promote algal growth, the greater concentration of phytoplankton cells in nutrient-rich water may restrict the light available on the seabed. Suspended sediment particles also restrict the depths to which sufficient light can penetrate to sustain seaweed growth. Sea temperatures are also important for successful growing conditions: too low may reduce rates of growth and too high giving potential stressful conditions during summer. Most species being considered for cultivation here have geographical ranges that extend into much warmer waters, implying that temperatures in Argyll and Bute are likely to be suitable for their production for some decades to come.

Satellite ocean colour sensors provide spectral information that allow estimation of surface chlorophyll due to the presence of phytoplankton (see Annex B for details). Around Scotland (Figure 29), chlorophyll concentrations are higher in coastal waters than further offshore, with major high concentration areas in firths and embayments. For Argyll and Bute, the main feature is the elevated levels (>5 mg/m^3) in the Clyde Sea. Satellite data masks the area immediately adjacent to the coast to avoid mis-attribution of spectral characteristics of land to coastal cells. For 4.5 km-resolution data, this means that estimated chlorophyll concentrations are not available for sea lochs in the inner Clyde and further up the west coast. It is highly likely, however, that inner lochs reflect the phytoplankton concentrations further offshore. Chlorophyll levels also appear to be elevated in the northern part of the Firth of Lorn, but to a lesser extent than in the Clyde Sea.

Suspended sediment in the water appears not to be an issue for the seas around Argyll and Bute, with low concentrations (<0.02 bbp) throughout the region. Phytoplankton may thus have a much greater influence on light penetration in the area.

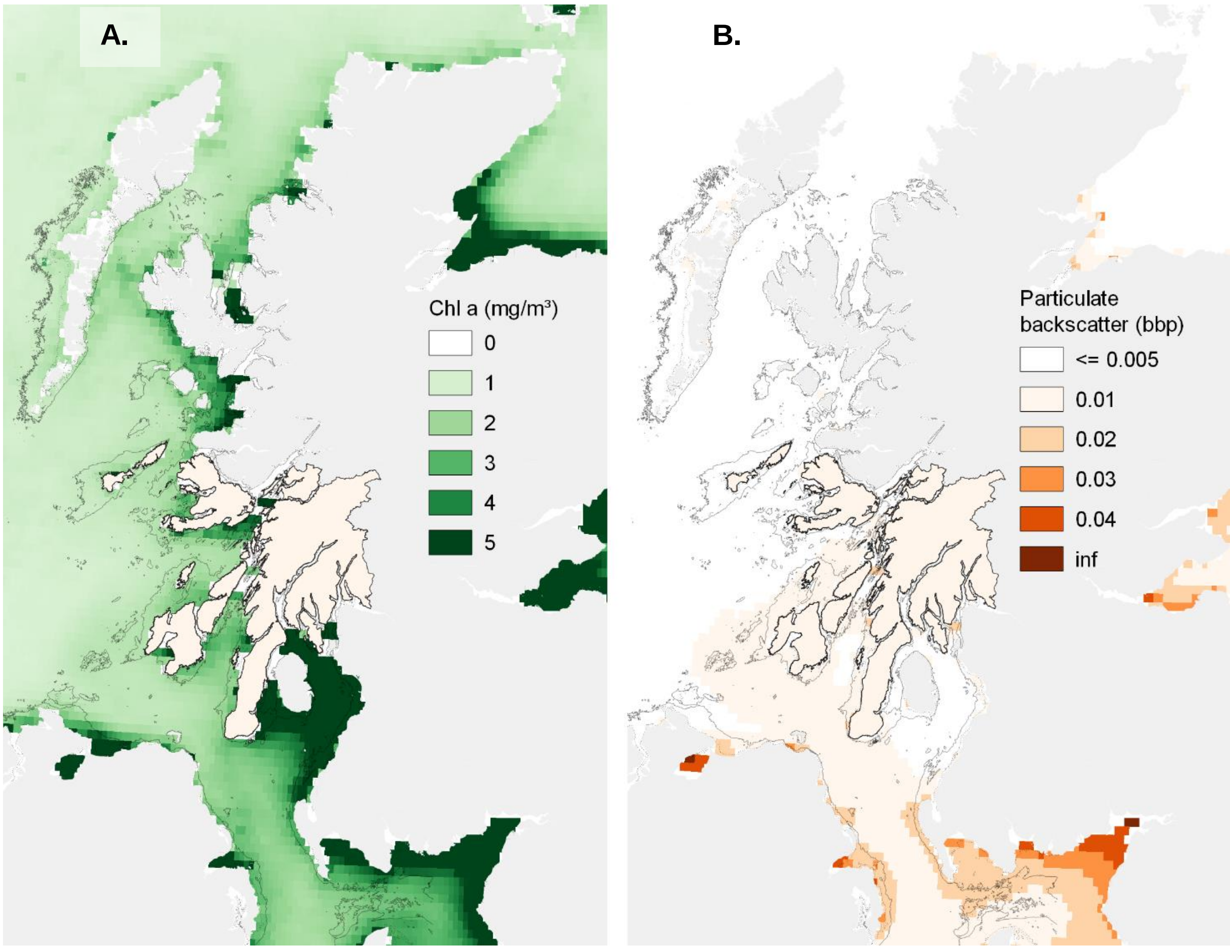


Figure 29. *Patterns of major influences on seaweed growth. Light: satellite-derived estimates of (A) surface chlorophyll* a*, (B) suspended sediment as a contribution to scattering of light at the sea surface.*

Average annual sea surface temperature is also consistent across the region with values around 10.5 °C next to the coast and about 0.5 °C warmer further offshore (Figure 30). Seasonal average temperatures (Figure 30) show the Clyde Sea as being warmer (15-15.5 °C) than the west coast (13.5-14 °C) in the warmest summer months, but with less of a difference in the coldest months of the year (Clyde Sea 7-7.5 °C versus 8-8.5 °C on the west coast). Differences in temperature among sites in Argyll and Bute are likely to have relatively little effect on rates of seaweed production.

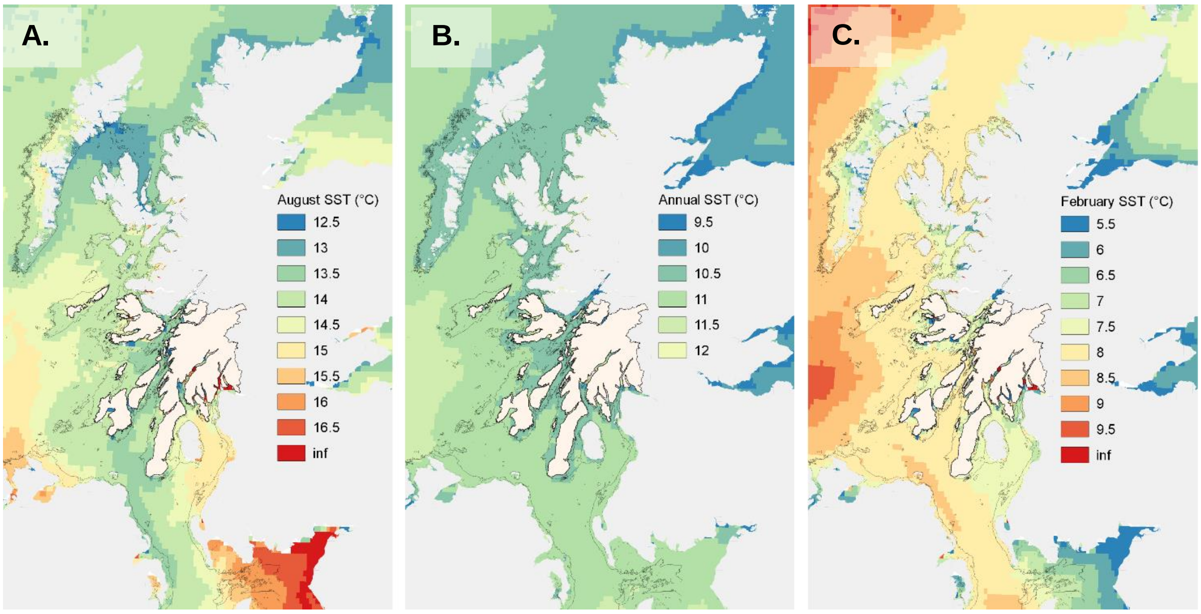


Figure 30. *Patterns of major influences on seaweed growth. Temperature: (A.) average August, (B.) average annual, (C.) average February sea surface temperature (note changes in colour scale).*

4.1.2 Local Geography and the Influence of the Coastline on Regional-Scale Patterns of Suitability

Placement of seaweed farms is likely to be strongly influenced by the need to attach lines for growing plants and other structures to the seabed, and by the need to be able to access the facilities in a wide range of weather conditions. Without well-constrained requirements for specific designs of seaweed farms, the conditions into which other aquaculture operations are currently installed can be taken as a good general guide to where seaweed cultivation may be possible.

Wave and wind conditions will be the main limiting factor for farm operations. While detailed models of physical conditions do exist for the Scottish west coast (Aleynik *et al.*, 2018), simpler metrics can give a good indication of the physical conditions at any one place. "**Wave fetch**" is the distance by sea to the nearest point of land from a specific place on the coastline, in the direction of the wind. Longer distances mean that waves will reach greater heights as the force of the wind acts on the surface of the water. The total distance to the nearest land around points on the coast (summed wave fetch) gives a useful proxy for the degree of wave-exposure and was originally developed to assess the suitability of coasts for particular seaweeds

(Baardseth, 1970). The effectiveness of this index can be slightly improved by weighting such distances by the average speed of the wind and proportional frequency of occurrence in each wind direction (Thomas, 1986). In practice this additional information adds little to the predictive ability of the index in predicting types of biological communities found at coastal sites (Burrows *et al.*, 2008).

GIS systems have enabled the automatic calculation of wave fetch across regions (Burrows, 2012) and bathymetric datasets are widely available (Annex B, Figure 31). The wave fetch layer discriminates sheltered (<2.5), moderately sheltered (2.5-3), moderately exposed (3-3.5) and exposed (>3.5) areas up to 5 km from the coast.

Comparing existing aquaculture installations with these data shows that no shellfish and finfish farms are to be found in highly wave-exposed conditions (>4 wave fetch units, blue areas on Figure 31), with 96% in <3.5 and the majority of installations (56%) in very wave-sheltered conditions (<2.5). Similarly, very few installations (4%) were in locations deeper than 20 m, with most (79%) in 20 m or less. On this basis, optimal conditions for aquaculture installations, and by extension seaweed farms, are considered to be in the depth range of 10-40 m and in areas of wave fetch less than 3.5 units. Overlaying these conditions shows areas that may be provide suitable conditions for seaweed farming (Figure 31).

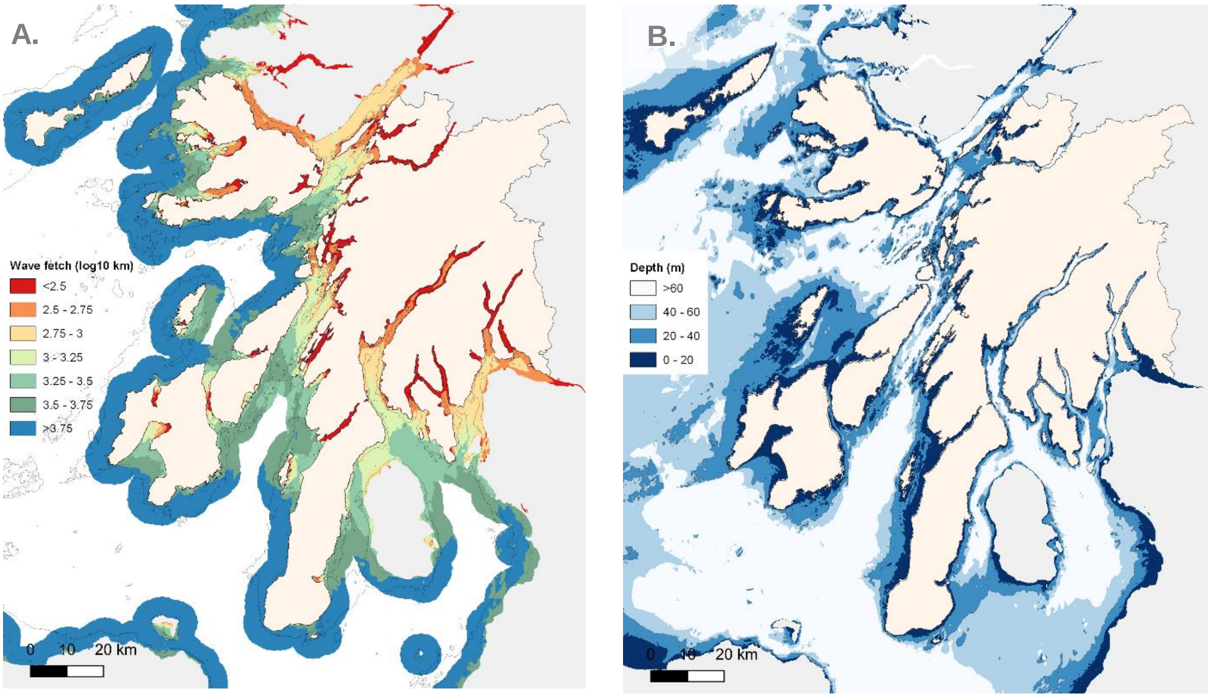


Figure 31. *Wave exposure (A) and depth (B) across coastal waters in Argyll and Bute.*

4.1.3 Water Quality, Nutrients and Salinity

Unlike for depth and wave exposure, maps of nutrient concentrations, salinity and other aspects of water quality including *E. coli* are not available. Nutrients vary considerably with seasons, with the highest levels of nitrogen and phosphorous in winter being rapidly reduced by growth of algae, primarily phytoplankton, in spring (in Loch Creran, for example; Laurent *et al.*, 2006). Nutrients remain low during the summer months and return to higher levels in the autumn as light once again limits phytoplankton growth and increasing winds mix higher levels of nutrients from greater depths. Inputs of nutrients from land runoff can be estimated from river flows, the size of watersheds and the extent and types of activities in the area (agriculture, urban areas). Effects of these inputs on coastal nutrients have been simulated in Scotland using an ecosystem model, the European Regional Seas Ecosystem Model (ERSEM; Heath *et al.*, 2002, Heath *et al.*, 2005). This model emphasises the importance of urban waste water as a source of nitrogen in the Clyde Sea and the contribution of finfish aquaculture as a source of nitrogen on the west coast. Patterns of nitrogen inputs around Argyll and Bute from the ERSEM model (Heath *et al.*, 2005) show higher levels in the Clyde Sea and the Firth of Lorn, consistent with the elevated chlorophyll levels seen in satellite images of the area (Figure 29).

Higher resolution maps of nutrients for the region may be feasible as outputs by linking ecosystem models (ERSEM) to those of water flows in the area (SAMS WestCOMS model) planned for the near future. In the absence of such maps, existing information on sea lochs (the Scottish Sea Lochs Catalogue; Edwards & Sharples, 1986) give a guide to the likely influence of land runoff in enclosed areas of the coast. Two metrics are considered useful. (1) The ratio of supplies of fresh and tidal water, from the volume of rainfall across the watershed of the loch less evaporation, and the tidal volume (calculated from the tidal range in the loch and the areas of the loch at low and high water). High values of this ratio suggest a greater influence of reduced salinity. On this basis Lochs Etive, Caolisport, Riddon and Holy Loch (Figure 32) would be places to avoid for cultivation of seaweed with a reduced tolerance of low salinity events. (2) The ratio of fresh water to the width of the loch is also thought to indicate the potential freshwater influence in lochs and gives a similar pattern to the fresh to tidal water ratio (Annex B, Figure B2) but also implicating Lochs Creran, Feochan, Fyne, Long and Goil as areas where the potential impacts of reduced salinity may be important.

4.1.4 Suitable Areas for Seaweed Aquaculture in Argyll and Bute

Taken together, maps of wave fetch, depth and the potential influence of fresh water inputs on salinity suggest extensive areas with potential for seaweed farming around Argyll and Bute (Figure 32). The upper Firth of Lorn, west Mull, east Colonsay, large parts of the Sound of Jura and to the east of Gigha emerge as candidate locations on the west coast. In the Clyde Sea and Clyde sea lochs, large stretches of the Kintyre coast and Loch Fyne appear as potentially suitable locations, as does the coastal area around Bute. However, the potential influence of increased nutrients, and increased phytoplankton levels on light availability may limit the usefulness of the eastern areas compared with the west coast. Whether the positive influence of higher nutrient levels will outweigh the negative influences of reduced light on production from seaweed farms is an open question, and likely deserving of some limited growth trials.

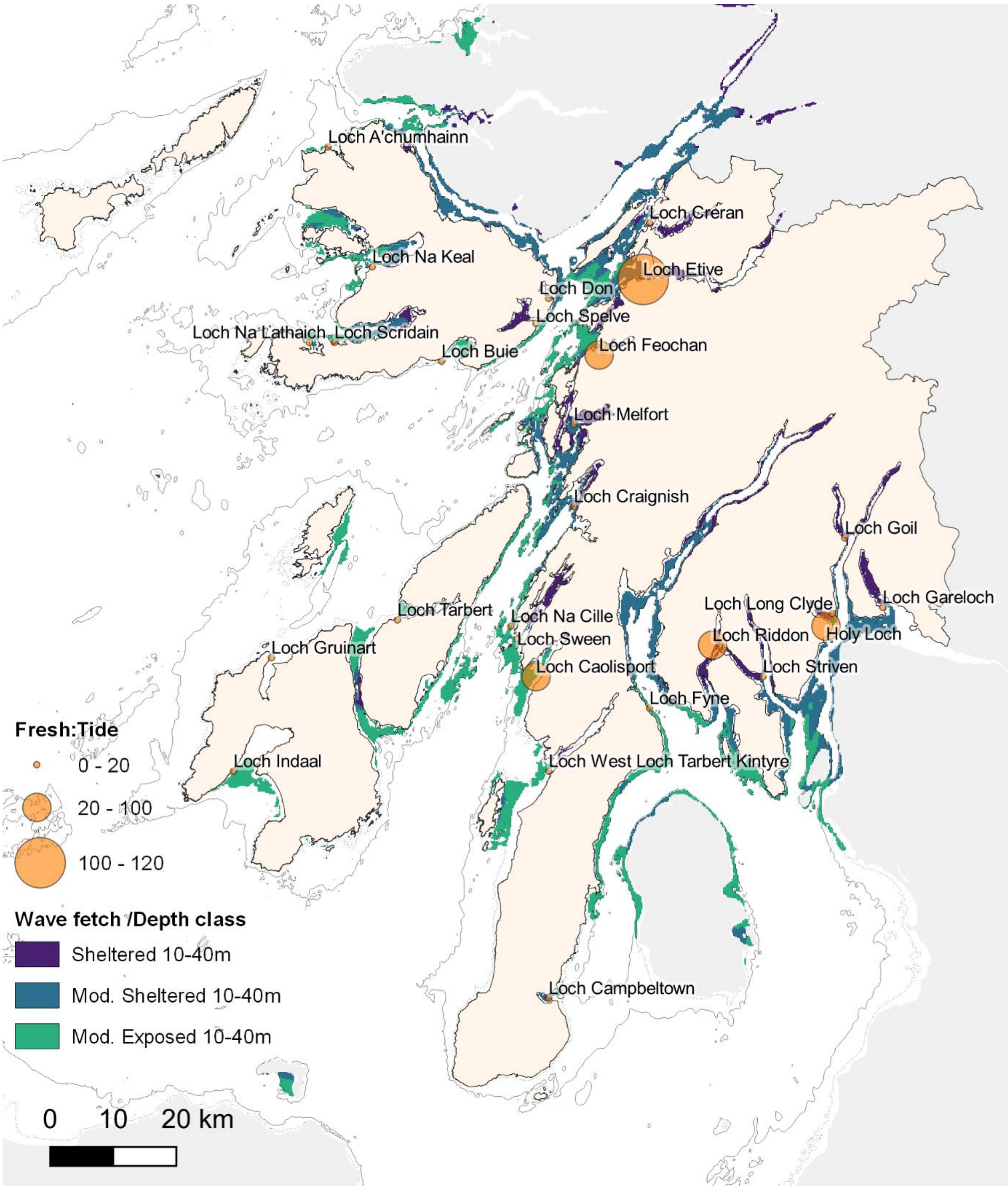


Figure 32. *Areas of coastal Argyll and Bute with suitable combinations of depth (10-40 m) and wave exposure (0-3.5) shaded in blue/green. Likely influence of land runoff on sea loch salinity is shown for each loch in the region by symbols sized to reflect the ratio of freshwater input to tidal exchange.*

4.1.5 Local Geographical Features and Constraints

Decisions to develop seaweed cultivation facilities will ultimately depend on more thorough investigation on the suitability of specific local areas than the above maps can provide. The same datasets on wave fetch and depth resolved at finer scales can help guide where the placement of specific sizes and designs of seaweed farms can “fit” into the landscape of suitability (Figure 33). Using the area around the SAMS near Dunbeg as an example, it can be seen that the SAMS experimental seaweed farm is located in a suitable area, and fits well with the predicted layout of favourable locations.

Finer scale suitability layers should prove useful in considering specific plans for deploying seaweed farms of different sizes and designs.

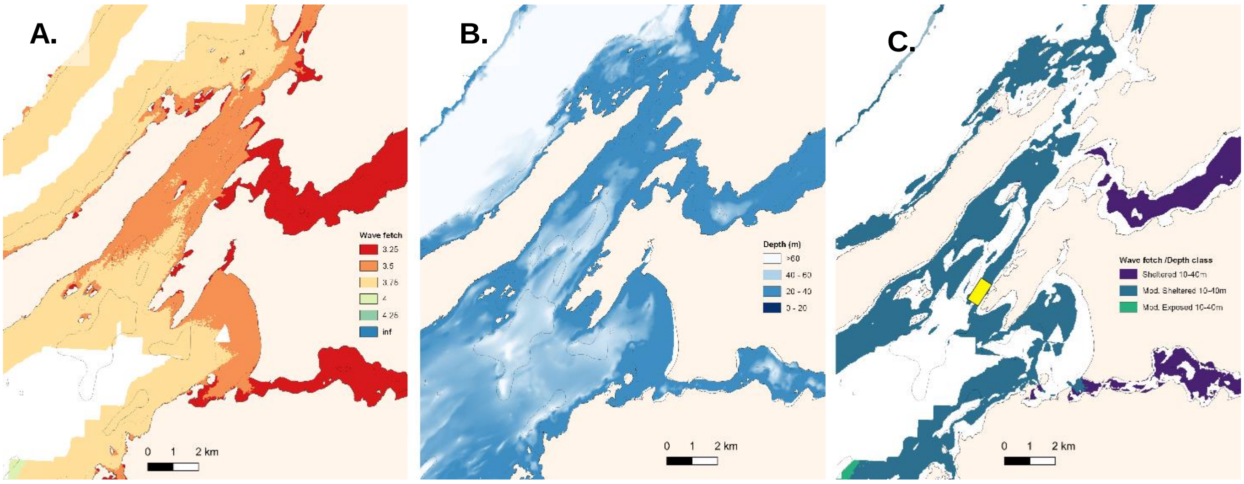


Figure 33. *Local-scale suitability of areas for seaweed cultivation based on high resolution layers for (A) wave fetch, (B) depth, (C) cross classified into regions where wave exposure is suitably low (<3.5) and depth is in the 10-40 m range. The yellow box on the right hand plot shows a 1 x 0.5 km-sized farm placed in a suitable area, approximately corresponding to the current location of SAMS’ experimental seaweed farm.*

4.1.6 Other Considerations

The predictive modelling undertaken as above has examined several variables to identify potentially suitable areas for siting seaweed farms. However, there are a number of additional factors that need to be considered when assessing whether a particular area is suitable for establishing a seaweed farm, such as the presence of protected areas, distance to landing ports etc. Depending on the outlook of the parties looking at ‘optimum’ farm locations, there is likely to be a difference in how much weighting particular spatial data is given with regards to how important it is perceived. Table 4 below outlines the factors that may constrain the suitability of areas of kelp harvesting.

Table 4. *A summary of factors that may constrain the suitability and availability of areas for establishment of seaweed cultivation sites.*

Constraint	Rationale	Notes
Designated natural conservation features	The boundaries of designated conservation areas (e.g. MPAs, SACs, SSSIs, SPAs) may overlap or be adjacent to possible farm sites. Depending on the habitats/ species designation for each area, there may be concern over impacts from seaweed farming on the health of these features	See Section 5.
Maritime Heritage	The presence of wrecks and other maritime cultural heritage features on the seabed may prevent establishment of seaweed farms	
Navigational lanes	Ensuring the safe passage of vessels may mean that seaweed farms may not be possible in certain areas	
Seabed infrastructure	The presence of seabed infrastructure such as telecommunication cables and pipelines may be a barrier to establishing seaweed farms	
Presence of local wild seaweed	Local, healthy population of the target cultivation species will provide a base for collection of fertile material to start cultivars, and will be an indicator of potential growth.	
Commercial fisheries	Areas of other maritime activities may be closed to further developments form other sectors	
Aquaculture	Areas of other maritime activities may be closed to further developments form other sectors	There may be potential opportunities for collaboration / colocation with existing aquaculture sites
Maritime infrastructure	The distance of a farm to potential landing sites may limit the areas where farms can be situated, as may the availability of vessels to carry out farming activities	
Seafloor sediment	The type of sediment underlying the planning seaweed farm site may limit and dictate the type of infrastructure that can be deployed	Areas where the holding power of the sediment may be reduced should be avoided

Constraint	Rationale	Notes
Hill shade	Shadowing caused by local topography may result in areas of the sea receiving less light due to shading effects.	
Pollution/ waste outflow	Location of outflows from sewage networks or industrial plants may make areas unsuitable for farm establishment	Data on point sources of pollutants are held by SEPA in the Scottish Pollution Release Inventory (SPRI)
Recreational use	If areas are popular for other maritime users, then there may be additional objections to siting seaweed farms in specific locations	See Section 6 on social licence
Visual impacts	The visual presence of the seaweed farm on the seascape may raise objections from local communities	See Section 6 on social licence

It should be noted that the table above may not be a comprehensive list of potential constraints; engagement with the Regulators and stakeholders for specific sites may highlight additional areas of concern. Early engagement with these groups is essential to understanding potential constraints that may impact the viability of a given location for successful establishment of a seaweed farm. The spatial mapping of all these constraints is beyond the scope of this current project. Data layers that show the geographical spread for many of these factors can be accessed and downloaded via the Marine Scotland National Marine Plan Interactive website.[4]

[4] https://marinescotland.atkinsgeospatial.com/nmpi/

5. ENVIRONMENTAL IMPACTS

Seaweed cultivation at sea may have a number of positive and negative impacts on the environment. Further research is required to identify environmental impacts to ensure they are mitigated; monitoring the farms and industry as it grows will therefore be crucial. Environmental risks have been detailed in Campbell *et al*. (2019) and cover everything from the absorption of carbon as a positive impact through to biosecurity, which if not handled appropriately can be viewed as a negative impact. This section summarises some of potential environmental impacts associated with seaweed cultivation activities. Having an understanding into how cultivation sites may impact the surrounding marine environment is essential to navigate the consenting process as detailed in Section 3 of this report.

5.1 Absorption of Carbon

Aquaculture of fed species such as finfish contributes carbon dioxide to the global carbon cycle chiefly through reliance on capture fisheries and terrestrial agricultural production (Pelletier *et al*., 2009). In contrast, large-scale aquaculture of non-fed invertebrates and macroalgae can remove large amounts of carbon from the coastal environment (Tang *et al.,* 2011; Hughes *et al*., 2012a, b) and thus represent low carbon food and energy resource if managed in a resource efficient manner. Life Cycle Assessments (LCA) of macroalgae cultivation have concluded that under appropriate management, macroalgae cultivation can be competitive with other alternative biofuel crops (Aitken *et al*., 2014; Ellen *et al.,* 2015*)*, although the use of petrol and diesel in the grow-out phase of production can be the highest energy cost in biofuel production (Alvarado-Morales *et al*., 2013), highlighting the need to improve the mechanisation of cultivation strategies.

The removal of carbon dioxide (CO_2) necessary for photosynthesis in algae is unlikely to lead to any detrimental effects within cultivation sites and surrounding areas. When CO_2 reacts with water it forms a balance of ionic and non-ionic chemical species including free carbon dioxide, carbonic acid, bicarbonate and carbonate, the ratio of which depend on many factors such as temperature and alkalinity. The removal of carbon species will result in its replacement and in an open freely moving water body the effect of carbon removal is likely to be negligible at large scale cultivation operations. Conversely, large bodies of photosynthetic material may absorb enough carbon to increase the pH locally and mitigate impact caused as a result of ocean acidification. For example aiding shellfish calcification downstream. However, no studies to date have demonstrated this affect. Bivalve calcification is often viewed as an atmospheric carbon-sink, but they have been shown to be a net CO_2 source if bivalve respiration is accounted for in models (Morris & Humphreys, 2019).

The effect of cultivation activities on carbon cycling is currently poorly understood, however kelp habitats remain an important source of organic carbon for marine food webs (Burrows *et al.*, 2017; Campbell *et al*., 2019). Additional research will be necessary to further understand the effect of cultivation activities on natural carbon cycling.

5.2 Absorption of Light

Competition for light is important in structuring aquatic algal communities, and this has been demonstrated in the understory algal communities shaded by kelps (Reed & Foster, 1984; Clark *et al*., 2004; Flukes *et al*., 2014; Benes & Carpenter, 2015). Light intensity and its quality is directly altered by the water column itself (Morel, 1978; Platt *et al.,* 1988), as well as indirectly by vegetation (Reed & Foster, 1984; Clark e*t al*., 2004). Therefore, light is often more limited in the marine environment than under terrestrial settings.

The vertical bottom-up structure of giant kelp habitats has been compared to that of terrestrial forests (Dayton & Tegner, 1984). Benthic shading by kelp can affect understory algae, as kelp canopies are capable of reducing light that reaches the benthos by <3% of surface influx (Reed & Foster, 1984). Natural macroalgae communities are limited by available habitat where light conditions are suitable for growth (Burrows, 2012). Cultivated seaweeds habitats differ from natural macroalgal habitats as the crops must be cultivated in surface waters at a depth that optimizes levels of Photosynthetically Active Radiation (PAR). Excessive light can cause photo-oxidative stress, resulting in reduced photosynthetic efficiency (Heinrich *et al*., 2012). Whereas levels of PAR which are suboptimal for the species being cultivated result in low levels of photosynthesis and growth. Cultivation of seaweeds on surface waters may therefor shade underlying habitats containing autotrophic organisms (e.g. pelagic phytoplankton and benthic macroalgae). It is therefore important to understand whether cultivation projects overlap with habitats containing important autotrophic species.

The scaling up of cultivation practices in Europe, may require a modular approach similar to other aquaculture activities. Rocky, shallow (e.g. less than 10 m) water environments are technically challenging places to deploy cultivation systems as there is more potential for breaking waves coupled with poorer mooring possibilities. Deeper (e.g. more than 60 m) water cultivation systems have other technical challenges including longer mooring systems possibly subjected to greater drag forces. Given these considerations it is unlikely that cultivation systems currently being developed in Europe will overlap with shallow habitats supporting productive benthic macroalgae communities. Maerl beds and seagrass communities should be avoided when considering possible sites as such species are afforded a high level of protection in Europe and may be sensitive to shading effects and/or disturbance. However, even these communities are likely to be located in shallower environments than cultivation practices (<20 m). The possibility of negative benthic shading effects should be considered when siting projects. Assuming that cultivation projects will have limited overlap with sensitive benthic environments and avoid habitats that are afforded high levels of protection, cultivation projects are unlikely to cause significant detrimental effects by benthic shading at small-medium and large scales.

Shading has implications for the pelagic environment as cultivation systems will be designed to efficiently absorbed irradiance at the water's surface. Similar shading can be observed in giant kelp communities where floating kelp fronds reduce irradiance sharply in the upper meter of the canopy. Light penetration has been shown to be exponentially related to canopy density, but was higher than predicted from transmission through individual kelp blades due to the heterogeneous distribution of canopy tissue (Gerard, 1984). In well vegetated areas, average irradiances at 1 m water depth were low enough to limit macroalgal photosynthesis even under sunny conditions (Gerard, 1984). Despite the possibility of shading effects on sessile organisms located under cultivation projects, water movement required for efficient nutrient and gas exchange among cultivated species mean that phytoplankton communities will only experience shading for the length of time it takes to travel through the site. Therefore significant shading effects on pelagic communities are highly unlikely at small-medium scales for individual projects but may act cumulatively with other projects.

At large scales, changes to the planktonic communities are possible as phytoplankton will experience increasing level of competition for light from cultivated species. Massive kelp cultivation in Sanggou Bay (Yellow Sea) has been shown to suppress the abundance of phytoplankton during the growing season (Shi *et al*., 2011). Alterations to the quantity and type of primary production can affect trophic flow through affected marine food webs. Ecosystem structure was studied in an area of intense kelp cultivation by using Ecopath to model trophic structure (Wu *et al*., 2016). Kelp cultivation in these areas was shown to have restricted trophic flow into the water column primary production and strengthened the benthic food webs by provision of habitat and food resources directly and indirectly through enhancing detrital biomass (Wu *et al*., 2016).

Water bodies characterized by high levels of seaweed cultivation (large scale and cumulative effects) may contain altered planktonic communities. The consequence of which is not currently understood. Determining the cause of changes to the phytoplankton community is complex and must consider a number of factors including, competition for nutrients (see Section 5.3), increased grazing pressure from epibenthic species (see Section 5.13.3) and altered hydrodynamics (see Section 5.4) in addition to elevated completion for light (this section). Phytoplankton communities are afforded some protection within Europe. This protection is centered primarily on maintaining Good Ecological Status at a regional scale (e.g. MSFD).

Shading effects are likely insufficient to cause significant negative environmental effects at small-medium scales. A focused monitoring program (assessing multiple components of the ecosystem) would be required to determine the potential negative interaction at larger scales.

5.3 Absorption of Nutrients

Depending on their connections with the ocean, coastal seas receive nutrients from a range of natural marine and atmospheric sources (Jickells, 1998; Paerl, 1995; Prospero *et al*., 1996; Baker, 2003). In addition, nutrients are added to the marine environment from anthropogenic sources (e.g. finfish aquaculture, agriculture and urban wastewater) (Smith, 2003). These sources of nutrient fluxes are often related to increasing occurrences of harmful algal blooms (Anderson *et al*., 2008; Heisler *et al*., 2008). Human induced changes to sources and sinks of nutrients can have negative impacts on coastal ecosystems altering local ecology and ecosystem services (Anderson *et al*., 2002; Heisler *et al*., 2008; Shumway, 1990).

Seaweeds in suspended cultivation will remove inorganic nutrients from the marine environment during growth (Kerrison *et al*., 2015; Marinho *et al*., 2015). Positive remedial effects might occur if crops uptake of nutrients are similar in quantity and proportion to those added by anthropogenic activities. However, undesirable effects could occur if cultivation activities result in nutrient concentrations which are below levels required to maintain natural primary productivity. Very large-scale culture of macroalgae will extract commensurate amounts of nutrients from the surrounding water body (Lüning & Pang, 2003) and there are circumstances where growth might become nutrient limited, especially for plants in the interior of the farm as demonstrated at a kelp cultivation site in China (Shi *et al*., 2011). Suspended aquaculture systems used to cultivate seaweed affect local hydrodynamics movements through increasing surface drag (see Section 5.4). Alterations to water flow can affect the carrying capacity of a water body through reducing water exchange necessary for maintaining levels of nutrients required for growth (primarily Dissolved Inorganic Nitrogen) (Shi *et al*., 2011).

The potential impact of large-scale macroalgae farms was assessed using a combined kelp phytoplankton box-model (Aldridge *et al*., 2012). Results suggested a reduction in phytoplankton biomass in the vicinity of production areas (20 km^2, 20 t/ha dry weight production) with >10% reduction in chlorophyll concentration at distances in excess of 7.5 km compared to no-farm controls. The same authors also employed a hydrodynamically driven ecosystem model to simulate the spatial effects of nutrients taken up by a very large kelp farm (112 km^2) in the North Sea at various stocking densities. The results showed significant effects only at the highest stocking densities and the authors conclude that at realistic stocking densities effects would be classified as “marginal significant” for large scale operations (Aldridge *et al.,* 2012).

Currently, observed site production and stocking density values within Europe are generally lower than that reported in Aldridge *et al*. (2012) and those observed in China where nutrient depletion has been observed. China produces up to 18 t of dry kelp per hectare in the most productive areas (Aldridge *et al*., 2012). Assuming similar water content between kelp species this equates to approximately 151 wet T/ha (10,000 m^2) (*Saccharina latissimia* dry/fresh = 0.12). Although it should be noted that dry vs fresh weight ratios vary with species and throughout the growing season (Broch & Slagstad, 2012; Peteiro & Freire, 2013b). The grid systems employed in China use either vertical or horizontal (preferred) rope raft culture methods that are densely packed (stocking density estimated at approximately 0.66 linear meters of growing line per meter squared of cultivation area) (Shi *et al*., 2011). Reported growing systems in Europe are generally less space efficient (Peteiro & Freire, 2013b). Using the above figure, China is therefor able to produce 22.9 kg per liner meter of growing line to achieve a biomass of 151 t/ha. To achieve similar yields within European sites, growing systems must firstly increase the density of growing substrates whilst increasing yields per liner meter of substrate from current levels [average 9.1 kg wet weight per linear meter (Seghetta *et al*., 2016)]. For example, observed biomass of *Saccharina latissima* cultivated at a site in Spain produced approximately 16 kg m^{-1} on growing lines in one season (Peteiro & Freire, 2013b). Production at this site was 4.7 t/ha dry weight (4 m spacing between lines). To achieve greater stocking densities more effective cultivation infrastructure will need to be developed whilst mitigating competition nutrients and other resources such as light.

Aldridge *et al.* (2012) modelled the nitrogen requirements for a hypothetical large scale farm (20 km^2) in the Clyde estuary in Scotland and showed that it would extract approximately 480 t of nitrogen from the marine environment per year if operated at the target site production value of 20 t/ha dry weight. This represents a significant reduction in local nitrogen resources.

At the time of a typical harvest the nitrogen content of dry material is approximately 0.012% (Broch & Slagstad, 2012). Therefore, assuming future productivity per liner m of line would be equivalent to those observed in China (22.9 kg m^{-1} per line). Small-medium scale operations (<50 200 m lines) would produce up to 229 t of biomass (27 t dry weight) and extract 0.33 t of nitrogen. At these scales, negative environmental effects from diminished nitrogen resources are highly unlikely assuming cultivation practices are located in areas with modest to high nitrogen resources required for growth.

Anthropogenic sources of nitrogen inputs to marine environments are large. For example, it is estimated that 7500 t of nitrogen was released as a result of the Scottish salmon farming industry in 2010 (Aldridge *et al*., 2012). If careful consideration is given to siting cultivation projects to ensure that the local carrying capacity of the environments is not unduly stressed, negative environmental effect caused by local depletion of nitrogen resources may be avoided. At larger regional scales, cultivation projects may contribute substantially to remediation of excess nitrogen if co-located in suitable areas of high anthropogenic nitrogen input. However, the timing of effluent release and uptake, dispersal characteristics of the site along with an understanding of nitrogen recycling in the environment are needed to better understand nitrogen mass balance within each water body used to cultivate seaweed. Such information would support a more holistic approach to managing nutrient levels and allow for the scaling of cultivation projects to the characteristics of the surrounding water body. However, presently the seaweed biomass required to remove the nitrogen effluent from a typical salmon farm is much greater than small-medium seaweed farm operations can produce (approximately 1,000 wet t; Broch & Slagstad, 2012). Negative interactions associated with cultivation infrastructure (e.g. reduced flow) may diminish the overall benefits of such an approach. Therefore, the development of coupled hydrodynamical-biological models at industry realistic stocking densities will support future developments by providing more clarity to estimated sources and sinks of nitrogen.

Competition between cultivated algae and phytoplankton can be expected at time intervals in the production cycle where algae growth is rapid and natural renewal of nitrogen resources is affected by altered water exchange. Where projects are large scale and intense (i.e. high stocking density), depletion of phytoplankton communities could have negative implications for some species in affected areas. The feasibility of large-scale cultivation projects will require site-specific modelling and monitoring work to ensure a strong evidence-base to determine the trade-offs and interactions associated with large-scale macroalgae production versus protecting, conserving and enhancing biodiversity.

5.4 Absorption of Kinetic Energy (Wave and Tide)

Seaweed farms require water flow to encourage growth. However, farms will absorb and deflect tidal and wave energy altering flow conditions in connected habitats (including local geomorphology at large scales). How cultivation structures alter coastal hydrology will be an important factor in determining the ecological implications for cultivation projects at different scales. Relevant observational studies on wild kelp beds have confirmed that standing crops of wild kelp dampen natural currents and cause microclimates within the canopy (Jackson & Winant, 1983), reducing average current speed to a third of the surrounding average. In some cases this microclimate can occur vertically beyond the extent of kelp fronds (Andersen *et al*., 1996). Natural kelp beds are anchored in the seabed and therefore have a bottom-up effect on currents rather than the predominantly surface impacting structure of suspended kelp culture. It has also been noted that cultivated kelp experience increased water motion as part of a suspended structure, thus increasing the rates of nutrient uptake (Neushul *et al*., 1992).

Flow rates along the open channels and within Sanggou Bay- a large-scale Chinese kelp cultivation site- were simulated using a two-dimensional vertically averaged model (Grant & Bacher, 2001). In this model, increased seabed friction simulated the presence of aquaculture structures. By increasing the drag coefficient of the seabed to simulate the frictional effects of suspended aquaculture structures, flow along the open channels within the farm was reduced by 20%, and within cultivation areas was reduced by 54%. In addition to reduced current speeds, the vertical structure of tidal currents in Sanggou Bay is predicted to be affected by the strengthening of a surface boundary layer created by suspended cultivation systems (Fan *et al*., 2009). This is supported by recent field measurements of tidal currents taken in Sanggou Bay, which demonstrated clear vertical structure of the observed tidal currents (Zeng *et al*., 2015). Observations showed that although total tidal exchange volume remains unchanged, there is a reduction in tidal flow at the surface where kelp is suspended, which causes the maximum flow point to occur below the suspended kelp fronds. Therefore, the depth between the lower limits of suspended kelp and the seabed will determine where the maximum velocity point will occur as a result of the increased drag by kelp at the surface. This could have implications for the benthic and pelagic habitats below, which would experience altered flow dynamics resulting from changes to surface boundary conditions.

Alterations to water flow can affect the cultivation carrying capacity of a water body through potential reduction in water exchange necessary for maintaining levels of nutrients required for growth (Shi *et al*., 2011). Furthermore, changes to the natural dynamics of water exchange and renewal may also have profound implications for associated marine ecosystems.

Careful consideration must be given to the sitting of cultivation projects in areas and at times (peak biomass would cause greatest friction coefficients) where alterations of natural hydrodynamics could result in significant changes to marine chemistry, sediment transport and associated biological communities. Risk will most likely increase with larger scale projects and siting in areas important for water exchange (e.g. the entrance to enclosed water bodies). Assuming sites are well located, negative environmental effects are unlikely at small to medium scales. However, the assessment of potential negative environmental effects must be made on a case-by-case basis and incorporate cumulative effects of other marine projects. Therefore, it is not possible to make general predicts regarding the extent and consequences of altered local and regional hydrodynamics.

It is unrealistic that small- medium scale operations will have the resources to carry out a worthwhile assessment of the extent of changes to local hydrodynamics as well as the consequence to associated habitats. Furthermore there size and location may make these projects relatively low risk. A strategic siting and modelling approach may be required to ensure licencing authorities are able to make informed decisions about the consequence of large scale projects as well as cumulative level assessment of smaller co-located projects.

5.5 Creation of Noise

Cultivation projects will result in a localised increase in vessel traffic and machinery required for site activities including installation, maintenance, seeding and harvesting. The extent that cultivation projects will elevated local noise above background is currently unknown but it can be considered proportionate to the scale of operations.

Vessel engines are a source of anthropogenic noise and negative environmental effects (e.g. habitat displacement and barrier effects) could be observed where noise produced causes a behavioural response that contributes to local or regional population decline. However, the sensitivity of marine species to small vessel noise is likely to be low assuming the location of the project has been considered with respect to sensitive features (e.g. avoiding protected seal hall-out areas) (Southall *et al*., 2008; De Robertis & Handegard, 2013).

At small-medium scales, the increase in magnitude of vessel traffic associated with project is likely to be small and therefore unlikely to cause significant ecological changes assuming cultivation project are sited away from sensitive features. Elevated risk associated with larger cultivation projects will require additional consideration. Such considerations can be made during the consenting process.

5.6 Release of Reproductive Material

The increasing requirement for marine based commodities, along with the difficulty in sustainably exploiting natural populations is driving a shift from humans as fishers of the marine environment to cultivators (Valero *et al*., 2017). The domestication of wild seaweed cultivars will be an unavoidable consequence of large scale seaweed cultivation practices (Valero *et al*., 2017). Cultivated seaweeds will most likely be characterised by a human imposed shift in their reproductive strategy (e.g. from outcrossing to self-fertilising and from sexual reproduction to vegetative reproduction) introducing genetic bottle-necks that may narrow the genetic diversity of cultivated stands potentially making them more susceptible to environmental changes and disease as observed in vegetatively propagated domesticates of *Gracilaria* (Leonardi *et al*., 2006; Valero *et al*., 2017). Studies have resulted in the production of improved varieties of kelps with respect to commercially valuable traits (e.g. stipe length, frond length, width and thickness, and iodine content) (Liu *et al*., 2014; Li *et al*., 2016) and these have been widely applied in cultivation activities (Li *et al.,* 2007, 2008, 2016). The consequences of the producing cultivars that are genetically and phenotypically distinct from natural populations is unknown but there is the potential for significant environmental effects through both direct competition with wild populations and hybridisation with natural stands (Halling *et al*., 2012; Loureiro *et al*., 2015; Valero *et al*., 2017).

Cultivation practices supported by the supply of locally sourced cultivars still have the potential to genetically depress natural populations through so called “crop-to-wild” gene flow (Loureiro *et al*., 2015; Valero *et al*., 2017). Therefore breeders must focus on strategies that optimise the selection of desirable traits whilst maintaining the domesticates evolutionally potential to ensure good yield in variable environmental conditions whilst reducing impacts on natural populations (Valero *et al*., 2017). Such a task will require a paradigm shift in breading strategies which will demand the maintenance of a large number of locally sourced cultivars phenotypically optimised to ensure suitable genetic variance.

The effect of gene flow from cultivated seaweed species is as yet unknown and focussed monitoring and research activities will be required to understand both variability in natural populations and the effect of cultivated domesticates on surrounding population fitness and associated ecosystems (Loureiro *et al.,* 2015; Valero *et al.,* 2017).

The widespread production of sterile cultivars may be technically feasible and should be considered as an important step to mitigating the effects of gene depression and introducing locally absent cultivars and species (see Section 2.4) (Loureiro *et al*., 2015). Furthermore the establishment of national seed banks which are responsible for maintaining a high health status of seedstock has been recommended to ensure that breading strategies are appropriate to reduce negative environmental effects (Cottier-Cook *et al*., 2016).

5.7 Release of Particulate Organic Matter

Organic matter (OM) can be released by macroalgae as either Particulate or Dissolved Organic Matter (POM and DOM respectively). In a kelp cultivation site POM tends to result from wave action and decomposition of plant tissue matter and is often suspended in the water column before settlement on the benthos (Ren *et al*., 2014). Natural kelp beds already play an important role in providing organic matter to the coastal ecosystem (Duggins *et al*., 1990; Leclerc *et al*., 2013; Steneck *et al*., 2002), and can provide significant organic matter beyond the immediate kelp habitat (Harrold *et al*., 1998; Wada & Hama, 2013). Similarly, POM is lost from seaweed cultivation sites, and at an existing large-scale site (several km^2) in Sanggou Bay in China, three modes of kelp tissue loss can be observed; fall-off from kelps, where the holdfast becomes detached or there is a break in the stipe; break-off, where there is a clear break leaving part of the blade and distal erosion which occurs at the edges and tip of the kelp blade where there is continual decay (Zhang *et al.,* 2011). The proportions of each mode of loss at this site is dependent on seasonality and stage of growth. Fall-off occurs early in the grow-out season (Jan-Feb), and can result in an estimated 4.2% of overall loss of kelp from sampled long lines. Break-off peaks later in the grow-out season (Jun-Jul) resulting in approximately 4.5% of overall loss. Distal erosion increased through earlier growth months (January to April), remaining high in the months after and equated to 91.5% of loss at the sampled cultivation site. These observations suggest the loss of POM on a large-scale cultivation site will predominantly be lost from the cultivation site as smaller tissue fragments and loss will increase with increasing biomass. These observations were taken from a shallow and sheltered production site, and as the most likely sites for production in Europe will be in moderately sheltered sea loch/fjord sites, there is a risk that in the event of increased disturbance at sites due to storms etc. that POM loss through fall-off early in the season, and break-offs later in the season could be more significant. During harvest, the crop will be subject to damage by removal from the long lines could drop off. Hand harvesting inevitably results in some kelps being torn and broken as long lines are hauled on-board small vessels. It is recommended that the siting of cultivation sites takes into consideration the dilution of such POM loss, and should be considered in models used in similar aquaculture processes which generate POM (i.e. DEPOMOD for finfish cage farming, (Cromey *et al*., 2002) and be adapted for seaweed cultivation systems.

The destination of POM from each site will depend on local hydrodynamics and biomass growth at the site as is observed in fish farm sites (Mayor *et al*., 2010), which have been observed to be 'localised' and 'episodic' (Brager *et al*., 2015). The impacts of benthic organic enrichment have been studied extensively for fish and shellfish sites, from the immediate changes in biogeochemical processes (Chamberlain, 2001; Holmer *et al*., 2005), to the subsequent changes in fauna where species abundance and richness can be reduced with proximity to finfish cage sites (Hamoutene *et al*., 2015). As previously mentioned these impacts are currently minimised and monitored using hydrodynamic models, which could be adapted to seaweed cultivation sites provided that baseline data is collected to validate model adaptations. The contribution to carbon sequestration (blue carbon) that cultivation losses could make when buried in sediments or exported into the deep sea needs to be assessed in a cultivation context (Krause-Jensen & Duarte, 2016; Duarte *et al*., 2017). However, continuing trends towards increased seaweed aquaculture could still provide a significant contribution to climate change mitigation and adaptation though providing additional benefits through carbon capture (estimate 1,500 tons CO_2 km^{-2} $year^{-1}$), animal feed supplements that reduce levels of methane production, substituting synthetic fertilizers and mitigating coastal erosion through absorbing wave energy (Duarte *et al*., 2017).

To assess the magnitude and severity of environmental changes associated with POM further research is required to benchmark models against observations (e.g. auto-DEPOMOD and MEROMOD are used to set the boundaries of an allowable zone of effect). In order to minimise POM loss due to storm events early in the grow-out period, it is recommended that research into methods that reduce this risk are conducted. In addition, further research is required to develop methods for cultivation and harvest which reduce the loss of biomass due to damage. Maximising crop biomass is also in the interest of the cultivator.

5.8 Release of Dissolved Organic Matter (DOM)

A large proportion of DOM is observed as photosynthates in the seaweed tissue, and these photosynthates are released by kelps as DOM into the water column (Khailov & Burlakova, 1969; Sieburth, 1969; Fankboner & de Burgh, 1977; Abdullah & Fredriksen, 2004; Wada *et al*., 2007; Hulatt *et al*., 2009). This released DOM is thought to be a complex mixture of mainly carbohydrates which can enter the oceanic Dissolved Organic Carbon (DOC) pool (Wada *et al*., 2007). It is unknown whether this release occurs as a passive or active function in the tissue. However, it has been suggested that exudation is increased during time of greater growth rate when excess photosynthates are assimilated (Abdullah & Fredriksen, 2004).

Seaweed exudate studies have mainly identified and monitored the carbon content of exudates as Dissolved Organic Carbon (DOC). A proportion of this released DOC is thought to be refractory DOC (rDOC), due to the long turnover rates in coastal seawater (Wada *et al*., 2008). This suggests that a proportion of kelp exudates may be resistant to biological breakdown, and refractory carbon components (DOC) will join the oceanic carbon pool which is estimated to be 4000-6000 years old (Bauer & Druffel, 1998). As carbon entering this pool from seaweed cultivation will effectively be sequestered (Hughes *et al*., 2012), the potential environmental consequences of the refractory portion of seaweed exudates may be less direct. Although, it has been observed that exudates may alter light attenuation due to their colorimetric nature (Hulatt *et al*., 2009).

The alternate fraction of these carbohydrate rich exudates will be bioavailable to microplankton such as bacterioplankton and phytoplankton, and could be rapidly utilised by marine microbes (Azam *et al*., 1983). Dissolved substrates are important intermediates in the rapid cycling of bioactive compounds by bacterioplankton in the "microbial loop" (Azam *et al*., 1983). Therefore, high concentrations of bioavailable exudates have the potential to alter the balance and composition of the local microbial assemblages. However, the extent and significance of this change would likely be negligible for small-medium cultivation projects when compared against naturally occurring level of bioactive compounds from other sources. The scale and wider ecological implications of large scale projects are currently unknown, and will be dependent on the hydrodynamics and seasonality of the site.

As part of the management process of offshore aquaculture sites, wastes produced by farms are now widely modelled to allow for predictive management of the environmental impacts (Weise *et al*., 2009; Cromey *et al*., 2002, 2012). Unlike finfish aquaculture, seaweed cultivation requires almost no additions of carbon to the marine environment and losses will be minimised through attempts to optimise production. Therefore it is unlikely that any concerning changes will be apparent at small-medium scale. However, it is recommended that further research investigating the magnitude and consequences of redirecting of carbon through larger scale operations be undertaken.

5.9 Release of Dissolved Inorganic Matter (DIM)

Despite the importance of inorganic nutrients in the growth of suspended macroalgae, very little is known about the composition of the dissolved inorganic nutrients within large-scale cultivation areas (Abdullah & Fredriksen, 2014). Therefore, understanding the net uptake and release of dissolved inorganic matter by cultivated macroalgae species is necessary to make predictions concerning the significance of environmental change associated with cultivation projects.

5.10 Biosecurity

The creation of biosecurity plans are crucial at each step of the cultivation process to protect the environment. The release of non-local or non-native species or diseases could have detrimental effects on the local of ecosystem and be a breach of local regulations. Species or diseases could transfer to the local environment if seeding lines with seaweed is collected from a different region or environment (e.g. two different sea lochs) or if wastewater from the hatchery is released without treatment into the environment may also be a potential source of escape. For more information on hatchery biosecurity see Section 2.5.2. The implementation of a biosecurity protocol also contributes to increased quality assurance through cleaning standards and assurance of stock provenance.

Further research is urgently needed on the genetic structure of wild seaweed populations, but studies so far indicate populations will vary on local scales in the 10s of kilometres and between different water bodies such as different sea lochs.

5.10.1 Disease and Pest Management

The prevalence of disease and pests affecting aquaculture production worldwide is a major global concern (Kim *et al*., 2014; Stentiford *et al*., 2017). This issue is intensified by a reduction in genetic diversity associated with the domestication of wild seaweed species making crops more susceptible to abiotic stressors, diseases and parasites (Valero *et al*., 2017). Unlike terrestrial agriculture, a reduction of genetic diversity of open sea cultivated marine species in favour of a few selected traits cannot be supported by the use of pesticides and fertilisers to support growth. Cultivated stands will likely experience a large reduction in yield where disease and pest are prevalent and may also act a reservoir for disease which could impact natural populations (Loureiro *et al*., 2015; Valero *et al*., 2017). For example, carrageenophyte (*Kappaphycus*) producing countries have seen a dramatic decline in production following rising sea water temperatures which cause bleaching of the thallus making cultivated individuals more susceptible to infection from viruses and bacteria (Vairappan *et al*., 2008). Protocols that mitigate crop losses are often rudimentary (centred on removal of affected crops) and chemical treatments are known to reduce crop quality (Loureiro *et al*., 2015). Knowledge regarding the epidemiology of seaweed pathogens is very poor and in many cases pathogens responsible for disease are difficult to identify and study using current microbial methods (Gachon *et al.,* 2010). Further investigation is required to inform appropriate mitigation measures and prevent significant ecological impacts. Mandatory biosecurity planning will ensure actions are taken that mitigate risk where practical and will benefit all stakeholders. Mitigation measures hinge on developing and enhancing biosecurity programs (see below) through capacity building (Cottier-Cook *et al*., 2016). This must include training in quarantine procedures and farm management practices to enhance biosecurity measures. In addition to the development of diagnostic techniques to rapidly detect disease to inform management practices. Finally, farmed species should be bred to ensure sufficient genetic diversity and the promotion of disease resistance.

5.10.2 Non-Native Species

Non-Native Species (NNS) are classified as those organisms that have been intentionally or unintentionally introduced outside their native range as a consequence of human activity. NNS may cause ecological damage to the receiving environments and may also be associated with economic losses within affected marine industries, including aquaculture (Pimentel *et al*., 2001). Once established, species that threaten biodiversity and/or cause economic damage are referred to as 'Invasive' (INNS). It is widely accepted that once a NNS has been introduced to a new environment, is it very challenging, and in the majority of cases practically unfeasible, to eradicate. Therefore, preventing the introduction of new NNS and restricting the likelihood of secondary introductions is typical of marine management policies in Europe.

The relatively recent boom in aquaculture has often contributed to the global spread of non-native marine organisms (Naylor *et al*., 2001). Despite the largely sedentary life history of macroalgae, they have often been the subject of invasive spread through aquaculture (Fletcher and Farrell, 1999). The deliberate introduction of reproductively active species in addition to the creation of possible introduction pathways greatly increases the chance for spread and establishment of NNS (Schaffelke *et al*., 2006). In a global assessment of invasive macroalgae introductions, 121 of 223 introductions were derived from aquaculture either through macroalgae cultivation or indirectly through shellfish farming (Williams & Smith, 2007). In some areas, the introduction of non-native species through abandoned cultivation efforts has had a serious effect on local ecosystems and the economy. In Hawaii, a number of invasive species have been recorded within reef areas and have caused phase-shifts from coral to algae (Smith *et al*., 2002). In particular, the previously cultivated red alga *Gracilaria salicornia* subsequently colonised the prized reefs of Waikiki (Smith *et al*., 2004).

In 1983 the brown kelp *U. pinnatifida* native to Asia was introduced to the French Atlantic coast for commercial cultivation (Kraan, 2017). Although it was believed that it could not reproduce, it soon became established in the local environment and since then has spread widely, typically becoming the dominant biofouling species on artificial substrate (Fletcher & Farrell, 1999). To date this species is farmed along the Brittany coast where it has been established for 33 years (Kraan, 2017). Allowing farming of this species in the North Atlantic undermines efforts to control the spread of this species within other parts of Europe adopting a more precautionary approach to controlling the spread on NNS in general.

Despite a poor history of species introductions associated with the global seaweed production practices the introduction of species outside their native range are unlikely to be permitted within a European context. However, it is important that there is more clarity regarding which target cultivation species are permitted throughout Europe to ensure comparable approaches across neighbouring countries. Furthermore, if growing cultivars present in the "local" environment is considered best practice in the future, consideration of what "local" means in different countries for different species is necessary as the degree of genetic variation varies greatly between countries. For example, some seaweed species are characterised by low intra-specific genetic diversity in the northern extent of their range due to founder effects of range expansion caused by global climate change (Assis *et al*., 2016).

Artificial structures used to cultivate seaweed may provide a novel habitat that will favour the establishment of NNS (Glasby *et al*., 2007; Mineur *et al.,* 2012). In addition the presence of vectors (e.g. movement of biofouling associated with vessels and other structures) must be managed in such a way as to reduce the potential risk that cultivation activities will result in the spread on NNS. Although the risk of unintentional introductions can never be managed fully, cultivation practices are unlikely to cause significant environmental effects assuming native species are cultivated and operations are managed to reduce the potential risks of introducing NNS.

European countries typically restrict the introduction of NNS to avoid documented negative environmental consequences (e.g. Regulation no. 708/2007; no. 535/2008 and Regulation (EC) no. 506/2008 amending Annex IV to Council Regulation (EC) no. 708/2007). Current advice in the UK now promotes the use of Biosecurity Planning as a way to assess and manage any potential risks created by marine activities that may lead to the accidental introduction and/or spread of NNS (Cook *et al.,* 2014). The principle component of any Biosecurity Plan is a record of the actions that will be taken in order to minimise the spread of NNS. Biosecurity Plans can be combined with disease management plans to increase efficiency. The ultimate goal of a Biosecurity Plan is to help an organisation manage its activities to minimise the risk of introducing disease, pests and NNS out-with their natural range. A Biosecurity Plan may consist of four principle stages.

- A Description of the Activity: A description of the planned activities to aid the Risk Assessment and subsequent review of the Biosecurity Plan;
- Risk Assessment: Identification of the level of risk associated with the planned activities (as described in Step 1);
- Resulting Actions: List of steps to be followed after consideration of the recommendations above;
- Contingency Plan: What should be done when a problem is identified.

A Biosecurity Plan should contain a set of instructions for personnel to follow including the production of a Contingency Plan (as part of the Resulting Actions) and plays a very important role in protecting both the environment and the cultivated stock.

5.11 Entanglement

Incidental mortality of marine megafauna (e.g. marine mammals, marine turtles, sharks, rays and large bony fish) caused by entanglement in subsurface mooring lines and fishing gears, is a significant conservation problem throughout the world (Benjamins *et al*., 2014). The development of seaweed cultivation will create similar structures that may pose a threat to marine mega fauna through entanglement. There are a number of risk factors which are associated with a greater likelihood of entanglement. These include, moorings and lines that have low tension, poor visibility leading to reduced avoidance and moorings and components that are unable to resist the forces of an encounter (e.g. grey seal [≈0.1 KN] or Minke whale [≈16 KN]) (Benjamins *et al*., 2014). The use of nets to cultivate algae may pose a significant threat of entanglement to both small and large megafauna species. The diving behaviour of marine mammal puts them at risk of interaction with cultivation activities as it may not be possible to avoid infrastructure when resurfacing for air.

The true extent of entanglement risk from well-established marine activities is poorly understood. A study into the cause of death of 422 cetacean carcases across England and Wales found that entanglement of megafauna in fishing gear (by-catch) was the principle cause of death in most cases (Kirkwood *et al*., 1997). The global estimate of marine mammal by-catch is approximately 600,000 animals and entanglement with stationary gear is more likely where nets and pot-type gear are used (Read *et al*., 2006). The contribution that an emerging cultivation industry might have to mortality within megafauna populations is currently not know. Entanglement of animals cannot be ruled out, even when assuming cultivation practices will be managed to reduce the likelihood of entanglement. Small-medium scale cultivation projects pose a similar threat of entanglement to many existing aquaculture activities. Entanglement events (disregarding bycatch in fishing gear) are reported infrequently but the true extent of mortality caused by this these activities is currently unknown. Large scale cultivation projects may have to consider the risk of entanglement carefully due to the comparatively large amount of infrastructure required for such projects.

Many marine megafauna species are slow-growing and have low reproductive rates and are commonly afforded a high level of protection within many European countries. Therefore, entanglement-related injuries and mortalities a critical conservation problem. Siting of cultivation activities is a crucial consideration to avoid negative environmental interactions There is limited evidence to suggest whether marine mammals and other megafauna will avoid or be attracted to cultivation activities and any responses are likely to be location- and species-specific. Cultivation activities may enhance foraging opportunities for some species (see Section 5.13). However, such an interaction, although positive, could lead to increased risk of entanglement if poorly managed. Larger species of marine mammals are often observed with greater frequency in deeper offshore areas (Ried *et al*., 2003). Therefore, cultivation activities that are sited in deeper offshore areas may have to take extra precautions to avoid entanglement.

5.12 Release of Plastics into the Marine Environment

Farm infrastructure is usually made of plastic ropes and buoys, as it is a durable material suitable for marine use. This creates a risk of releasing plastic pollution into the environment. When a farm is (a) constructed effectively to secure materials in place and prevent wear points; and (b) managed correctly, including regular site inspection, there should be no risk of ropes detaching and drifting away from the site. The connection of buoys tend to be a focus for wear, and so there is a risk of buoy loss from the site, particularly during storm events.

Plastic ropes are made from filament strands, and so their wear will cause the release of small plastic particulates/ fibres (mm-cm scale). Furthermore, these strands will be broken down into smaller fragments over time in the marine environment, becoming a source of microplastic (MP) pollution. Seaweed growing on plastic rope is not thought to degrade the rope structure (i.e. seaweed growth itself does not appear to cause the detachment of plastic fibres). Nevertheless, the release of plastics from seaweed cultivation has never been quantified. In the absence of evidence, technologies that minimise the loss of plastic and promoting the development of new biodegradable natural fibres such as bioplastics should be encouraged where possible.

Seaweeds may offer the opportunity to mitigate against MPs. Gutow *et al*. (2016) demonstrated the ability of *Fucus vesiculosus* to accumulate MP particles on the surface of their thallus via adhesion to the polysaccharide rich material they naturally excrete (Wotton, 2004; Gutow *et al*. 2016). This seaweed exudate is released as a response to environmental stress, e.g. desiccation, and the majority of macroalgae produce these types of compounds (Wotton, 2004). Gutow *et al*. (2016) also found that MPs were found to bind strongly to the surface of the seaweed e.g. *F. vesiculosus*, if they were allowed to dry onto the seaweed's surface, washing of the seaweed did not result in MP removal from the biomass. MPs may also accumulate through an electrostatic charge interaction between the MPs and the cellulose which is a major component of the algal cell wall (Gutow *et al*., 2016), providing further evidence of the potential of seaweed biomass to provide bioremediation of MPs from the marine environment.

5.13 Artificial Habitat Creation

Cultivation projects will replace existing habitats with novel man-made habitats by virtue of physical and biological changes associated with suspended cultivation infrastructure. Habitats created may be characterised by: increased complexity including the physical presence of the structure itself; the addition of hard artificial substrate; pulses of seaweed growth consistent with growing cycles; as well as altered physical and chemical properties of the surrounding water. Some of the potential changes associated with this type of habitat creation are summarised below, focussing on three species groups (plankton, benthic species and epifauna and megafauna species).

5.13.1 Plankton

There have been several studies on the interactions between macroalgae and microalgae. While a range of species-specific effects have been observed, some major interactions have been identified. Generally, in both low and high nutrient situations, macroalga can affect the composition of the phytoplankton assemblages through competition for nutrient resources (Fong *et al*., 1993). In addition, macroalgae can inhibit microalgal growth both through allelopathy (Jeong *et al*., 2000; Nan *et al*., 2004, 2008), and through shading of the water column by dense macroalgal canopies (Borchers & Field, 1981). More complex interactions are also observed to occur as a result of nutrient competition, and resource availability. For example when nutrients are low, macroalgae may outcompete microalgae by utilising previously stored nutrients in tissues (Lüning & Pang, 2003; Solidoro *et al*., 1995). Under high nutrient concentrations micro algae may benefit from having a larger surface to volume ratio than microalgae (Fong *et al*., 1993). A recent study on picoplankton abundance in an Integrated Multi-trophic Aquaculture (IMTA) site in Sanggou Bay, China, observed abundance to be lower within the kelp cultivation area than the shellfish area (Zhao *et al*., 2016), and attributed changes in abundance and distribution largely to grazing by protists, as opposed to nutrients in the shellfish area. This indicates that more complex interactions are occurring in large-scale kelp cultivation sites, and is reflected in emerging work from wild kelp forests. A study on the microbial community structure and function within a kelp forest on Vancouver Island, Canada (Clasen & Shurin, 2015), found that total bacteria abundance was increased within the kelp forest, bacteria were subject to increased viral-mediated mortality, and effects correlated with kelp forest size. Therefore, kelp cultivation sites may have a similar impact on microplankton assemblage and function, and will be determined not only by the size of the cultivation site, but also through a cascade of indirect effects which will require further investigation.

5.13.2 Benthic Species

As with finfish (Cromey *et al.,* 2012) and shellfish (Chamberlain, 2001; Weise *et al*., 2009) farming, large areas of suspended kelp cultivation may affect sedimentation patterns on the seabed around the farm which will likely have effects on benthic community structure and function unless its scale and intensity are well matched to the level of dispersion of the site. During the kelp growth cycle, biomass is lost through removal of entire individuals (during winter storms), breakage in sections of the thalli (summer) and erosion of distal tissue (peaking in late spring) (Zhang *et al*., 2011), thus inputs of organic matter (OM) will be strongly seasonal. Depending on its buoyancy/settling velocity, lost plant tissue may deposit on the seabed and stimulate benthic microbial metabolism and affect macrobenthic community structure. The scale of impact will be related to the distance that solid material lost from the farm and advected (directly and after any resuspension) before its remineralisation is complete, with low settling-velocity fragments travelling long distances. The biogeochemical consequences of large amounts of material decomposing in depositional areas might include sedimentary anoxia and hypoxia in bottom waters, together with enhanced sediment nutrient fluxes, particularly in areas with long water residence times.

A study on organic enrichment of a submarine canyon (153-454 m) from macroalgal drift adjacent to a natural *Macrocystis pyrifera* bed estimated that 20% of drift ‘parcels’ observed from an ROV were composed of kelp tissue (Harrold *et al*., 1998). At a distance of 9 km away from standing crops, a continental shelf habitat (87-357 m) was observed to have few drift parcels, however, of those observed 50% were composed of kelp particles. This emphasises the importance of understanding OM drift from large-scale kelp culture and how it may impact deeper benthic environments.

In an area of extensive macroalgal cultivation in China (Sanggou Bay), benthic species diversity was low in general but greater in summer and autumn than in spring and winter (Zhang *et al*., 2009). The Norwegian Modelling-Ongrowing fish farms-Monitoring (MOM) system (Hansen *et al*., 2001) was used to assess impacts with all stations being categorised as either 1 or 2 – both “good”. The impact of long-term large-scale aquaculture of shellfish and seaweed on the benthic environment was considered to be low (Zhang *et al*., 2009). In a recent study of a fish/kelp polyculture system in Sandu Bay, East China Sea, sedimentary acid volatile sulphide content under kelp culture was high (1.22 mg/g dw) in comparison to a control station (0.14 mg/g dw), but slightly lower than that recorded at a fish farm station (1.4 mg/g dw) (Zhou, 2012). Both the fish farm and kelp farm stations (separated by ca. 10 km) showed reduced benthic biodiversity compared to a control station with diversity generally slightly lower over the 9 month sampling period but with considerable temporal variation. The differences between impacted and reference sites were small, however, the levels of impact were high (Pearson & Black, 2001) at all stations indicating a generally degraded ecosystem.

As cultivated kelp is held in suspension and harvested frequently, it is likely to facilitate a different benthic assemblage than that associated with natural kelp beds. It might be expected that the interactions with the benthos will be linked to changes in physical conditions such as; light intensity, sedimentation rates, interactions with planktonic species and interstitial flow rates between cultivated kelps. Duggins *et al.* (1990) studied the influence of kelp canopies on benthic recruitment and found that sedimentation, flow and reduced light intensity played significant but varied roles in the recruitment success across a range of taxa exerting bottom-up influences on the benthic assemblage composition. As sedimentation, flow and light are likely to be altered where kelp is hung from the surface in suspension, impacts on the benthos will be an important consideration in site selection.

5.13.3 Epifauna and Megafauna Species

Sub-littoral kelps are recognised as important habitats for a range of invertebrate macrofauna (Christie *et al*., 2009; Norderhaug & Christie, 2011) which in turn supports a diverse ichthyofaunal assemblage (Norderhaug *et al*., 2005). Indeed one of the arguments for cultivation rather than wild harvest relates to the ecological importance of kelp forests. Large-scale intensive cultivation of kelps is likely to provide additional habitat for a range of invertebrate and fish species, and kelp farms will naturally act as fish aggregating devices, as do shellfish (Davenport *et al.,* 2003) and finfish farms (Dempster *et al*., 2009, 2011).

Extensive information exists on macroinvertebrates which live in close association with wild kelps (Ojeda & Santelices, 1984; Dayton, 1985; Anderson *et al*., 1997; Duggins *et al*., 1990; Hepburn & Hurd, 2005; Christie *et al*., 2009; Zahn *et al*., 2016). This relationship is thought to be a result of increased habitat size and complexity in addition to increased filter feeding opportunities as a result of heterogeneity in flow rate (Christie *et al.,* 2009). Holdfast communities of *Laminaria digitata* cultivated in Ireland provided habitat for a different and more diverse macroinvertebrate assemblage compared to wild kelp beds although both had similar volumes of epifauna (Walls *et al*., 2016). This could provide an additional positive impact on the local ecosystem through ecosystem services provided by kelp holdfasts including increased food resources for grazers and shelter, traits that are also associated with wild kelp beds. However, the positive impact that kelps have on macroinvertebrates may be overpowered by the negative impacts from physical abrasion by the canopy (Connell, 2003). Therefore, as kelp cultivation occurs in increasingly energetic coastal marine environment, a decreasing trend in the benefit suspended kelp provides the macroinvertebrate community may be observed and should be considered.

There is limited evidence to suggest whether marine mammals and other megafauna will avoid or be attracted to cultivation activities and any responses are likely to be location- and species-specific. The consequence of displacement effects from cultivated area will depend on the relative importance of that habitat for foraging and migration and breading (Tim M. Markowitz et al., 2004). Avoidance of poorly sited operations may interfere with and restrict normal migration routes leading to ‘barrier effects’. Conversely, cultivation activities may enhance foraging opportunities for some species. Larger transient megafauna including adult female bottlenose dolphins (*Tursiops* sp.) in Shark Bay Western Australia, avoid shellfish culture longlines (Watsoncapps & Mann, 2005), and Dusky dolphins (*Lagenorhynchus obscurus*) in New Zealand generally avoid areas occupied by longline structures (Markowitz *et al*., 2004). This is most probably due to the lines and buoys restricting the normal movement of schooling fish and making it difficult for the dolphins to carry out fish aggregation manoeuvres (Wiirsig & Gailey, 2002). Thus it is possible that there will be some exclusion of cetaceans from large-scale macroalgal farms. In contrast, common seals are observed around mussel long lines (Roycroft *et al*., 2004) and the diet of young common seals can include crustaceans and fish (Anderson, 1990), which are known to occupy macroalgal habitats. In most jurisdictions, marine mammals are protected and there is a statutory responsibility to consider interactions when planning marine developments. Little is known about the interactions of marine mammals with large-scale macroalgal farms but, given their potential to attract fish, these may present marine mammals with foraging opportunities.

It is likely that many bird species would benefit from increased foraging opportunities around kelp farms and research will be required to understand this interaction and to optimise management practices with respect to birds. However, in contrast to both finfish farms (Nemtzov & Olsvig-Whittaker, 2003) and shellfish farms (Zydelis *et al*., 2008) where birds may be a nuisance, kelp farms are unlikely to be negatively impacted by birds and it is probable that they would become useful habitat for several species by providing foraging opportunities.

5.14 Key Knowledge Gaps

There is currently insufficient knowledge of the potential consequences of seaweed cultivation activities on the marine environment, and how that may vary with respect to the scale of operations, legislative obligations, and standard environmental practices. However, it is possible to identify several important impact pathways. Many of these can be considered a high priority requiring further investigation as the industry grows. High priority impact pathways include:

- **Absorption and release of dissolved nutrients.** There is a need to understand the effect of cultivation projects on dissolved nutrient dynamics both in terms of positive and negative effects on natural populations of micro- and macro-algae but also to avoid siting project in areas were competition with other developers may lead to elevated environmental impacts and lower yields;
- **Genetic depression of natural populations of algae.** The effect of gene flow from cultivated seaweed species is as yet unknown and focussed monitoring and research activities will be required to understand both variability in natural populations and the effect of cultivated domesticates on surrounding population fitness and associated ecosystems;
- **The facilitation of algae diseases.** Diseases caused by a variety of agents are wide-spread throughout most aquaculture and agricultural industries. This should remain a high priority for the industry;
- **Changes to the physical environment through the alteration of hydrodynamic regimes.** The development of large scale farms may have significant and far

reaching effects on current and wave regimes in addition to altering the levels of suspended sediments. Modelling and model validation through in situ measurements will be required to ascertain the extent and significance of these changes;

- **Predicting scale dependant environmental changes to habitats both within the farm and surrounding areas.** Cultivation projects are likely to provide habitat for a range of species whilst simultaneously changing many of the prevailing physical and chemical conditions.

Arguably other impact pathways could be deemed as demanding less attention in terms of specific targeted research and can be manage in part by standard mitigation options. Impact pathways included pollution, entanglement, shading effects and noise created by elevated vessel movement. For all of these impact pathways good site selection to avoid sensitive areas, farm design and farm management are important considerations in the mitigation of risk. Furthermore, monitoring by growers may be undertaken for some impact pathways through the mandatory reporting of issues encountered within cultivation sites (e.g. entanglement events or infrastructure loss) to establish whether there is indeed a cause for concern. Furthermore biosecurity planning for controlling the prevalence of disease and non-native species could also be considered standard mitigation practice.

Predicting scale dependant environmental changes to habitats both within the farm and surrounding areas should be given careful consideration. Discerning which environmental changes are effects (encompassing both positive and negative) and which should be considered as significant impacts will require more investigation ensuring that complex interactions are resolved through focussed research efforts spanning a range of geographical locations. Separate to this, many of the monitoring options available to growers and environmental managers centre around ecosystem monitoring and it is important to consider what components should be monitored and why. For example, if maintaining the composition and abundance of existing benthic communities is considered important, what metrics should be used to describe change, what scale is important when considering change, and what is an acceptable level of change.

For many impact pathways the siting of cultivation projects in areas which minimise risk to sensitive marine features will be a critical step in minimising the overall environmental cost, if any, of proposed projects. Many impact pathways created by the absorption of nutrients (namely nitrogen) or through alteration of the hydrodynamic conditions can be modelled to select areas that promote the absorption of anthropogenic sources of nitrogen whilst selecting productive sites for cultivation projects. Therefore, the development of models used to determine the ‘carrying capacity’ of coastal areas will allow for the minimisation of negative environmental interactions whilst supporting the industry to develop successful cultivation projects.

5.15 Sustainability

While seaweed farming has been practiced in Asia for over 50 years it is still a nascent industry in Europe. The development of a new industry gives the opportunity to learn from good practices in other industries to ensure its long-term sustainability. Currently, seaweed is viewed as an environmentally sustainable product, which is one of the products strongest selling points, protecting the credibility and environmental standard of seaweed cultivation can therefore be beneficial for the whole industry's future success. Similarly, the interaction between the industry and local communities where seaweed is grown and processed is important to gather local support and a social licence. For more information on social licence see Section 6. Seaweed farms need to comply with local planning regulations and meet restrictions my local and national marine plans, in Scotland the National Marine Plan sets out a framework for aquaculture developments.

5.15.1 Certification

Food safety certification standards are generally a voluntary set of rules set by an impartial third party which assures products meet set standards. The standards can provide quality assurance, traceability as well as assurances of food safety and environmental sustainability. Certification can help businesses improve practices and may provide a competitive advantage. No standards are currently required by law for seaweed products, however, several certifications are available. It is important to note that not all certification schemes are legitimate or backed up by an impartial third party.

Seaweed produced in European member states can be certified organic under EU regulations 834/2007 Reg 710/2009 for farmed seaweed and under EC Directive 2006/113/EC for wild harvested seaweed. In the UK there are eight approved control bodies that can inspect and certify organic produce. The Soil Association has created a standard specific to seaweed (Table 5). Globally 21% of the seaweed market is certified organic, but in Europe over 85% of seaweed produced (farmed and cultivated) is certified as organic as they fetch higher prices (Organic Monitor, 2014).

Other certifications are available food products, but not many seaweed specific certifications exist. The Aquaculture Stewardship Council and Marine Stewardship have created a joint Seaweed Standard which focuses on minimising environmental impacts and promoting socially responsible practices, this standard is available to companies globally. So far one company has been certified with the standard and one is under assessment. In Maine, the Maine Seaweed Exchange offers certification for seaweed products and a certified skills course for seaweed farmers. As the seaweed industry grows new certifications are likely to be created alongside regulations to manage the standards in the industry. It is important to note that come certifications may not be supported by rigorous controls or managed by independent third party organisations.

Table 5. *Seaweed standards and certifications*

Standard	Organisation	Area	Scope	Focus
ASC-MSC Seaweed Standard	Aquaculture Stewardship Council & Marine Stewardship Council	Global	Wild harvested Farmed	Requires harvesting and farming practices to minimise environmental impact and be socially responsible.
Soil Association Organic Seaweed standard	Soil Association	UK	Wild harvested Farmed	Certifies seaweed harvested or farmed using organic management systems.
MSE Seaweed Farmer Certification	Maine Seaweed Exchange	Canada	Farmed seaweed Seaweed farmers	Certifies products and offers training courses

6. SOCIAL LICENCE

This section briefly outlines the value of working towards social license for marine activities. The meaning of this concept is described in some detail before presenting the relevance of it for the emergent seaweed cultivation industry in Europe, Scotland and then in Argyll and Bute County.

6.1 Defining Social License

Social license is an industry-coined term (Gehman *et al*., 2017*)* relating to the relationship that industries, which have social and environmental costs, have with local communities (Gunningham *et al.,* 2004; Moffat *et al*., 2016). It is described as an on-going relationship between a host community and an organisation (industry, Non-governmental organisation (NGO), business) where the organisation is held to certain standards set by the community, in exchange for acceptance by the community (Rooney *et al*., 2014). It was first established in the mining industry and used to explain how some mines were able to operate unobstructed or supported by local communities, whereas others were met with opposition at every corner (Boutililier & Thomson, 2011; Franks *et al*., 2014).

Social license can empower communities to seek benefits from industries that have social and environmental costs and provides a framework for industries to go beyond legal compliance with environmental and social regulations. These costs can include the use of space, environmental and visual degradation, and disruptions to normal social life.

6.2 Social License and the Aquaculture Industry

Recent years have seen the idea of social license gain traction in the aquaculture industry, with it becoming a popular theory in trying to understand and improve relationships between host communities, aquaculture activities and operators (Leith *et al.*, 2014; Marine Scotland, 2014; FAO, 2016; Hughes & Black, 2016). For example, a study in New Zealand documented how transactional relationships (e.g. company pays for new roads in exchange for support) were not as successful at gaining the approval of local communities as relationships that were more emotional and immersive (e.g. workers live locally and become part of the community) (Baines & Edwards, 2018).

A Brief History of Social License

Social licence to operate first came into use in the mining and hydrocarbon sector in the early 1990's (Rooney *et al*., 2014)

At that time, social attitudes were changing towards the natural environment (Moffat *et al*., 2016). The Convention on Biological Diversity and the United Nations Framework Convention on Climate Change both of 1992 are just two examples of an international shift in how humans value the environment.

This heightened sensitivity to the social and environmental impacts of industry resulted in more cases of local action against new or existing developments (Moffat *et al*., 2016). These actions caused (and still cause) frequent stoppages or delays in many resource-use projects across the globe (Boutililier & Thomson, 2011).

The cost of such delays and the staff time required to handle community-company conflict can run into the $billions per year. A review of the Australian Stock Market identified AUS$21.4 billion in negative share-price impact due to "environmental, social, and governance risks" associated with lack of social license (Boutililier & Thomson, 2011).

The concept of Social Licence to Operate was developed to help industry identify the causes of and prevent costly conflicts with local communities (Rooney *et al*., 2014). Since its inception, it has been applied to energy, farming and agriculture, pulp and paper manufacturing, forestry, and aquaculture (Boutililier & Thomson, 2011).

Having or not having social license can impact the viability of an operation through informal processes such as word of mouth, and formal processes such as legislation and voluntary industry standards (Gunningham *et al*., 2004). Social license can increase or decrease the reputational capital of an industry through e.g. campaigns, legislative action, or word of mouth. This can affect the base cost of producing the commodity, and/or the end price of the commodity for consumers. Of particular importance to seaweed cultivation, there is evidence showing that not having social license can reduce the availability of space for expanding and/ or developing new sites (Strand & Bergh, 2017). More detail on how social license interacts with markets can be found in Section 7.

6.3 How Social License Interacts with Industry Operations

Campaigns (from the perspective of social license) are normally used by communities or Non-governmental organisations (NGOs) to create awareness around the negative impacts of an industry. For example, a local NGO in West Scotland ran a campaign against a proposal for a finfish farm. It involved distributing fliers, creating petitions, and promoting a website through social media and word of mouth. The result was that over 800 people objected to the fish farm planning application an ongoing discontent around operations in the area (Strand & Bergh, 2017; Billing, 2018).

Word of mouth is a grassroots level of communication within and between communities and is one of the ways that communities receive information about the activities of a company or organisation. If a company does not have people living in local communities who naturally feed into the information that is circulated via word of mouth, it can cause speculation and feelings of mistrust and resistance to operations (Baines & Edwards, 2018).

Legislative action can involve communities, individuals or NGO's taking companies or planning authorities to court over their conduct or in the case of the latter, failure to follow proper procedures (Billing, 2018). Legal opposition is costly due to direct legal charges, loss of time, and reputational damage (Gunningham *et al*., 2004).

The three examples given above – campaigns, word of mouth (local information networks), and legislative action – can affect the formal regulation of industry by the state and company policy. Company policy can include the use of voluntary standards set within the company itself but also those set by industry groups such as ISO 14001 (an international environmental framework for businesses), or third parties such as the Marine Conservation Society. These mechanisms can influence the operations of a company and the cost of production, it might also influence the end cost of the product, both positively and negatively. For example, Organic certified products can sometimes be sold for more than the cost of undertaking the certification, however certification is a costly process and can add to business risk (Gambelli *et al*., 2019).

Both voluntary standards and regulation are important factor in social license for aquaculture as voluntary standards can be influenced by local communities and the general public, but these standards can also influence how communities interact with the operator. Operator polices which actively promote transparent and open relationships with local communities have been shown to contribute to social license (Moffat & Zhang, 2014)

Social license interacts with the formal process of law for many reasons, the significant one being that companies can try to gain social license as a strategy for managing 'social risk' – the risk of society campaigning against them. In other words, if they are able to gain social license then environmental regulatory changes are more likely to be voluntary, less strict and/or cheaper to implement than the cost of enforced regulation (Moffat & Zhang, 2014; Gehman *et al.,* 2017).

From the perspective of communities (Figure 34), social license is a way to push industries to better comply with environmental regulation, improve the social and environmental conditions in their localities, and to go beyond regulatory environmental and social compliance (Gunningham *et al*., 2004). It is a way for local communities to hold companies accountable for their actions, as well as a way for companies to make their operations legitimate and acceptable in the eyes of local communities (Gehman *et al*., 2017).

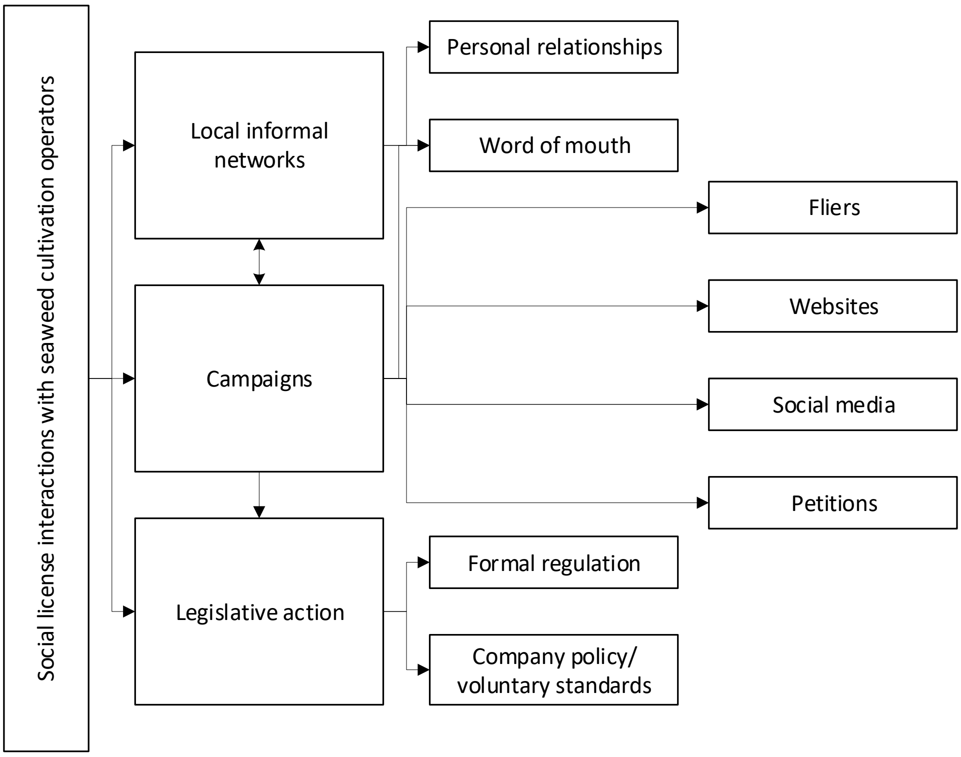


***Figure 34**. Depiction of how lack of social license for seaweed cultivation can interact with local communities.*

6.4 The Case for Social License in Sustainable Management of Aquaculture

Environmental and social conservation is sometimes seen as antagonistic to industrial development. For example, a proposal to expand a finfish farm in a Marine Protected Area on the coast of the island of Arran, Scotland, was met with opposition from the local community. The justification for the opposition was based on the reasoning that the expansion would degrade the environment – the very reason for having an MPA (Community of Arran Seabed Trust, 2016).

The basic case for social license for aquaculture is to empower communities to engage with industry so that the social and environmental costs of the industrial activity are not solely born by local communities. However, we prefer to see social license in the context of the evolution of social-ecological systems – where humans are seen as part of the natural environmental system rather than as isolated entity (Berkes *et al*., 1998).

Industrial development is necessary to provide people with employment, income, goods and services, but it must take place in a way that is socially and environmentally sustainable. Positive engagement of communities in the industrial development process, and the build-up of trust between citizens and industry representatives, helps to ensure that social license can be gained.

The processes relating to acquisition of social license can be seen as amongst those recommended by the 'Ecosystem Approach' of the Convention of Biological Diversity (Secretariat of the Convention on Biological Diversity,2004), concisely expressed in the three principles of the FAO's 'Ecosystem Approach to Aquaculture' (Aguilar-Manjarrez *et al*., 2017). As such, aquaculture should;

- Be developed in the context of ecosystem functions and services (including biodiversity) with no degradation of these beyond their resilience;
- Improve human well-being with equity for all relevant stakeholders (e.g. access rights and fair share of income);
- Be developed in the context of other sectors, policies and goals, as appropriate.

6.5 Going beyond Compliance (the Importance of Social License for Seaweed Cultivation)

In order to be economically efficient, commercial seaweed farms will need to be/ are spatially extensive (for most species). However, there is more to gaining social license than resolving sectoral conflicts through planning processes.

There is currently no peer-reviewed literature specifically on the social interactions that commercial scale seaweed production has or is likely to have in Europe. However, work done on the AquaSpace H2020 project has identified that a demand for space for aquaculture industries can create stakeholder and user conflicts (Strand & Bergh, 2017; Billing, 2018). There is also (currently) unpublished evidence from Scotland and France that user conflict and spatial issues will crop up if/ when the seaweed cultivation industry expands to commercial scale farms.

It is timely to consider how the seaweed cultivation industry in Argyll and Bute can develop in a socially sustainable and acceptable manner, given its current small scale. The opportunity for creating a marine industry covers all three pillars of sustainability is unique. Often economic and environmental considerations are reflected on (especially in the context of aquaculture), only to find after investments and mitigation measures have been made, that the way in which the industry has been developed is not sustainable from a social perspective (Krause *et al.,* 2015).

The specific location and type of activity of marine industries, and the world-views of members of the local communities, have a bearing on the social acceptability of different uses of the marine environment (STEFA, 2014; Hofherr *et al*., 2015). At a commercial scale, seaweed production will have environmental interactions, both positive and negative (Campbell *et al*., 2019). People are aware of environmental impact, and can use arguments based on such impact to justify opposition to enterprises or industries.

Social license could provide a useful framework for the seaweed industry to manage the social risk of opposition to expansion, by developing communication and best practice strategies, and for communities and other users of the marine environment to negotiate beyond compliance behaviour from the industry.

6.5.1 How can Seaweed Cultivation Develop in a Socially Sustainable Manner?

In order to try and understand societal perspectives on seaweed cultivation in Argyll and Bute County specifically, a Q-method[5] study was conducted in collaboration with the H2020 Project GENIALG (https://genialgproject.eu/), asking the question: how can seaweed cultivation develop in a sustainable manner? In Argyll and Bute it was found that there were three prevailing narratives:

1. ***Environmental sustainability as a priority*** – environmental sustainability and good environmental practice for those operating seaweed farming was viewed as the most important aspect of developing a socially sustainable industry for this narrative. Participants with this view also agreed that cultivators should; engage beyond planning measures with communities where seaweed cultivation is likely to take place; provide local jobs and; provide local benefits (beyond jobs).

2. ***Global market focus supported by domestically-owned companies*** – the priority for this narrative is to ensure that seaweed products that are produced in Argyll, by locally-owned companies, can be globally competitive. "Locally-owned" pertained to companies that were owned by people living in Argyll and Bute, rather than other areas in Scotland. The participants with this view also agreed that cooperatives were a desirable mechanism for maintaining competition in the global market, providing community benefits, and ensuring that seaweed cultivation businesses in Argyll and Bute are not bought out by large international companies. This narrative did not include the need for engagement with local communities and stakeholders by operators. The participants advised that this was not a requirement when operators are local as communication is *'organic in nature'* and is funnelled through informal networks and personal relationships.

3. ***Community benefits and local jobs as a priority*** **–** the focus of this narrative was on benefits and jobs for the communities that would be hosting the cultivation activities, including the onshore aspects such as drying facilities, biorefineries, slipways, transportation routes etc. This was the only narrative to slightly disagree that small to medium scale farms are the best model for Argyll and Bute. Participants reasoned that the industry should not be constrained by prior scalar barriers, but should develop where there is demand (for this industry within local communities). Communication, engagement, and local ownership were seen as key to gaining acceptability for larger-scale farms.

All three narratives were in agreement that large-scale internationally owned seaweed farms were not a desirable model for seaweed cultivation development in Argyll. They were all also in agreement that advantages to local communities should include jobs and wider community benefits (e.g. funding schemes). There was an understanding however, that it will take time for the industry develop to a stage where it is making enough money to contribute further than providing jobs.

[5] Q-method is a quantitative method for analysing subjective viewpoints. A technical overview if this method can be found in Annex A.

Crucially, every participant agreed that communication and engagement with local communities, either through organic processes when farms are locally owned, or through more formal processes when they aren't, was key to developing the industry in a social sustainable way. This includes but is not limited to;

- Understanding the context of a potential site including land-side activities – the current uses and users, history, environmental and place-based significance to local people, whole communities, NGOs and other interested parties;
- Providing accurate and timely information on licencing proposals – listening to and acting on relevant concerns raised by local communities and stakeholders;
- Providing accurate and timely information on activities of significance or interest (e.g. harvesting, new site layouts, change of licenses etc.);
- Allowing access to sites for educational and interest purposes (e.g. providing access where possible to local people who have interest, linking up with schools and colleges to run field trips/ information days etc.).

7. BUSINESS FEASIBILITY

This chapter of the report covers the business feasibility of seaweed cultivation in Argyll and Bute, describing the emergent industry and exploring routes for its development. Drawing upon insights from consultation with both new and established actors along the seaweed value chain, together with learning from wild harvesting and comparator industries, it presents case studies which illustrate issues of commercial feasibility and provides indicative costings for setting up and running a commercial seaweed farm. Areas for investment are discussed, including opportunities for economic development, employment and training, and achieving community benefit and buy-in.

7.1 Mapping the Seaweed Industry

In order to better understand the seaweed industry and the potential for the sustainable development of seaweed cultivation businesses, it is important to understand how the market system currently functions. A CEFAS report (Capuzzo & McKie, 2016) on the UK seaweed industry found that factors including lack of information on the operational costs and ecological effects of seaweed farms, as well as an unclear regulatory context (i.e. marine licensing), are stifling the development of seaweed aquaculture.

7.1.1 A Market Systems Approach

The purpose of this section of the report is to conduct a feasibility assessment of the viable cultivation models that have been identified in order to identify the business models best suited for development in the region aligned to level of investment and return. The assessment of the feasibility of individual companies is considered within the wider infrastructural requirements for operating a seaweed industry, i.e. research capacity, logistics, licensing. This approach has been tried and tested across aquaculture and fisheries using a Market Systems approach (mapping the gaps and capabilities of a sector). A summary of a Market Systems approach is shown in Figure 35.

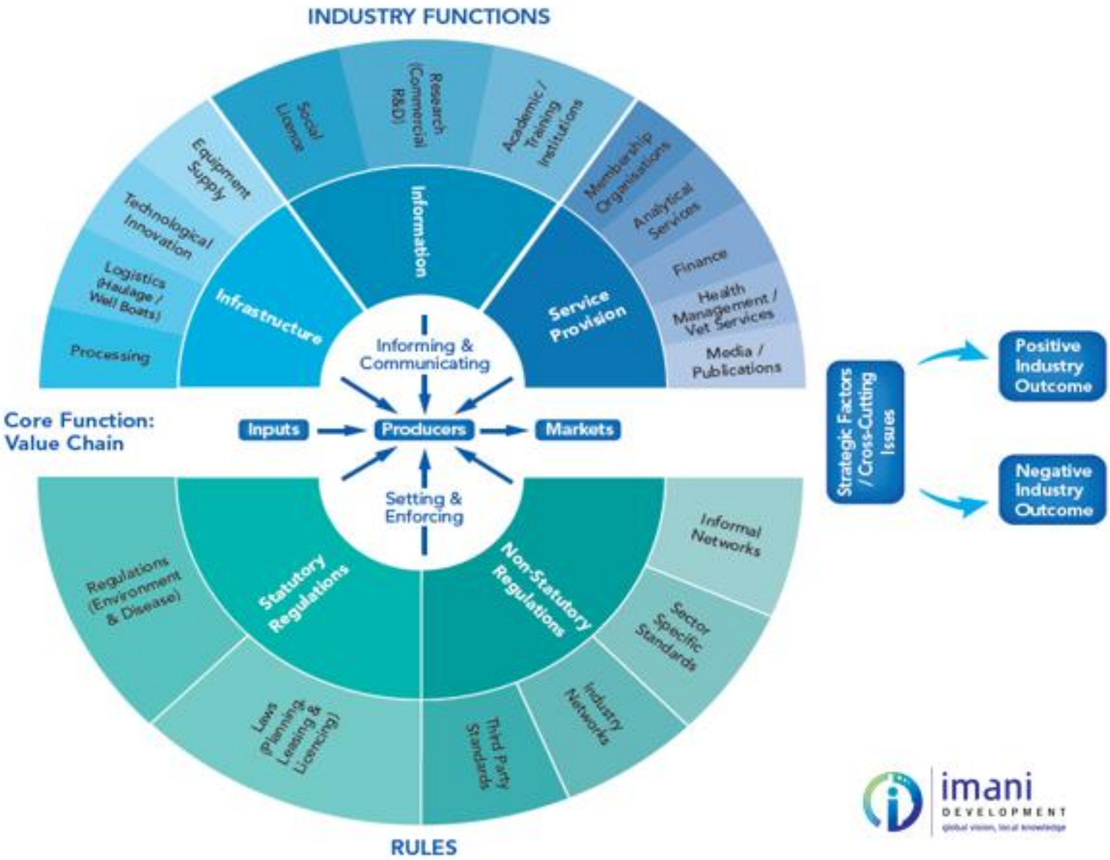


Figure 35. *Schematic diagram of a market systems approach.*

Using the market systems approach helps to map out key industry players and understand how they function within the wider industry context. This includes the regulatory context (both formal and informal) as well as the state of infrastructure, information and service provision within the industry/sector. Figure 36 shows a schematic of the market system for the Scottish seaweed sector.

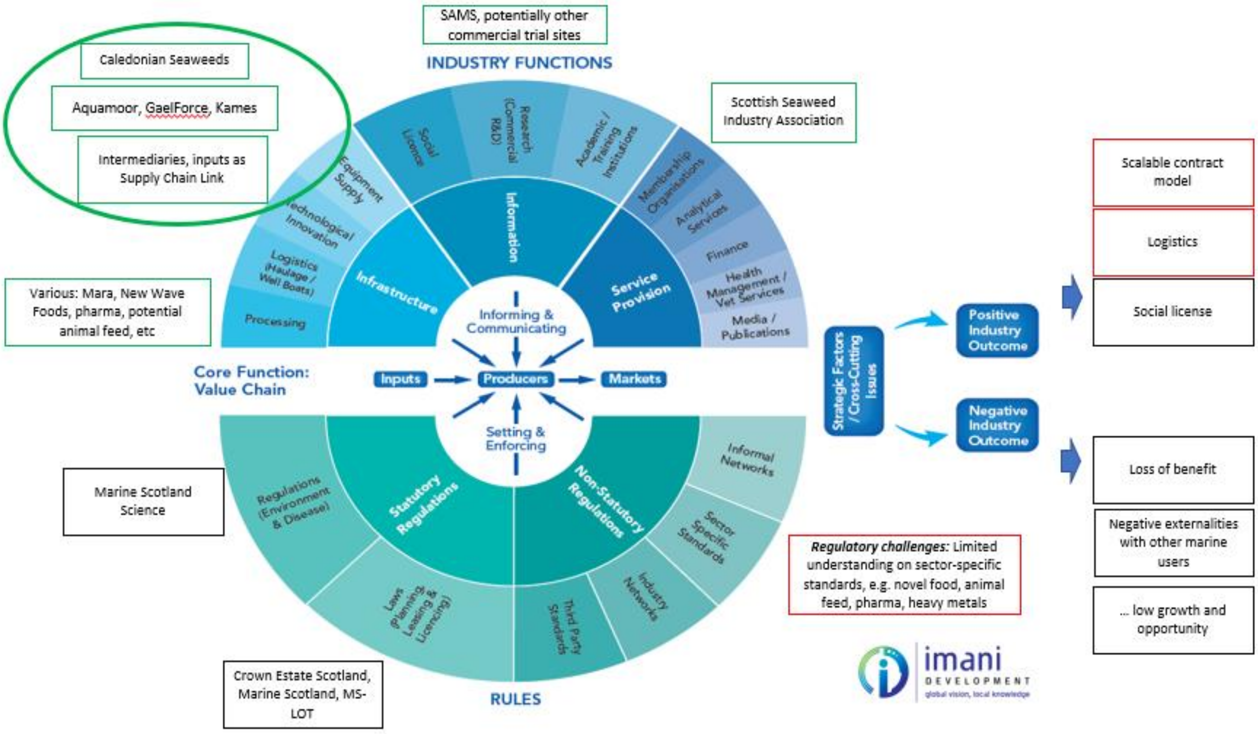


Figure 36. *Scottish Seaweed Market System*

The areas of relative or potential strength for the Scottish (particularly Argyll & Bute) seaweed sector are highlighted in green. The supply of equipment and services seems sufficient to develop the sector, and the Scottish Seaweed Industry Association (SSIA) is keen to play an active role. Areas of weakness include (1) some unknowns about food standards and what is required (thought these seem surmountable), (2) the logistical implications of a fully functioning sector (these will need to be addressed in each end-market strategy) and (3) more broadly the development of a contract model that allows everyone to invest in their respective functions.

7.1.2 The Feasibility Framework

Just as the strengths and weaknesses of the current seaweed industry / market system are important, so too is the feasibility of each link in the value chain. To some extent, the failure to go to scale in seaweed is currently a matter of systemic alignment and dependencies of one value chain (VC) actor on another, but equally they can be costed and described link by link in the chain.

7.1.2.1 A Whole-Value-Chain Approach

Often the price of the raw material is negligible and other value chain activities (processing, logistics, marketing and provenance) are far more important. In a recent analysis of wild harvesting feasibility, it was recognised that the cost of the primary product was not the whole proposition. The value of unprocessed freshly harvested seaweed was substantially lower than the end products. When examining the full value chain, the potential costs associated with any monitoring and management of the wild seaweed resource becomes more feasible than when only considering the price of seaweed per unit biomass harvested (Figure 37).

For cultivation, determining the feasibility of whether production can compete with global market prices and attract buyers must factor in the price sensitivity and product differentiation possible through using Scottish-provenance seaweed. There is certainly a limit to how much buyers will be willing to pay, but if seaweed is a small part of their overall product price, consultations suggest price is not a definitive barrier.

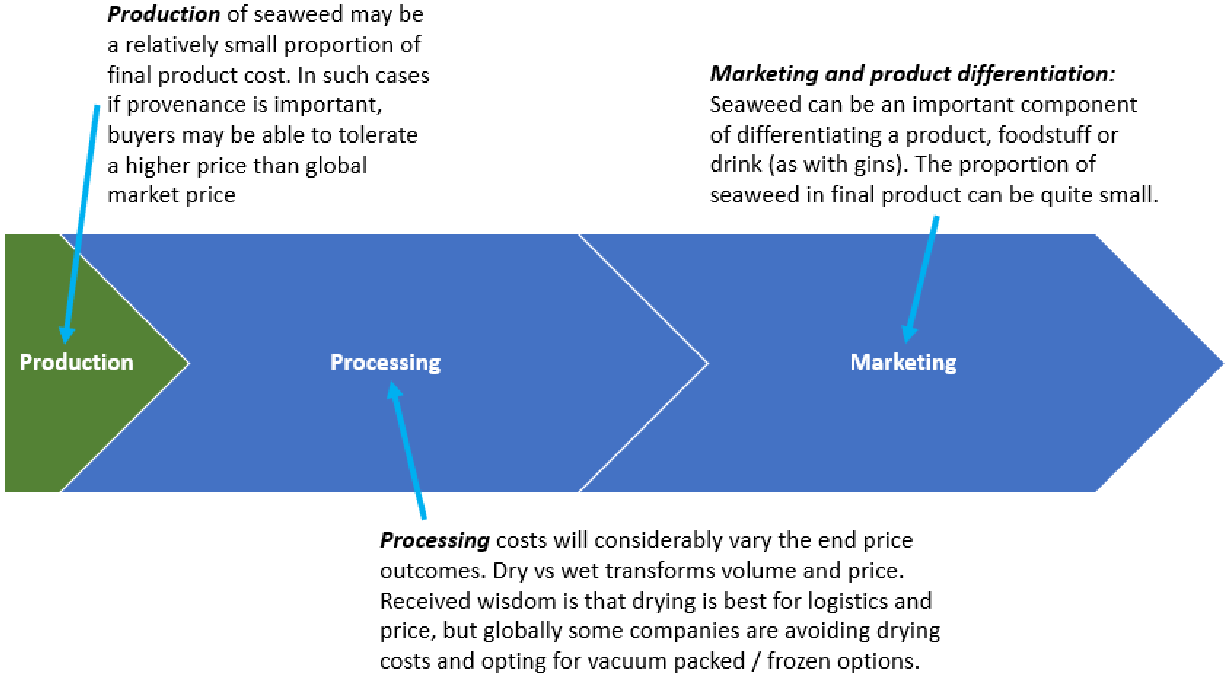


Figure 37. *Full value chain potential for seaweed.*

The feasibility framework outlined in the table below reflects the evaluation requirements one might find in basic due diligence processes and the development of business models. Where appropriate, this has been used to describe a specific organisation as a case study, or more generalised to cover different types of actor, e.g. different intermediaries / aggregators, and where there is a higher degree of commercial sensitivity and intellectual property.

In some cases, the feasibility of production might be strongly dependent on the market – for example, a producer may not be competitive on price but their market may simply want their local provenance and specific seaweed source, and therefore price sensitivity is not a determining factor. This may strengthen the case for a greater degree of vertical integration, which is explored in the case studies.

The feasibility framework is adaptable and can be effectively tailored to the context of analysis (Table 6). In the case of seaweed aquaculture, there are a number of factors to be considered within each section of the framework, some unique to the sector, and others with more general relevance. For example, when considering feasibility of production, factors to consider include species, seeding method, seasonality, location, and prevailing environmental conditions. Analysis of market feasibility will include issues of competition, market segmentation, and marketing issues such as provenance, consumer preference, shelf-life and so on.

Table 6. *Feasibility framework*

1	Stakeholder	Can we get the necessary people on board?
2	Production	Is it possible to produce the requisite quantity and quality at a reasonable cost?
3	Logistical	Can we source inputs and get outputs to market?
4	Market	Is there a market for the outputs?
5	Operational	Can the company be run/managed effectively?
6	Financial	Is the project financially viable and sustainable?
7	Investment	Can the required investment be sourced at a reasonable cost?
8	Growth	Can production be scaled up?

7.1.3 Seaweed Industry Actors

The following summary of seaweed industry actors (Table 7) is not comprehensive but gives an indication of the different players active along the seaweed cultivation value chain.

Table 7. *Seaweed industry actors*

Role	**Group / Organisation**
Planning & Licencing / Regulatory	Marine Scotland Crown Estate Local councils Aquaculture Stewardship Council Marine Stewardship Council
Research Organisations	Scottish Association for Marine Science The James Hutton Institute North Atlantic Fisheries College Marine Centre Queens University (Belfast) Swansea University
Producers *(new entrants / transitioning from wild harvest to cultivation)*	New Wave Foods South West Mull & Iona Development Hebridean Seaweed The Highland Seaweed Company The Cornish Seaweed Company SeaGrown (Yorkshire)
Intermediaries	AquaMoor Ltd. Caledonian Seaweeds Atlantic Sea Farms (USA) Islander Kelp (NI)
Market / Off-takers	Mara Seaweed Davidsons Animal Feeds
Producer Organisations	Scottish Seaweed Industry Association Scottish Shellfish Marketing Group (comparator sector) Scottish Beef Association (potential market)
Local Community	Fishing community Tourist trade Activists & community groups Working age population
Civil Society Organisations	Scottish Natural Heritage Scottish Wildlife Trust Marine Conservation Society Zero Waste Scotland
Funding Bodies	Highlands & Islands Enterprise Scottish Land Fund Social Investment Scotland

7.1.4 Seaweed Value Chain

The seaweed value chain can be conceived of in two generalised forms (see Figure 30). The first relates to the bulk seaweed industry, which includes initial stages of processing and packaging which take place before seaweed is distributed on the wholesale market. The second relates to the seaweed processing industry, involving additional stages or processing and/or repackaging. These additional stages lead to increased value addition before the seaweed reaches the retail market. Value addition activities might include grinding down for use in nutritional supplements or seasonings, or processing into high value products such as candles, cosmetics, or food and drink products (see Figure 38).

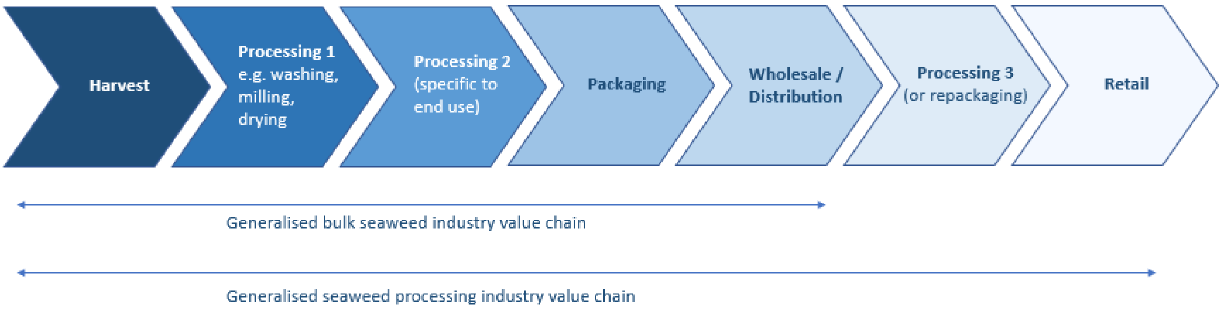


Figure 38. *Generalised Seaweed Value Chain (adapted from Walsh & Watson 2013)*

In Scotland, most of the initial processing that takes place is still done manually, though there are some exceptions such as the new processing facility being developed by Hebridean Seaweeds on the Isle of Lewis and Uist Asco's facility on North Uist. Manual processing can be costly and inefficient, requiring significant time, energy, and labour inputs – though this is an assumption that may depend on scale and particular market (Walsh & Watson 2013). Figure 39 displays a range of the Scottish seaweed products that are currently available.

There are several different processing steps depending on the intended end market for seaweed. These can include processing wet product, such as blanching, freezing or extracting. One of the most common processing methods is to first dry the fresh seaweed material.

Drying is an initial processing step, reducing losses due to spoilage or contamination, and allowing seaweed to be more easily stored and transported. Whilst drying technology does exist, it is too costly to be accessible for most producers. Consequently, basic drying facilities such as containers or polytunnels with metal shelving (e.g. as in commercial bakeries & kitchens), fans, heaters and dehumidifiers are often used.

Once dried, further stages of processing might involve, for example, grinding, chopping, mixing, and packaging. Involvement in these value addition activities is potentially highly profitable. For example, freeze-dried seaweed granules and fine seaweed powders are used in high-end products within the cosmetics and food sectors. However, these require advanced milling technology which is again costly and is not always available in Europe.

Several consultees report significant investments in bespoke processing technology imported from China. In the US, Maine processors clean, vacuum pack and freeze wet seaweed – this goes somewhat against the received wisdom that drying seaweed is necessary to avoid handling and transporting wet seaweed in bulk.

Figure 39. *Range of Scottish seaweed products on the market*

The ratio of the volume of seaweed produced to its value at end market is pivotal to establishing commercial feasibility. Whilst the value of macroalgae for bulk applications such as biofuel and animal feed is low (<£1/kg), the price can be higher for added-value commodities (£1-£5/kg) and considerably higher for cosmeceuticals and neutraceuticals (>£2,000/kg) and specialist applications (>£5,000/kg) (Capuzzo & McKie, 2016). Figure 40 below summarises some key value:volume considerations including variation in risk and return.

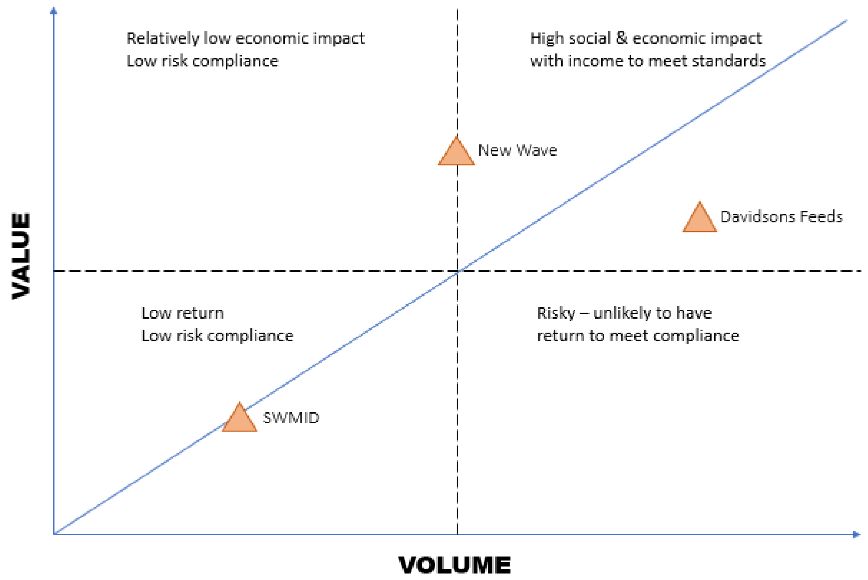


Figure 40. *Volume-value considerations*

7.1.5 Seaweed Cultivation Value Chain: a Typology

Analysis of the market system has led to the definition of a typology, presented in Figure 41, which highlights the roles (both well-established and emergent) of different actors in the seaweed cultivation value chain.

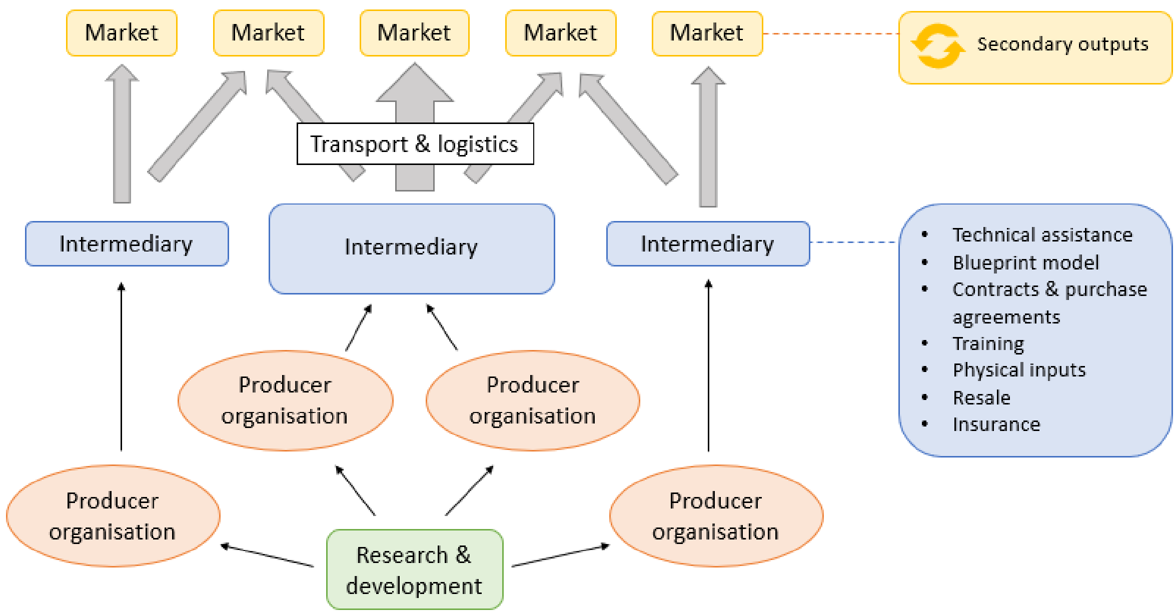


Figure 41. *Seaweed cultivation value chain typology*

The typology identifies four general categories into which key industry players fall: R&D, producer organisations, intermediary services, and off-takers / end market. The following sections deal with each category in turn, using case studies as specific examples of important feasibility issues arising for each, before drawing out general learning and /observations relevant to different actors within the categories. These general observation (in blue) are compiled into a feasibility matrix provided in Annex D.

Table 8: *Costs and transactions along the seaweed cultivation value chain*

	Research & Development		Producer Organisations (lease site & distribute benefits)		Intermediaries & Aggregators		Market / Off-takers
Costs: (per kg, operational, wet/dry, semi processed)	- Hatchery running costs (inc. energy, labour) - Seeding equipment (e.g. tanks, pumps, lines, storage containers) - Sell price	**Sale**	- Mooring system (inc. installation & maintenance) - Monitoring visits (inc. fuel, vessel hire, maintenance) - Harvesting (inc. labour, vessel hire, fuel) - On-site processing - Compliance (e.g. licensing, reporting, stakeholder engagement) - Sell price	**Sale**	- Sell string - Technical assistance & training (consultancy fee) - Buy back seaweed - Transport & logistics - Further processing/ packaging	**Sale**	- Buy price - Transport & infrastructure - Processing & packaging - Marketing - Management - Alternatives (e.g. soya protein) - New product development - Industrial research
Disaggregated VC [EXAMPLE]:	SAMS (hatchery)	→	SWMID	→	AquaMoor	→	Davidsons
Vertically Integrated VC [EXAMPLE]:	SAMS (hatchery) / New Wave Foods	→	New Wave Foods	→	New Wave Foods	→	New Wave Foods

7.2 Planning & Licensing

This section briefly covers planning and licensing from a business feasibility perspective. For a more in-depth discussion of planning and licensing issues see Section 3.

Seaweed planning and licensing requirements are covered under aquaculture consenting, as summarised in Figure 42 below. However, there are conceptual challenges to this process that, while possible to mitigate, must be considered in any new seaweed production:

1. Seaweed cultivation may cover a large production area (hectares).
2. Seaweed production could find scale and efficiencies by integrating with other aquaculture products (finfish, shellfish) but these are parallel processes with different compliance requirements.
3. Modes of production can vary between rafts and mooring points – compliance will need to take into account these variations.

Application	Competent Authority	Legislation	Aquaculture Type		
			FF	SF	SW
Planning permission	LPA	Town and Country Planning (Scotland) Act 1997 (as amended)	✓	✓	
Environmental Impact Assessment (EIA) (if necessary)	LPA	Town and Country Planning (Environmental Impact Assessment) (Scotland) Regulations 2017	✓	*	*
Marine Licence	MS-LOT	Marine (Scotland) Act 2010 (within 12 NM) Marine and Coastal Access Act 2009 (beyond 12 NM)	✓	✓	✓
Seabed Lease	Crown Estate Scotland	The Crown Estate Act 1961**	✓	✓	✓
Authorisation to operate an APB	Marine Scotland - FHI	The Aquatic Animal Health (Scotland) Regulations 2009	✓	✓	
CAR licence	SEPA	The Water Environment (Controlled Activities) (Scotland) Regulations 2011	✓		
Habitats Regulations Appraisal (HRA) (if necessary)	All of the above	The Conservation (Natural Habitats, &c.) Regulations 1994 and its amendments	✓	✓	✓
Works Licence	Shetland Islands Council (SIC)	Zetland County Council Act 1974			✓

* If an EIA was required for a shellfish farm (e.g. for a major application) the competent authority would be the LPA; if an EIA was required for a seaweed farm, the competent authority would be MS-LOT;
** The Scottish Crown Estate Act is pending and will be implemented in 2019

Figure 42. *Aquaculture Consenting Process Summary (Source: SARF 2019)*

7.2.1 Lease and Licence Requirement

Consultees report uncertainty around some aspects of leasing and licensing, such as a lack of guidance on the conditions under which a full EIA is required (Wood *et al*., 2017). A key challenge faced by diversifying value chain actors is that seaweed production does not easily tessellate with many parallel licensing and standards models – this ranges from site selection to food standards. One potential growth area is using fallow or underutilised aquaculture sites, but the use of sites for seaweed is not automatically approved or covered by existing licensing. Indeed, complexity and incompatibility across consenting processes for different aquaculture activities has been acknowledged by the Scottish Aquaculture Research Forum (SARF) which commissioned a report on the feasibility of a single marine licence development consent for aquaculture in Scotland (SARF, 2019).

Social license may become a key determinant of planning and licensing as the industry develops and applications for more and bigger sites are considered. Social license is discussed in more detail in Section 6, and is also raised in relation to the social and economic benefits of commercial seaweed cultivation and how commercial operators can work with communities at the end of this chapter.

7.3 Research & Development

Research and development (R&D), or more accurately, what knowledge is a pre-requisite for the industry, is a key determinant of the industry's growth. For some modes of operation, the cost of trial-and-error or iterative approaches are more suitable for unlocking market potential. Often this can be done by building a market, and supplier relationships, initially through harvesting then progressing into cultivation. For others, such as tank cultivation of technically more complex propositions, an iterative model will be less suitable. Nevertheless, either way the cost of R&D is likely to be high and challenging, and not reflective of ongoing OPEX costs. R&D can also be a slow process, with a full cultivation cycle required to work out what effects a change to the system brings about.

7.3.1 Cultivation Trials

SAMS has been the lead organisation in Argyll & Bute undertaking cultivation trials on Kerrera and Port a' Bhuiltin, including previous tank cultivation trials. Tank cultivation trials between SAMS, partnering with Otter Ferry and Mara Seaweeds, concluded that commercialisation was not yet feasible at that stage compared to sourcing elsewhere. However, through consultation it has been confirmed that this is still a desired goal from a market perspective.

These trials can provide learning about techniques, success rates and challenges. SAMS have undertaken trials including:

1. Establishing the suitability of various growing materials (ropes, nets), seeding techniques, and surface cultivation systems using a variety of local species.

2. Trials to understand the effect of out-planting time, stocking density, cultivation depth and prevailing environmental conditions on yield, composition and quality of several species of seaweed.
3. Monitoring to understand the environmental changes and risks associated with seaweed cultivation.

In order to narrow down the options and interdependencies set out in the rest of this document, and based on consultation with seaweed sector players, it is likely that semi-commercial trials would be a good way to identify and develop winners and rationalise operational models quickly, i.e. within the next 3 years.

7.3.2 String Production

Consultation with key stakeholders has consistently highlighted string/seeded line production as one of the most contentious areas of the emergent seaweed cultivation industry, where bottlenecks are inhibiting growth. For example, there are thought to be a number of licensed but inactive sites in Ireland because seed cannot currently be produced at a cost acceptable to market. The cost of R&D is high, and if passed on to the farmer can be prohibitively high – particularly for new entrants trying to get established. Commercial suppliers of seeded line are being established, with Hortimare, based in the Netherlands, been one of the first examples. They currently supply companies across Europe, including commercial growers in Norway, the Faroes and England. As the industry starts to develop, mature and with future innovation other suppliers of seeded line will start to be established resulting in competition in this part of the market.

A different scenario has unfolded in the US, where research institutions have offered string at a highly subsidised rate in order to catalyse production, sometimes even giving it away. Anecdotal evidence suggests that this has threatened to undermine the commercial viability of new businesses leading some entrepreneurs to go back to research institutions and request that a sufficient market value is placed on the string.

Some producers have taken more of a trial and error approach and have developed their own hatcheries. Whilst lower investments in research and development may lead to suboptimal string, production at a realistic cost and the long-term benefit of IP ownership may make this an attractive pathway, or even the tipping point that makes cultivation feasible. Seaweed cultivation is unpredictable even under the most controlled conditions. Whilst a good harvest can't be guaranteed even using the highest quality seeded line, wild kelp can naturally settle on *unseeded* lines to produce potentially the species of interest or other kelp and seaweed species (Rolin *et al.,* 2017). There is no control over this natural process and it has a very clear link to the geographical area where cultivation is occurring. The dominant natural seaweed species are likely to settle ranging from greens through to kelps. This may not fit with the end market the biomass is destined for. It is therefore worth considering the balance between investment in technical R&D and more practical trial and error approaches to the production of string / seeded line.

The start-up costs for setting up a seaweed hatchery can be high. Basic facility requirements are likely to include:

- Seawater filtration system
- Temperature control
- Air supply
- Fluorescent & UV lights
- Nutrient supply
- Microscope
- Equipment for working with sterile cultures (e.g. autoclave, laminar flow hood)
- Equipment to support biosecurity protocols

For this reason, some recommend developing new facilities within existing marine hatcheries in order to avoid some of the more expensive initial costs (Rolin *et al.,* 2017). Alternatively, it is possible to source a culture suspension from an existing hatchery and seed your own line / material. This involves payment of a one off 'batch fee' (£1-2,000) and is therefore significantly cheaper, also leaving biosecurity considerations in the hands of the hatchery rather than the producer (see Sections 2.5.2. and 5.10 for more information on biosecurity).

7.3.3 Processing & Product Development

Processing and product development represent significant research and development costs. Comments from two well established companies suggest that investments in the development of processing techniques, purchasing processing machinery, and prototype and product trials, are some of the highest costs involved in getting products to market. The necessary processing machinery isn't always available in Europe and may have to be imported (e.g. from China) or sometimes designed and manufactured to order.

The cost of the seaweed itself (inclusive of the cost of cultivation and harvesting) can pale in comparison to the cost of value addition through processing and product development. Knowing where significant opportunities for value addition lie is therefore vital to ensuring that cultivation can compete with wild harvest. Whilst for some industries processing and product development may be relatively infrequent or one-off investments with decreasing marginal cost as production is scaled up (e.g. animal feed), in the food industry the need to develop new products that appeal to changing consumers trends and differentiate themselves in a competitive market is constant.

7.3.4 Environment & Sustainability Issues along the Seaweed Value Chain

The diagram below (Figure 43) identifies some of the potential positive environmental impacts of seaweed VC development. This area of research and development is paramount to the sustainable development of the sector and also has huge marketing potential. The carbon capture potential of aquatic plants is receiving increasing attention in the media (including Leonardo DiCaprio's new climate change documentary *Ice on Fire*[6] and various news articles[7,8])

[6] https://www.youtube.com/watch?time_continue=87&v=Elf0RFBhr8I
[7] https://www.nationalgeographic.com/environment/2019/08/forests-of-seaweed-can-help-climate-change-without-fire/
[8] https://www.telegraph.co.uk/news/2019/09/03/new-seagrass-restoration-scheme-could-used-fight-uk-emissions/

and may help to establish the social acceptability of seaweed farming. Furthermore, the UK imports approximately 2 Mt of soya meal and a further 750,000 t of soya beans each year. Around 90% of the EU's soya imports are used for livestock feed, largely due to its high protein content (UK Roundtable on Sustainable Soya, 2018). The environmental implications of this trend are significant, both in terms of the carbon impact of importing goods and the deforestation associated with soya cultivation.

Figure 43. *Environmental Benefits along the Value Chain*

There is also strong potential for circular economy innovations along the value chain (Figure 44). For example, there is strong demand for seaweed for the biofuels market. Seaweed has a higher quality of cellulose than terrestrial plants. This means that once the desired compound has been extracted the leftover biomass may be used for other purposes e.g. extracting vitamins for use in health products or extracting proteins for use in beauty products.

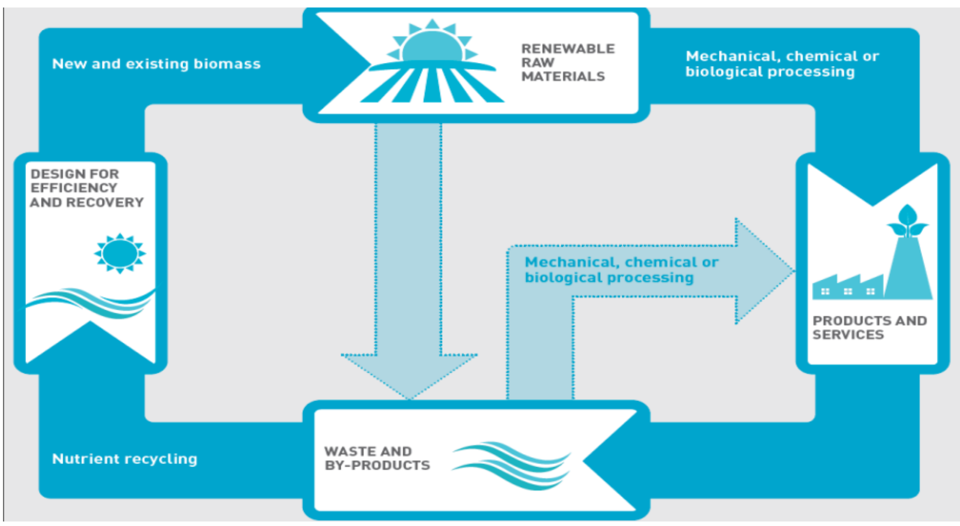


Figure 44. *Seaweed in the circular economy (Source: Zero Waste Scotland)*

7.4 Industry Development

7.4.1 On-ramps Development

The industry's development has come from multiple sources and will continue to do so. Historically, seaweed use has been built on seaweed harvesting and processing, then moved into sourcing non-Scottish product for processing (for alginates, foodstuffs). These activities are relevant as an on-ramp for cultivation, along with other routes into the sector. However, many of the on-ramps are still nascent and not always building on established operational models. Ways to enter the seaweed cultivation value chain are as follows:

- Formalise farm production from an established wild harvesting model: wild harvest businesses may migrate into cultivation as part of their business plan;
- Diversify from similar private SME aquaculture production systems (e.g. mussel farmers, fishers), including supply chain providers e.g. moorings, marine services.);
- Diversify from other community investments (e.g. SWIMD): community or estate managers seek to have seaweed within a portfolio of initiatives in rural areas.);
- Diversify an end-product (e.g. Davidson's Animal Feeds): introducing seaweed into an established demand base.);
- Market pull: demand for seaweed products becomes investable and market players or agents 'work back' to supply sources;
- Climate and environmental management: potentially significant large-scale demand may come from seaweed as a carbon capture method or being used to manage coastal erosion and changing weather, though viability is still to be determined.

7.4.1.1 Formalising Farm Production from an Established Wild Harvesting Model

Established commercial operators engaging in wild harvesting may need to formalise farm production to meet the demand for volumes of particular species. This could involve establishing a network of out-growers (e.g. Mara) or a large centralised farm (e.g. New Wave Foods). The scale needs to be significant to compete with cost of wild harvest i.e. there is a negligible cost of taking a van to the shore compared with operating a boat.

Current seaweed food retailers have built low volume demand using harvested product, then developed cultivation linkages. This has helped establish the business case for cultivation.

For example, Mara Seaweed started wild harvesting but have been exploring options for cultivating, particularly for species that are more limited in terms of site suitability such as those which only grow in intertidal areas.

7.4.1.2 Diversifying from another Aquaculture Production System

The case for integrating seaweed into other aquaculture production is strong on paper – seaweed can absorb and use waste nutrients, can occupy dormant sites (to avoid a 'use it or lose it' scenario whereby sites go unutilised or could be lost), and could be a very low cost way to produce seaweed by integrating it as a marginal cost product within a setup with existing fixed costs.

In practice, the combination of two aquaculture systems together can pose a regulatory compliance challenge and can have access and equipment implications. Seaweed is relatively low in value compared to salmon and even shellfish aquaculture, and often the effort to grow seaweed might be put into fish production instead. The same is true of shellfish aquaculture; mussels are a known quantity and so are lower risk than seaweed cultivation and would likely be favoured unless a) commercial seaweed cultivation becomes demonstrably feasible or b) something threatens the commercial feasibility of mussel production.

However, it is possible that IMTA or a more systemic model of rotating or utilising dormant sites may prevail as a useful model and make large scale seaweed production relatively cheap (e.g. Loch Etive is no longer suitable for mussel production due to an invasive species). There is a potential window in the mussel farming calendar between November and May when there is only mature stock and 2/3 of the farm is unutilised – during this period seaweed cultivation could take place at low marginal cost using existing boats and lines.

Diversifying from similar private SME aquaculture is a route with strong potential. Infrastructure and equipment can be recycled or converted, making for a more cost-effective setup process. These businesses are likely to have at least some of the necessary equipment and skills and knowhow and they will also be acquainted with leasing and licencing requirements for their industry, even if these differ somewhat from seaweed. The cost of conversion very much depends on the site. If you have mussel infrastructure then it is unlikely to be cost-effective to do seaweed at scale, but if there is extra capacity then seaweed could be added at little extra cost.

Mussel producers with licensed sites have indicated that if an investor could commit to financing a trial without guarantee of quantity/quality of production, at least in the beginning stages, then cultivation options could be usefully explored. Spending £3-5,000 to put down an unseeded line and moorings during the fallow mussel season could be another option to explore. Whilst there would be no guarantee of success and little control over the species that might self-seed, this low-cost approach could be a proving ground to attract further interest and catalyse investment in bigger trials. Dormant aquaculture sites could present a good opportunity for developing such trials with the additional pay-off of keeping sites at risk of losing their licenses active – this is a particular issue for the salmon farming industry.

7.4.1.3 Diversify from another Community Investment

Coastal communities with existing investments (e.g. in forestry or renewables) may be well placed to diversify into seaweed cultivation with relevant experience and skills e.g. in management and finance. Community-owned enterprises have the added benefit of fewer barriers to social license with the assurance that benefits of the development will remain largely within the community.

7.4.1.4 Diversify an End Product

Demand for Scottish provenance is high. There is also keen public interest in issues of health and climate change, as reflected in the increasing popularity of plant-based diets. This translates into strong potential for seaweed as an end product diversification strategy. Marketing strategy is key to converting this potential into commercial success (Table 9).

Table 9. *Points of differentiation for product diversification with seaweed*

	Provenance	***Climate benefits***	***Health benefits***
100% seaweed food products	✓	✓	✓
Animal feed with seaweed	✓	✓	
Seaweed-infused gin	✓		
Seaweed-infused soap	✓		
Seaweed-based fertiliser		✓	
Seaweed supplements			✓
Processed food products using seaweed as a salt alternative			✓

7.4.1.5 Market Pull

The degree of nascent demand for seaweed products across a number of markets was evident in consultation – but currently Scottish production is desirable but not 'mission critical' for buyers. This may change over time, or interest will simply tip the balance of risk into encouraging production – this latter scenario seems likely, with some pioneer producers taking the first steps.

7.4.1.6 Climate and Environmental Management

While there is some scepticism about the ability to cultivate at sufficient scale, seaweed is mooted as a useful coastal defence and could mitigate impacts of climate change. It may also become in demand as a means of carbon capture.

Other environmental impacts include the potential for seaweed to play a role in the circular economy: *inter alia* absorbing waste, use as a biofuel, and as a biodegradable alternative to plastics (though not all seaweed-derived products are automatically better in this regard).

7.5 Cultivation / Production

The role of the primary producer/cultivator will be a function of the ownership, technical control, and interests of the business or community organisation involved. The impetus and knowledge of seaweed cultivation may not lie with the producer in the first instance – for example, it may be a group interested in diversifying their activities to include seaweed production, or similarly fisheries or aquaculture (particularly mussel farmers) operators who wish to move into the sector. They may, therefore, be a node or out-grower for a larger enterprise. One such example is a community organisation based in Mull.

7.5.1 South West Mull & Iona Development

South West Mull & Iona Development (SWMID) is a company limited by guarantee and a member of the Development Trusts Association Scotland (DTAS). Formed in 2014, the purpose of the company is to enhance the strength and wellbeing of the local community, to secure a competitive and prosperous economy, and to develop attractive and sustainable settlements. Having developed a community plan based on extensive engagement with local people, SWMID is committed to undertaking projects which contribute to meeting the following outcomes:

- A larger and more balanced population
- A fit-for-purpose infrastructure
- A stronger more diverse business base
- Increase in average household income
- Strengthened local culture
- Improved community resilience
- A fully developed social infrastructure

SWMID commissioned a feasibility study to assess the potential for developing a commercial seaweed cultivation operation. The study identified four potential cultivation sites based on analysis of a number of factors relating to i) local environmental conditions, ii) existing uses, and iii) operational considerations. The most suitable of these is based 5km offshore from a site encompassing some shoreside land, a building, and a slipway and jetty. The land has good potential for development to support a small seaweed cultivation operation, with the slipway and jetty providing a suitable landing site and the building able to house a simple pre-processing (drying) facility.

SWMID has been granted funds from the Scottish Land Fund to help acquire the land and is currently in the process of negotiating the purchase. The organisation has secured a lease option agreement with the Crown Estate for a three year period whilst they go through the licensing process with Marine Scotland. They would like to work in conjunction with a commercial partner that could offer technical assistance and a guaranteed market in exchange for exclusive buying rights for a three year period. SWMID is currently considering a number of options, and will need to explore which specifics such as species and cultivation technique before deciding who to partner with.

SWMID plans to start with a 2 ha cultivation area, expanding to 6 ha within 5 years. SWMID would most likely work within a contract farming model, employing local fishermen to harvest the seaweed, and receiving training and support from an intermediary organisation/aggregator. Essentially, SWMIDs approach is about **finding a low-cost model based on existing capacity and infrastructure**. The organisation projects a modest contribution of £40,000 to the local economy, providing additional income/job security for a few local people. Seaweed cultivation may also be complemented by other business activities including a small water sports centre that could, for example, offer kayak tours of the cultivation site.

7.5.2 Feasibility Assessment

7.5.2.1 Stakeholder

<u>SWMID</u>

Social License: As a community-based organisation SWMID are in many ways more in tune with local views than an 'outsider' would be. The purpose of the organisation is to bring local benefits - there is significant focus on positive local engagement (e.g. meeting people informally 'on the pier' in order to hear all voices). Engagement to date has highlighted a number of local priorities - some people are very interested and are wild harvesting themselves already. Some interested in local benefits and job creation. Others pleased to see SWMID do well financially because of the wider benefits that stem from that.

Sustainable Jobs for Local People: This is a key objective for SWMID, though an employee would initially only be needed for around 90 days meaning the creation of seasonal work rather than stable employment opportunities. Wild harvesting in the off-season is one suggestion for securing a full-time post. SWMID's focus is on creating a sustainable model with local benefits - creating jobs, boosting income, maintaining the working age population etc. It may be possible to do this on a small local scale without the need for too much additional investment by building on the existing capacity of local people e.g. fisherman who may be able to carry out the work during periods of inactivity and who already have vessels and relevant skills.

<u>General</u>

Social License: Ability to secure and maintain social license to operate will depend on how a producer organisation relates to the local community. This is likely to be easier for organisations rooted in the community or with strong local connections. Those less connected will benefit from investing in positive engagement by, for example, taking time to understand the social context, ensuring local benefits, and building relationships with local people (Billing & Tett, 2018). However, while it may be desirable for social license and for economic impact to have localised benefit, this may come in the form of vibrant locally owned producer operators. In the case of large multinational or corporate ownership, this can pose risks to social license and mean that value is externalised. The argument for such a structure is that it can bring operational efficiency, scale, market and economic benefit across many communities, though net profits would be less likely to be captured locally.

7.5.2.2 Production

<u>SWMID</u>

Technical Expertise: SWMID lacks in-house technical experience and so would benefit from the technical assistance offered by an intermediary who could train and advise local people. If operations were to scale-up then it may become necessary/desirable to employ someone. (SWMID has just gone through this transition with its forestry project, employing a full-time forestry manager).

Species: Though SWMID has the findings of a feasibility report to work with, the species to be chosen for cultivation is still uncertain. The decision will be largely guided by the requirements of the chosen commercial partner, within the constraints of site conditions/suitability.

Processing: SWMID plans to start with a small, simple and low-cost setup with a quad and trailer, using a polytunnel for initial drying then inside for further drying. This approach to drying is along the lines of the methods used by the successful Shetland Seaweed Growers project, where a disused walk-in freezer was adapted into a drying room with metal racks, dehumidifiers, heaters and fans (Rolin *et al*., 2017). Established producers indicate that milling is essential to reduce volume and therefore manage storage and transport costs. It may therefore be necessary for SWMID to invest in milling capacity.

General

Species for Potential Development: Limited site availability may have a knock-on effect on what species can be cultivated. This will directly influence a producer organisation's suitability for involvement in a contract farming operation depending on the end market targeted by the intermediary.

Quality & Quantity: Smaller community-based producer organisations may struggle to produce the requisite quality and quantity for market on a consistent basis. However, integration into a contract farming operation may dilute these effects e.g. through training and aggregation provided by an intermediary.

Technical Expertise: Whilst larger organisations are able to employ experts to run their cultivation operations, community-based organisations lack that capacity. Lack of in-house technical expertise is a strong driver for operating within a contract farming model and benefiting from training and technical assistance from intermediaries.

Drying Capacity is likely to present a challenge to producers. Consultees indicate that it may be possible to dry an average of 200 kg in a 24 hour period with basic drying facilities. Planning for harvest and managing drying capacity effectively will be essential to minimise spoilage.

Synergies with Other Local Producers/Processors: It is possible that working in partnership with other local producers (e.g. oysters & mussels) could provide benefits such as shared use of marine space/suitable sites, labour, other resources that could cut the costs and/or increase the productivity of both operations. For example, one producer in the Faroes is co-located with a company that processes fish byproducts, allowing for savings through shared use of drying and milling facilities.

***Establishing Production: Setup Costs*:** Table 10 gives a breakdown of costs new producers can expect to encounter when setting up a seaweed farm. The time and cost parameters are broad, encompassing anything from the smallest and simplest new setup to a mid-sized commercial farm. However, the commentary gives an indication of the conditions under which these vary, as well as highlighting other key issues at each stage of setup.

Table 10. *Establishing production: Setup costs*

ACTIVITY	FIXED COSTS	VARIABLE COSTS	DEPENDENCIES	TIME & COST PARAMETERS[9]	WORKING ESTIMATE (MID-LEVEL ENTRANT)
Site selection	• Desk research • Site data collection	• Business planning • Stakeholder consultation • Wave climate assessment • ADCP • Site survey operations	• Incumbent stakeholders • Client appetite for risk • Ease of access to site location • Species	Min 3 months Max 12 months Min 2K Max 50K	**± 6 months** **± 10K**
	Commentary: The level of desk research required will depend on specifics e.g. species, site access, but can be relatively low if key considerations are known. Site data collection (e.g. depth & wave fetch) is relatively costly (around 5K) if comprehensive i.e. full wave climate assessment with ADCP (gathering data on currents, tidal flow etc.) but will provide key data which can significantly reduce risk. Wave climate assessment takes 4 weeks – full lunar cycle. Intermediary/consultancy services can provide tailored assistance e.g. site assessment, business steering document. Not consulting with incumbent stakeholders is high risk and can impact upon the time and cost of licensing. Some species are much more limited in terms of site suitability e.g. require inter-tidal growing conditions. The max 50K is based on exceptional circumstances e.g. large site with specific problems.				
Prospective leasing & licensing	• Completion of application forms • Preparation of supporting documentatio n • Business plan • Fixed licensing fees	• Design & specification of farm • Pre-application meetings • Stakeholder engagement events • Response to consultees	• Scale • If site location is contentious • Unforeseen obstacles • Owner/ operator vs investment project	Min 9 months Max 24 months Min £5K Max £50K	**± 12 months** **± 20K**
	Commentary: This section covers marine leasing and licensing but does not extend to issues such as planning permission for buildings. The Crown Estate will want to see a comprehensive business plan to give assurance that rents will be paid. Reference materials may be available to support the development of this and other relevant documentation e.g. Imani Development's Social & Economic Impact Template for Aquaculture Investments. Adequate attention should be given to pre-application meetings (e.g. with Crown Estate) and stakeholder engagement events, particularly if a site is contentious – being overly cost conscious at this stage can backfire.				

[9] NB the timeline is not always consecutive – in some cases activities can happen in parallel

Farm setup / infrastructure	• Marking navigational hazard • Farm structure, moorings & buoyancy system • Growing medium / lines	• Hydro-dynamic modelling • Weather on site • Mobilisation/ demobilisation costs • Marine ops contingency	• Client budget • Scale & site • Client appetite for risk	Min 6 months Max 12 months Min £2 0K Max £250 K	**± 9 months** **± 100K**
	Commentary: There are a range of growing mediums available (e.g. textile mat, net, ropes) with different cost implications. Mobilisation and demobilisation costs are site-specific depending on access, conditions, distances etc. It is important to account for marine operations contingency – things often go wrong at sea. Whilst budget may be limited, quality of equipment should be carefully considered to maximise performance and lifespan and to minimise maintenance costs.				
Seeded line / string	• Culture suspension or seeded material • Production batch fee	• Growing medium for direct seeding • Direct seeding equipment • Growing lines for seeded material	• Species • Supply & delivery logistics • Application & deployment logistics	Min 3 months Max 18 months Min £10 K Max £100 K	**± 6 months** **± 40K**
	Commentary: The cost of seeded string and direct seeded rope varies and is linked to the quantity supplied. Lower levels incur a higher cost per m than larger amounts because the costs of setting up seeded line in terms of keeping cultures etc. are the same. There are trade-offs to be made between the cost of material and the level of performance / risk. In the longer term it is likely to be more commercially sustainable to produce your own seeded material if you are a larger grower. Small to medium size producers are likely to be accessing commercial hatcheries. This will reduce their risk, meeting developing biosecurity demands and ensuring quality of seeded line. Timing will depend on seasonality – if starting from scratch with a new strain then it will take a full growth cycle - could be up to 18 months from start to finish.				
Implementation	• Installation vessel • Crane / loading facilities	• Vessel availability • Charter terms • Mobilisation/ demobilisation costs • Marine ops contingency	• Access to shore base • Access to site • Crew competence • Weather	Min 3 months Max 12 months Min £20 K Max £100 K	**± 6 months** **± 50K**
	Commentary: Vessel availability may be dependent upon timing of competing uses e.g. mussel harvest. Planning will be required to ensure contracting arrangements are in place ahead of harvest.				
Contract management	• Deployment • Scheduled maintenance • Harvesting	• Upkeep • Repairs	• Farm structure design • Fouling	Seasonality Q1: 15 days Q2: 15 days Q3: Nil Q4: 10 days	

		• Adjustments to ballast & buoyancy	• Weather events • Operational knowledge & experience • Harvesting capacity	circa 40 days per annum Min £20 K Max £100 K	**± 50K**
	Commentary: Post-winter repairs and adjustments will need to be made in Jan/Feb (Q1) Harvesting: capacity is dependent upon stocking density, rig arrangement, harvesting technique, equipment, daylight hours etc. (Q2)				
Drying / pre-processing	• Dedicated facility	• Fuel / power source • Contract drying • Mobile facility	• Capex investment available • Process tolerances	Window of activity dependent on market sector requirements Min £30 K Max £200 K	**± 60K**
	Commentary: Market sector requirements will affect the timings of pre-processing e.g.: food = 50-day window for best quality; fertilizer = 100 day window for suitable quality. Relatively simple, low-cost drying facilities can be effective e.g. container fitted with racking, dehumidifiers, fans, heaters etc. Time required for drying may slow processing activities down more than harvesting capacity – a processing plan should be developed to ensure smooth operation e.g. managing harvesting volume according to drying capacity to prevent spoilage. Milling after drying will reduce volume and therefore reduce the cost of transport and storage.				
Logistics	• Delivery of culture • Reefer rates to shore base	• Fuel • Availability • Back loads • Haulage	• Time sensitive • “Grow your own” culture • Type of transport: • Bulk carrier • Container • Poly crates	Max harvesting capacity = 20 Mt/day (1x lorry load) Min £30 K Max £50 K	**± 40K**
	Commentary: Refrigeration may be required e.g. for delivery of culture or for fresh-frozen market. Volume to transport = max production/harvesting capacity x 4 weeks. Could expect up to 20Mt/day from a mid-sized farm with good growth and stocking density. Logistical considerations are highly site-specific i.e. dependent upon site size, drying capacity, distance to drying facility etc.				

7.5.2.3 *Logistical*

<u>SWMID</u>

Transport: *SWMID have identified the potential for pre-processed* seaweed (partially dried) to be collected by trucks already in operation collecting shellfish in the region. The similar timelines regarding freshness make this an attractive prospect. However, there may be complications relating to cross contamination.

<u>General</u>

Site Accessibility: will have a significant impact upon logistical feasibility i.e. easy access by road is desirable.

Loading: suitability and efficiency of loading equipment?

Transport: Consultees have highlighted the significant difficulties and costs involved with moving seaweed. There are potential efficiencies to explore such as backloading delivery trucks (e.g. equipment, fish feed), though again contamination may be an issue.

7.5.2.4 *Market*

<u>SWMID</u>

Working with a commercial partner: will help to establish SWMID's route to market. Limited technical input to date means that the species, quality and quantity that can be produced is as yet unclear. Operating within a contract farming model would reduce the risk of such unknowns.

<u>General</u>

Intermediaries & commercial partners: These partners are likely to be pivotal to the success of community producer organisations, bringing important technical and market knowledge to the table.

Developing 'local products': Some intermediaries are willing to operate on a less than 100% volume contract, allowing producer organisations to develop their own local products. Such products (e.g. seaweed soaps & candles) have a high mark-up and can be marketed as part of the local experience (on tours, in gift shops etc).

Though it is important to have an established market link before engaging in production, this is likely to become easier as the market develops and demand grows e (e.g. if seaweed becomes an established salt alternative in processed food products).

7.5.2.5 Operational

SWMID

Spatial / Water: SWMID is limited in terms of site selection with only two suitable sites identified through the feasibility study conducted on their behalf. This will affect the species that can be cultivated. However, SWMID has successfully identified suitable shore land with road access and a landing site within a reasonable distance of the cultivation site.

Planning / Management: SWMID has a direct line to the planning authority through a contact which helps facilitate communications and limit unforeseen blockers.

Regulatory pathways: SWMID have notably capable internal capacity and experience in planning and regulation issues that others might not be expected to have, yet still sometimes find it difficult to know how to proceed.

General

Spatial / Water: Community-based organisations will be limited to a certain area in terms of site selection (which also has implications for what species can be cultivated). This may be further affected by ability to acquire land in a suitable location close to the cultivation site, and by competing uses of marine space in the locality. This will be less of an issue for bigger outfits with more flexibility in site selection.

Land ownership: concerns over how land ownership affects the ability of rural communities to realise their economic potential[10].

Regulatory pathways: can be opaque and difficult to navigate, particularly for producer groups who have no experience in aquaculture. Planning, licensing and regulatory matters could be usefully supported or mediated by an intermediary organisation that offers a package / toolkit for producers to navigate challenges.

7.5.2.6 Financial

SWMID

Scale: "Should work commercially" - hoping to get 30,000 t a year from 2 ha plus additional from wild harvesting.

Growth: Whilst SWMID would eventually like to expand production and become profitable, the initial focus is on covering costs and wages – providing jobs and increasing local incomes being central to the organisation's purpose. This may be helpful as they get started but suggests that in the long term an external driver may be needed to achieve scale.

Diversification: It may be that the financial viability/reduced risk requires a diverse offering with seaweed cultivation as one element e.g. water sports, local tours (including a seaweed element), local product development etc.

[10] https://landcommission.gov.scot/wp-content/uploads/2019/03/Scale-Concentraion-External-Briefing-20190320.pdf

General

Pre-processing: This is likely a necessary step, depending on the end use of seaweed.

Staffing: Personnel costs are likely to be one of the biggest costs faced at the production stage and may prove challenging for smaller and community-based producers that wish to provide full-time, meaningful job opportunities. The degree to which labour can be flexible, seasonal, internalised with other functions (like checking seaweed along with parallel mussel operations, reducing boat and capital costs for seaweed) or outsourced to a lean intermediary operator under contract is likely to be a relatively strong driver of viability.

Preferential prices for smaller producer organisations: Intermediaries buying / producing seeding materials and other equipment in bulk may facilitate preferential prices for smaller producer organisations.

Table 11 below provides a breakdown of costs involved in setting up a seaweed farm. It is based on the development of a fixed mid-sized farm. In contrast with the previous table, this breakdown is specific and sets out underlying assumptions in order to provide a clear indication of the cost of setting up a seaweed farm of this scale.

Table 11. *Indicative medium-sized seaweed farm: Setup and running costs,*

Activity	Cost	Assumptions
Site Selection	± £10 K	Relatively uncontentious site Basic package of intermediary services (can include wave climate assessment depending on level of detail required) Reasonable level of business planning and stakeholder consultation
Leasing & Licensing	± £20 K	Basic package of intermediary services to assist with completion of application forms (incl. fixed licensing fee of £587), preparation of supporting documentation & business plan, farm design & specification Reasonable attention to pre-application meetings, stakeholder engagement events & response to consultees Degree of contingency for unforeseen circumstances
Farm Setup / Infrastructure	± £60 K	Scale of 10,000 sq m (medium scale setup with potential output of 20 Mt/day) 50 lines - requiring suitable number of anchors, buoys etc. for the site Covering equipment, installation, mobilisation & de-mobilisation costs Including some leeway for marine ops contingency Site has road access and jetty/slipway for boat +£5 K for Hydro-dynamic modelling of structure if site condition if challenging (this is separate from wave climate assessment at site selection stage)
Seeded Line / Direct Seeding Medium	± £4 0K	10,000 m seeded line @ £5/m or Cultured seeded material to be applied directly to growing substrate (equivalent to 10,000 seeded line at £3/m from Europe)
Implementation	± £25 K	Distance maximum 1 hour from jetty/slipway to site Including installation vessel hire (assuming available), crane / loading facilities (£15 K) Good access to shore base, good access to site and competent crew Mobilisation and de-mobilisation costs relating to £10K Workable charter terms assuming dedicated vessel and factoring in some marine ops contingency
Contract Management / Farming	± £50 K	Covering deployment, scheduled maintenance and harvesting and factoring in upkeep and repairs Based on 40 days per annum (incorporating 5 days contingency) Harvesting capacity of 20 Mt based on standard AquaMoor system
Drying / Pre-processing	± £60 K	Site has containerised drying facilities with capacity of 2 Mt per day, with a view to full drying shed if required in 3 years Or for example intermediary has mobile drying unit with capacity 1 Mt per day. Used for 3 harvests a year and lasts for 10 years so cost of setting up & running/30 = £2 K
Logistics	± £2 K	Based on 20 (dry) loads over the harvesting season Argyll & Bute, 2.5hrs to Glasgow = 100 miles by road 100 kg each load @ £50-100 travel costs per load (If value addition takes place before transport then logistics costs will vary depending on the nature of the end product. A 20 Mt lorry load to the central belt is approximately £300)
Total Cost:	**±£267K**	

The breakdown of costs presented above was used to develop an economic calculator for setting up and running a seaweed farm. The following tables summarise the key inputs to and outputs from the calculator, with costs based on best known estimates (Tables 7 & 8). The numbers are illustrative, based on particular scenarios, with the objective of demonstrating how the calculator works and what information is required for modelling. In practice the numbers will vary considerably depending on factors such as species, cultivation and harvesting methods, processing requirements, end market etc. As an example, the costs of £3 per m of direct seeding medium and £5 per m of seeded line cited in the table above represent the historical prices to date. However, as R&D advances and economies of scale take effect, industry costs are beginning to come down. Seeded line is becoming available from research bodies such as SAMS, and other commercial operators, at a cheaper working price, as reflected in the economic calculator.

The calculator should be viewed as a working model for refinement by commercial actors in the sector rather than as confirmation of general profitability. It can be made available to commercial actors wishing to input figures relating to their own operations in order to arrive at more robust cost and profitability estimates. This will allow them, for example, to translate their wet volumes to dry volumes and think through the implications in terms of transport costs, processing costs, and ultimately profitability. (It should be noted that while still using best estimates, the set-up cost tables presented above can be used more directly as a guide around process and as a basis for cost estimation).

Table 12. *Economic calculator: Inputs*

Farm size	What is the total area of the farm site (Ha)(10,000m2)?	20
Farm size	What proportion of the farm area (%) is under cultivation?	50%
Labour	What is the average day rate for labour?	£140.00
Diving	What is the average day rate of inspection divers?	£1,000.00
Equip	What is the average day rate of Boat Hire?	£400.00
Harvest	What is the average volume rate of harvesting (biomass kg / day / boat)?	6000.00
Trans	What is the cost of transport (£/tonne/hr)	£60.00
Trans	What is the average transport travel time (Hr) - including loading time?	6.00
Rigs	What is the length of the long line (m)?	200
Rigs	What is the length of the Cross Lines (m)?	50
Rigs	What is your stocking density (linear metres / m2)	1
Rigs	What is the cost of installation (£/m)?	£10.00
Seed	What is the annual cost (£) of seeded twine per metre?	£2.50
Yield	What is the expected average yield (kg/m) harvestable biomass?	6
Drying	What is the relative mass of dry product to wet product (%)	20%
Specs	What percentage of output undergoes dehydration for dry markets?*	50%
Drying	What are the dehydration costs per unit of dried output (£/kg)?*****	£0.60
Value	What is the expected net Value Addition (%) from drying?**	5%
Margin	What is the minimum sales margin, all products (%)?	5%
MP	WET SP: What is the market price: wet £/Kg***	£1.10
MP	DRY SP: What is the market price: dry £/Kg****	£7.05
Rigs	Materials: What is the cost of steel rope growing / cross line per metre?	£0.18
Exp	What is the capital replacement year?	10

*Assump: all remaining output (Total - dried product) is sold into wet markets

** {(P[dry_prod]) - (P[wet_prod]*0.15)}*100

*** Range for wet per kilo biomass expected @ £0.50 - £2.00

**** Range for dry per kilo biomass expected @ £2.00 - £8.00

***** I.e. what is the cost to dry e.g. 5kgs wet biomass to 1 kg dry biomass

Table 13. *Economic calculator: Outputs*

Efficiency	Cost Price to produce 1kg of Wet Product (100% Wet)	£1.09
Efficiency	Cost Price to produce 1 kg of Dry Product (100% Dry)	£7.07
Output	Total Output / Farm (kg, wet mass)	600000
CAPEX	Total Capital Investment / Farm / 10 Years	£520,500.00
OPEX	Total Operating Expenditure / Farm / Year (100% Wet)	£656,342.00
Modelled Farm Output: Current Scenario		
Cost	Total Operating Cost + Depreciation + Processing per Year	£752,282.00
Revenue	Total Revenue generated from Product Sales*	£753,000.00
Profit	Gross Operating Profit (After Depreciation, Before Tax)	£718.00
Alternative Scenario 1: 100% Wet Product		
Cost	Total Operating Cost + Depreciation + Processing per Year	£656,342.00
Revenue	Total Revenue generated from Product Sales*	£660,000.00
Profit	Gross Operating Profit (After Depreciation, Before Tax)	£3,658.00
Alternative Scenario 2: 50% Wet Product & 50% Dry Product		
Cost	Total Operating Cost + Depreciation + Processing per Year	£752,282.00
Revenue	Total Revenue generated from Product Sales*	£753,000.00
Profit	Gross Operating Profit (After Depreciation, Before Tax)	£718.00
Alternative Scenario 3: 100% Dry Product		
Cost	Total Operating Cost + Depreciation + Processing per Year	£848,222.00
Revenue	Total Revenue generated from Product Sales*	£846,000.00
Profit	Gross Operating Profit (After Depreciation, Before Tax)	-£2,222.00

7.5.2.7 Investment

SWMID

Financing: SWMID has received funding from the Scottish Land Fund towards purchasing the landing site and will take out a loan to cover the rest of the cost. SWMID is "not scared" of loans, having previously taken out a loan of £200,000 from Social Investment Scotland to purchase the community forest, also in combination with grant funding from the Scottish Land Fund. The loan was later refinanced at a lower rate through Triodos and is nearly paid back.

Trust Status: As a Community Development Trust, SWMID is well-placed to benefit from funding streams that may not be available to other new entrants and is hopeful that this kind of innovation funding will give them an edge as they get started.

General

Community based organisations have the advantage of **access to finance streams** not available to others. Financing similar SMEs such as mussel farms and inshore fishing boats has proven a challenge in the past. **Learning lessons and constraints is crucial** – some inshore fishing groups help coordinate individuals and banks (as in the Western Isles) or financed directly as organisations; while in Shetland, Nordic Banks have been interested in lending to mussel farmers and now Scottish banks are being encouraged to do the same.

7.5.3 Summary

Plugging into a community-based supplier network / contract farming model allows communities to benefit from the experience of more developed commercial operators whilst maintaining ownership of the local land and resources. Such an arrangement also reduces the risk of new ventures in seaweed, securing a market for the output in spite of the relatively low volume of seaweed produced.

The case of SWMID points to the fact that operating a diversified income model (as they are doing with forestry, seaweed etc.) might work favourably for community-based organisations i.e. unless you can do it full time then there will likely be a need to integrate with other activities – at least during the initial stages – it may be more feasible to specialise after several years in development.

7.6 Intermediary Services / Aggregation / Contractor

For the seaweed cultivation sector to grow, particularly among community groups or in remote areas, there will be a need to bring expertise to many producer groups (or individuals) who currently do not know how to grow seaweed. There are a number of roles and functions here for different intermediaries to provide services and organisational structure/scalability. This section will cover what intermediary functions are available, and may be available in future, using case study examples where relevant.

Happily, some of these are already present with capacity to service the Argyll and Bute coastal area. They may be integrated with the market buyer, but not always, and unless there is strong vertical integration, the buyers are willing to see a market develop from which they can draw their supply rather than be in a full contractual relationship with growers. Intermediaries may perform some or all of the following functions, which are also shown in Figure 45:

- **Site identification** (site assessment, planning and license applications)
- **Site development** (moorings, access to site, monitoring equipment)
- **Site management** (seeded line, monitoring, boat leasing, harvesting, trouble-shooting)
- **Training of site licensees** (training producer organisations – SMEs or community orgs)
- **Aggregation and market** (serve as market link or as farm-gate buyer)

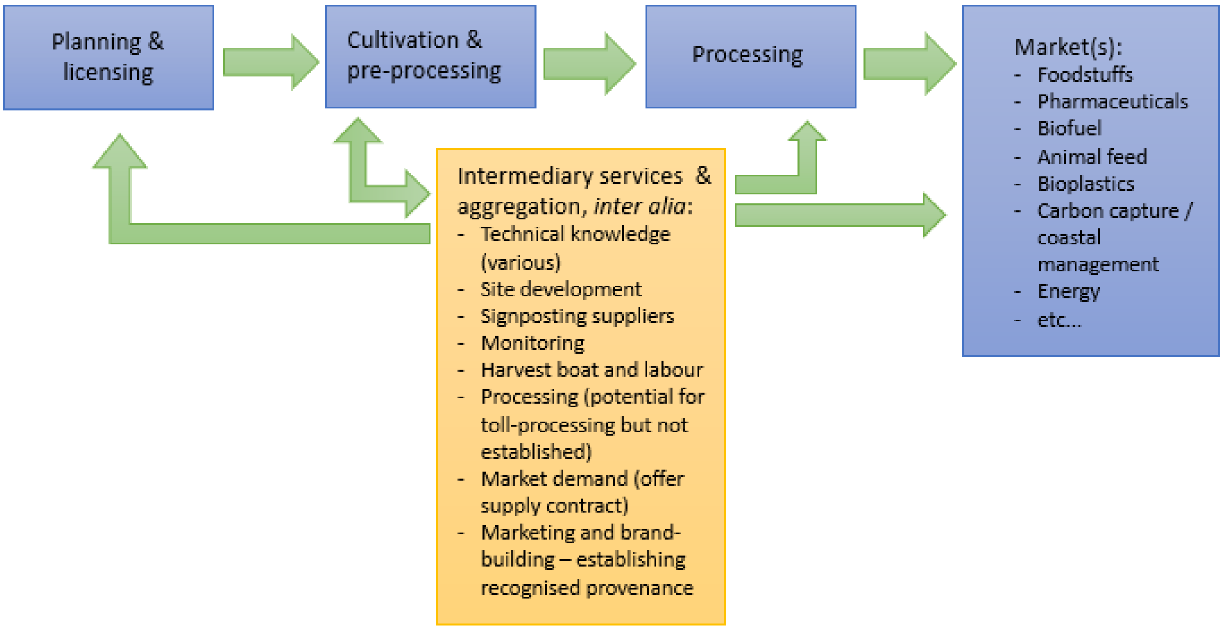


Figure 45. *Intermediary role in the value chain*

Intermediaries and aggregators will generally hold knowledge of other areas of the value chain beyond the production site – this can be to the advantage of new entrants in production. Currently, the intermediary function may be more critical in the development of the industry than the producer, in that the producer may be a relatively passive site licensee rather than being expected to run the site from year 1 without experience. It is likely, however, that over a few years, many of these functions will be handed over to the producer group.

In the same way, intermediaries work with coastal communities and development trusts, providing training, advice and support to develop their seaweed operations. They may act as aggregators whereby the producer organisation / community is contracted to sell their output to the company for a certain period in a contract farming model. The company then either processes the seaweed itself or sells on the aggregated volume of seaweed to a third party for processing.

The intermediary services role is still emerging in Argyll and Bute, with no firmly established player but with emergent firms and others in Scotland. The SSIA is another body which sees the need to have an active rather than passive coordination role as a membership body. This is likely to be important in the current stage of development. However, there are strong comparators from other national contexts which can provide useful insight, so this section will cherry-pick useful insights from a basket of examples in order to assess the business feasibility of the intermediary role in the value chain.

Caledonian Seaweeds

- Local Argyll and Bute intermediary contractor – could work across a number of producers
- Limited established business to date
- Links with SAMS knowledge hub

AquaMoor Ltd. (and other marine equipment suppliers e.g. Gael Force, Kames)

- Mooring company working in aquaculture – this involves site selection and consenting technical support and may extend to include contract growing and harvesting
- Has costings and working models – has worked with SAMS and private sector
- Clearly identified packages of capital investment, planning consultancy support and contract management

Scottish Seaweed Industry Association

- New board structure - seeking to develop new activities and functions
- Would like to be acting as an intermediary of sorts but needs staffing and funding

Islander Kelp (Northern Ireland)

- Started local in Ireland and still there – outreach to Argyll and Bute only tentative to date
- Shows the value of ‘getting going’ – trial and error and close local ties, learn by doing
- Potentially replicable model but unlikely to be key player in Argyll and Bute

Atlantic Sea Farms (USA)

- Formerly *Ocean Approved* – the first commercially viable seaweed farm in the USA. Ocean Approved now refers the sustainability standard that sea farms must adhere to
- Works with fishermen in Maine assisting them with starting their own kelp farms
- Provides technical assistance to get farm leases, set up equipment, learn how to seed and harvest, and engage in business planning
- Provides free seed to farmers and buys back product

7.6.1 Feasibility Assessment

7.6.1.1 Stakeholder

<u>The Intermediary</u>

Stakeholder engagement is a crucial part of aquaculture development because operating in a shared marine space requires identification and consideration of interactions. Local communities have a say in such developments and can potentially be direct (as well as indirect) beneficiaries as community owners, employees, or service providers.

Investing time and resources in stakeholder consultation can be seen as an additional cost or hurdle to overcome, including the risk that additional considerations must be taken into account that have not been foreseen by the applicant. However, experience in other aquaculture subsectors, and in seaweed production itself in Scotland and England, highlights the dangers of not adequately consulting and gaining the acceptance of the relevant stakeholders. Some producers may have experience from previous projects (e.g. SWMID from forestry) but some commercial entrants may underestimate the risks of inadequate consultation and need an experienced intermediary. Even established / experienced commercial operators can fall foul of local communities if consultation / engagement is not perceived to be a priority, as has been demonstrated in the salmon industry.

<u>General</u>

Planning & consultation: The intermediary technical assistance provider will have more experience in dealing with planning and stakeholder consultation than many new entrants seeking to grow product (e.g. they will have knowledge of the statutory consultees and stakeholders that must be considered, for example where there are shipping lanes, fishing activities, waste discharges etc.). For this reason, it is advisable that the feasibility of seaweed production considers sufficient intermediary assistance to avoid delays, additional costs and possibly above all avoiding antagonism through mismanagement of stakeholder relationships, given that sites are likely to be in shared marine space. The intermediary would have knowledge of which stakeholders may need consulted, and to what extent.

7.6.1.2 Production

The Intermediary

US production models: The intermediary role is more developed in the US system, where the likes of Green Wave and Atlantic Sea Farms provide seed and technical assistance. Production models tend to be through contract growing with community groups, and potentially with mussel farmers or fishermen, rather than 'owning' the production under a salmon aquaculture model. The principles of engagement are likely to be relevant i.e. getting buy-in and relations with communities, and building trust with those who would see the emerging benefit and need for cultivation proper. However, the degree to which an intermediary sees themselves as a buyer / processor compared to a producer is important (e.g. in Maine one of the leading seaweed companies is focusing on processing, working with producer partners). The Maine model / cooperative approach is realistic for small-scale producers and may be a good way to reach scale while maintaining social license.

General

The experience of intermediary players is likely to translate into benefits at the production stage. This may be in the form of technical assistance to the party implementing cultivation, resulting in greater efficiency and ultimately higher production volumes. These benefits are likely to increase as the level involvement of the intermediary increases i.e. they will be most significant when the intermediary is more hands-on / essentially takes on the role of producer. **If an intermediary acts as an aggregator then there may also be efficiency gains in processing.**

The degree of risk and responsibility an intermediary takes on requires consideration – they may be responsible for sourcing seed, site development and timely harvesting. The **sharing of risk may ultimately drive greater integration between intermediary and producer group.**

7.6.1.3 Logistical

The Intermediary

Perhaps the area where current intermediary services are weakest relates to logistics. Seaweed has a high drop in volume from wet to dry mass, and this suggests (possibly mistakenly in some cases) that drying is essential and should take place close to production rather than far off-site.

There are possible intermediary roles from boat harvesting under contract with producers, to landing, to transport, to processing, to export. Leasing of marine equipment including boats and cranes (e.g. Inverlussa) is already established as a business ecosystem in Argyll & Bute and can be crowded in to seaweed production.

Transporters in Argyll & Bute and the Highlands are accustomed to specialised products e.g. salmon & other agriculture and food grade produce, and are likely able to adapt to transport requirements for seaweed.

General

Logistics will largely depend on the degree to which processing takes place local to production, or off-site at the market end. Some buyers will want to have as much control over handling and processing as possible. If the intermediary acts as an aggregator then there may be **efficiency gains** in relation to transportation. Transporting wet seaweed is bulky; wet or dry, logistics would require alignment with transport of similar products in terms of cross-contamination and cleaning between loads.

7.6.1.4 Market

The Intermediary

Many intermediaries are approaching the production end from the market, i.e. market-end companies (e.g. Mara) are seeking out producers to cultivate seaweed for them according to species or (more-so at the current industry level) by provenance. However, those at processing-market end are likely to still want intermediary services so as far as possible the responsibility for supply is not wholly dependent on them. This can be because where there is global supply there may be a strategic advantage to having a supply relationship, but not 'mission critical' i.e. if a buyer has other sources they may not wish to get too actively involved in one area of production. This has parallels in the inshore fishing sector where there is a dislocation between producer and buyer, but this is changing as buyers need to 'secure' supply with deeper integration, either through contracts, financing, or full ownership.

General

The intermediary has a role to play in **narrowing down options for potential market buyers and linking them with feasible producers**. They may also be able to access higher volume markets through aggregation. The degree to which this service can be paid for will likely change as the market matures – currently **there is a strong need for a 'scouting' function**, which would reduce search costs. In a future, more mature market, the market buyers and organisers will perhaps be more proactive and vertically integrated in their approach, as with salmon and shellfish sectors.

'The market is there'…. but commercial opportunities are limited by the chicken-and-egg limitation of **not having producers to supply it**. This seems a common theme that, when overcome, can allow intermediaries to build volumes in line with their ability to supply.

It is important to recognise the **value of harvesting as a preliminary / breakthrough strategy to build markets**.

7.6.1.5 Operational

The Intermediary

Intermediaries may provide a range of operational functions across the production cycle, for example:

- Regular monitoring – checking seaweed lines across a range of 'hands-off' producers
- Testing and compliance
- Boat operations (and crewing for harvesting)
- Processing, possibly with dryers that may be able to operate across seaweed farm sites, similar to agriculture machinery rings and contract dryers for haymaking

It is possible that these functions could over time be taken up more by the producer organisations as the industry rationalises, but equally there has been a tendency in other sectors such as salmon production to standardise and find common production efficiencies. In mussels, a relatively positive hybrid model has separated production know-how (kept at SME / owner level) from processing and marketing know-how (in a cooperative model).

General

Operational know-how is possibly the key factor driving the intermediary role and will be the conduit for rationalisation and new techniques in the industry, including, for example, finding efficient harvesting models across boat, line and a short season. For example, a site with a certain water depth may require different methods to one that is shallower, and large-scale harvesting using a specialised boat may require different spacing between equipment. These **trade-offs are understood by intermediaries who would seek to maximise production within the constraints of particular sites**. Low cost operational models will be required for some products while high value production (including tank cultivation) may be more focused on specific quality requirements.

Intermediaries are likely to have **established relationships with regulators** and significant **experience with planning and licensing issues** which can help to ensure smooth operations.

7.6.1.6 *Financial*

The Intermediary

One of the leading seaweed companies has had funding from finfish aquaculture but it is not clear how much pre-existing capacity influences the cost structure of operations. Currently production / cultivation is hedged (if not subsidised) through existing supply chains and funding structures (e.g. Mara & New Wave Foods) with volumes and income from other sources and trials through R&D grants and private funding e.g. SAMS research and business incubation.

General

Intermediary organisations will take a cut / margin and may require certain contract arrangements but working with them may be key to overall feasibility, particularly for new entrants.

The reliability of costing of intermediary functions is variable – technical assistance time can be estimated and geared relatively clearly, while functions like having a roving harvester that can travel across different producer sites may be harder to fully cost at this stage in the sector’s development.

Similarly, **the degree to which the intermediary gets involved in drying and transport is still unclear** – there is a strong case for having mobile drying units that could be loaded onto a truck and transported across different producer organisations e.g. 20 ft container units with drying capability. This could also reduce risk of spoilage under transport constraints.

7.6.1.7 *Investment*

The Intermediary

It is not yet clear the degree to which intermediaries may be able to invest in site-level cultivation – currently the onus is on the producer to take on risk and invest in a site, with the intermediary as a hired agent to support the development, or as a tacit or contractually explicit buyer. For market players to invest there needs to be suitable contract arrangements to attract investment from the market end (i.e. security and exclusivity of supply). This could ensure predictable demand for community groups or SMEs and stimulate their involvement in investment, but equally it would constrain their control over market development and would amount to a more vertically integrated model. Nevertheless, if ownership and benefits were maintained at a community or SME level this may be a desirable way to mitigate risk and may be perceived as more desirable than a supply chain which is 100% company owned.

General

Currently, those with intermediary knowledge are funded either through:

1. A vertically integrated model (e.g. Green Wave or Islander Kelp) where the same organisation is selling final product to the market
2. Being hired by a producer to develop a site, with a view to producing seaweed, possibly having built a market through harvesting the same species
3. Institutional capital seeking to invest heavily in the seaweed market and gain first-mover advantage, but prepared to take significant risk
4. A buyer seeking to establish a controlled / dedicated supply source but not wanting to get bogged down in ownership of sites
5. Public funding seeking to provide R&D infrastructure to the sector e.g. Scottish Aquaculture Innovation Centre (SAIC) is now led by industry actors to ensure research is fit for purpose
6. Academic funded spin-off companies selling IP to the market e.g. SAMS

Having an experienced intermediary on board may **help new entrants to leverage finance** e.g. through development of a strong business plan or demonstrable technical capacity.

7.6.2 Summary

The role of intermediary is *essential* in an unintegrated (esp. community-owned) industry system. Most producers and buyers will not be experts in seaweed cultivation. In fact, some are coming in with almost no knowledge or business plan.

Though there is a necessary cost to intermediary services, the role removes some of the risk from both the producer end (i.e. lack of knowledge & expertise, finding a market) and market end (i.e. inconsistent quality & quantity of supply) of the value chain. Some of the cost may be absorbed by increased efficiency of an aggregation system, for example through centralised testing, larger scale processing, or securing a known market.

7.7 Market / Off-taker

Market-end buyers and off-takers may express interest in intermediary functions, or need to provide input into the production process, but in many cases the nascent market is currently using non-seaweed alternative products, or seaweed supplied in the global market (but ideally could be cultivated in Scotland with Scottish or local provenance). The advantage of this is that many operators producing high value products in Scotland are sufficiently 'hedged', i.e. their processing or market sales are not currently jeopardised by the lack of Scottish (or A&B region) supply. However, the downside is that they are not obliged to commit to production unless sufficient certainty around feasibility is established.

An example of a market off-taker is Davidsons Animal Feeds, who have a number of interesting characteristics of a market player. They are generally interested in a distinctive or unique seaweed product, and as such are open to explore price points. They are willing to engage with producers rather than expect a product bought on a shelf. They also have transport logistics capacity that they hope will help unlock the opportunity.

7.7.1 Davidsons Animal Feeds

Davidsons is a family run business based in Shotts, North Lanarkshire. The company produces 250,000 t of ruminant feed a year, distributing them throughout Scotland and the north of England. The business has differentiated itself from its competitors on the basis of quality and efficiency, having developed the capacity to receive an order and manufacture a batch of feed on the same day, delivering to the customer on the following day.

The company submitted an application to the Scottish Funding Council through Interface, which resulted in a £50,000 funded research project in partnership with the SAMS. This allowed Davidsons to begin thinking through the issues they will face in getting a seaweed feed product to market. Figure 46 provides a summary of the seaweed value chain for Davidsons Animal Feeds.

Davidsons has taken on a Knowledge Transfer Partnership (KTP) associate in partnership with the James Hutton Institute (Dundee) in order to move forward with plans. This is a funded 3-year position designed to bring in the knowledge and research capacity needed and foster the relevant links to bring the plan to life.

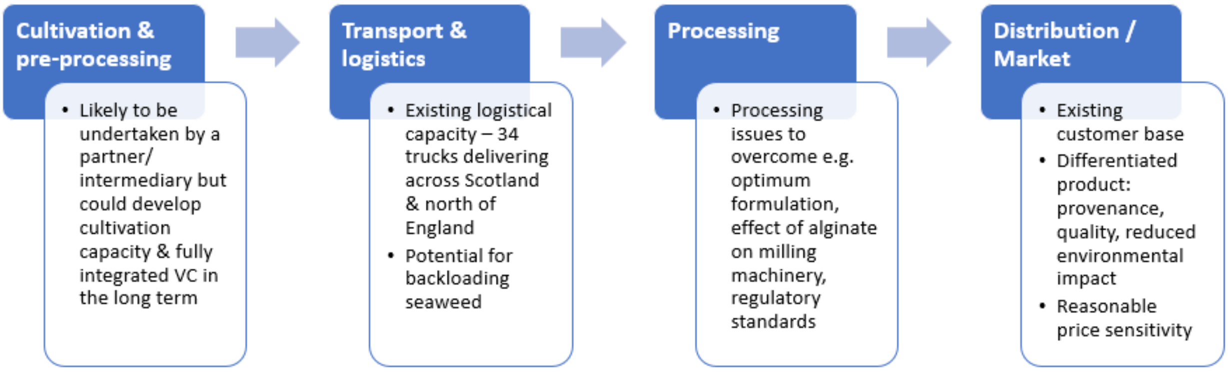


Figure 46. *Davidsons Animal Feeds seaweed value chain summary*

7.7.2 Feasibility Assessment

7.7.2.1 Stakeholder

Davidsons Animal Feeds

Research partners: Further technical input is needed from research partners (e.g. James Hutton Institute) to unpack uncertainties e.g. around species, seasonality, site selection etc.

General

Engagement with relevant stakeholders for research and development is likely to be required by market players developing new seaweed products, particularly new entrants and those with little experience of working with seaweed.

7.7.2.2 Production

Davidsons Animal Feeds

Quality & consistency of supply: The value proposition of the company rests on supplying a high-quality feed product that delivers as much energy, nutrients and protein as possible for the lowest price. Davidsons has built up a 'Bible of ingredients' from which it is able to formulate a wide range of feeds, adapting recipes as needed, and mixing to customer specifications. In order to ensure sufficient consistency of nutritional quality and continuity of supply across seasons there are many questions that need answering, such as:

- How the protein content varies between species
- Whether a range of species can be cultivated to address seasonality issues
- Whether different species can be blended together, or with other ingredients (e.g. soya) to achieve the right protein content across seasons

Processing: There are many questions relating to processing that need addressed, such as pellet size & form, taste & aroma, and the effects of alginate on milling machinery. Davidsons has extensive product development experience and good existing processing capacity to draw upon in addressing these issues.

Circular economy: There are potential opportunities with waste and byproducts e.g. extraction of alginates for use in other industries. However, these are unlikely to be easy wins. For example, the extraction of some compounds is likely to change the nutritional quality of the seaweed.

General

Some pre-processing is likely to have been undertaken by producers or intermediaries. However, some market players will want to maintain complete control over processing themselves, and most are likely to undertake further steps (e.g. integrating into final product, packaging). **The type and degree of processing undertaken will vary according to the target market.**

There is potential for **circular economy** connections with waste & byproducts to be made.

Packaging of products may be pitched so as to overcome supply constraints, i.e. if seaweed needs to come from a range of sources it will not be as locally branded as when there is greater industry maturity. There is a reasonable expectation that once supply from A&B (or Highland regions generally) comes on-stream, this would be an advantageous branding opportunity.

7.7.2.3 Logistical

Davidsons Animal Feeds

Wet mass: There are logistical uncertainties arising from the need to transport wet mass e.g. degree of pre-processing (drying) required to reduce the potential for mould (currently only transporting dry ingredients).

Transport model: Davidsons has an efficient in-house transport model to work with, but there are potential limitations and costs associated with accessing remote regions. If supplied mainly from up and down the west coast then the existing system could be used, but further afield may require contracting in a haulier.

There is potential for a partnership (e.g. backloading fish feed deliveries serving coastal areas with seaweed), although there may be possible issues of cross contamination, different standards etc.

Storable states: The storage potential of seaweed will depend on how it is processed. Drying can help to overcome issues of seasonality and continuity of supply as seaweed meal dried to 20% moisture content or lower is considered stable. This has complex cost implications: whilst dry seaweed is cheaper to transport and easier to store, drying is a costly process and dried seaweed will need to be at least partially rehydrated before feed formulation.

General

Depending on the nature of the relationship, the intermediary / aggregator or the market player may be responsible for transport and logistics. Logistical needs for the market / off-taker will depend on the degree of pre-processing undertaken local to production i.e. whether the seaweed to be handled, transported and stored is wet or dry. They may also depend on the nature of the end product e.g. compliance with handling requirements to meet food standards.

7.7.2.4 Market

Davidsons Animal Feeds

Product differentiation: Some evidence has shown that inclusion of seaweed in cattle feed can have a positive impact on meat quality. It may also provide other benefits such as improving coat condition which can be important to farmers who show their animals. There is strong potential for product differentiation, building on Davidsons' success with previous high-value products and good reputation for customer service, though the extent of demand is not entirely clear.

Positive environmental impacts: Reduced dependency on soya bean imports will result in a smaller carbon footprint. Research also indicates that ruminants on a seaweed-based diet may produce less methane (though there is some evidence that this effect drops off after a certain period). This is a significant factor for farmers who are under increasing pressure to reduce their emissions, as well as for environmentally conscious consumers. Scotland recently committed to net zero carbon emissions by 2045.

Scottish provenance can contribute to the company's reputation as a family run business making a positive contribution to the local economy. To achieve the full potential of this it will be important to tell the provenance story i.e. from seashore and field to plate.

Byproducts: There may be potential to develop secondary revenue streams from byproducts e.g. biomass.

General

There is **strong potential for differentiated seaweed products** to do well on the market, capitalising on consumer health trends, environmental consciousness and the high value of Scottish provenance. However, there is fierce competition in these market segments and success will likely require a **targeted marketing strategy including strong branding**. This has happened to varying degrees in other aquaculture products: in salmon with strong Scottish provenance and branding, and increasingly more regionalised provenance; with mussels the pooling of product under Scottish Shellfish Marketing Group (SSMG) to be largely branded as 'Scottish', and occasionally more specific references to region.

7.7.2.5 Operational

Davidsons Animal Feeds

Quality standards: There is tight regulation around animal feed, heightened by the outbreak of BSE in the UK and the discovery of its link to CJD in the 1990s. Regulation may change after Brexit.

Site selection: Uncertainties relating to the appropriate species for inclusion (i.e. protein & nutrient content as well as issues such as taste & aroma) carry over into questions of site suitability (including site conditions e.g. exposure & water flow, and infrastructure e.g. jetty & road access), either for Davidsons itself of for a partner producer organisation. Site priorities for Davidsons include:

- Mainland
- Site access for trucks
- Proximity to processing plant (i.e. cost of transport)
- Water quality (i.e. impact on nutrient & heavy metal content)

There is potential compatibility with salmon farming where sites are licensed, and there is appropriate infrastructure, storage, loading equipment, access for trucks etc. However, consultees suggest that there are probably no easy wins due to incompatibility issues such as fouling.

De-risking: There is potential for Davidsons to increase resilience by reducing dependence on imports & associated costs / risks e.g. currency fluctuations, long lead times, carbon footprint. Aggregation could further de-risk the process but with possible knock-on effects e.g. inhibiting traceability which may be important to the 'food story'.

<u>**General**</u>

The **tight regulations** around animal feed are matched by those around food for human consumtpion. Depending on the waters in which it is cultivated, seaweed can have high iodine and heavy metal content. In the past this has caused environmental health issues with seaweed brought in from Northern Ireland without sufficient information on the packaging. Seaweed cultivated for human consumption requires a similar class of waters as mussel cultivation.

The above issues again raise questions for **site selection** as there is a lot of variation between locations and water types (though higher levels of heavy metals can be flushed out), as well as between species, and depending on harvesting methods. If the rate of inclusion of seaweed in a processed product is relatively low then this can be less important as the levels of heavy metals may be diluted so far as to become insignificant.

7.7.2.6 Financial

<u>**Davidsons Animal Feeds**</u>

Competitiveness: Davidsons is currently dependent on imported ingredients such as Brazilian soya bean which is an important protein source for feed. Long lead times on orders, currency fluctuations and delays represent weaknesses of this system and point to the considerable benefits that could arise from reduced dependency on imports.

Cost of protein: The cost of soya bean is low making it potentially difficult for seaweed to compete in the animal feed market as an alternative protein source. However, at a relatively low rate of inclusion and with strong provenance-based product differentiation it may be feasible to develop a seaweed feed product with a higher market value. The protein content is likely to come with a very different set of minerals and other characteristics (including taste), and at the current stage in development the learning costs per kg are high relative to established products. Blending seaweed protein with cheaper protein sources will therefore be the norm for some time to come (Figure 47).

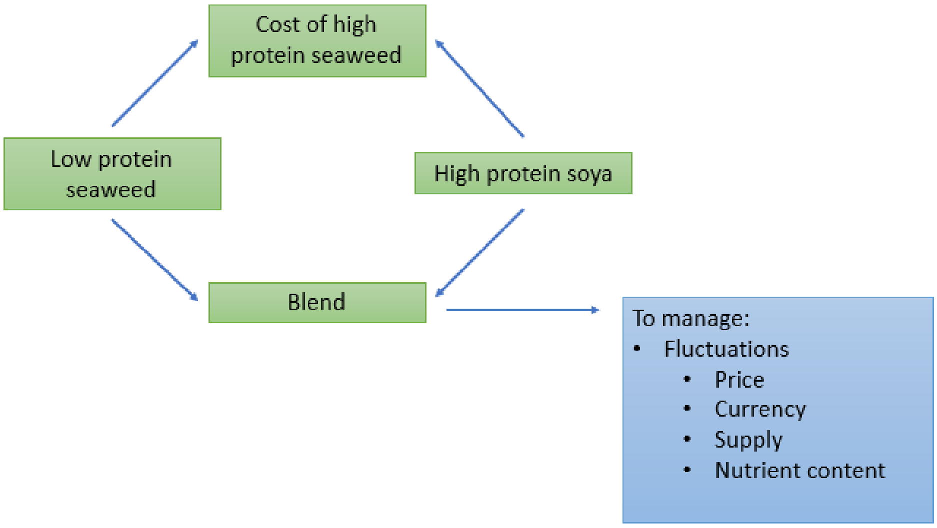


Figure 47. *Blending to manage constraints.*

Profitability: Past experience with other high value products suggests that a seaweed feed may be less price sensitive than expected because of differentiation through quality & customer service. However, farmers waiting for new prices to come in before bulk ordering suggests otherwise – they may demand high value feeds but may also be forced to use them in quite targeted ways depending on price. Further, the cost of processing and transporting a raw material like protein, possibly starting wet or unprocessed, could add cost beyond the cost of cultivation.

General

Research and product development is likely to be costly e.g. may require purchase of new machinery. Market players with knowledge and experience of seaweed (e.g. those diversifying from wild harvesting) will have an advantage over those seeking to integrate seaweed into their product lines for the first time.

Davidsons Animal Feeds: Indicative Cattle Feed Case Study

As an example, Davidsons may intend to sell 2,000 Mt of a new product range – "*Seaweed Special".* From a seaweed farm with 10ha cultivation area the company could reasonably expect to produce 700 Mt of seaweed per year, translating into perhaps 150 Mt when dried and after post-harvest losses have been accounted for.

The cost of soya bean is in the region of £350/Mt = £0.35/kg. The soya bean content of cattle feed is often around 30%, so to produce 1 kg of feed 300g of soya bean is required at a cost of £0.105.

The table below presents the price impacts of different rates of seaweed inclusion, assuming a base feed price of £0.30/kg. Figures are presented for dry seaweed prices of £5/kg, £3/kg and the target price of £2/kg to demonstrate the potential effects of reducing the cost of production. Assuming that a price increase of up to 20% is tolerable (i.e. can be recovered in final product price through differentiation) then when the price of dry seaweed is £5/kg, an inclusion rate of 1% is feasible but at 2% and above the impact on market price is too high. When the price of dry seaweed is £3/kg an inclusion rate of 2% is tolerable. If the price of dry seaweed were to drop to the target price of £2/kg then an inclusion rate of up to 3% would be tolerable. Of course, determining the right balance between the rate of seaweed inclusion and increase in target price will be important to achieving sales i.e. a lower priced product may prove more attractive whilst still achieving differentiation in spite of lower seaweed content.

Seaweed inclusion rate	Additional cost per kg of feed	New feed price	Percentage price increase
Dry seaweed price of £5.00/kg			
1%	£0.05	£0.35	15.5%
2%	£0.09	£0.39	31.0%
Dry seaweed price of £3.00/kg			
1%	£0.03	£0.33	8.8%
2%	£0.05	£0.35	17.7%
3%	£0.08	£0.38	26.5%
Dry seaweed price of £2.00/kg - **target price**			
1%	£0.02	£0.32	5.5%
2%	£0.03	£0.33	11.0%
3%	£0.05	£0.35	16.5%
4%	£0.07	£0.37	22.0%

*The additional processing cost of including seaweed is not accounted for here but will also have an impact on the final product pricing.

7.7.2.7 *Investment*

Davidsons Animal Feeds

Co-investment / partnership: Davidsons previously made a bid to the Scottish Funding Council which resulted in a funded research project with SAMS. Other funding, investment, and partnership opportunities that have been explored include:

- Innovate UK
- Agri-EPI Centre (Government Agri Tech research, development & demo centre)
- Scottish Enterprise
- Highlands & Islands Enterprise
- Argyll & Bute council
- EU funding (may depend on Brexit outcomes)

General

Significant investment may be required to overcome constraints and uncertainties of developing new seaweed products or integrating seaweed into existing products. However, there is strong potential for a **good return on such investments** e.g. good product differentiation & first-mover benefits in some industries.

Some market players have **developed incrementally from harvesting small volumes**, then increased scale. This should be seen as a **low-risk entry point** for investment in the market end.

7.7.3 Summary

Operators producing high value products in Scotland using seaweed sourced in the global market or seaweed alternatives are well placed to integrate cultivated Scottish seaweed into their products, benefiting from the marketing potential of Scottish provenance. Demonstrating quality and consistency of supply will be key to securing their commitment to production. Aggregation through supplier networks / contract farming models and intermediary services will go some way to addressing these concerns. However, trials demonstrating feasibility will likely be crucial to securing investment in production and getting the buy-in of some market actors.

7.8 Alternative & Emerging Models

7.8.1 Vertical Integration

Whereas the typology presented above is based on a disaggregated value chain, there is also potential for a fully integrated value chain approach. The benefits of such a system might be, for example, increased control over quality and supply.

However, there are also challenges. Planning is difficult; nobody yet knows what the perfect seaweed farm will look like. Regulatory pathways aren't entirely clear, for example changing a licence from mussel to seaweed farming or IMTA, and the associated EIA pathways. There are also many different seeding, cultivation, harvesting and processing methods being tested, with no one successful model as the clear frontrunner to pursue. It will take a new entrant several years to understand the running costs of a vertically integrated operation, and details such as where scale dependencies lie. Those who are willing to jump in and take a risk may reap rewards but there is also likely to be a brutal attrition process.

7.8.2 Tank Cultivation

Seaweed can be cultivated in tanks of seawater. Light, temperature and water flow is controlled to create what is called a 'tumbling culture'. Tank cultivation can be costly, requiring significant investment in infrastructure (e.g. water filtration systems) as well as day to day running costs. It is therefore not commercially viable to produce lower value seaweeds in this manner. However, there is potential for commercially viable tank cultivation of higher value seaweeds, particularly those that are difficult or costly to grow and harvest in the sea such as inter-tidal species. Because tank cultivation allows for controlled conditions (light, temperature, water flow etc.) it is possible to cultivate seaweed all year round and to more particular specifications (e.g. nutrient content) than wild harvest or sea-based cultivation would allow. They do result in reliable and consistent production in and out of season also making it easier to respond to market demand.

Palmaria palmata ('dulse') and *Ulva lactuca* ('sea lettuce') are examples of seaweeds potentially suitable for tank cultivation. Different species of macroalgae have different life cycles and significant research and development is needed to develop suitable seeding techniques for line cultivation. Tank cultivation mainly utilises the vegetative stage of the species being grown and over comes the need to be develop a seeding strategy. In Scotland both dulse and sea lettuce are still in the hatchery development stage but have been grown in tank cultivation, as has pepper dulse. This is only at the development stage in Scotland. However, tank cultivation has progressed further elsewhere. For example, in Canada *Acadian Seaplants* are producing high value sea vegetables under controlled lab conditions[11]. In some countries (e.g. China and South Africa) tank cultivation of lower value kelps is sometimes used as part of an IMTA process to help cleanse water and provide a food source for abalone production (Correa *et al.,* 2016).

[11] https://www.acadianseaplants.com/edible-seaweed-nutritional-supplements-ingredient/edible-sea-vegetables/production-of-hana-tsunomata

Green and circular economy innovations have potential to improve the commercial viability of tank cultivation. For example, surplus renewable energy can be utilised to reduce the (energy intensive) cost of production, particularly relevant for rural and island communities. The Algal Solutions for Local Energy Economy (ASLEE) project has been working with communities affected by grid constraints to channel renewable energy into running a photobioreactor for cultivation of high value microalgae[12]. Similar principles could be applied to cultivation of macroalgae.

7.8.3 IMTA

Exploratory work around cultivating seaweed within a polyculture marine farming system has been taking place over recent years. Growing seaweed, fish and shellfish in close proximity has circular economy benefits which can include maximising nutrient uptake, reducing nutrient waste (e.g. nitrogen recycling), more resilient production systems, and increased overall productivity (Figure 48). IMTA is usually confined to small scale aquaculture. However, a collaborative project between Scottish Salmon Company (SSC), Loch Fyne Oyster Company and SAMS involved a 4-year trial to assess the potential for integrating IMTA within the salmon farming industry. Species used in the trial included mussels, oysters, queen scallops, sea urchins and kelp (Zero Waste Scotland[13]).

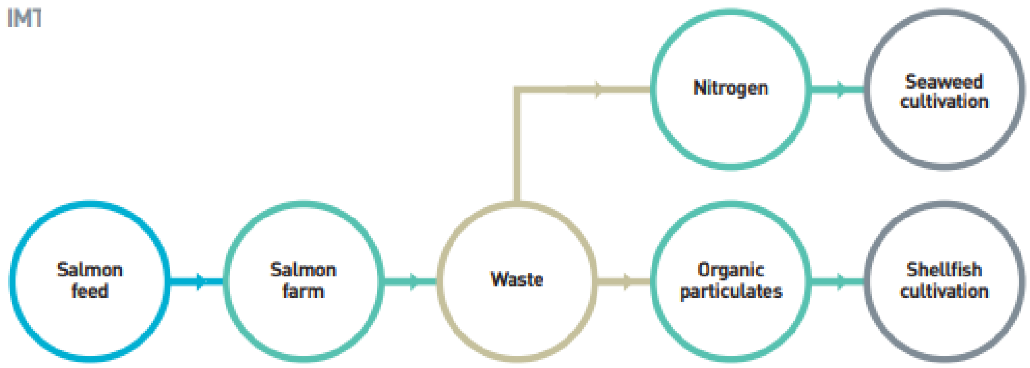


Figure 48. *IMTA nutrient flow (Source: Zero Waste Scotland)*

Whilst there is strong potential in this kind of approach, there are challenges around site suitability, licensing, and different species' lifecycles to name just a few. In reality it may therefore prove difficult to find workable synergies. However, organisations such as *Green Wave* in the USA claim to be reaping the benefits of IMTA systems.

[12] https://www.alienergy.org.uk/community-renewables-local-energy-economy/algal-solutions-for-local-energy-economy-aslee/
[13] https://www.zerowastescotland.org.uk/content/integrated-multi-trophic-aquaculture

GreenWave

"GreenWave is a non-profit ocean farmer and fisherman-run organization dedicated to building a new blue-green economy that creates jobs, mitigates climate change, and grows healthy food for local communities"

IMTA has received a good deal of attention in the USA, in particular from Connecticut-based non-profit GreenWave. The organisation has coined the phrase *"3D ocean farming"* to describe its *"vertical polyculture"* IMTA model (Figure 49). GreenWave runs a two-year farmer training program involving hands-on training (including technical assistance, permitting processes, farm setup, harvesting and market access) for up to 10 farmers each year. The approach to seaweed cultivation is hailed as easily replicable with low barriers to entry, requiring just *"20 acres, a boat, and $20 K"* to get started. GreenWave runs a hatchery and provides free seed (for sugar kelp) and incubation services to new farmers, aiming to have 500 farms operating in 10 regions within a 5-year period.

GreenWave has teamed up with scientists, industry representatives and NGOs to work on *Blue Carbon,* a project which aims to develop a carbon credit protocol that would be recognised by international carbon credit agencies. Seaweed is widely recognised as an important carbon sink, and such a scheme may contribute to the economic viability of seaweed cultivation in the long term.

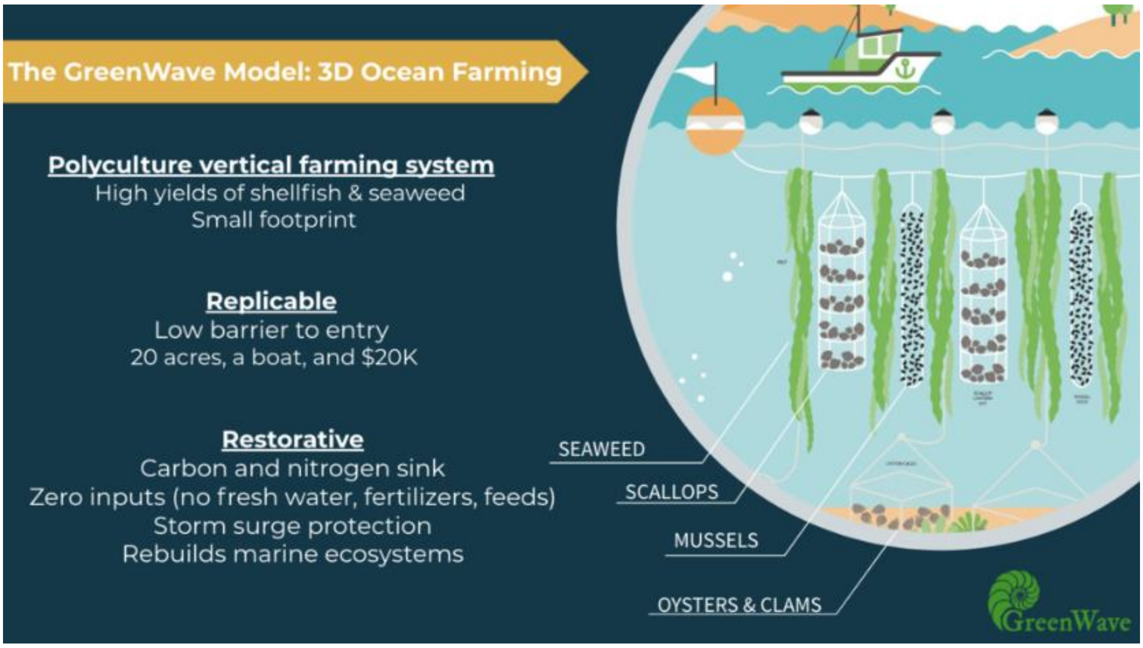


Figure 49. *Green Wave '3D Ocean Farming Model' (https://www.greenwave.org/our-work)*

7.9 Other Useful Comparators

7.9.1 Producer Organisations

The Scottish Shellfish Marketing Group (SSMG) is a cooperative company with 16 farmer members (Figure 50). Members would have struggled to consistently supply mussels to supermarkets as individuals and grouping together has achieved scale as well as lucrative processing and marketing income for farmer members.

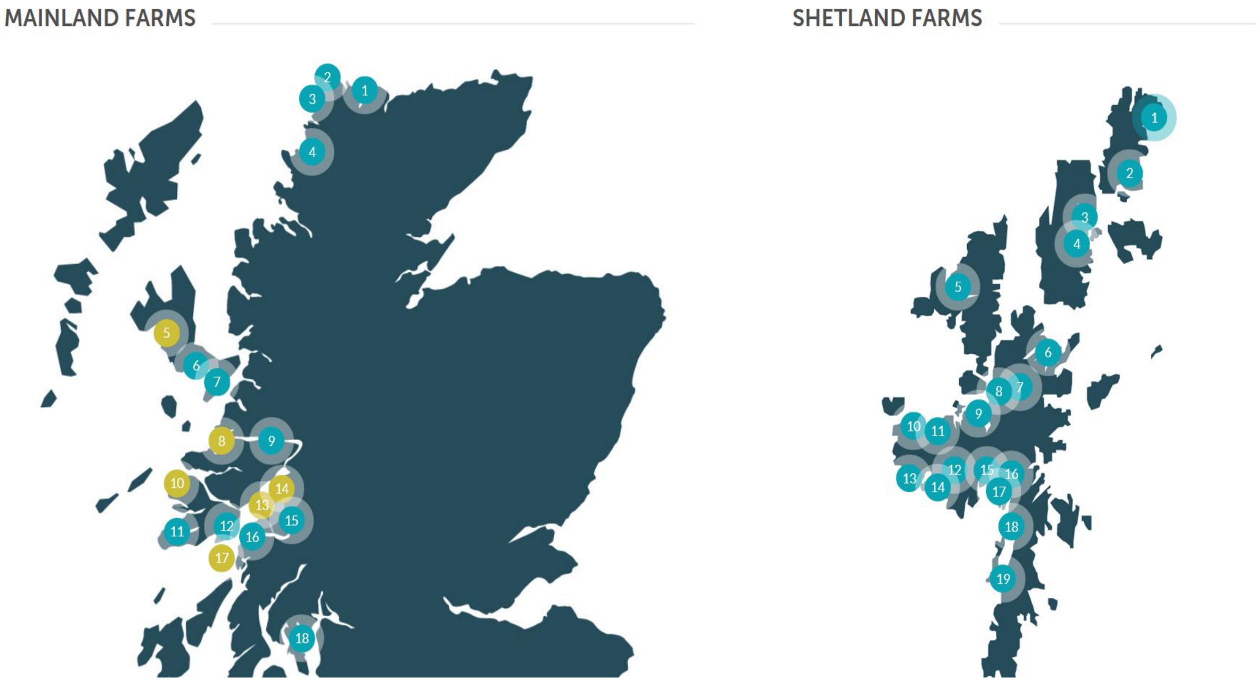


Figure 50. *Location of Scottish Shellfish Marketing Group sites (most processing takes place in Bellshill[14])*

The SSMG model recognises that those doing the farming might be geographically disparate, and more focused on farming challenges rather than marketing. Significantly, when there was an algal bloom in Shetland in 2013, the supply risk was managed by sourcing more from West Coast growers.

Seaweed farming may find scale with such cooperative models, though currently the different uses of seaweed (compared to mussels) may preclude such a strategy. Nevertheless, an active coordinator and aggregator can transform the opportunities for individual and otherwise isolated producers.

[14] http://www.scottishshellfish.co.uk/our-farms/

7.9.2 Lessons from Wild Harvesting

Seaweed companies engaging in wild harvesting and operating at both large and small scale have lessons for cultivation in terms of:

- Aggregation models
- Price and market benchmarks
- Processing feasibility
- Investors in seaweed

Such insights can help inform the development of the cultivation e.g. understanding which models are likely to be better suited to community development and which may attract more business investment.

Uist Asco is an example of an established player in wild harvesting from which lessons can be carried across to the nascent cultivation industry (Figure 51).

- Acquired in 2017 by Canadian biotech company Acadian Seaplants – large independent manufacturer of seaweed-based products for food, biochemical, agricultural and agri-chemical markets
- Acquisition has secured further investment in processing facility and in local harvesting infrastructure e.g. landing sites. It has also brought in experience and technical expertise from the more developed Canadian industry
- Improved processing facility can accommodate increased volumes. Wood sources from a local forest is used as biomass to power the drying facility
- Employing local people in full and part time harvest, offering support such as harvesting training, tools (e.g. sickles, nets & ropes), and financing arrangements for boats & motors

Figure 51. *Uist Asco - conveyor dryer, hand harvesting* [15,16]

[15] http://www.europeanmarinesciencepark.co.uk/news-events/2018/uist-asco-increase-harvesting-rewards/
[16] https://www.uistasco.com/

7.10 Optioneering / Investable Ways Forward

There are a number of interdependencies between market and production, and the reason a study such as this is required is to examine what is feasible, but equally to establish a pathway to circumvent deadlock. Often the emphasis to date has been on species, which is important, but not a sufficient determinant of success – at this stage in the industry's development, the organisational capacity and confidence in production results is proving to be at least as important.

While coordination is required, there does appear to be sufficient market interest to build the nascent infrastructure for a seaweed sector, and the regulatory barriers in doing so should be possible to overcome. A demand-led approach would be advisable, but so long as there is still lack of clarity about what products are on offer or possible, there will be stasis.

7.10.1 Investment in Trials

Whilst the need for the development and maintenance of pilot farms to investigate seaweed species, growth rates, yield, costs, environmental effects has been highlighted (Capuzzo & McKie, 2016), there has been relatively little investment in trial sites to date. Given the relatively low costs of developing trial sites, and the willingness of new entrants to 'give it a go' to make the sector work, it is feasible to set up a trial as detailed in Table 14 below.

Table 14. *Options for developing trial sites and processing activities*

Activity	**Timeline[17]**	**Indicative costs**
Select 5 or 6 sites	6 months	£25 k
Fund a technical assistance budget for producers and intermediaries to organise consented sites	12 months	£30 k (planning costs assuming use of some already consented sites)
Fund trial harvesting and drying equipment	18 months	£75 k
Trial up to 10 species across different sites	18 months	£50 k
Invite market participants to trial processing and feedback preferences and requirements	6 months	£30 k
Support producers and intermediaries to contract and invest	6 months	£40 k
TOTAL COST		**£250 k**

It is expected that by rapidly progressing through a valley of trial and error, it can quickly (and safely) be established what potential business models can be progressed.

[17] NB the timeline is not always consecutive – in some cases activities can happen in parallel

This is in a similar manner to wave and tidal energy development, where a level of attrition in pilot projects was expected, before successful models emerged. However, it is thought that the full cost of trials in seaweed production would be considerably lower. As with the EMEC wave and tidal model, a platform for trials will allow the sector to rationalise and convene around viable operations.

Specific proposals even at a scale of one or 2 sites may deserve support in the short run as any and all trial intelligence will help to inform future rounds and provide an evidence base for future trials and industry investment.

Trials may ideally involve contributions from private sector actors, including buyers and intermediaries, either funded by themselves or as implementing partners.

Existing consented sites may not be illustrative of different marine conditions across Argyll & Bute but may still be valuable to utilise. For example, they may increase ease and speed of implementation, bring operational benefits, and help trial a process of starting with the business capability rather than starting 'cold' with the species, which is not always the key determinant of production. Sites may cover different operational and production models as well as species, and different string production sources.

Beyond trial sites, it is important to consider other value chain functions such as drying. Trials may be effective here in allowing the deployment of mobile drying facilities across sites – it is likely that this will inform producers whether to continue with 'toll-drying' or whether to invest in their own facilities.

Market buyers have a wider range of differing needs and may have less value in trying to manage through a trial process, with more constraints in terms of commercial confidentiality. Market buyers such as Davidsons would likely incur costs in trialling their feed mix – this kind of activity may benefit from technical assistance support (though Davidsons are already working with similar through a Knowledge Transfer Partnership). Market buyers such as Mara would likely be in full control of their market development but again may benefit from some technical assistance funding if it could be shared, e.g. food standards development.

7.10.2 Opportunities for Economic Development, Employment & Training

Opportunities for economic development include **making sure that value addition activities take place within Scotland**, providing employment opportunities as well as other social and economic development benefits. This will require **investment in technical capacity development**. The emergence of the marine training centre in Oban (in development) may go far in providing the requisite skills for seaweed production.

Opportunities also lie in less processed seaweed both for the domestic food market and for export. There is **unmet demand locally**, particularly in the health food market, and this is only likely to increase. Some value added, branded products are being sold abroad, such as Mara's range of seaweed flakes and powers, and Seaweed & Co's *'Weed & Wonderful'* seaweed infused oils. There is significant room for growth here, **drawing on the strength of the brand power of**

Scottish provenance demonstrated in some of its biggest food and drink export products (e.g. Whisky, salmon, and shellfish).

> *"The share of algae-containing food and drink launches in Europe has grown over the past few years, from 0.6% between October 2012 and September 2013 to 1.4% between October 2016 and September 2017" (Mintel, 2018)*

Opportunities need coordination from the industry, and the benefits should be recognised beyond the primary production site. Successful Argyll & Bute production will result in economic benefit to other areas of Scotland, as is currently the case with the nascent industry. This may be more likely with the emerging labour effects of Brexit.

The industry would benefit from the SSIA taking an active and interventionist role in building the market and troubleshooting gaps. One area of focus is to work with intermediary organisations in actively connecting up the value chain. A priority for the SSIA appears to be identifying which producers may be willing to partner with them to implement production.

From the producer's perspective, guaranteeing a market and having processing and value addition in viable volumes and in a more centralised way is likely to bring results. It may be that some producer organisations wish to take their production from growing through drying to final market sales, but currently those potential candidates are not identified or likely to be the norm.

According to the Pegasus report (Barbier *et al*., 2019)**, if market growth of 6-8% per year is maintained, marine biotech revenues in Europe could reach €1 billion within 5 years, resulting in the creation of 10,000 new jobs.** This will rely on a significant step-change in volume and overcoming the consequent potential spatial impacts of production. Land-based tank cultivation is increasingly mooted as a solution in the salmon industry, but it is likely to have larger energy requirements and a different set of compliance challenges, and relies on a high value per kg.

7.10.3 Community Benefits Summary

The feasibility analysis highlights several key points regarding the potential for communities to benefit from the development of seaweed cultivation businesses.

1. Communities should be ready to link with intermediaries

Communities may have skills and experience that translate to starting a seaweed cultivation business. For example, SWMID demonstrate clear business management and development capacity, and local fishermen are likely to have much of the required marine experience. Lack of technical expertise with seaweed and knowledge of specific cultivation and harvesting processes is, however, likely to present a challenge. The analysis demonstrates that there are a number of intermediary service providers who could partner with communities to fill this gap. Acknowledging the value of partnering and choosing the right partner will be key to the success of community seaweed cultivation projects.

2. Communities should not engage in cultivation without establishing a market

There is a risk that without adequate consideration of potential markets, community producer groups may struggle to find a buyer for their crop. Researching market opportunities should take place during planning stages, as it will impact upon many other considerations including site and species selection, harvesting techniques, and pre-processing requirements. Again, the role of a partner / intermediary organisation is potentially very important here and can vary in nature. For example, partnership with an established processor/retailer may (or may not) guarantee offtake of the product but bring less in the way of technical assistance. Alternatively, partnering with an intermediary consultant may offer high-level technical assistance and help link to market opportunities but with less guarantee. For this reason, establishing clear terms / mode of engagement with intermediary service providers is paramount.

3. Community ownership of production is likely to have long term benefits

One important benefit of community ownership is the high likelihood of securing social license to operate. The Development Trusts Association Scotland highlights further benefits of community ownership of local assets, including:

- **Delivering Social & Economic Purpose** e.g. protects key local services / facilities that may otherwise be lost, allows generation of income that can be re-invested locally, provides jobs, training and business opportunities.
- **Changing Attitudes and Relationships** e.g. gives the group credibility with funders / other stakeholders, instils a renewed sense of pride and confidence in the community, can increase participation - membership, volunteering, attendance at meetings.
- **Moves Communities towards Financial Self-Sufficiency** e.g. the organisation can generate income from the asset, ownership avoids rent payments / increases, there is incentive to invest in building to reduce running costs - e.g. energy efficiency.
- **Builds Organisational Sustainability** e.g. independence / control over future of asset allowing you to make long-term plans, leverage, enabling you to negotiate further investment, development of skills and capacity locally, attracting new people with additional skills.

These kinds of benefits can be seen in community-owned renewable energy schemes in Argyll & Bute and across Scotland. For example, **Islay Energy Trust** (IET) developed a community-led plan to put a wind turbine on Islay, with support from a CARES loan and the Big Lottery Fund. The project cost £1.2 m; over £0.5 m was raised in local equity and the balance was covered by a loan from the Renewable Energy Investment Fund. The turbine was completed in 2015, and all loan and interest payments are up-to-date. Shareholders receive a 4% annual interest payment, and all additional income is distributed to community projects through Islay Energy Community Benefit Society. So far 53 projects have been supported to a value of £91K[18].

[18] https://www.localenergy.scot/projects-and-case-studies/case-studies/community-owned/islay-community-wind-turbine/

7.10.4 Working with Communities

Non-community owned seaweed cultivation enterprises will need to think carefully about how they work with communities (Figure 52). In order to establish and maintain social licence to operate, they will need to regularly consult and engage with the communities in which they operate. Whilst there may or may not be a moral inclination to do this, research and experience tell us that it makes good business sense for companies to operate as good citizens and good neighbours[19]. Indeed, not having community buy-in can limit access to new sites for development as well as being costly in terms of time, money, and reputation. On the other hand, engaging with communities, and doing so early on to establish a good working relationship can boost a company's reputation, winning local support and opening up opportunities for expansion (Billing & Tett, 2018).

Figure 52. *Engaging for social licence (Source: SSPO Community Charter)*

Communities may benefit from such engagement in a variety of ways, including:

- Understanding of company operations
- Direct and indirect employment opportunities
- Skills development, training and apprenticeship opportunities (important for maintaining a working age population in rural and island communities)
- Localised economic benefits e.g. shops, restaurants, services
- Diversified economic opportunities e.g. value addition for Scottish products
- Improved economic case for local services e.g. transport & infrastructure
- Community projects and sponsorship of local teams etc.

[19] http://scottishsalmon.co.uk/wp-content/uploads/2016/09/community_charter_2016_digital.pdf

8. CONCLUSIONS

8.1 Knowledge Gaps

Seaweed cultivation is an emerging industry within Scotland and the rest of the UK. Gaps in knowledge exist across the supply chain. These gaps need to be filled to ensure the viability of industry in the long-term. Some of the key knowledge gaps are summarised below.

8.1.1 Yields and Running Costs

The FAO provides estimates on global production of seaweed, but there is a lack of accurate numbers for production in the UK. There is a need to model income over running costs, with a requirement for different models from low to high value products, which may enable industry development. Once these have been developed, establishment of local markets will likely follow, ultimately leading to a chance to compete globally. There is also currently a lack of any life cycle analysis of products.

The cost of maintaining and running cultivation sites are also very poorly understood in the UK, partially due to uncertainty over the cost of environmental monitoring. This is related to the unknowns with respect to the potential environmental impacts of cultivation sites, and how the scale of farming may influence the surrounding marine ecosystems.

8.1.2 Business Development Support

The development of a seaweed cultivation industry would provide important economic growth to the Highlands and Islands both supporting national strategies to increase seafood production and providing jobs in the area. Businesses and entrepreneurs wanting to enter the seaweed industry have many barriers to overcome, these businesses face high start-up costs and risks. Key to developing the industry will be commercialising research knowledge and providing business support through innovation assets.

In Scotland, local authorities offer guidance through Business Gateway which offer advice and signposting for other services. Support can also be accessed through enterprise bodies Scottish Enterprise and Highlands and Islands Enterprise (HIE). New businesses can access support from HIE through programmes such as the Northern Innovation Hub and Accelerate Aquaculture Innovation Fund. *Just Enterprise* offers business development support to social enterprise and the third sector, *Firstport* offers start-up advice and funding to social entrepreneurs. *Zero Waste Scotland* offers funding through their Circular Economy Investment Fund. Support may also be accessed from private companies. The Argyll Rural Growth Deal is expected to provide investment to support the growth of the marine economy in Argyll & Bute.

Access to business support and innovation funds are crucial to support small-medium enterprises to set up within the industry. Scottish research institutes have world-class expertise within seaweed cultivation and specialist knowledge of the region, this expertise is an important resource for knowledge transfer to industry and development of novel technologies. Setting up networks and innovation funds to enable new connections between enterprises and research institutes can help accelerate the growth of the industry.

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ANNEX A: Q-METHOD STUDY

Q-method is a semi-quantitative technique used to explore subjective views on a particular topic in a clear and structured way (Zabala, 2014) – in this case seaweed cultivation in Argyll and Bute. It has been used to study perceptions of aquaculture in several different locations, revealing areas of consensus and areas of conflict (Bacher *et al*., 2014).

There are typically five phases to Q-method: 1) development of the concourse, 2) development of the Q-set (statements), 3) development of the P-sample (participants), 4) the Q sort and 5) data analysis (Watts & Steinner, 2005). A more detailed breakdown of how these steps were followed for the feasibility study can be seen below.

Research question:
How can seaweed cultivation develop in a socially sustainable way?

1. Concourse

A comprehensive list of statements reflecting all possible around the opinions concern. These statements can be drawn from several sources including; policy documents, interviews, scientific articles, workshops, media sources etc. For this study the researcher used workshops (x2), interviews (x8), policy documents, and scientific articles.

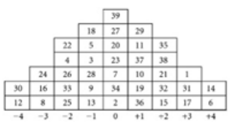
2. Q-set

Selection of a representative sample of statements from the concourse that participants will rank. The approach taken can vary, however in this case, statements were categorised into four topics and a balanced number of statements were chosen from each topic – 20 in total.

3. P-sample

The aim of Q-method is to cover a broad diversity of opinions. In turn the people chosen to complete the task form a purposive sample. In this case, those who have interest in seaweed cultivation either from a development or a concerned perspective. The sample used in this study included 16 people who represented seaweed cultivators, harvesters, researchers, policy-makers, planners, certification agencies, supply-chain, community groups and, other local interested parties.

4. Q-sort



The participants are asked the arranged the set of statements – the "Q-set" labelled 1-20 – across a normal distribution (bell curve) that indicates agreement/disagreement and in relation to one another, in this case from -4 to +4. The result of each ranking is called the Q sort.

5. Data analysis

Each Q sort was then analysed using a software called PQmethod. The sorts were factor-analysed to capture a small number of ideal factors that capture an acceptable amount of the study's overall vector variance. The narratives presented are derived using a statistical process (Principal Component Analysis) and are the product of any subset of the participants who revealed similar views through the distribution of the sorted statements. For this study, the researchers chose a solution with three factors that represent groups of shared societal perspectives.

In addition to asking participants to rank the statements (Q-sort), they were also asked to explain the rational behind their choices. This provided qualitative data to back up each of the three narratives described in Section 6. The purpose is to understand the differences in reasoning leading up to participants choices of ranking, as they can differ despite coming to the same ranking conclusions (Zabala *et al*., 2018).

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ANNEX B: SUMMARY OF DATASETS FOR MAPPING OF SUITABLE CULTIVATION SITES

All maps were created using QGIS 3.6.1 GIS mapping software. The following summary briefly describes the datasets that were used to create the site suitability maps shown in Section 4.

Broad-scale (5-100 km) information, from satellite data products:

Composite time-averaged data on chlorophyll a, sea surface temperature and particulate backscatter was obtained from the NOAA Giovanni web data portal (https://giovanni.gsfc.nasa.gov/giovanni/). Averages across all images from 1/1/2003 to 31/12/2018 produced each layer. Chlorophyll *a* estimates were from MODIS Level 3 4.5 km resolution images, time-averaged and downloaded 30/8/2019 and using the Hu *et al.* (2012) spectral algorithm to give estimated mg/m^3. Particulate backscatter was similarly derived from the same MODIS satellite averaged over the same period, expressed as the backscatter coefficient (bbp) at 443 nm (Werdell *et al.*, 2013).

Sea surface temperature data, as the MODISA L3m SST product from the same satellite derived from nighttime infrared (11 microns) irradiance, were averaged over the same period. Average temperatures were calculated for the whole year and for each month of the year separately (Fig. 30).

Sea loch catalogue data

Data from the Scottish Sea Lochs Catalogue (Edwards & Sharples, 1986) were obtained from SAMS archives (also at https://www.bodc.ac.uk/resources/inventories/edmed/report/647/)

Wave exposure

A 200 m resolution wave fetch model (Burrows, 2012) (data available at Marine Scotland's National Marine Plan Interactive website) was used for large-scale indication of likely areas of suitable wave exposure. A scaled-down version of this model at approximately 20 m resolution was used to evaluate wave-fetch/depth suitability patterns for the placement of seaweed farms of particular sizes and designs

Inshore bathymetry

Oceanwise 6-arcsecond (190 m x 100 m) and 1-arcsecond (18 m x 30 m) bathymetry were obtained from digimap.edina.ac.uk under the terms of the Marine Digimap Educational User License https://digimap.edina.ac.uk/webhelp/marine/terms_of_use/digimap_marine_eula.pdf.

Locations of Scottish aquaculture installations

Fish and shellfish farm site locations were used to determine the operational ranges of depth and wave exposure for aquaculture in Scotland (Figure B1; data from http://aquaculture.scotland.gov.uk/data/site_details.aspx).

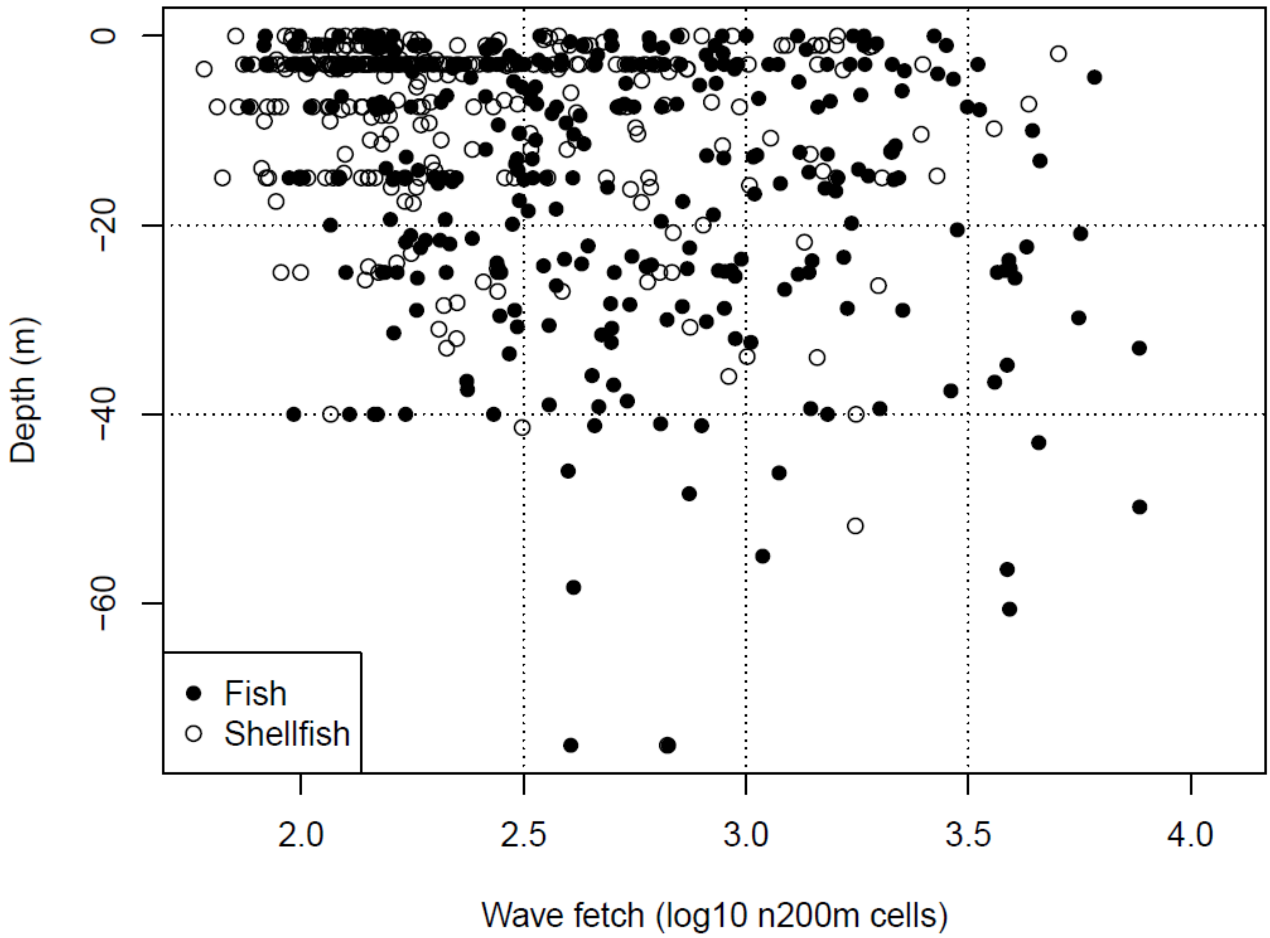

Figure B1. *Depth and wave fetch for Scottish marine aquaculture locations. Based on practice, most locations are in <40 m depth and <3.5 wave fetch units.*

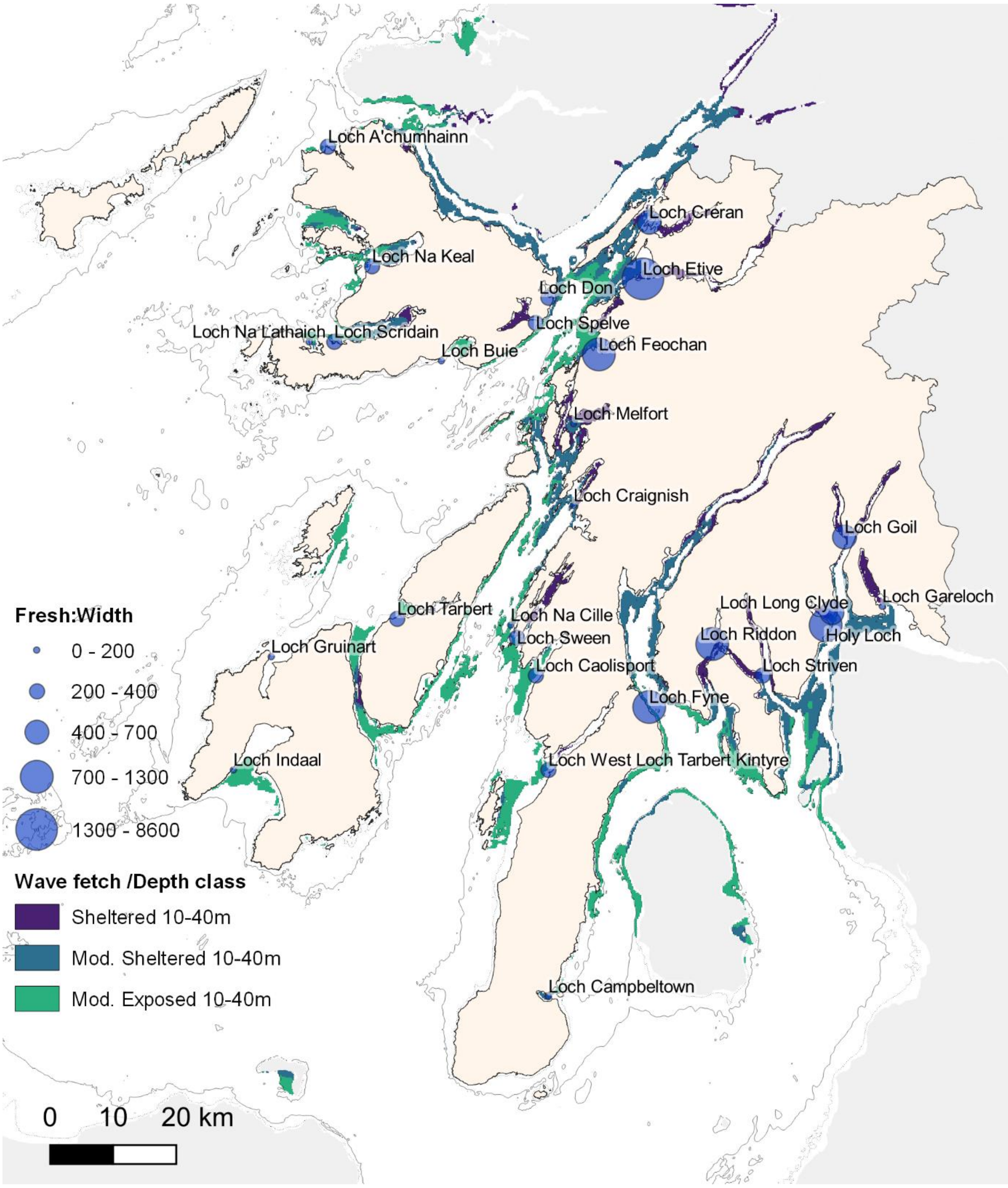

***Figure B2**. Areas of coastal Argyll and Bute with suitable combinations of depth (10-40 m) and wave exposure (0-3.5) shaded in blue/green. Likely influence of land runoff on sea loch salinity is shown for each loch in the region by symbols sized to reflect the ratio of freshwater input to the width of the loch, a known additional indicator of the likely freshwater influence.*

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ANNEX C. VOLUME-VALUE MATRIX

	Value	Volume	Examples	Needs to be viable	Reliant upon integrated VC?	Competition	Price Characteristics - likely to be …	Economies of scale / marginal cost	Scalability
General	High	Low	Gin, soap, candles, high end food products	Marketing, brand, provenance	Yes	Low	Not price sensitive	High fixed, low marginal cost	Low
	High	High	Gaviscon	Quality and specific compounds or large market	Yes	High	Price sensitive?	High fixed, medium marginal cost?	High
	Low	High	Feed, fertiliser	Scalable but price sensitive Large market	No	Medium - High	Dependent on percentage of total volume	Lower fixed, high marginal cost (transport)	High
	Low	Low	Community project, sporadic use	Would need another reason (e.g. local provenance)	Yes	Low	Not price sensitive	Lower fixed cost, low marginal costs	Low
Other: R&D	High	Low	R&D (SAMS)	Often public funding initially and research spin-off vehicle	No	Low	Not price sensitive	Assumes creation of a viable private sector	Low
Other: Contract Farming	Processed and on-sale	High - contract farming?	Contract farming (international example) - also Uist Asco	Effective contract farming model, sale farm gate vs final sale price	Yes	Low initially	Not price sensitive	High economies of scale, low entry costs	High

			harvesting precedent						
Other: Cooperative Models from proximate sectors (shellfish SSMG)	High	High	SSMG (shellfish aggregation, processing and marketing platform	Some members at scale	Yes	Low	Not price sensitive	High economies of scale, low entry costs	High

	Social benefit - likely to be …	Human	Physical	Natural	Financial
General	TBC - strong potential benefit for similar producers / community through provenance	G	G	G	G / R
	Likely to be professionalised, benefit in core supply chain impacts, high skilled jobs	G	G	G	G / R
	Possible employment impact	G / R	R	R	R
	Possibly high but at low scale, possibly limited supply chain impacts.	R	G	G	R
Other: R&D	High professionalisation and skills demand, wider impacts through construction / supply chain	G	G	R	R
Other: Contract Farming	High access and inclusion, scalable. Assumes good working relationship between actors.	G	G	R	R
Other: Cooperative Models from proximate sectors (shellfish SSMG)	High access and inclusion, scalable. Assumes good working relationship between actors.	G	R	G	G

ANNEX D. FEASIBILITY SUMMARY BY CATEGORY

	Producer Organisations	Intermediaries / Aggregators	Market / Off-takers
Stakeholder	Ability to secure and maintain **social license to operate** will depend on how a producer organisation relates to the local community. This is likely to be easier for organisations rooted in the community or with strong local or possibly regional connections. Those less connected will benefit from investing in positive engagement by. Level of ownership by stakeholders may influence social license, but in comparator sectors SMEs with a local presence should be able to maintain support.	Intermediaries are likely to have more experience in dealing with **planning and consultation** than new entrants. This can help to avoid delays, additional costs and the possibility of antagonising local stakeholders e.g. other users of marine space.	Engagement with relevant stakeholders for **research and development** is likely to be required by market players developing new seaweed products, particularly new entrants and those with little experience of working with seaweed.
Production	Limited site availability may have a knock-on effect on **what species can be cultivated**, with direct implications for producer organisations' suitability for involvement in contract farming operations. Smaller producer organisations may struggle to produce the **requisite quality and quantity for market** on a consistent basis, though integration into a contract farming operation may dilute these effects.	The **experience** of an intermediary player is likely to translate into benefits at the production stage. This may be in the form of technical assistance to the party implementing cultivation, resulting in greater efficiency and ultimately higher production volumes. These benefits are likely to increase as the level involvement of the intermediary increases i.e. they will be most significant when the intermediary is	Some pre-processing is likely to have been undertaken by producers or intermediaries. However, some market players will want to maintain complete control over **processing** themselves, and most are likely to undertake further steps (e.g. integrating into final product, packaging). The type and degree of processing undertaken will vary according to the target market.

	Producer Organisations	Intermediaries / Aggregators	Market / Off-takers
	Whilst larger organisations are able to employ experts to run their cultivation operations, community-based organisations will likely lack that capacity. Lack of **in-house technical expertise** is a strong driver for operating within a contract farming model / training and technical assistance from intermediaries, at least in the short term, with the option of greater operational independence over time. **Drying & processing capacity** is likely to present a challenge to producers - planning for harvest and managing drying capacity effectively is essential to minimise spoilage. External mobile dryers for hire seem a viable model (as with agricultural machinery 'rings' to overcome seasonality and underutilisation. **Working in partnership with other local producers** (e.g. oysters & mussels) could provide benefits such as shared use of marine space/suitable sites, labour, other resources that could cut the costs and/or increase the productivity of both operations.	more hands-on / essentially takes on the role of producer. If an intermediary acts as an aggregator then there may be **efficiency gains** in processing. The degree of **risk and responsibility** an intermediary takes on requires consideration – they may be responsible for sourcing seed, site development and other timely harvesting. The sharing of risk may ultimately drive greater integration between intermediary and producer group.	Potential for **circular economy** benefits through use of waste and byproducts. **Packaging of products** may be pitched so as to **overcome supply constraints**, i.e. if seaweed needs to come from a range of sources it will not be as locally branded as when there is greater industry maturity. There is a reasonable expectation that once supply from Argyll and Bute (or Highland regions generally) comes on-stream, this would be an advantageous branding opportunity.
Logistical	**Site accessibility** will have a significant impact upon logistical feasibility i.e. easy	Logistics will largely depend on the **degree to which processing takes**	Depending on the nature of the relationship, the intermediary /

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	access by road is desirable. **Suitable and efficient loading equipment** is also an important consideration. **Transporting seaweed** can be difficult and costly. Potential efficiencies to explore include backloading delivery trucks, though this can raise issues e.g. contamination. Drying and milling seaweed significantly reduces its weight & volume and therefore the cost of transportation.	**place local to production**, or off-site at the market end. Some buyers will want to have as much **control over handling and processing** as possible. If the intermediary acts as an aggregator then there may be **efficiency gains** in relation to transportation.	aggregator or the market player may be responsible for transport and logistics. Logistical needs for the market / off-taker will depend on the degree of pre-processing undertaken local to production i.e. whether the seaweed to be handled, transported and stored is wet or dry. They may also depend on the nature of the end product e.g. compliance with handling requirements to meet food standards.
Market	**Intermediaries and commercial partners** are likely to be pivotal to the success of community producer organisations, bringing important technical and market knowledge to the table. **High value local products** (e.g. seaweed soaps & candles) can be developed and marketed by community producers as part of the 'local experience'. Though it is important to have an **established market link** before engaging in production, this is likely to become easier as the market develops and demand grows.	The intermediary has a role to play in **narrowing down options for potential market buyers and linking them with feasible producers**. They may also be able to access higher volume markets through aggregation. The degree to which this service can be paid for will likely change as the market matures – currently there is a **strong need for a 'scouting' function**, which would reduce search costs. In a future, more mature market, the market buyers and organisers will perhaps be more proactive and vertically integrated in their approach, as with salmon and shellfish sectors.	There is strong potential for differentiated seaweed products to do well on the market, capitalising on **consumer health trends**, **environmental consciousness** and the high value of **Scottish provenance**. However, there is fierce competition in these market segments and success will likely require **strong branding** and a **targeted marketing strategy**. This has happened to varying degrees in other aquaculture products: in salmon with strong Scottish provenance and branding, and increasingly more regionalised provenance; with mussels the pooling of product under SSMG to be largely

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			branded as 'Scottish', occasionally with more specific references to region.
Operational	Community-based organisations will be limited in terms of **site suitability** and further affected by ability to acquire land in a suitable location close to the cultivation site. This will be less of an issue for bigger outfits with more flexibility in site selection. **Regulatory pathways** can be opaque and difficult to navigate, particularly for producer groups who have no experience in aquaculture. Planning, licensing and regulatory matters could be usefully supported or mediated by an intermediary organisation.	**Operational know-how** is a key factor driving the intermediary role and will be the conduit for rationalisation and new techniques in the industry, including, for example, finding efficient harvesting models across boat, line and a short season. **Opportunities and trade-offs** are understood by intermediaries who would seek to maximise production within the constraints of particular sites. Intermediaries are likely to have **established relationships with regulators** and significant **experience with planning and licensing** issues which can help to ensure smooth operations.	**Quality standards** are high around both animal feed and food for human consumtpion, with **strict regulatory requirements**. Depending on the waters in which it is cultivated, seaweed can have high iodine and heavy metal content. Such issues can raise environmental health concerns and have implications along the value chain e.g. processing, transportation and labelling. Quality standards also raise questions for **site selection** due to variation in conditions between locations and water types, as well as between species, harvesting methods etc. This may be less relevant if the rate of inclusion of seaweed in an end product is low and heavy metal content is diluted beyond significance.
Financial	**Processing** (i.e. drying & milling) is likely to be required before transporting and can represent a significant cost.	**Intermediary organisations will take a cut / margin and may require certain contract arrangements** but working with them	**Research and product development** is likely to be costly e.g. may require purchase of new machinery. Market players with

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	Staffing is likely to be one of the biggest costs faced at the production stage and may prove challenging for smaller and community-based producers that wish to provide full-time, meaningful job opportunities. The degree to which labour can be flexible, seasonal, internalised with other functions (like checking seaweed along with parallel mussel operations, reducing boat and capital costs for seaweed) or outsourced to a lean intermediary operator under contract is likely to be a relatively strong driver of viability. Intermediaries buying / producing seeding materials and other equipment in bulk may facilitate **preferential prices** for smaller producer organisations.	may be key to overall feasibility, particularly for new entrants. **The reliability of costing of intermediary functions is variable** – technical assistance time can be estimated and geared relatively clearly, while functions like having a roving harvester that can travel across different producer sites may be harder to fully cost at this stage in the sector's development. The degree to which the intermediary gets involved in drying and transport is still unclear – **there is a strong case for mobile drying units** serving different producer organisations. This could also reduce risk of spoilage under transport constraints.	knowledge and experience of seaweed (e.g. those diversifying from wild harvesting) will have an advantage over those seeking to integrate seaweed into their product lines for the first time.
Investment	Community based organisations have the advantage of **access to finance** streams not available to others e.g. Scottish Land Fund, Social Investment Scotland. Financing similar SMEs such as mussel farms and inshore fishing boats has proven a challenge in the past. **Learning lessons and constraints is crucial** –	Currently, those with intermediary knowledge are funded either through i) **a vertically integrated model** where the same organisation is selling final product to the market, ii) being **hired by a producer to develop a site**, with a view to producing seaweed, possibly having built a market through harvesting the	**Significant investment** may be required to **overcome constraints and uncertainties** of developing new seaweed products or integrating seaweed into existing products. However, there is strong potential for a **good return on investment** e.g.

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	some inshore fishing groups help coordinate individuals and banks (as in the Western Isles) or financed directly as organisations. In Shetland, Nordic Banks have been interested in lending to mussel farmers and now Scottish banks are being encouraged to do the same.	same species, iii) **institutional capital** seeking to invest heavily in the seaweed market and gain first-mover advantage, but prepared to take significant risk, iv) **a buyer seeking to establish a controlled** / dedicated supply source but not wanting to get bogged down in ownership of sites. Having an experienced intermediary on board may **help new entrants to leverage finance** e.g. through development of a strong business plan or demonstrable technical capacity.	product differentiation & first-mover benefits in some industries. Some market players have developed incrementally from harvesting small volumes, then increased scale. This should be seen as a **low-risk entry point** for investment in the market end.