Irish Macro-Algal Cultivation
Strategy to 2030

BIM
Ireland's Seafood Development Agency

A STRATEGIC REVIEW OF IRISH **MACRO ALGAE CULTIVATION**

Rialtas na hÉireann
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Section 1
Introduction

The global focus on developing a healthy and sustainable ocean economy has never been stronger. An upscaled, responsible & sustainable blue economy is seen as vital to attaining the UN's Sustainable Development Goals and reaching the objectives of the European Green Deal.

Seaweed (macroalgae) is regarded as a promising resource with the potential to support new and revitalising industry within a blue economy, whilst delivering significant environmental and social benefits. As evidenced by a number of recent European and global initiatives – Seaweed For Europe[1], United Nations Seaweed Manifesto[2], The Safe Seaweed Coalition[3] – each delivering a vision for the transition to safe, sustainable and unified upscaled industry.

In 2018, over 30 million wet tonnes of seaweed, with an estimated market value of €11 billion, were harvested [1]. Of this crop, 95% came from Asia (China, Indonesia, Republic of Korea & Philippines). Some wild harvest of seaweeds still occurs but around 97% of the global seaweed crop comes from cultivated biomass. It is globally accepted that any future upscaled industry has to be based on farmed biomass and whilst this brings numerous challenges there is also scope for restorative action and to address green recovery.

1. See: https://www.seaweedeurope.com/
2. See: https://unglobalcompact.org/library/5743
3. See: https://www.safeseaweedcoalition.org/

The health of our oceans is irrefutably linked to the health of our planet and the Climate Crisis. The large-scale cultivation of seaweed that will be required to feed any new industry is expected to deliver significant environmental benefits (mitigation of CO2 emissions, uptake of nitrogen & phosphorous) and ecosystem services (creation of new habitat, food supply, nursery grounds for marine species).

The seaweed harvest in Europe is small, currently around 300,000 wet tonnes (approx. 1% global industry by volume) and is essentially based on wild biomass stocks with around 1,000 tonnes being cultivated. However, the industry is described as being "on the cusp of transformation" and there is strong conviction that Europe can accelerate and significantly grow production capacity. Recent projections estimate production in excess of 8 million wet tonnes (market value of over €9 billion) by 2030 [2].

Ireland has one of Europe's most active seaweed industries, but the seaweed harvest is relatively small (approx. 30,000 wet tonnes per annum) when compared to Norway and France and is still dominated by the wild harvest of *Ascophyllum nodosum* for use in agriculture, horticulture and feed (approx. 95% of the total market) [3]. Cultivation of seaweed is still small scale but with an estimated value of around €50,000-€150,000 (FAO statistics 2017). There is a paucity of reliable data in the public domain about the status of the culture of seaweed in Ireland. This is reflected in the variation of production output quoted in public sources.

BIM has been leading a EU funded Seaweed Development Programme since 2004 and has stated that an annual production of 900 tonnes (wet) could be possible by 2025 [3]. Although efforts to cultivate several species of seaweed in Ireland have been made, it is largely species of brown seaweed *Alaria esculenta, Saccharina latissima and Laminaria digitata* that produce the majority of biomass (as is the case elsewhere in Europe). Efforts to expand cultivation activity into the potentially more valuable species appears such as *Palmaria palmata* and *Porphyra umbilicalis* remain a research challenge.

Similarly, the structure of the seaweed culture sector is not clearly defined. The most recent directory on Irish Aquaculture and Seafood whilst including a list of 39 what are terms seaweed producers, the list does not differentiate between wild harvest and culture segments, and contains entries e.g. Bord Bia, Marine Institute that are not producers [4].

Ireland's seaweed sector, as with the rest of the maritime economy has changed quite dramatically over the past 20 years. The recent attention on Ireland's marine resource as highlighted in documents such as e.g. Sea Change 2007 to 2013, Harnessing Our Ocean Wealth and various BIM strategies recognised the role of the seaweed industry in marine and costal economies and gave insights to development opportunities [5, 6].

However, the seaweed sector remains diverse, and with few exceptions, largely oriented towards the use of wild harvest stock for relatively low value products requiring minimal processing. Several investments by the state that enabled research into exploring and profiling bioactive components marine bioresources, appear to have stimulated new interests in seaweed as a valuable commodity. There are some indications that a shift to processing seaweed as the basis for higher value products has occurred in Ireland [7]. However, these ventures remain largely reliant on wild harvest stock and imported materials for their products.

Irish government departments have adopted a positive view of seaweed cultivation. DAFM highlighted the importance of mapping the resource and improving production systems for seaweed in its strategy for sustainable food production and food for health and the Department of Housing Planning and Local Government recognised the sector a key part of Ireland's coastal economy [8, 9].

As with any wild species, cultivation always faces natural threats, from climate change to disease. Seaweed in open water cultivation is vulnerable to disease of pest species leading to reduced quality and loss of yield [10], [11]. Despite these challenges, there is an expectation that more selective targeting of species coupled with new production and processing methods will lead to increased output in Europe. It is also projected that there will be a shift in outlook with producers seeking species to use in high-value food and non-food products and applications, with an emphasis on sustainable production including from land-based production and IMTA [12].

The 2019 Pegasus report (detailing guidelines for the European seaweed aquaculture sector) stated that the Irish seaweed aquaculture sector showed enormous potential for sustainable growth but that despite this potential, major challenges needed to be met in order for Ireland to catch up with aquaculture leaders [13].

1.1 Scope

Recognising the opportunties and challenges as detailed above, this report has been prepared in order to support the development of a strategic roadmap for the Irish macro algal sector, to maximise its potential and value to the irish economy.

There are many unknowns at play in the sector, and where possible the report attempts to bring clarity to these. BIM, the national state agency responsible for developing the irish seafood industry, has identified that there are significant opportunities for the expansion of the Irish macro algal sector.

Opportunities may arise in terms of functional foods, nutraceuiticals, cosmetics, bio-stimulants, bioremdiation and animal feed. These opportunities may involve the use of bio-refinery, and in relation to feed may involve the anti-methanogenic proprties of seaweed of interest to the dairy and beef sectors.

In undertaking this report, Steelesrock Strategy Consulting has:

- Undertaken a review of available reports and other publicly available literature.
- Endeavoured to characterise national and global production, market, and product trends in the use of seaweeds.
- Identified macro-algal species (brown, red, green) suited to aquaculture production in Irish waters; production, products and by-products which lend themselves to economically viable commercialisation come; and to provide insights to possible future products and species that could be utilised by the sector.
- Considered a wide array of production, product, processing, markets, competitiveness, regulatory and uses of seaweed. In doing so we have drawn extensively from accessible literature, stakeholder consultations and domain knowledge of specialists.
- Identified market leaders and carried out a benchmarking of Ireland's seaweed culture activity against a selection of other jurisdictions with an emphasis on biomass use, innovation, support infrastructures, business models, biorefining facilities, and supply chains.

- Identified support for seaweed aquaculture activity and relevance to seaweed aquaculture within national and EU policy statements/position papers concerning sustainability, climate action, the bioeconomy including the blue bioeconomy, and sectoral plans/programmes.
- Identified national research and innovation infrastructures available to the sector from within Ireland's public sector research organisations and others that are being developed with support from national agencies.

In addition to the above, we have undertaken a detailed review of the issues surrounding hatchery facilities as the apply to the sector, including consideration of costs.

1.2 Format

This report comprises of six sections, including this introduction. Each section is intended to be reatively discreet in its scope. The remaining sections are as follows:

Section 2: European value chain for cultivated seaweed biomass.

This section sets out the context of European production of seaweed based products across the entire value chain. It examines volumes and species under cultivation in Europe, and benchmarks the state of play in three regions, namely Norway, France and the North Sea Community (Netherlands, Belgium and Germany). This section also examines issues surrounding macro-algae cultivation, and post production processing.

Section 3: Macro algae markets.

This section examines issues surrouding market supply, and profiles seven distinct market segments.

Section 4. Profile of the Irish macro algae industry and its supports.

This section sets out the policy, legislative and funding context in Ireland; and considers the national production profile and the markets served. It also considered the research capacity available nationally to the sector. In concludes with an overview perspective on seaweed aquaculture based on the interviews conducted as part of the preparation of this report.

Section 5. Hatchery requirements in the Irish Seaweed Industry.

This section opens with an overview of the development of hatchery capabilities in Ireland today. It then examines the capabilities and characteristics required of a hatchery. It examines the various options available to the sector going forward with repsect to hathery development, including the economics of hatchery set up and operation. It concludes with discussion of the issues that need to be considered by the sector.

Section 6. Towards a strategy for the Irish Macro Algae Industry to 2020.

This section is reflective of the research carried out in the preparation of the earlier sections, and provides a commentary on the sector, together with the authors' key conclusions. It includes the results of a number of analyses carried out and identifies 12 thematic areas within 3 strategy pillars.

Section 2
European value chain for cultivated seaweed biomass

2.1 Introduction

In very general terms, seaweed value chains comprise three main elements: biomass supply, some level of processing and end use in various market sectors (Figure 1). This section provides an overview of the European situation set within the context of the wider global industry that is essentially driven by the supply of cultivated biomass. There is a specific focus on cultivation and processing as detail on hatcheries and markets is provided elsewhere in Sections 3 and 5 of this report (respectively).

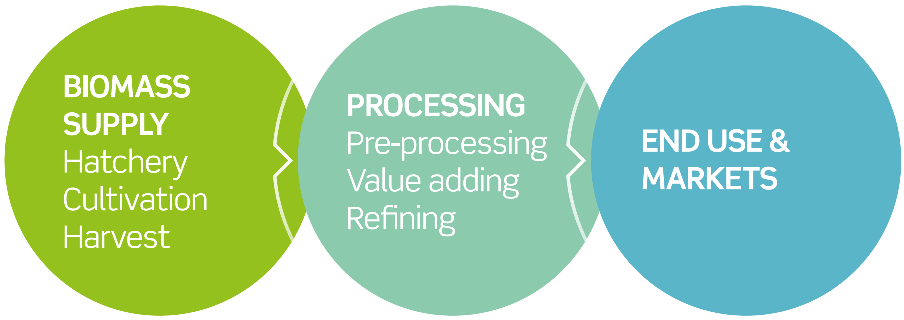


Figure 1 – Simplified seaweed value chain

2.1.1 Global context

Reports about the cultivation of seaweeds reference the practice as having originated as far back as the 17th century in response to the overharvesting of the wild stocks of Nori (*species of Porphyra and Pyropia*) in Japan [14]. The high nutrient content and other properties inherent in many seaweeds are behind the long history of their use by coastal communities across the globe. Seaweeds have been used in the raw, dried and composted forms as a source of food, food ingredients, animal feed and in fertilising the land for centuries [15]. Whereas seaweeds continue to be used as food particularly in Asian countries, consumers in western populations have only started to rediscover their food potential [16]. This is despite the longstanding industrial use of some species as a source of food ingredients (thickening and gelling agents).

Globally, seaweed production is increasing and whilst most seaweed is cultivated in Asian countries, production is also increasing in other regions. This growth trend is visible in FAO data covering the period 1990 to date showing an annual increase in seaweed aquaculture and an increasing share of global production by Asian countries [17].

The total global seaweed output in 2012 was 23,776,499 tonnes, increasing by 46 percent to 34,697,134 tonnes by 2019. The majority of cultivated seaweed remains destined for use in food and food related applications including as a raw food, in a minimally processed form e.g., dried, or as a source of food ingredients [15].

There are indications that the potential of seaweeds is recognised by other industries including human and animal health, biomaterials, pharmaceuticals, cosmetics and biofuels and of other uses for seaweeds and seaweed derived compounds, as fertilizers and soil conditioners, animal feed, fish feed and in bioremediation [18, 19, 20, 21].

These growth trends are expected to continue into the future. A recent commercial market report (Markets and Markets) estimated the global market value for cultivated seaweeds was US$16.7 billion in 2020 [22]. In describing a healthy market growth for cultivated seaweeds globally, they expect Asian producers to continue their dominant market position as leading producers. This results from the availability of raw materials, a low-cost base and a climate that is conducive to the growth of seaweeds.

Market growth is projected to rise to a value of US$30.2 by 2025; a compound growth rate of 12.6 % over the period 2020 to 2025. Behind this projected growth is the increased interest and demand for seaweed-based products in the consumer foods, industrial, agriculture and feed sectors. Europe is the fastest growing market geographically owing to an increase in customer awareness of the possible health benefits of seaweed-based products.

The global cultivated seaweed biomass by region is summarised in Table 1 below. Whilst the brown seaweed *Saccharina japonica* and red "carrageenan seaweeds" primarily species of *Kappaphycus and Eucheuma* represent the largest global seaweed crop by volume. Species belonging to the genera *Porphyra* and *Pyropia* often described as Nori Seaweeds are the most valuable of the seaweed crops. These species, produced for food and with a global market value of US$ 2.7 billion 2019) are not cultivated in Ireland although cultivation of *Porphyra* is being trialled [17, 23].

Table 1 – Global seaweed production 2019

	Total seaweed production		**Cultivated seaweed**	
Country/region	*Tonnes (wet)*	*Share of global production (%)*	*Tonnes (wet)*	*Share of cultivated biomas in total production (%)*
World	35,762,504	100	35,697,134	96.97
Asia	34,826,750	97.38	34,513,223	99.01
Americas	487,241	1.36	22,856	4.69
Europe	287,033	0.8	11,125	3.88
Africa	144,909	0.41	117,791	81.29
Oceania	16,572	0.05	14,140	85.32

Source: FAO [24]

The remainder of this section explores the global trends in macro-algae production, with a particular focus on the situation in Europe.

2.2 Profile of macroalgal production in Europe

There is a long-standing recognition that marine algae have the potential to strengthen Europe's economy [25]. Macroalgae as source of high added-value chemicals and bioactive compounds make them an attractive alternative to animal and other land-based sources, particularly at a time when there are concerns about land-use and the sustainability of water supply for some land crops [26].

There are high expectations that deployment of the EU Bioeconomy Strategy will support the sustainable growth and development of the EU bio-based sectors while creating jobs, innovation and services [26]. This strategy acknowledges the importance of macroalgae as a valuable source of biomass with significant scope for increased levels of production. In addition to identifying macroalgae as an additional source of protein, the strategy also draws attention to its contribution to other high value applications in chemical, health and food sectors. A strong positive view about the future of the European seaweed sector exists amongst policy, NGO's and companies. This enthusiasm is reflected in the large number of seaweed related projects supported by EU and National funds [27].

Despite the high profile of macroalgae in European policy and its potential as a source of added value, many knowledge gaps concerning the scale, structure and organisation of the industry exist [13, 15, 24],. More fundamental is the doubt expressed about the accuracy of data concerning production levels and the capabilities of the sector [18].

The popular press portray seaweed as a healthy food; as a result, consumer demand for seaweed products has increased. Different industries maintain a positive view of the benefits of seaweed following its long-standing use in food, chemical and cosmetic products. Industry specifications for seaweed are demanding in terms of volume and quality, requirements that European producers find challenging to meet consistently [20].

The majority of European sourced seaweed is used in food and food related applications e.g., nutraceuticals and nutritional supplements. Together these markets account for just over 50 percent of seaweed biomass use. Firms in the cosmetic, agriculture and horticulture industry are other sizeable users of seaweed biomass [18]. Other sectors, often described as offering high potential as users of seaweed biomass include pharmaceutical, biomaterials and biofuels.

2.2.1 Volumes of seaweed produced in Europe

Most seaweed used in Europe is from the harvest of wild stocks [17]. There is however, a positive trend reported in the cultivation of seaweed This is believed to be in response to the increased recognition of the potential of seaweed derived compounds by different industries, and an increased demand from consumers for food products containing seaweeds.

Total European seaweed production (wet weight) in 2019 was 287,033 tonnes, accounting for 0.8 percent of overall global production; cultivated biomass (wet weight) was 11,125 tonnes (3.88 percent of total output). The majority of European production was within the Russian Federation, with other significant contributions from Norway, France and Ireland [24]. Table 2 gives a breakdown of biomass production by country based on data provided by the FAO. It should be noted that there are discrepancies between FAO reported data, and those data reported directly by individual countries. Ireland's proportion of cultivated seaweed in 2019 amounted to 42 tonnes (0.38 percent of total European cultivated stock).

Table 2 – European seaweed output 2019

	Total seaweed production		Cultivated seaweed	
Country/region	*Tonnes (wet)*	*Share of global production (%)*	*Tonnes (wet)*	*Share of cultivated biomas in total production (%)*
World	35,762,504	100	35,697,134	96.97
Norway	163,197	0.46	117	0.07
France	51,476	0.14	176	0.34
Ireland	29,542	0.08	42	0.14
Russian Federation	19,544	0.05	10,573	54.10
Iceland	17,533	0.05		
Rest of Europe (5 countries)	5,741	0.02	217	3.78
European totals	287,033	0.08	11,125	3.88

Source: FAO (2021) [24]

2.2.2 Species of macroalgae cultivated in Europe

An estimated 1,700 species of seaweed grow in European waters, however, few species are commercially exploited and fewer still are cultivated [15, 18]. In recent years, around 10-15 different seaweeds have been cultivated in Europe at a commercial scale (albeit small in some cases) although this number is likely to be higher on account of experimental cultivation activities. The majority of European seaweed production from aquaculture is of brown seaweed species, principally the kelps. Red and green algae are also cultivated though at much lower volumes.

Table 3 summarises the range of species currently cultivated in Europe both at sea and onshore. Other species are being cultivated but only at experimental scale. There is scant data available on biomass production for species other than the kelps and in light of the earlier caution about data reliability, there is little certainty about the quoted annual production rates. The estimated annual production of kelp in Europe is 533 tonne/annum [18]

Table 3 – Species cultivated in Europe

Countries cultivating seaweed	Brown (Phaeophycean)	Red (Rhodophyta)	Green (Chlorophyta)
Norway, Spain, Portugal, France, Norway, Denmark, Sweden, Iceland, Ireland, Russian Federation, UK, Netherlands, Belgium, Faroe Islands and Estonia	*Laminaria digitata* *Laminaria hyperborea* *Saccharina latissima* *Alaria esculenta* *Undaria pinnatifida* *Fucus species*	*Chondrus crispus* *Gracilaria species* *Gracilariopsis longissima* *Porphyra species* *Palmaria palmata* *Asparagopsis armata* *Mastocarpus stellatus*	*Ulva species* *Codium tomentosum*

Source: Araújo R (2021) [18]

For the industry to grow there is a perceived need to cultivate a wider range of seaweed crops with higher market value e.g., for high value or niche applications and/or seaweeds that contain specific valuable components for valorisation. Also, there is a need to cultivate spring and summer crops (April to September) to fill the gap in the brown seaweed cultivation cycles and thus improve farming efficiency [13].

2.2.3 Selected benchmark countries

A number of European countries have notable aspects to their macroalgal industries. In this section we select three such regions to provide a benchmark of the state of the art in a European context and against which to compare Ireland's performance. The countries selected are:

- Norway –an industry with a rapidly developing cultivation sector and strong blue-bio ethos.
- France – a thriving "seaweed economy".
- North Sea Community – developing regional cluster based on multi-use offshore cultivation.

A comparison of the key aspects of these three industries vs the Irish situation is given in Figure 2 below. Figure 2 also summarises the key factors that will impact on the ability of these regional industries to increase scale and expand in the future. Greater detail on the Irish industry is given in Section 4 of this report.

	Current situation	Potential to scale cultivation	Key markets & drivers
Ireland	• **> 99% from wild harvest** • ~ 30,000 wt/yr mostly Ascophyllum • 40-60 wt cultivated, mainly Alaria, Saccharina & Laminaria ~ 9 companies cultivating • Cultivation efficiency ~6 kg/m or 15 wt/ha • Farm size typically < 1 ha	• Limited to inshore in short term • 230 ha licenced but not fully operational • Predicted scale 1000s wt short term • Potential co-location with wind farms • IMTA possibilities with seafood industry • Other species at small scale/in trial • Limiting hatchery capacity	• Food, feed, biostimulants, cosmetics, nutraceuticals • Renowned national food brand • Positive export markets • Industry clusters emerging – key to facilitating greater collaboration & more integrated industry
France	• **> 99% from wild harvest** • 50-80,000 wt/yr mainly Laminaria spp. • ~ 170 wt/yr cultivated, mainly Undaria, also Saccharina & Alaria ~10 companies cultivating • Farm size typically <12 ha • Commercial tank culture (red & green spp.)	• Algolesko has concessions for 150 ha • Other species at small scale/in trial • 30 species approved for cultivation at sea • Commercial hatcheries operating • Strong aquaculture & seafood industry • IMTA developing	• Food, hydrocolloids, feed, biostimulants, cosmetics, nutraceuticals • Strong, lucrative export markets • Dedicated industry groups driving growth • Integrated "seaweed economy" • Dedicated seaweed/ marine research infrastructure

	Current situation	Potential to scale cultivation	Key markets & drivers
Norway	• **99% from wild harvest** • 185,000 wt/yr – Laminaria hyperborea & • Ascophyllum • > 180 wt/yr cultivated, Alaria & Saccharina ~ 25 companies cultivating • Cultivation etticiency 2-20 wt/ha • Farm size 1-16 ha Seaweed Solutions	• Very long coastline (inshore & off shore) • ~ 500 licences granted but not operational • Offshore growing rigs in development • Predicted scale of millions wt by 2050 • Other species at small scale/in trial • Commercial hatcheries operating • Strong aquaculture & offshore industry	• Food, hydrocolloids, feed, biostimulants, • health & pharma • strong blue economy potential • International interest/ investment identified • Strong, lucrative export markets • Dedicated industry groups driving growth
North Sea	• **In range 100s wt/yr, mostly cultivated** • Main species Saccharina & Alaria • Small scale harvesting only ~ 5 companies cultivating • Farm size typically <7 ha • Onshore tank cultivation in develoement	• Access to off shore multi-use farms • Offshore pilot facilities in place • Predicted scale of millions wt in future • Commercial hatcheries operating • Other species at small scale/in trial • Companies already selling boats & equipment for large scale mechanisation	• Primary focus on large scale, off shore production • Sort term focus on food market • Long term focus on value adding and production of cheap, bulk biomass • Dedicated industry groups driving growth • Strong collaborative approach

Figure 2 – Summary comparison of key European seaweed industries

France

France is Europe's second largest producer of seaweed with an estimated value of over €400 million [18, 24, 28, 29]. The industry is still largely based on the harvest of wild biomass although cultivation activity is growing. Over 30 seaweed producers (harvesters and cultivators) were identified in 2021 although the wider industry comprises around 85 companies and employs 1,600 people. The French industry is essentially clustered in and around Brittany where a regional seaweed economy exists.

It is a diverse industry utilising around 20 different seaweeds and servicing a range of sectors including food, human health and nutrition, pharma, cosmetics, feed and bio-packaging. Companies range from large multinationals (cosmetics, speciality ingredients) to SME/artisanal producers and processors [30, 31, 32]. The industry is well organised with a number of clusters and industry associations to support and drive the industry forward. These include the Chambre Syndicale des Algues & Végétaux Marins[4] and the Syndicat des récoltants d'algues[5].

4. See: https://www.chambre-syndicale-algues.org/
5. See: https://srparb.assoconnect.com/

In 2018, 76,333 wet tonnes of seaweed were harvested from wild stocks. Volumes typically vary on an annual basis (50,000 to 80,000 wet tonnes) depending on winter conditions. Most harvesting activity (ca. 90%) is centred around the coast of Brittany. The key species that are harvested (accounting for > 90% of total production) are *Laminaria digitata and Laminaria hyperborea*. These are mechanically harvested by boat (around 35 operators) and essentially used for alginate extraction. In 2018, this harvest had an estimated value of €1.7-€2.7 million.

However, the annual harvest does not satisfy the requirements for alginate extraction each year thus extra biomass is imported to meet processing demand. France imports around 30,000 tonnes (dry weight equivalent) of fresh, frozen and dried seaweed biomass each year for processing, most of which (ca. 80%) goes for hydrocolloids extraction [29, 28].

Algaia[6] is a biomarine ingredients company, producing alginate, carrageenan, speciality algal extracts (food, cosmetics, industry) and biostimulants. The focus is on developing sustainable, green processes to optimise the use of seaweed biomass and reduce waste. In this role Algaia provide advice to seaweed harvesters and growers concerning production methods, analysis and insights to help them maximise biomass output. Algaia utilises >60,000 wet tonnes of wild harvested seaweed/year for alginates extraction but the company is actively involved in research projects that have a focus on cultivated biomass. JRS Marine Products[7] has an alginate processing facility at Landerneau near Brest. They use an estimated ca. 35,000 wet tonnes of harvested *Laminaria digitata and Laminaria hyperborea* annually.

Olmix[8] is a biotech company that delivers seaweed based, natural ingredient solutions for plant, animal (livestock and pets) and human health (food, nutraceuticals, supplements and pharma). Agrimer[9] is based in Brittany and produces high quality seaweed derived ingredients from various seaweeds for use in the agriculture, cosmetic and nutrition sectors. The site is located close to the supply of wild biomass with harvesting, drying, R&D, production, formulation and packing all carried out in house.

Agriculture products are essentially based on *Ascophyllum* and *Fucus*. Extracts for use in cosmetics and nutrition/supplements are derived from 13 different seaweeds. Cultivated biomass is also used. Algopak[10] produce algal based plastics and blends for use in the plastic processing industry and by users of plastic. The company utilises beach-cast Sargassum from the Caribbean and local beach cast *Laminaria spp* when it is available.

Algues et mer[11] produce extracts for use in cosmetics and nutraceuticals, which are marketed as organically certified. Mostly based on wild harvested material (*Ascophyllum*). The company is reported to be also cultivating biomass. C Weed Aquaculture[12], located in St Malo is cultivating *Undaria, Saccharina and Alaria* for the food and cosmetics sectors. The company has its own hatchery and drying facility and concessions for 12ha.

6. See: https://www.algaia.com/
7. See: https://www.jrs.eu/jrs_en/alginate/
8. See: https://www.olmix.com/
9. See: https://www.agrimer.com/en/home/
10. See: https://www.algopack.com/en/
11. See: http://www.algues-et-mer.com/en/home
12. See: https://www.c-weed-aquaculture.com/en/

They also harvest other red and green seaweeds locally. Aleor[13] are also cultivators and processors of seaweed. The company has its own hatchery and produces organic certified products for the nutrition, health, cosmetic and pharma sectors. Lessonia[14] design and manufacture ingredients for use in the food and cosmetics industries with specialist knowledge in seaweed processing. Lessonia is also a major supplier of edible seaweed to the food and nutraceutical sectors.

Other species of seaweed are hand harvested in France. These include *Ascophyllum nodosum* (ca. 5,000 wet tonnes), *Chondrus crispus* (ca. 15,000 wet tonnes) and edible species that are used for food including *Fucus vesiculosus, F. spiralis, Himanthalia elongata, Pelvetia canaliculata, Mastocarpus stellatus, Palmaria palmata, Porphyra umbilicalis and Codium* (ca. 1,000 wet tonnes/annum). Stranded Ulva sp. is also harvested in Spring. Harvesting occurs in 12 regulated zones by a work force comprising around 50 professional harvesters and 300 seasonal cutters [29, 28].

There are around 10 companies with cultivation capability in France, 5 are located in Brittany. Upwards of 150 wet tonnes of seaweed is currently produced each year. In 2020 the FAO reported ~170 wet tonnes of seaweed were cultivated, including 100 wet tonnes of *Undaria pinnatifida.*

In addition to *Undaria,* some S*accharina latissima and Alaria esculenta* is also grown. The estimated value of this crop in 2019 was in excess of €500,000, with an average value of €3.50/kg (dry weight). Currently, farms are located in shore and range in size from 1 to around 12 ha although Algolesko[15] has concessions for 150 ha. There is also some onshore tank cultivation of valuable species. Cultivated biomass is mostly used in the food and cosmetics sectors [28, 29].

Norway

Norway is Europe's largest producer of seaweed (by volume) and 9th largest global producer [24]. The industry was founded on the supply of wild harvested brown seaweeds for alginates extraction and the production of seaweed meal for horticulture and agriculture markets. Today, it has a rapidly developing cultivation sector and has become one of the most active in Europe.

The industry is diversifying to service other sectors including food and health, feed, biostimulants, cosmetics and aquaculture. Producers report high demand for seaweed ingredients in high-end food products. There are currently around 20 seaweed producers (harvesters and cultivators) [18, 30, 33, 34].

Over 150,000 wet tonnes of seaweed was harvested from wild stocks in 2020 with an estimated harvest value around NOK 45 million (€4.5 million). The key species and volumes as reported by the Norwegian government were the brown seaweeds *Laminaria hyperborea* (134,000 wet tonnes) and *Ascophyllum nodosum* (17,000 wet tonnes), used for alginates extraction and in the production of horticultural products and animal feed [35].

IFF[16] is a leading player in wild harvest; following a merger with DuPont Nutrition and Biosciences in early 2021 it is now Norway's largest processor of seaweed, focussing on food, health, pharma and biotech sectors. IFF is the largest producer of alginates in Europe. In 2017 the Norwegian alginates business (operating as FMC) was estimated to account for 80-90% share of the EU and global markets (value and volume) for pharmaceutical excipients.

13. See: https://www.cluster-mer-nutrition-sante.org/en/membres_cluster/aleor-english/
14. See: https://www.lessonia.com/en/food-ingredients/
15. See: https://www.algolesko.com/
16. See: https://www.pharma.dupont.com/pharmaceutical-brands/alginates.html

Algea/Valagro[17] wild harvest and process *Ascophyllum nodosum* (primarily) for feed/fodder and bio-stimulants/fertilizer. The Norwegian industry benefits from having these larger, established seaweed processors with presence in global markets. Alginor ASA[18] is a marine biotech company, biorefining wild harvested *Laminaria hyperborea* for pharma and nutraceutical products. This small company currently operating at pilot scale, secured NOK 427 million investment in 2021 to proceed with a major scale up.

The coastline of Norway is reported as being highly suited to aquaculture including seaweed cultivation [36]. Production in 2020 was around 185 wet tonnes with a value of NOK 8.6 million (ca. €850,000) according to the Norwegian Directorate of Fisheries [35]. This represents the largest annual crop from cultivated biomass in Europe to date. The key species grown were *Saccharina latissima* and *Alaria esculenta*, in more or less equal volumes. Currently there are around 25 companies operating 182 licences over 93 different sites, although a total of 703 licences have been issued: *Saccharina latissima* (106), *Laminaria digitata* (93), *Alaria esculenta* (98), *Palmaria palmata* (84) and other seaweeds and/or mixed licences (322) [18].

Cultivators currently operate mostly at small scale (10-100 wet tonnes). Norwegian Seaweed Farms[19] is an association of 7 seaweed producers that are working together for collective benefit, to develop and promote the industry. There are some larger companies with the capacity to farm hundreds of wet tonnes. Seaweed Solutions AS[20] has concessions in place for 65 hectares with potential to grow > 3,000 wet tonnes. In 2020, the company announced the completion of a 19 ha farm with the capacity to produce 500 wet tonnes of kelp. Ocean Forest is a collaboration between the Bellona Foundation[21] and the Lerøy group[22] to develop and establish new forms of biomass production tied to aquaculture. Currently the group is farming *Saccharina latissima* (>100 wet tonne/annum) including IMTA. The future cultivation potential for Norway is estimated to be in the region of 4 million wet tonnes by 2030, increasing to 20 million wet tonnes at a value of US$ 4 billion by 2050 [33].

Norway already has a thriving aquaculture industry with expertise in cultivation, processing technology, storage and logistics, marine ingredients business, public/consumer awareness and acceptance – much of which benefits the developing seaweed sector. There is firm belief that a thriving Blue-Bioeconomy based on more efficient/value added use of currently underutilised/undervalued resources including algae and fishing industry by-products is possible for Norway [37, 33]

Opportunities for joint venture and/or R&D initiatives with overseas partners have been identified, to bring in investment, build knowledge on cultivation and processing and add value in-country rather than just export raw material for processing elsewhere [34]. Norway generally has good regulation and support (financial and other) for a developing Blue Economy although the regulation of seaweed cultivation falls under that for general aquaculture [13, 33].

17. See: https://www.algea.com/
18. See: https://alginor.no/
19. See: https://www.norwegianseaweedfarms.com/
20. See: https://seaweedsolutions.com/
21. See: https://bellona.org/projects/ocean-forest
22. See: https://www.leroyseafood.com/en/tasty-seafood/product-range/seaweed/

A review by SINTEF, a Norwegian research organisation, identified a number of knowledge gaps and challenges for developing the Norwegian industry. These include: (i) the need for better processing capability including basic equipment e.g. drying/milling for new companies; (ii) solutions for post-harvest handling of seaweed, to improve product quality and to enable more efficient storage and transport/logistics; (iii) mechanisation to speed up and reduce the cost of seeding and harvesting, particularly if the industry is to increase its scale; (iv) solutions for biofouling which typically occurs late spring/early summer and has a substantial impact on the quality and yield of crops [13, 37, 33].

North Sea Community

Seaweed cultivation and harvesting is currently at small scale in the Netherlands, Belgium and Germany. However, significant effort is being invested in the development of an inter-regional and cross-sectoral seaweed industry with the potential to be the largest in Europe. The driving force behind the North Sea seaweed community is the North Sea Farmers[23] initiative. This is an international membership foundation for the seaweed sector, based in the Netherlands and working towards joint investment projects and knowledge exchange on all aspects of sustainable seaweed cultivation.

The overall aim of the group is to accelerate and strengthen the seaweed industry in and around the Netherlands. Activities are focused on (but not limited to) the North Sea. Membership is currently in excess of 100 companies and organisations from a diverse array of sectors. The group has an offshore test site that is licenced for 6 x 1km^2 plots for seaweed cultivation and IMTA trials.

The North Sea seaweed community shares a common vision to develop large scale, offshore, multi-use farming activity for the future development of a sustainable seaweed economy. The plan of the Dutch industry is for the development of a 500 km^2 area that will produce 10 million wet tonnes of seaweed with a revenue of €1 million [38]. The Belgian view is for 10% utilisation of planned offshore windfarm space for seaweed aquaculture to support 4,000 farms of 20 ha each, with a potential production of >16 million wet tonnes/annum [39] .

Currently, small amounts of seaweed are harvested, and individual cultivators are at the experimental to 10's of tonnes/annum (wet weight) scale. Zeewar[24] was the first to farm seaweed in the Netherlands and is currently growing *Saccharina, Alaria and Ulva.* The Dutch Seaweed Group[25] is farming *Undaria pinnatifida* and *Saccharina latissim*. These groups have their own hatcheries. There is no commercial cultivation in the North Sea at the moment. Farms are still located inshore in sheltered conditions although off-shore trials are underway. Typically, inshore farms are at a scale of 1-7 ha. A number of companies are also developing onshore tank culture [40].

Hortimare[26] is a Dutch company with specific expertise in the breeding and seeding of different seaweed crops. Hortimare offers seeded twine and direct seeding, and is currently focussing on *Saccharina latissima, Alaria esculenta* and *Palmaria palmata.* Hortimare is also growing the red seaweed *Asparagopsis*.

23. See: https://www.northseafarmers.org/offshore-test-site
24. See: https://www.zeewaar.nl/uk/
25. See: https://www.dutchseaweedgroup.com/en/
26. See: https://www.hortimare.com/

At Sea Nova[27] is a Belgian company that supplies turnkey seaweed farms based on innovative linear and 2 dimensional growing substrates and seed for red and brown seaweed species (seeded twice and direct seeding), the supply of green seaweed is imminent. In 2020 the company launched SeaHarvester I, a custom designed boat to mechanise the seeding, harvesting and cleaning of long lines and 2 dimensional structures. Oceanwell[28] is a German company that produces active ingredients from kelps for use in health and wellness products, they farm *Saccharina latissima* in the Kiel Fjord.

2.3 Macroalgal Cultivation

Seaweed cultivation can be sea-based (inshore or offshore) or land-based (tanks, ponds/lagoons and raceways) [13, 41, 42, 43]. Currently around 30% of European seaweed companies are actively cultivating, and of these, most are cultivating at sea (76%) with around a quarter (24%) using onshore systems [44]. It is anticipated that an increase in production at sea and on land, including integrated multispecies farming systems, will be needed to meet the market demand for different seaweeds.

Land-based systems will also play a key role in the domestication of new, commercially interesting, species. In the recent Seaweed for Europe modelling exercise that presents a vision of the European industry in 2030, sea-based cultivation is predicted to occupy in the range 7,000 to 26,000 ha depending on how much potential is realised. The same study predicts land-based systems will occupy in the region of 300 to 1000 ha [45].

There is a range of factors that influence the choice of cultivation systems, including species type, intended use, costs and logistics, and the availability of technologies. These factors will influence potential yields, costs of production, and choices relating to the production cycle.

2.3.1 Cultivation Techniques

Inshore Cultivation

European seaweed cultivation is primarily an inshore activity. These at-sea systems typically comprise a series of vertical and/or horizontal growing structures that are maintained in the surface waters (around 1-3m) using buoys and secured to the seabed with a mooring device. Some systems are adjustable and allow for growth at different depths. Growing structures include ropes (long-lines), nets or cages depending on species under cultivation and site location [41, 42].

The use of long-lines for kelp is the standard set-up on most Irish farms. They essentially comprise a number of parallel growing lines (ropes) set an optimal distance apart; anchored at each end, a series of buoys to keep the lines near to the surface. Long-line systems are relatively cheap to deploy and easy to lift for inspection, harvest etc. However, they do not scale easily on account of the number of anchoring points needed [41, 42].

Grid or frame systems offer an alternative growing system. These systems comprise a tensioned sub-surface rope grid secured to the sea-bed and buoyed to the surface. Optimally positioned growing lines (horizontal & vertical) are fixed to the grid and buoyed to the surface.

27. See: https://atseanova.com/
28. See: https://www.oceanwell.de/en/our-claim/story/

The Norwegian company Seaweed from Norway[29] use such a frame system to grow several kelp species. Grid systems are reported to be suited to larger scale production as many units can be joined together without excessive anchorage but because they are tensioned below the surface the growing lines are less easy to access and mechanical winches might be required [41].

Other configurations have been trialled successfully. Belgian company At Sea Nova, offer turnkey farming solutions including 2-dimensional sheet and net systems. Seaweed Solutions, Norway also has a patented 2 dimensional system. There are reports of a yield of ca. 14 kg/m2 of Saccharina latissima in Irish trials of the At Sea Nova system [42]. The seeding, harvesting and cleaning of 2D growing structures is better suited to mechanised processes, particularly at larger scale, and At Sea Nova now provide a machine that mechanises all steps in the cultivation process.

The vast majority of inshore cultivation in Europe is of species of brown seaweed, essentially the kelps S*accharina latissima, Alaria esculenta, Undaria pinnatifida* and species of *Laminaria.* Juveniles are laboratory/hatchery reared and inoculated onto twine (seeded twine) or mixed with a binder or bioglue for subsequent out planting at sea. Seeded twine is wrapped around the growing lines at sea, whereas the binder/bioglue is applied directly to the cultivation surface (i.e. direct seeding) [41]. Both seeding methods can be used for rope cultivation, but direct typically seeding is used for 2D surfaces such as meshes and sheets. Longlines, nets and cages are also used for the at sea cultivation of red and green seaweeds e.g., *Palmaria palmata. Ulva spp* [46].

Offshore (Open Water)

"Offshore" or "open water" cultivation generally implies that activities are based in open water and exposed to the elements. Any infrastructure, equipment and operations (seeding, harvesting, servicing, maintenance) are likely to be subject to significant wave and wind exposure. It follows that cultivation systems for such environments need to be robust. The installation and operation of these systems can be costly, presenting a challenge in maintaining a competitive cost of production.

Ocean Rainforest[30], Faroe Islands and the North Sea Farmers[31] offshore test site have successfully demonstrated the offshore cultivation of kelp species. Ocean Rainforest has developed the Macroalgal Cultivation Rig (MACR) for use at depths of 50-200m. The main structure comprises a sub-surface rope line (at 6-10m depth) that is heavily anchored and buoyed to the surface, with vertical growing lines that are individually buoyed to the surface. Each rig can have >250 growing lines [47].

The whole structure is flexible to enable it to move freely in high energy environments. The North Sea Farmers facility is situated 12km offshore and provides the opportunity to trial cultivation under challenging North Sea conditions. Successful offshore cultivation of *Ulva fenestrata* has also been demonstrated in an offshore sea farm in Sweden, using seeded twine and a long line system [46].

29. See www.seaweedfromnorway.no
30. See www.oceanrainforest.com
31. See www.northseafarmers.org

As the European cultivation industry develops, and the number and size of farms increases, it is inevitable that, where possible, cultivation will have to move offshore. In doing so it will become mechanised, resulting in more innovative seaweed farming practices. This approach is very much a long-term option for Ireland. However, the recently released Report of the Seafood Task Force [48] mentions the potential to locate Irish seaweed aquaculture activity within offshore multiuse platforms and windfarms.

Onshore Cultivation

Onshore seaweed cultivation can be in tanks, ponds/lagoons and raceways. These can be closed systems in which the seawater is recirculated; or alternatively, controlled flow-through systems. The size and type of the cultivation unit depends on the facility, scale of production and species under cultivation.

In general, units are not very deep so as to allow for maximum sunlight to penetrate the water column. The use of aeration or paddle wheels keep the seaweeds afloat/moving in the water column [13, 43].

Closed systems have the enormous benefit of being controllable. This allows the manipulation of factors such as stocking density, nutrient availability and physico-chemical parameters (temperature, pH, CO2, salinity, light) during production to optimise growth and yield. Similarly, the manipulation of these variables can stress species to maximise targeted nutritional and/or bioactive components.

This level of control over the system is important in developing cultivation techniques for the domestication of new, commercially interesting species. Control also allows for the production and traceability of biomass of consistent quality and yield; key attributes for buyers in the food, feed and health and wellness sectors [13, 43].

A land-based cultivation system is the only way to grow some species; whilst others perform better in these systems than in open water. This is primarily due to their need for specific propagation methods and growing conditions. Whilst sea-based cultivation may be possible for some species, the yield and quality of the biomass obtained may not outweigh the cost and effort involved (now or in future) [49].

The use of land-based systems in common in Europe to grow smaller red and green seaweeds such as *Chondrus, Palmaria, Gracilaria, Ulva* and *Codium*. They are suited for use with species that can be vegetatively propagated e.g., *Ulva*, and for those with frequent harvesting periods due to ease of access for harvesting. The potential for controlled and/or manipulated cultivation also lends itself to the production of high-quality crops for high value sectors.

IMTA and Multi-Species Cultivation

Integrated Multi Trophic Aquaculture (IMTA) systems involve the cultivation of multiple species from different levels in the food on the same site or within close proximity. ITMA can be sea based or land based. The design of IMTA systems allow species such as fish that need supplementary feed to grow along-side "extractive species"; species that utilise the by-products (uneaten food, faeces) from fish. Extractive species may be bottom feeding animals like sea cucumbers and sea urchins, or filter feeders such as mussels and scallops. Seaweeds are useful extractive species in that they can utilise the dissolved nutrients.

Kelp species are successfully cultivated in Europe alongside fish, mussels and oysters in sea-based systems and various red and green seaweeds with fish in land-based systems [50, 51]. The Portuguese company ALGAplus[32], produces a range of organic certified seaweed (including *Ulva, Codium, Gracilaria and Porphyra*) using different land-based systems coupled to a fish-farm.

32. See: https://www.algaplus.pt/en/about-us/

The Lehanagh Pool Research facility off Connemara is a 23 ha licenced multi-species cultivation site, managed by the Marine Institute, for non-commercial research. Its IMTA system can be used to cultivate finfish, molluscs, and seaweed (*Alaria esculenta* and *Ulva spp*). The site was used as a demonstration facility in the recent EU funded IMPACQT project[33].

IMTA is not yet widely used at a commercial level in Europe. Most activity is research-focussed and/or at small scale using a relatively small number of species. Whilst IMTA has numerous perceived benefits, significant knowledge gaps exist. These concern the integration of different species, best farming practice and requirements for upscaling. The regulatory environment for mixed species cultivation is also a challenge [50].

2.3.2 Factors affecting the choice of cultivation system

The choice of cultivation system essentially hinges on the following;

- the species to be cultivated, its reproductive life history and conditions required for optimal survival and growth;
- the intended end-use, market size and demand for any particular traits e.g., high protein content;
- cost and the logistics of harvesting and subsequent downstream handling and processing and;
- the developmental status of available farming technology.

Figure 3 lists some of the reported benefits and challenges of different cultivation approaches. Other key considerations common across all farming systems, include [13, 41, 43, 45];

- Limited availability of species – there is a need to cultivate more and varied species to satisfy market demand in different sectors and to allow for extended and/or year-round growing cycles.
- Optimised production – to improve quality and yield, with implications for access to high-value markets and for lowering the cost of production for lower value/bulk markets.
- Cost of production – could be partially reduced by up-scaling and mechanisation where appropriate and technological improvement.
- Market needs analysis – market demand must drive biomass volume and seaweed variety.
- Research and development – all farming practices need greater R&D effort to fill the many knowledge gaps and resolve technical challenges.
- Regulatory – there is a need for national and regional frameworks to simplify and standardise application procedures, licencing and operation activities and to address issues of biosecurity.

33. See: www.impaqtproject.eu

	Benefits	Challenges
Inshore	• Well established in some regions • Regional best practice exists • Possibilities forlinear, 2D & 3D systems • Relatively low cost, possibilities to re-purpose existing fishing gear • Global interest in blue carbon is driving investment	• Seasonal growth, short/intense harvesting period • Issues with disease & epiphytes • No control over local environmental conditions • Competition for space may limit scaling • Storage & transport of biomass • Distance from processing sites • Requirement for environmentally friendly substrates
Offshore	• Some offshore demo sites available in Europe • No competition for space, potential to scale • Potential to co-locate with other infrastructure and services • National & European interest in offshore wind • Global interest in blue carbon is driving investment	• Challenging, high energy environments • Logistics • Distance from landing & processing facilities • Significant knowledge gaps • Expensive installation and operational costs • Jurisdiction
Offshore	• High yield, year round production • Full control over production criteria & quality • Possibilities for targeted biomass production • Traceability • Easy access for operation and harvesting • Easy to couple with with existing fish/ shellfish cultivation and on-site or local processing	• Competition forland space – issues for scaling • High infrastructure costs • Potentially high operational costs • Limited knowledge – biological & technical • Requirement for seawater
IMTA	• Some offshore demo sites available in Europe • No competition for space, potential to scale • Potential to co-locate with other infrastructure and services • National & European interest in offshore wind • Global interest in blue carbon is driving investment	• Challenging, high energy environments • Logistics • Distance from landing & processing facilities • Significant knowledge gaps • Expensive installation and operational costs • Jurisdiction

Figure 3 – Comparison of cultivation techniques

2.3.3 Cost of production

The estimated market value for bulk harvested European seaweeds i.e., *Laminaria digitata, Laminaria hyperborea, Ascophyllum nodosum* is in the region of €50 to €100 per wet tonne. For hand harvested edible brown seaweeds e.g., *Fucus spp., Himanthalia elongata, Saccharina latissima, Laminaria digitata* prices range from €5 to €19 per dry kg or > €1,500 per wet tonne. The price of edible red and green species is typically higher [52, 53].

Estimates for the market value of cultivated biomass vary substantially depending on the scale of production and cultivation methods, for example in Scotland reported pricing for *Saccharina latissima* ranges from €100 to €500 per wet tonne [41]. In 2018, BIM reported that the average price of cultivated seaweed in Ireland was €1,000 per wet tonne [3]. Significant cost reductions are associated with scale up and mechanisation and the potential to produce *Saccharina latissima* for €17-€45 per wet tonne is reported [54]. This would allow cultivated biomass to be competitively positioned against wild harvest kelp, currently around €50 per wet tonne in France.

The MacroCascade[34] project received a comparison of production costs for *Saccharina latissima* under 4 different cultivation scenarios at Ocean Rainforest in 2019, 2020, a future scenario where a mechanical harvesting machine is used (developed under the MacroCascade project) and a future scenario where an underwater harvesting machine is used (currently in development) [54].

The cost of production in 2019 was €244 per wet tonne seaweed, improvements to yield during 2020 brought this cost down to ca. €90 per wet tonne. The estimated cost based on mechanised harvesting is ca. €40 per wet tonne whereas underwater harvesting is estimated to drop the cost to ca. €17 per wet tonne.

Significant cost reduction is also afforded by a reduction in seeding costs. The value of *Saccharina latissima* grown at the North Sea Farm pilot facility, Netherlands was estimated to be €1,200 per dry tonne, based on 2,000 m of ropes and a yield of < 3.8 wet kg per metre. By scaling production up to 5,000 m, the cost was reduced by over a third (€780 per wet tonne), and further reductions followed lowering seeding costs (€380 per wet tonne) [55].

2.4 Post-production processing

Commercially available products that incorporate seaweed are many and diverse and make use of seaweed in different forms. The first sale use of the seaweed can influence the level of processing. However, it is the end-use for the seaweed that dictates the processing steps. Processing post-harvest seaweed fresh for a food product, is different to processing a food ingredient.

Processing seaweed for a compound for the cosmetics market, is different to the production of a compound for a human health application. The extent of processing by the seaweed producer depends on the level of integration that exists in the firm. The greater the level of integration, the more value the producer can add.

Figure 4 identifies stages in the value chain to divert biomass to meet the requirements of different end users. In this model, End-user 1 has minimal processing requirements, corresponding to the use of the seaweed in a fresh state.

Meeting End-user 2 requirements needs a higher level of processing possibly requiring stages such as drying, milling or a consolidation of biomass into a bulk format, e.g., liquid, solid etc and packing. The third scenario is the most complex; here the bulk biomass undergoes further transformations, such as more specific extraction, fractionation and purification.

34. See www.macrocascade.eu

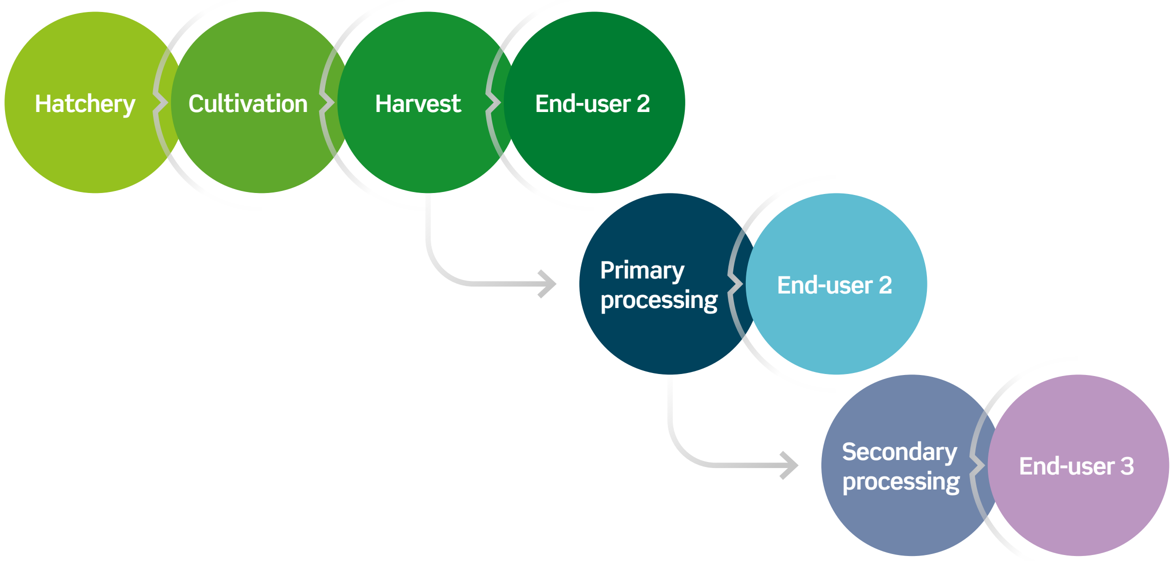


Figure 4 – Different end users in the cultivation value chain

2.4.1 Primary processing

Most value chains involve some relatively simple, initial **primary processing steps**: washing; chopping and grinding; de-watering; drying; ensiling; and on occasion freezing or other stabilisation methods. Particularly if the biomass is to be transported or stored. Once harvested, seaweed biomass must be stabilised to prevent microbial degradation and to ensure the safety and quality attributes of the seaweed. From the moment of harvest, seaweeds generally start to decompose, and in doing so, can leach valuable components.

Cultivated biomass may not be available year-round and thus long term storage might be necessary. Current production methods for *Saccharina latissima* have proven harvesting periods from April to July in most Northern European countries, extending into October in the Faroe Islands [56]. Harvesting is an intensive activity with substantial volumes of biomass handled in relatively short periods of time 4-6 weeks [13]. Insights to some of the key primary processing steps follow.

Washing:

A washing step with clean saltwater or fresh water is normal to remove any extraneous matter that could reduce product quality and/or damage processing equipment. Removing epiphytes from the biomass may require additional processing.

Chopping and grinding:

Most downstream processing will require the supply of material of a certain particle size. Particle size can affect extraction and processing efficiency. Excessively long fronds or large chunks of biomass can stall stirrers, clog outlet valves or reduce flow rates etc. Most processors will have specific delivery requirements that suit their equipment and processes.

De-watering:

Some processes include a de-watering step or a primary fractionation step *e.g.*, filtration or screening, that separates a crude liquid and a crude solid fraction. Fresh biomass can contain more than 80% water, its removal improves yields and reduces drying costs. Use of a spiral filter press to remove water is common.

Stabilising:

Processing from fresh biomass is often a preferred approach as it eliminates potentially energy consumptive drying steps and limits the degradation of unstable bioactive components e.g., polyphenols. However, transport and storage of fresh biomass is logistically difficult, expensive and can have quality implications as fresh seaweed biomass degrades quickly. Unless the processing facility is located close to the seaweed production areas (ideal scenario) biomass typically has to be stabilised for subsequent transport and/or storage. Salt or brine can be used to preserve edible seaweeds but for long-term stability, biomass is typically stabilised by drying, ensiling or freezing.

Drying:

The biomass volume and intended end-use influence how it will be dried. Low temperature drying (<450C), convective air-drying and dehumidification are preferred options to maintain the nutritional and functional quality of the biomass. Typically, dried products have a moisture content of around 10% which means that there is a requirement to drive off substantial amounts of water from the raw seaweed materials.

Drying is one of the most energy consumptive and costly steps in the value chain and can be a limiting factor in environmental and economic sustainability. Drying may be a viable option if other processing infrastructure exist but the general preference (currently) is to ensile the biomass.

Ensiling:

Ensiling or lactic acid fermentation essentially involves preserving the biomass under low pH conditions (ca. 4) using biological or chemical methods. The approach has been successful and is increasingly used by seaweed producers, in particular where larger volumes of biomass are being handled in a short space of time. Preparations to ensile seaweed can start onboard harvesting vessels [56].

A recent study of the Norwegian industry found that 68% of seaweed producers were using ensiling techniques to stabilise their biomass compared to 16% that use drying and 15% freezing [37].By breaking down the matrix, ensiling alters the composition of the biomass and liberates key bioactives or nutritional components. Some such as mannitol and laminarin, feed microorganisms during the fermentation process, which reduced their yield.

Challenges in controlling the fermentation process and unpredictable product quality, may limit its use in food [57] and feed applications. A recent study [58] into the use of ensiling *Saccharina latissima* prior to its processing into animal feed concluded...

> *"ensiling had a minor effect on the phlorotannin content of brown seaweeds but a better understanding of their biological activity post-ensiling is needed to improve our appreciation of their contribution to the nutritive value of seaweed silage. Further questions regarding optimal dietary inclusion rates and the potential effects on animal productivity, including milk and meat quality, need to be addressed before the use of seaweed silage as a ruminant feed can be implemented."*

This suggests, considering the widespread interest in the use of seaweed extracts for many applications, the impact of different preservation and indeed other processing methods needs further scientific evaluation, particularly given the high expectations for the use of seaweeds in the human food chain.

Freezing:

Freezing is a costly process however it may be a viable option if infrastructure is already in place e.g., existing seafood processing facilities or access to excess waste energy streams.

2.4.2 Secondary Processing

Traditional seaweed value chains have targeted the production of a refined material for a single application. Typical examples being the backbone sectors such as feed, biostimulants/agri extracts and hydrocolloids. The pre-treatments or primary processing steps described above in Section 2.4.1 typically prepare the raw material for further processing.

This secondary processing, depending on the target material(s) usually involves a mechanical or chemical disruption of the seaweed cell wall to prepare the biomass for subsequent extraction. A wide range of extraction techniques exist ranging from water (both cold and hot), steam, various chemicals, enzymes, sonic, the use of steam, etc.

Such value chains generally employ several sequential or serial steps and generate one or several "waste' streams along the way. Nowadays, there is a growing requirement to move away from such processes towards more resource efficient processing and for the valorisation of by-products and "waste". As such, more complex processing approaches that deliver multiple products are sought.

Processing capabilities influence choice around compounds to be extracted. With limited processing capabilities as currently exist in Ireland, processing options are few. The most basic level of processing involves the separation of soluble and insoluble fractions. Subsequent fractionation of the soluble stream using cascading aqueous extractions and/or fractionation by molecular weight (membrane filtration methods) can produce extracts of compounds for targeted markets. The insoluble fraction may have applications as a seaweed fibre for use in food or as a feed additive [3].

2.4.3 Biorefinery for cultivated seaweed

By definition, a biorefinery is a facility that converts biomass/organic matter into a variety of end products for use as food, feed, chemicals, biomaterials, fuel. Typically using multiple technologies to deliver multiple product streams in a cascading and/or integrated approach. The overall focus should be on sustainable and resource efficient processing. The overall aim should be to maximise the use & value of the biomass and minimise the waste.

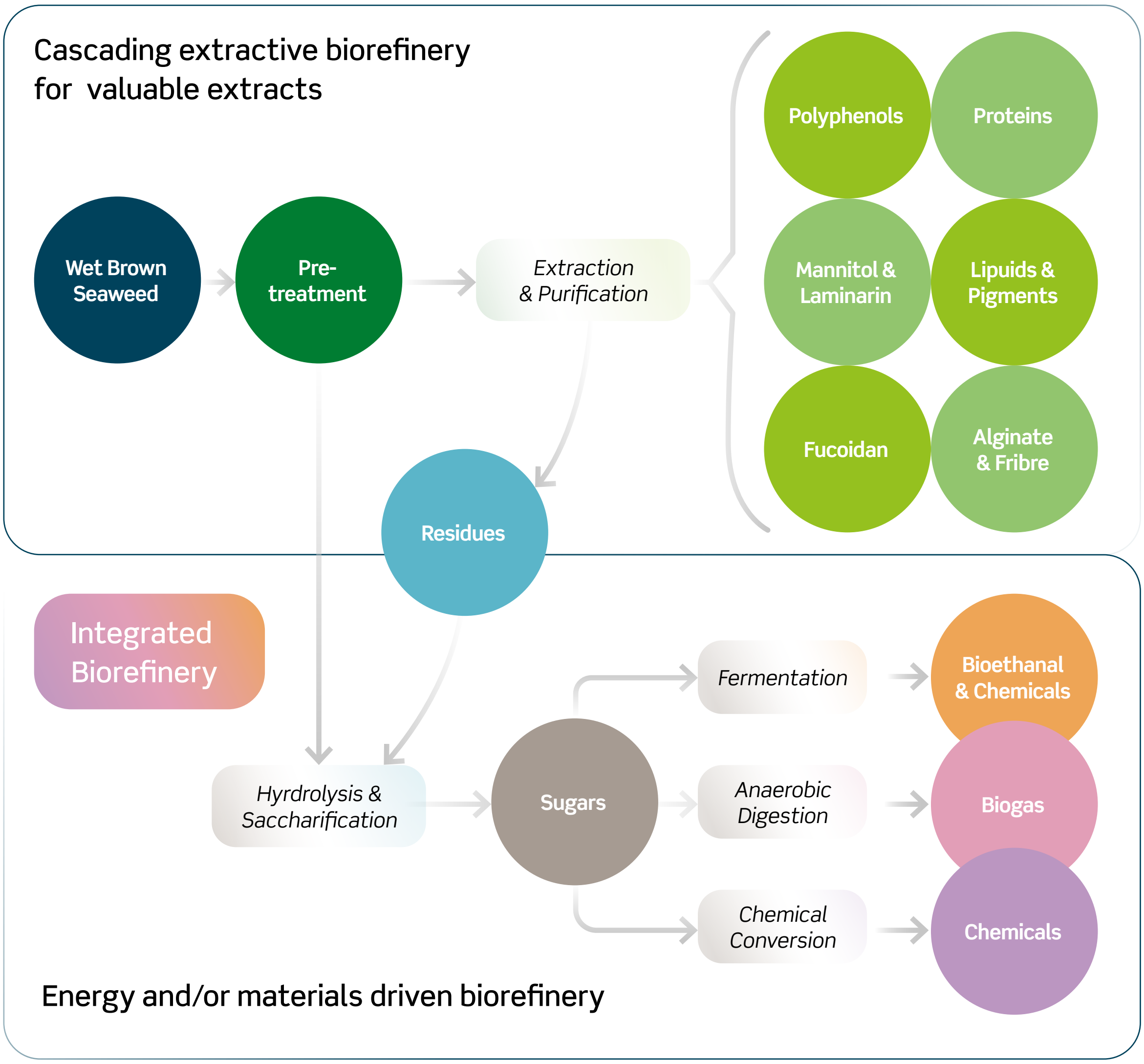
Biorefining of macroalgae has attracted major attention over the past 10 years leading to major investments by private and public sector organisation and numerous publications. A sample of eight EU funded research projects (PROMAC[35], SEABEST[36], SEABIOPLAS[37], SEAREFINERY[38], SEAWEED AD[39], VALGORISE[40], MACROCASCADE[41], GENIALG[42] and MABFUELP), including three projects with an Irish involvement, received grants totalling €33.67 million over the period 2011 to 2020. The source biomass in each project was various common species of kelp, and the project goal was to develop a pilot facility.

Biorefinery projects in the USA, the UK, China, Australia, New Zealand and nationally funded European, received grants of €49.8 million over the period 2010 to 2021, with national governments providing most of grant aid. Planned outputs from all these projects included pilot-scale/demonstration biorefining facilities. Typically, these projects recognised the possibility to extract different biochemical compounds and other substances from seaweed, with the levels of each depending on the source species [59].

35. See: www.promac.no
36. See: https://cordis.europa.eu/project/id/849793
37. See: https://cordis.europa.eu/project/id/606032/reporting
38. See: http://www.marinebiotech.eu/sites/marinebiotech.eu/files/public/SeaRefinery Project description ERA-MBT Call 1.pdf
39. See: https://cordis.europa.eu/project/id/274373
40. See: https://www.gre.ac.uk/engsci/research/groups/bio-biotech-research-group/valgorize-project
41. See: https://www.macrocascade.eu/
42. See: https://genialgproject.eu/

The BIM funded study on scoping a biorefinery concept for Ireland provides a detailed overview of various biorefinery models and potential product streams for key market sectors [3]. The reader is directed to the report for more detail. Figure 5 depicts a simplified biorefinery concept and shows how various processing approaches can be integrated to target end products for diverse market sectors.

Figure 5 - Schematic of a generic biorefinery showing potential for integrated approach



Thus, the ideal seaweed biorefinery aims to extract different constituents, and to ensure the full use of all the biomass through a succession of different processing steps. However, the challenge to realise this concept of seaweed biorefining and biorefineries is quite substantial, since they are less advanced than those using terrestrial sources of biomass, pointing to need for more study on the design of efficient processes [60]. Despite the significant funding committed to the subject, macroalgal biorefineries remain in their infancy; and whilst they show promise, they are slow to move from laboratory scale to industrial scale laboratory scale to industrial scale [59].

Alginor ASA, the Norwegian marine biotech company, has established a pilot scale refinery for wild harvested *Laminaria hyperborea.* Products are aimed at the pharma and nutraceutical sectors. The company has recently secured NOK 427 million investment to proceed with a major scale up. Another Norwegian company, Seaweed Solutions AS, cultivates seaweed and is reported as having validated a pilot biorefining facility to produce food related products from kelp species. However, reaching this stage has taken the company 12 years and investments of €14 million, secured from EU and Norwegian state funds in addition to private equity [61].

Recent reports from Norway describe the economic feasibility of a biorefinery as closely linked to volume of biomass available; suggesting an annual supply of consistent quality biomass of 65,000 tonnes, as the minimum required to support a viable biorefinery [62]. Large scale, *integrated* biorefineries with a biofuel output and based on cultivated biomass of Saccharina latissima or *Ulva spp* are reported to be feasible only at a scale requiring feedstocks of 1 dry tonne/hr [54] or upwards of 200,000 dry tonne per year [63]. Smaller scale production based on at 2,000 dry tonnes of *Saccharina latissima* or *Ulva spp* per year was not feasible.

2.4.4 Strategic issues relating to seaweed processing

Whether a biorefinery or other approach is taken, industrial scale processing must be competitive in extracting the inherent value from the biomass. Multiple factors influence the complexity and scale of a commercial biorefinery. These include, e.g., the volume, profile and condition of the raw feedstock, its intended use, specific product requirements, desired output volume, product quality attributes, certification etc., and costs of production. These factors combine to influence the economics of the conversion process. The following should be considered in defining the post-harvest processing of seaweed biomass;

- The specification of the final product required from the process and the capability of the process to deliver product at the required quantity, cost and quality
- Volume of total available biomass
- The individual species and the biomass (kg) of each to be processed
- The physical and chemical profile of the feedstock
- The timing of harvesting
- Security of supply of the feedstock
- Continuity of supply
- Handling, storage and transport of raw feedstock and processed material
- Available processing equipment and suitability to deliver the required output
- The potential impact of each stage of production on the environment
- Markets in which the product will be sold
- An understanding of the end-use
- An assessment of risks prior, during and after processing

Availability of biomass

Seaweed processors need access to a constant supply of biomass at volumes that match the capacity to process it and meet market demand for seaweed products. Difficulties in breeding species other than *Saccharina latissima* and *Alaria esculenta* has constrained Europe's ability to establish the large-scale cultivation of seaweed.

Seaweed cultivation at a scale that justifies cascade type biorefining requires high volume material input. Figure 6. gives an indication of the available biomass from Irish waters under different annual growth scenarios. The projected biomass output for different rates of increase in sea-area committed to cultivation is based on a typical yield of 20 tonne/ha (as reported for *Saccharina latissima*) [64]. Increasing the sea area from 254 ha by 25 percent/annum over 10 years to an area of 2,365 ha could support the production of 35,000 tonnes of biomass.

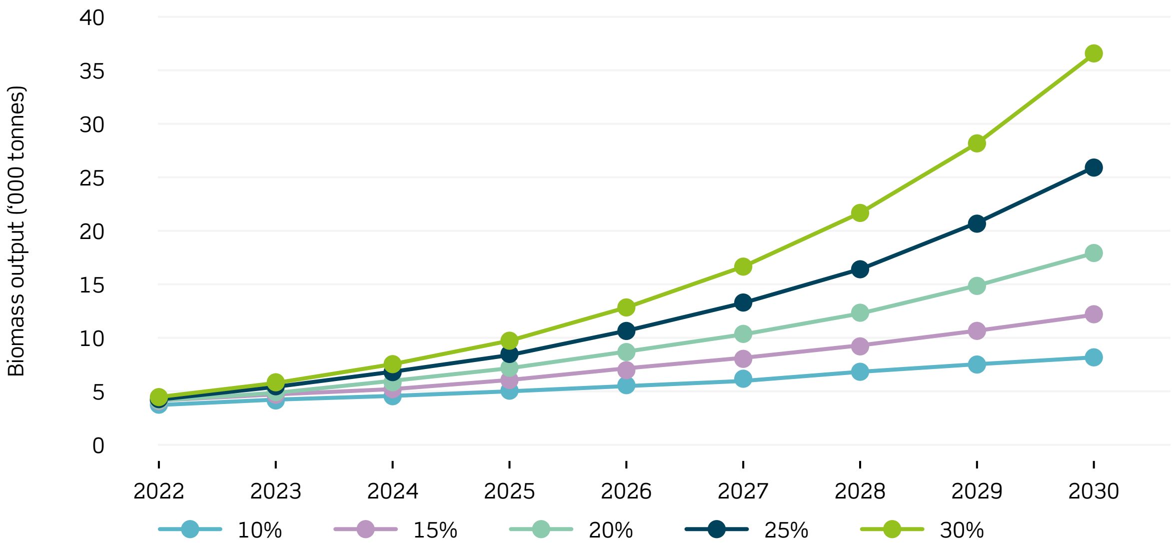


Figure 6 – Projected cultivated biomass output

Characteristics of the raw material

Seaweeds are not homogeneous raw materials. Considerable differences can exist within the same species; they typically vary morphologically, biologically and chemically; and respond to environmental stressors specific to where they grow. Multiple environmental factors influence their growth and biochemical profile and variation also occurs at parts of seaweed from holdfast to the tip. Variability in seaweed composition will impact on the nature of any product and the processing methods that are required.

Table 4 and Table 5 give the typical composition of currently cultivated Irish and European seaweeds Note that these data represent both wild harvested and cultivated biomass and that ranges are given due to the variability in composition. Note also that the methods used to extract and quantify the components of interest also give rise to variability and that quantification may be based on crude extracts or extracts that have had some degree of purification.

Developing an understanding of the variable nature of a biomass supply chain is critical to the success of any commercial enterprise. This is particularly the case where the target is the extraction or valorisation of specific components or nutrients/bioactives. Variability is a likely impact on the availability of biomass (timing and volumes), the type and nature of any processing and importantly the cost.

The ability to control cultivation in land-based systems and potential year-round cultivation, are real positives in this respect. Whereas at-sea cultivation experiences fluctuations in the natural environment, seaweed growth is typically seasonal, with individual plants generally harvested at less than 1 year old. Some farming systems have the capacity for multiple harvests of the same plants and/or year-round growth.

Table 4 – Typical composition of brown Irish & European seaweeds of commercial interest as % of dry weight

	Alaria esculenta	*Saccharina latissima*	*Laminaria digitata*	*Undaria pinnatifida*	*Fucus species*
Carbohydrates	46-56	23-61	22-68	11-70	23-66
Mannitol	<14	2-58	2-20	2	7.5-23
Laminarin	26-39	< 33	14-35	<3%	2.3-11
Fucoidan	2-3	2-12	<6	18-33	<10
Alginate	10-42	10-33	32-45	20-50	20
Cellulose	11-12	4-10	3-9	< 9	5-7
Protein	7-20	4-24	3-15	8-23	1-19
Lipids	<2.7	1-5	<2	<7	<5
Phlorotannin's	<4	<3	<0.2	<4.5	2-12
Fucoxanthin	<0.1	<0.1	<0.1	<0.5	<0.3
Minerals	14-35	10-45	10-40	12-40	11-30

Source: CyberColloids [65], CEVA [66]

Table 5 – Typical composition of red and green Irish & European seaweeds of commercial interest as % of dry weight

	Palmaria palmata	*Porphyra spp*	*Chondrus crispus*	*Ulva spp*	*Codium spp*
Carbohydrates	34-74	30-76	50-66	42-62	39-67
Carrageenan			30-40		
Porphyran		<	48		
Ulvan				8-36	
Starch	<25	<42			
Protein	7-33	15-47	5-25	7-30	8-19
Lipids	< 4	< 2.5	<6	<3	<2
Polyphenols	<1	<5	<0.5		<5
Minerals	12-32	15-35	17-23	14-35	2-12
Key vitamins	E, ProA, C, B1, B2, B5	A, C, B12, B2, B6	10-40	12-40	11-30

Source: CyberColloids [65], CEVA [66]

Processing capability

The available processing capabilities influence what compounds can be extracted and the selection of processes to perform the transformation. With limited processing capabilities as currently exist in Ireland, processing options are few. The most basic level of processing involves the separation of soluble and insoluble fractions. Subsequent fractionation of the soluble stream using cascading aqueous extractions and/or fractionation by molecular weight (membrane filtration methods) can produce extracts of compounds for targeted markets. The insoluble fraction may have applications as a seaweed fibre for use in food or as a feed additive [3].

Figure 7 gives insight to the complexity of a cascading biorefinery process developed to deliver multiple fractions from brown seaweed in the EU Biobased Industries Initiative funded project MacroCascade [67]. The project established to prove the concept of the cascading marine macroalgal biorefinery ended during 2021.

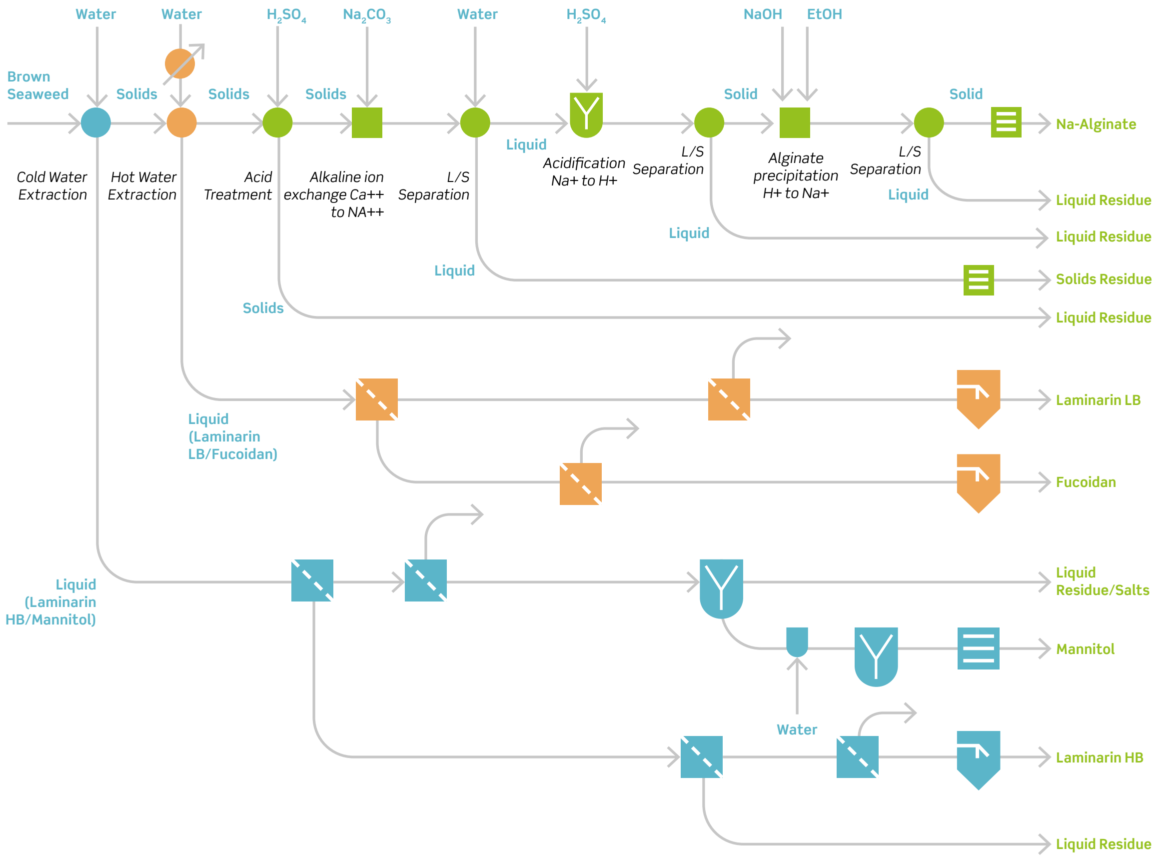


Figure 7 – Cascading seaweed biorefinery process fractionation schematic

Source: Reproduced from Techno-economics of the seaweed Value Chain [67]

This concept comprises 25 individual processing steps and 45 major equipment items in processing a brown seaweed to produce fractions of five compounds, excluding liquid and solid residues.

Market/product opportunity and end-use.

Many references point to the multiple opportunities to use seaweeds in a raw or processed state for products in different commercial markets. Such opportunities include high- and low-value products and require different volumes of biomass. To realise these opportunities, the composition of the seaweed species must include compounds that match the requirements of each product and be compatible with its end-use. Similarly, the processes used to extract the compounds, must have the capability to do so, and be compatible with end-use requirements.

The EMFF funded study of biorefining commissioned by BIM identified product opportunity areas within reach of Ireland's seaweed sector including food, human health and nutrition, plant health, animal health, and biomaterials, chemicals and biofuels [3]. In doing so, the study emphasised the need for far more research into both the products and the processes needed to realise the potential, and that any short-term delivery of this potential is unlikely. Section 3 of this report provides more detail on Macroalgal markets.

Section 3
Macroalgal markets

3.1 Introduction

The Seaweed for Europe roadmap presents an ambitious vision for a European seaweed industry (based on modelled data) that is worth in the region of €0.9-2.7 billion by 2030 – depending on how much potential is realised [45]. The roadmap outlines that in a best-case scenario this industry could supply about 30% of the European demand for seaweed based products across 8 key sectors: animal feed, biostimulants, food, bio-packaging, additives (i.e. hydrocolloids alginate, agar, carrageenan), pharma and nutraceuticals, cosmetics and biofuel. Although, the biofuel market is not expected to be cost competitive during this time frame.

Figure 8 illustrates a generic value pyramid for the seaweed industry with bulk, lower value products at the base of the pyramid – moving towards higher value, lower volume products at the top. Future mass cultivation of seaweed is predicted to allow the production of cheap biomass to supply very high volume, low value markets like biofuels and platform chemicals.

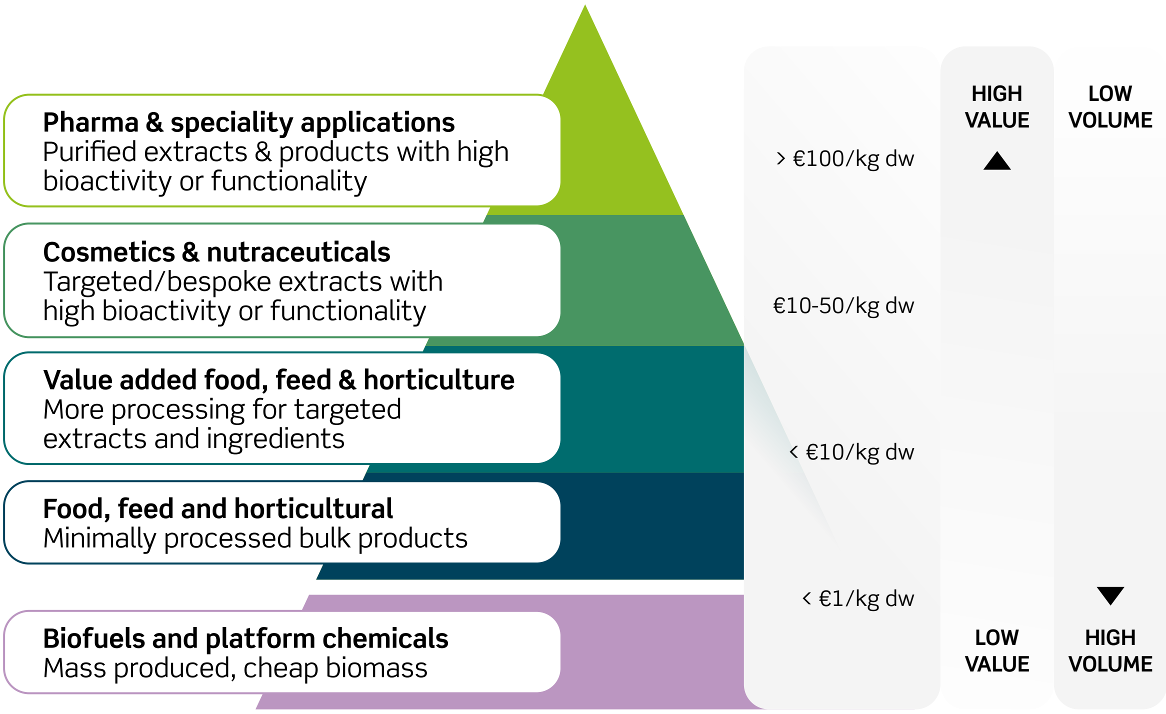


Figure 8 – Value pyramid for seaweed derived products

Three factors limit the availability of higher value products: supply of biomass, processing capability and supply chains based on clear market demands. Whilst there is great optimism and scope for potential in the European industry, detailed market analyses are not widely available and there is a critical need to conduct detailed, sector specific analysis in order to shape the demand, drive the industry forward and build confidence.

Table 6 presents an overview of different European seaweeds that are currently cultivated (albeit at different scales and not necessarily in Ireland) and how they are utilised in key sectors. This is based on detail given in available commercial literature and manufacturers' information that directly links a particular seaweed to its end use. In many instances, product information does not go beyond use of generic details (e.g. "red", "green", "brown seaweeds", "blend of....") and thus the information presented in the table should not be regarded as comprehensive. However, it does provide an insight into the potential breadth of application for cultivated seaweed biomass.

Table 6 – Key market sectors where European seaweeds with cultivation potential are used on a commercial basis

Species	Processed formats			Key market sectors					
	Dried meal & powder	Dry extracts	Liquid extracts	Biostimulants & liquid extracts	Animal nutrition (feed, aquatic & pets)	Biomaterials & packaging	Pharma, health & nutrition	Cosmetics	Food & Ingredients
Red seaweed									
Asparagopsis armata	✓	✓	✓		✓			✓	
Chondrus crispus	✓	✓	✓	✓	✓		✓	✓	✓
Furcellaria lumbricalis	✓							✓	✓
Gracilaria spp									✓
Mastocarpus stellatus	✓	✓	✓	✓			✓	✓	✓
Osmundea pinnatifida									✓
Palmaria palmata	✓	✓	✓		✓		✓	✓	✓
Porphyra species	✓	✓	✓		✓		✓	✓	✓
Green seaweed									
Codium spp.		✓	✓					✓	✓
Ulva regional species	✓	✓	✓	✓	✓	✓	✓	✓	✓
Brown seaweed									
Alaria esculenta	✓	✓	✓					✓	✓
Fucus serratus	✓	✓	✓	✓	✓		✓	✓	✓
Fucus vesiculosus	✓	✓	✓	✓	✓		✓	✓	✓
Laminaria digitata	✓	✓	✓	✓	✓		✓	✓	✓
Laminaria hyperborea	✓			✓	✓		✓		✓
Laminaria ochroleuca		✓	✓					✓	✓
Saccharina latissima	✓	✓	✓	✓	✓	✓	✓	✓	✓
Undaria pinnatifida	✓	✓	✓	✓	✓	✓	✓	✓	✓

Source: Based on commercial literature and manufacturer's information [65].
Species of direct relevance to Ireland highlighted in blue.

3.2 Supply

Europeans are consuming more and more seaweed according to the Valgorize project market report which values the European seaweed market at €840 million, compared to a global value of €8.4 billion [68]. Seaweed aquaculture is viewed as a means to meet the increased demand for traceable, high quality and predictable yields, whilst at the same time avoiding any over exploitation of wild stock [18]. Europe consumes 10 percent of the global seaweed output [69].

In general supply of seaweed does not meet European demand and Europe (as a whole) has to import seaweed. In 2020, more than 170,000 tonnes of seaweed and microalgae were imported into European countries (including EU27, UK and Norway) at a value of around €121 million. This included fresh, frozen and dried material for food use and non-food use as show in Table 7.

Global trade in seaweed and microalgae is classified as either fit for human consumption (HS code 12122100) or not fit for human consumption (HS code 12122900). In 2020 imports of food grade seaweed and microalgae into European countries (EU27+ UK & Norway) accounted for less than 5% of the trade by volume but 40% by value. Imports of non-food grade products accounting for 96% by volume and 60% by value. It must be noted that these data are indicative only and that the contribution of seaweed vs microalgae is not known. Also, the figures for Norway are derived from other member states' data where exports and imports, to and from Norway are reported.

In the same year, over 142,000 tonnes of seaweed and microalgae were exported from European countries (EU27, UK and Norway) at a value in excess of €90 million. Trade in food grade products represented only 6% of this trade by volume but 40% by value. Exports of non-food grade seaweed and macroalgae accounted for 94% of the trade by volume and 60% of the value. Note that these data do not differentiate between intra-European trade and that with other countries outside of Europe. There is significant trade of seaweed and microalgae within Europe [70] but on the whole, Europe is a net importer of seaweed. In 2020 the supply deficit was for around 30,000 tonnes and a cost of €30 million.

Table 7 – Import and export of seaweed and microalgae in Europe in 2020. Volumes in 1000t (kt) and value in €millions.

	Import			Export		
	Food use	*Non-food use*	*Total*	*Food use*	*Non-food use*	*Total*
Volume (kt)	7	164	171	8	134	142
Value (€ million)	49	72	121	37	56	93

Source: Data derived from EUROSTAT

Individually, the United Kingdom has been the largest importer; followed by France, Italy, Germany and Spain. Over the period 2012 to 2016 European imports fell from 66.5 million tonnes to 59.7 tonnes.

A recent industry mapping exercise identified 225 companies in Europe (excl. Russian Federation) that were producing seaweed. Spain, France, Norway and Ireland have more than 20 producers each, of which the majority are harvesting. Of these only 32% were cultivating at sea or on land [18]. France and Norway lead the way in seaweed aquaculture production. Other major players in the sector include Spain, Portugal, United Kingdom, Faroe Islands and Ireland.

There is a strong interest in developing large scale seaweed aquaculture by the Netherlands and Belgium under the auspices of the EU Interreg funded ValgOrize Project. Large scale aquaculture was also the focus of other major EU Horizon 2020 funded projects e.g. SeaBest, MacroFuels[43], AquaVita[44] and GENIALG. Cultivation is also occurring at small scale in Denmark, Germany, Sweden, Estonia and Greenland.

The focus of current seaweed aquaculture activity within Europe is towards food and food ingredients, cosmetics, animal feed and horticultural biostimulants. However, reflecting European priorities to establish a circular "blue" bioeconomy, new opportunity areas are emerging. There is an increasing level of interest in policy and industrial communities regarding the potential of seaweed based products and services to contribute to European sustainable development goals [26].

European interest in and support of largescale seaweed aquaculture is a relatively recent development, which appears to be driven by European ambitions to ensure food security and the protection of natural habitats and resources. This outlook has filtered through to European industry resulting in several major industrial initiatives.

Norway, and the Faroe Islands lead the way with Seaweed Solutions and Ocean Rain Forest, respectively having made significant commitment to large-scale seaweed aquaculture. Species cultivated produced by these companies include *Saccharina latissima*, *Alaria esculenta*, *Laminaria digitata*, *Ulva lactuca* and *Palmaria palmata*.

Whilst Norway has an emerging seaweed aquaculture sector, recent developments by Alginor indicate they intend to harvest 100,000 tonnes/annum from wild stocks for processing in a new biorefinery dedicated to the production of ingredients for pharmaceutical and nutraceutical applications. This operation will only process *Laminaria hyperborea*.

3.3 Market segments

There are many references to the potential of seaweed products and high expectations about the emergence of new markets and novel applications for the use of seaweed and seaweed derived compounds [71] in each of the market segments outlined earlier in Table 6. However, these are overshadowed by their widespread use in food and food related products. Indeed, two main markets dominate in global consumption: food; and the use of seaweed derived hydrocolloids. [72]

Seaweeds and seaweed derived compounds have gained a high-level of acceptance in a small number of market areas; as with their use in agriculture and horticulture as feed and biostimulants respectively. They have also become commonly used in skin care, cosmetics and health and wellness products. Many of the other commonly referenced product areas for seaweeds such as fuel, pharmaceuticals, nutraceuticals, biomaterials, packaging, despite the wide-spread optimism, remain to be more fully explored scientifically to establish commercial feasibility [73, 74].

43. See: www.macrofuels.eu
44. See: www.aquavitaeproject.eu

Below we examine the nature and scale of each of the markets outlined in Table 6 based on the limited literature available.

3.3.1 Biostimulants & liquid extracts

A comprehensive analysis of the European seaweed biostimulant market (within the context of the global biostimulants market) was conducted under the recent ValgOrize project and the reader is directed to that study for full detail [75]. The study was based on data for the market in 2016 when the Europe was the largest global market (40%). The study predicted that the global market for biostimulants would be around €2.66 billion by 2022 and that seaweed-based products would account for over 30% of that market by value (i.e. around €900 million).

The European market was predicted to remain as the primary market for biostimulants in general (>€1 billion) and also for seaweed-based products (€369 million). The study concluded that although biostimulants represent a relatively small sector within the larger global agricultural industry (including fertilisers and plant protection agents), seaweed derived biostimulants represented a significant target market for the European industry. A similar view was taken in the recent Seaweed for Europe roadmap which predicated the European seaweed based biostimulant market to reach €600-700 million by 2030 but with the potential to be much higher if full market potential is realised [45].

3.3.2 Animal nutrition (feed, aquatic and pets).

The use of seaweeds for animal feed and as a fertiliser in horticulture is well established. Initially confined to use within coastal communities they are now in widespread use. Traditionally, the brown seaweeds *Ascophylum nodosum* and *Fucus spp* were harvested and fed directly to cattle, now they tend to be used in the dry and milled form often combined with other nutritional materials to make up a complete feed. The chemical profile of these seaweeds comprising proteins, minerals, trace elements and carbohydrates made it a suitable cattle feed. Greater knowledge of the resource coupled with increased processing capabilities have extended the use of seaweeds in animal feed. In addition, species of kelp including *Laminaria digitata*, *L. hyperborea* and *Saccharina latissima* are also used as a source of feed supplements/additives for cattle, sheep, pigs and poultry.

Global feed production in 2019 was estimated to exceed 1,126 million tonnes [76]. The global market for animal feed is projected to reach US$460 billion by 2026, and to record a year-on-year growth of 4.9 percent from 2020 [77]. The feed additives market in 2021 was valued in excess of €30 billion and predicted to grow at an annual growth rate of 5.5 percent from 2021 to US$49.6 billion by 2026 [78, 79]. Europe, including Russia, is a key producer of feed (279 million tonnes in 2019), behind Asia (363 million tonnes).

Europe was the largest global producer of dairy feed in 2019 (45 million tonnes). Pig, poultry and beef were also key sectors (80, 34 & 22 million tonnes, respectively). The seaweed derived animal feed additive market is predicated to be the primary market (by value) for the European seaweed industry going forward with an estimated value of around €2 billion if full market potential is reached [45]. However, this prediction includes the growth of specific markets to target anti-methanogenesis which are currently developmental.

There are also rapidly growing niche markets for seaweed supplements for other animals including horses, dogs and cats [3]. European production of pet and equine feeds is smaller but still globally significant (8.8 and 1.8 million tonnes, respectively) and lucrative. The market value for wet and dry pet food was valued more than €100 billion worldwide in 2017 with the US market being the biggest at €22 billion. Wet pet food is reported at around 20% of the market on average [40].

European production of aquatic feed is currently around 8.8 million tonnes [76]. The global market has an estimated value in the region of €40 billion and is predicated to exceed €50 billion by 2025 [80]. Whilst application of seaweed-based additives and ingredients in this sector is of great interest, full commercial viability has not been demonstrated. High protein fish feed based on macroalgae is not yet at the point of being commercially competitive compared to traditional protein sources such as soy. Establishing a more competitive position requires increased scale of production and the optimisation of processing methods [81].

Despite evidence of growing markets and more widespread use, the health benefits of seaweeds used in animal feed as nutraceuticals is a contentious issue as are concerns surrounding the arsenic content of some species. Concerns exist about the trials conducted to assess their efficacy, nutritional benefits and the safety of their use in the food chain. There are calls for more detailed studies to determine their biochemical profile (macro and micronutrients, also seaweed metabolites), to fully understand the impact of seaweeds in animals [82].

3.3.3 Biomaterials and packaging

This is a diverse market with demonstrated application of seaweed in multi-million Euro industries including textiles, vegan leather, composites and plastics. The seaweed derived sector is an innovative sector that has attracted a lot of attention but is still an emerging market, [83, 84]. The global market for bioplastics is currently in the region of 8 billion tonnes, with an estimated value of €30 billion [85]. Within this, the global edible packaging market size is projected to grow from US$ 527 million in 2019 to US$ 679 million by 2025, at a compound annual growth rate of 4.3% [86].

Increased consumer awareness of environmental sustainability, and government policies designed to reduce the dependency of industry synthetic for packaging materials, are behind the increased worldwide demand for novel biobased packaging and edible packaging. Seaweed derived polymers offer scope to be used as the basis for new packaging materials. However, the future is not at all clear regarding edible packaging that is in direct contact with food. Several technical challenges have to be overcome to provide the food sector with approved packaging materials from seaweeds. Regulatory agency approval is required due to the propensity of seaweeds to accumulate heavy metals and toxins, supply chains that ensure safe quality approved raw materials must be developed, and industry scale processing has to ensure it can deliver products at a competitive price [87].

The seaweed derived sector still has a number of limiting factors (in the short term), including manufacturing capacity, algal biomass supply and optimisation. With some current technologies there is still a trade-off between biodegradability and durability which has obvious implications for transport, storage and shelf life and sensory properties. Europe is predicted to be a key provider of non-transformed or naturally biodegradable products such as films and coatings for use in a variety of food and non-food applications. Innovation and supply chain transparency are seen to be key drivers for Europe and the European industry is expected to be worth €180 million or more by 2030 providing that the sector can scale to be cost efficient [45].

3.3.4 Pharma, health and nutrition

The marine environment contains immense biological diversity and remains a relatively untapped source of biologically active compounds. Research into the use of marine natural products (MNPs) extends back to the 1950's, during this period marine organisms and micro-organisms associated with them yielded more than 30,000 MNPs offering pharmacological potential. Only eight marine origin drugs were approved for medical use, whilst twenty more remain at various stages in the approval pipeline. Of the approved drugs, only Carragelose® (Iota-carrageenan) an anti-viral agent for the treatment of respiratory diseases is derived from a seaweed [88].

Research into the use of seaweed derived compounds remains at the stage where few of the thousands of seaweed species have been fully screened for bioactive compounds that offer pharmaceutical or other medical potential [89]. Results from research on the pharmaceutical potential of seaweeds profile the composition of relatively few species. Although this is active research area, it is the first stage of a lengthy discovery, trials and approval process that typically takes up to 20 years or more to become a commercial reality.

Projections exist that describe the growth in global pharmaceuticals market will increase at an annual rate of 11.34% from 2021 to 2028 reaching US$ 957.59 billion by 2028 [90]. The marine derived drugs market as a sub-set of the total pharmaceutical market is also projected to account for sales of US$ 2763.8 million in 2025. Online estimates for the global marine pharmaceuticals and drugs market for the period 2018-2021 are variable, ranging from US$9 billion to US$26.5 billion. However, less variable growth is forecast (CAGR of 8-11%) in the coming period, with most optimistic forecasts reaching US$48 billion by 2027 [91, 92, 93].

It is difficult to get any consensus on the value of this market sector as it spans a wide breadth of applications and end use. The value of a product is dependent on purity/grade, targeted action (bioactive, nutritional, other), intended end use and effort used to manufacture it. Established global markets for seaweed derived products such as supplements, high grade alginates, fucoidan, laminarin, fucoxanthin, polyphenols are all reported to have multi-million Euro market value [94]. However, this is one area where targeted market needs analysis is required.

The use of seaweeds and seaweed derived extracts in supplements (tablets, capsules, tonics) and as functional ingredients is a growing market, in particular in Europe and there many products in the market [95]. It is very much a consumer driven market and is subject to a less rigid regulatory environment than that for medicinal products. Target sectors include weight management and associated conditions (diabetes, obesity) and immune support. These markets were estimated to reach US$37 billion and US$25 billion, respectively, in the next five to six years [96]. Other sectors include anti-inflammatory (general health, skin, joints and bones); antioxidant (general health, skin, anticancer) gut health (colonic function and satiety) and also cardiovascular health.

High purity and specific grade alginates and alginic acid are used in a range of pharma applications including medical textiles (wound dressings) and medical devices Common applications include controlled-release of APIs (Active pharmaceutical ingredients), anti-reflux preparations, enteric coatings and to improve solubility of poorly soluble APIs. Europe is the major producer for such products and was estimated to control upwards of 80%-90% of the global market in terms of volume and value in 2017 [97].

Alginate has long been used for making dental impressions however alginate based gels, films and foams are finding increased application in medical devices, for 3-D printing and for providing a matrix/scaffold for regenerative medicine. Viscous solutions/gels are also utilised in medical research for cell culture, storage/transport and preservation. These are innovative and emerging markets but also difficult to scope.

3.3.5 Cosmetics

The global cosmetic market was estimated to be worth over €200 billion in 2020 with the top three players, L'Oreal, Unilever and Estée Lauder accounting for over €70 billion share of this market. Each of these companies utilises algal and marine ingredients in their products. Europe was the third largest market by value (22%) behind Asia Pacific (43%) and North America (24%). Key sectors within the market in 2020 (by value) were skincare (42%), haircare (22%) and makeup (16%) – seaweed extracts are used in all these sectors [3, 94].

Increased consumer recognition of the global challenge of moving to more environmentally sustainable practices and products is particularly visible within this sector. Consumers now look for products based upon clean, naturally sourced ingredients; marine derived ingredients are perceived as such. Increasingly, seaweeds are used in skincare and hair care where they are promoted as offering superior performance over more traditional product offerings. Together these product areas account for 64 percent of the global cosmetic market [94]. Market demand for seaweed derived ingredients and bioactives is growing, already they are used in moisturiser, anti-aging, antioxidant, skin repair and regeneration, and cleanser products, amongst others.

The long-term growth potential of these products is driven by the rise of the middle and upper income classes and changing demographics – in particular, growth in the number of senior citizens and consumers that seek products that fit within lifestyle aspirations [98]. Market analysts project value the global skincare products market in particular at US$140.92 billion in 2020 and project an annual growth rate of 4.69% over the period 2021 – 2026 [99]. This econometric analysis suggests that the cosmetic industry is a market in expansion in which product innovation is a priority as consumers seek out natural based products.

Notable developments in the sector relevant to the use of seaweeds, include research designed to identify novel compounds to replace the use of synthetic materials in cosmetics. In addition to being expensive, some of these materials result in negative side effects for users [100]. Compounds found in many seaweed species with potential use in cosmetic products include phenolic compounds; phycocolloids and other polysaccharides; pigments; lipids; proteins; peptides and amino acids; and vitamins and minerals [101].

3.3.6 Food, ingredients and hydrocolloids

The largest global market for seaweeds, both cultivated and wild is food use. This comprises use for direct human consumption and for the production of hydrocolloids, that are used to provide texture in dairy products, confectionary, bakery, beverages, processed meat products, preserves and sauces. The global seaweed market for human consumption, including hydrocolloids, was estimated to be in excess of €8 billion in 2018 [68].

Most of the market (89% by value) is used directly as food, the remainder (11% by value) is attributed to hydrocolloids production. Ninety-seven percent of the global seaweed production is cultivated in China, Indonesia, Japan and the Republic of Korea. The European seaweed market for food (including hydrocolloids) is estimated to be around 10% of the global market at present but could reach €2 billion by 2030 (excluding hydrocolloids) if full market potential is realised [68]. At the moment, 99% of European produced seaweed that is used for food comes from wild harvested biomass [68].

The current global market for food and pharma hydrocolloids (excluding China) is estimated to be around 2.5 million tonnes and with a value more than €7 billion. The seaweed derived hydrocolloids account for about 15% of the total global market value. An estimated 58,000 tonnes of carrageenan (valued at $546 million), 18,000 tonnes of alginate (valued at $326 million) and 13,000 tonnes of agar (valued at $229 million)[45] [102]. The European market for these hydrocolloids is predicted to grow to €600-700 million by 2030 [45].

Recent reports on global seaweed markets point to continuing growth in demand for seaweeds in food related products and ingredients, stimulating a projected annual growth of between 9 to 12 percent over the period 2020 to 2024 [103]. The demand for edible seaweeds and hydrocolloids in Europe is also increasing [98]. Over the period from 2014 to 2016, European imports of seaweed, carrageenan and agar for human consumption and non-edible uses averaged 166,853 tonnes. The value of this trade was around €500 million in 2016. Note that these values are much higher than the import/export data reported in Table 7 earlier, but those data did not include any trade in carrageenan and agar. Based on market value, the European Union is the world's largest seaweed customer [72].

Evaluations of the nutritional properties of seaweeds point to the presence of fibre, proteins, fatty acids, vitamins, and minerals that make them attractive to the food sector as an alternative food source [104]. The food market is set to dominate seaweed consumption for the foreseeable future with demand from Europe for seaweed-based products outperforming growth in other regions.

Development of the European seaweed market for food is also seen as a driving force for development of the industry as a whole [27]. Growth is reported to be further driven by consumer concerns over their health and their perceptions that seaweeds as healthy, nutritious food, and low in calories. Global mega trends for "plant-based" and "ALT-protein" are predicted to influence the market for some time and seaweed fits well with these trends.

45. The values quoted exclude the Chinese market

Europe is currently unable to satisfy market demand for seaweed products due to limited supply; this constraint is expected to lead to increased imports and higher prices in the European market [98]. it is anticipated that this situation will continue in the next 10 years or more, the best-case scenario being that European production will satisfy 30% of the market demand in 2030 [45]. Large scale production of seaweed for food (including offshore cultivation) is reported to be on a tipping point to commercial viability. However, once surmounted is anticipated to attract the necessary interest, investment and confidence boost to propel the industry forward [13].

Because of the potential for the use of seaweed as a food product, a further analysis of food markets is contained in Appendix 2.

3.3.7 Biofuels

Despite the substantial investments over the past 30 years in exploring the potential of seaweed derived biofuels, the technical feasibility of large-scale conversion of raw materials into fuels remains at a laboratory scale. After Initially attracting the interests of the global oil companies, few have continued investments in biofuels [105]. However, research efforts continue to explore the fuel potential of macro and micro algae.

Recent finding from the EU Horizon 2020 funded MacroFuels project, which focused on fuel production from macroalgae concluded, having demonstrated the technical viability of the production of biofuels from seaweed remains at an early stage of development and the high costs of cultivation and processing coupled with the variation of seaweed composition between cultivation site, season and species present challenges for both the logistics within the supply chain and the business case [106].

Section 4

Profile of the Irish macroalgal industry and its supports

4.1 Introduction

Ireland's seaweed sector is dominated by the harvest and use of wild stock. Any consideration of the role and potential of cultured seaweeds has to acknowledge this dominance and the difficulties faced by consumers, processors and others in separating the use of cultivated seaweed from wild harvested stock or justifying cost differences between materials from each source. The majority of Irish harvested seaweed is ***Ascophyllum nodosum***, none of which is currently cultivated, and about which exist reservations concerning the feasibility of culturing it on a commercial scale.

Seaweeds harvested in Ireland in the year ending 2019 total 29,542 tonnes (wet weight) inclusive of 42 tonnes of cultured stock [24]. And whilst the species accounting for the majority of the annual harvest is known, only a broad indication of the range of cultivated stock biomass is available. Available data indicate between 20 and <100 tonnes per annum, mostly kelps, providing no detail of the cultivated biomass of individual species [24, 107].

Efforts to establish seaweed aquaculture in Ireland have met with varying degrees of success. The kelps – *Alaria esculenta, Laminaria digitata* and *Saccharina latissima* have emerged as the most successful, whist establishing any of the red seaweeds in anything other than experimental trials met with limited success; with *Palmaria palmata* reported by consultees to this study as the most promising [108].

4.2 Policy, legislative and funding context

Unlike fisheries, aquaculture policy is a competence of individual member states of the European Union. Nevertheless, the EU is a significant influence on the aquaculture industry: there are several relevant environmental and food safety directives which have a bearing on the methods of production and sale of aquaculture output. This situation applies equally to seaweed aquaculture. In considering the policy environment for seaweed aquaculture it is necessary to consider the policy and legislative drivers that arise at both a European and national level.

The European Union make use of the 'Open Method of Coordination' (OMC) in order to ensure coordination and cooperation between member states in matters relating to aquaculture production. The OMC is defined by the EU as a form of 'soft law' [109]. It is based on three core approaches:

1. Jointly identifying and defining objectives to be achieved. These are typically adopted by the European Council.
2. Jointly established measuring instruments, i.e. statistics, guidelines and indicators,
3. Benchmarking, i.e. the exchange of best practices, and comparison of member state performance.

In practice, a key mechanism used by the EU to achieve progress in areas such a aquaculture is through the adoption of European wide policies that are supported by legislation routed in EU competencies and through the use of funding mechanisms that encourage progress towards the objectives of those policies.

In this section we examine those policy, legislation and funding mechanisms that exist at both a national and European level which are relevant to seaweed aquaculture in Ireland.

4.2.1 European Policy

There are multiple policy statements at a European and national level that advocate the development of algal cultivation across a range of uses. In its communication to the other Institutions of the European Union in December 2019 on **The European Green Deal**, the European Commission single out seafood based on algae as an example of new innovative food and feed that will feature in a process within the EU's Farm to Fork Strategy to reduce the impact of food processing on the environment [110].

The **Farm to Fork Strategy**, published in 2020, commits the EU to examining EU rules to reduce the dependency on critical feed materials such as soya grown on deforested land by fostering alternative protein sources that include marine feed stocks such as algae [111]. The strategy commits the next European Maritime and Fisheries Fund to include targeted support for the algae industry, on the basis that algae should be an important source of alternative protein for a sustainable and secure food system.

The focus of EU policy in relation to seaweeds under the European Green Deal is primarily visible through its role in food production. The **EU Circular Economy Action** plan positions Algae as a natural mechanism for nutrient removal from aquatic and marine environments [112]. The **EU Biodiversity Strategy for 2030**, while discussing maritime governance, marine eco-systems and sustainable fishing, does not explicitly mention macro-algae or seaweed.

Studies on new and alternative sources of biomass by the EU have not focused on marine algae to the same extent as has been the case for terrestrial sources such as forestry, reflective of existing biomass production today. These studies point to uncertainty around worldwide production data at both an international and European level as an inhibitor to effective policy development for the sector [113].

It is in the European Commission's communication on **A new approach for the sustainable blue economy in the EU – Transforming the EU's Blue Economy for a Sustainable Future**, that tangible actions in relation the EU's approach to seaweed production emerge [114]. In this, the Commission highlight the role algae production has as an alternative to agriculture, and as a source of bio-based products and bio-fuels, while noting that the introduction of new algae-based foods may be subject to the requirements of the Novel Food Regulation. In the communication, the Commission committed to:

> *"...adopt a dedicated initiative on algae in 2022 to support the development of the EU's algae industry. The initiative will facilitate the authorisation of algae as novel foods by cutting application costs, facilitate market access, increase consumer awareness and acceptance of algae products and close gaps in knowledge, research and innovation".*

As part of this action, the Commission conducted a consultation in mid-2021, and has a scheduled adoption of suitable policy instruments in the second quarter of 2022. In the Inception Impact Assessment published as part of the consultation, the Commission identify the following as the principal challenges facing the EU macro-algae sector [115]:

- **Regulatory gaps:** no adequate legal and policy frameworks at EU or national/regional levels,
- **Market gaps:** lack of scaling-up and limited supply of algae biomass and algae-based products,
- **Unfavourable business environment:** lack of access to marine space, infrastructure and technology,
- **Social barriers:** lack of consumer awareness and acceptance of algae products, their nutritional value
- **Knowledge and R&I gaps:** e.g. cultivation systems, biorefineries, processing into multiple products, quantification of environmental services (carbon sequestration – blue carbon credits), nutrient absorption, habitat creation or restoration, coastal resilience, and potential opportunities, advantages and negative impacts and risks of cultivation and harvesting, and
- **Lack of targeted funding** e.g. for the construction of innovative bio-refineries.

The policy options envisaged for consideration in the Inception Impact Assessment include:

1. No Policy Change
2. Targeted activities to address the above issues, without regulatory measures. A wide range of activities are proposed including measures associated with spatial planning, harvesting guidelines, licencing, and labelling of algae-based products, improved implementation of existing regulations for algae-based products (including the Organic Regulation and the Novel Food Regulation), and social awareness actions.
3. All the activities in (2) above, and additional steps such as binding targets for substitution of fish-based fish feed, enhanced integration of algae in the Common Fisheries Policy, quotas for wild harvest and environmental impact assessment for harvesting live seaweed, and other measures as may emerge from the public consultation process.

While awaiting the policy developments at European Level, the general perspective of the Commission in relation to algae, and macro-algae in particular, can be discerned from the annual **Blue Economy Reports** published jointly by the European Commission Directorate General for Maritime Affairs and Fisheries, and the Joint Research Centre. These, including the most recent report for 2021, position algae production as a sub-sector of the Blue bio-economy which itself is described as an emerging sector [116]. Macro-algae cultivation is considered together with wild algae harvesting and micro-algae production. The 2021 report notes that

> *"The available data on the turnover and employment on the algae sector refer to the aquaculture industry. These data are very fragmented and cover only France (macro-, microalgae and Spirulina), Spain (macro-, microalgae and Spirulina) and Portugal (macroalgae). The analysis of the data show that 87% of the total number of algae aquaculture companies are micro-enterprises with fewer than five employees. The EU aquaculture (considering these countries) employs 509 persons, 399 in full time equivalent (FTE). The sector has a total reported turnover (in these countries) of €10.7 million".*

In discussion on new developments, the 2021 report observes that the algae biorefinery concept is being explored as an approach to increase environmental sustainability and economic feasibility of existing conventional industrial processes and cites a number of projects that are researching optimisation and upscaling of algae biorefinery production. Other emerging developments cited are offshore aquaculture techniques and Integrated Multi-Trophic Aquaculture (IMTA), in both cases highlighting technological challenges.

That marine alga are seen by the European Commission as being outside the mainstream of aquaculture production, is further evidenced by its absence from the European Commission's communication on **Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030** [117]. This references the commitments made in the Farm to Fork strategy regarding algae, and states that the Commission is

> *"...working on a separate and specific initiative to support the production, safe consumption and innovative use of algae. This initiative will address the challenges and opportunities of algae farming and propose concrete actions".*

While the European Commission has stated that it will publish policy instruments relating to algae in the second quarter of 2022, the EU's principal funding mechanism for aquaculture projects entered into force on the 14th of July 2021. The **European Maritime, Fisheries and Aquaculture Fund (EMFAF)** is intended to support the sustainable exploitation and management of aquatic maritime resources. The preamble for the regulation governing the fund states that the fund may support aquaculture which includes the farming of plants to produce food and other raw material [118].

In real terms, the EMFAF represents a further cycle of the EU's previous European Maritime and Fisheries Fund (EMFF) which ran from 2014 to 2020. Under the EMFAF, Ireland will receive €142m of co-funding to be distributed to projects co-funded by the Government of Ireland under a shared management mechanism. Allocations to individual member states is in the same proportion as under the EMFF. Additional funding may also be available directly from the Commission under direct management programmes.

The EMFAF is closely aligned with the Common Fisheries Policy, which requires each member state to develop a multiannual national strategic plan for aquaculture. A National Strategic Plan for Sustainable Aquaculture Development 2021-2030 is currently being prepared for Ireland under the direction of BIM [119].

The European Commission have stated that the implementation mechanisms for the EMFAF will be simpler than those for the EMFF, which had been described as precise, rigid, and complicated for member states to implement [120]. The fund will have 4 priorities, which include:

1. Fostering sustainable fisheries and the restoration and conservation of aquatic biological resources
2. Fostering sustainable aquaculture activities, and processing and marketing of fishery and aquaculture products, thus contributing to food security in the Union
3. Enabling a sustainable blue economy in coastal, island and inland areas, and fostering the development of fishing and aquaculture communities
4. Strengthening international ocean governance and enabling seas and oceans to be safe, secure, clean and sustainably managed.

Each of these priorities will comprise of objectives, which broadly describe the scope of support to be provided on thematic lines, such as protection of biodiversity, promotion of sustainable aquaculture and collection of scientific data. Eligibility rules will be largely devolved to member states, with limited rules being set at an EU level in comparison to the EMFF.

Also of relevance to the aquaculture sector, including seaweed aquaculture, is the **Brexit Adjustment Fund**. This fund, which was approved in 2021 is designed to help member states tackle negative impacts of the withdrawal of the United Kingdom from the European Union (BREXIT) [121].

The reserve is a special one-off emergency instrument agreed by the institutions of the European Union, of which Ireland is expected to be the largest beneficiary in real terms, with a provisional allocation of €1.16bn of which a minimum of €55.6m is to be spend on local and regional coastal communities [122]. Under the regulation establishing the fund, substantial amounts of the fund are to be disbursed as pre-financing to member states, in three instalments in 2021, 2022, and 2023.

4.2.2 National Policy

The predominant current national food strategy is **Food Vision 2030**, which sets out the broad objectives for Ireland's agri-food sector. This sector includes primary agriculture, food and drink processing and manufacturing, forestry, equine breeding and service, and fisheries, aquaculture and fish processing. In order to achieve a vision of Ireland becoming a world leader in Sustainable Food Systems, it sets out four mission areas (each with a number of goals) as follows:

- A climate smart, environmentally sustainable agri-food sector;
- Viable and resilient primary producers with enhanced wellbeing;
- Food which is safe, nutritious and appealing: Trusted and valued at home and abroad;
- An innovative, competitive and resilient agri-food sector, driven by technology and talent.

As an action towards the first of these mission areas, Food Vision 2030 identifies the development of new bio-based value chains based on Ireland's comparative advantage in the production of grass, legumes and other perennial species [123]. It notes that the oceans and seas offer potential for cascading use bio marine resource in the bioeconomy, including through algal biorefineries and seaweed faming, together with the multi-use of marine space in offshore platforms.

A further action, that Ireland will play a leading role in shaping how greenhouse gas emissions from livestock farming are understood, note the potential role anti-methanogenic properties of certain seaweed species.

The previous national food strategy, Foodwise 2025 was significant in explicitly recognising the potential of seaweed unlike its predecessor Food Harvest 2020 [124, 125]. The Foodwise 2025 strategy identified actions for the seafood sector, an action was included to prioritise research and development in seafood-based product development, food ingredients and functional foods to include both harvested wild and farmed seaweeds together with their by-products. A further innovation action charged DAFM, the Marine institute and industry to develop further research programmes on the potential of marine life, including seaweed, as possible high values sources of pharmaceutical, cosmetic, and renewable energy products.

In October 2021, the Seafood Task Force published its report, Navigating Change [48]. The task force was established by the Minister for Agriculture, Food and the Marine, Charlie McConalogue TD, to examine the implications of the UK/EU Trade and Cooperation Agreement (TCA) for the Fishing Industry and Coastal Communities. The report in a comprehensive and wide-ranging examination of the Irish Seafood and related sectors; including aquaculture; which usefully summarises legislative, funding, legal and structural aspects. Of particular note are:

- **Investment schemes:** The report notes that national and EU co-funded EMFF funding is administered through grant aide programmes administered by BIM. These are the Sustainable Aquaculture Scheme (SAS), and the Knowledge Gateway Scheme (KGS). The SAS supports new aquaculture enterprises to enter the sector and existing enterprises to scale, diversity, and increase competitive efficiency and competitiveness. Under the scheme, higher rates of funding (50% versus a standard 40%) are available to projects relating to seaweed farming. The KGS promotes knowledge, innovation and technology in the aquaculture sector through specific projects.
- **Aquaculture Licensing:** the report notes the need for DAFM to continue the implementation of recommendations from the report of the Independent Aquaculture Licencing Review Group, and to streamline the administrative procedure.
- **Market Dynamics:** the report states that the development of the aquaculture sector will depend on understanding of domestic, EU, UK and global markets, alignment with consumer orientation, and public expectations in those markets of issues relating to healthy food, climate and animal welfare. It also stresses the need to differentiate sustainable Irish products around taste, nutrition and lifestyle attributes.
- **Vision:** the report advances a vision for the aquaculture sector; "A sustainable, profitable, competitive, and market focused aquaculture industry making the maximum long-term economic and social contribution to coastal communities and Ireland as a whole. To deliver this vision, priorities for development are identified: Market focus; Sustainable production increases, employment creation; reliable economic and efficient route to market; sustained ancillary services, self-sufficiency, climate positive; and innovation.

In relation to seaweed aquaculture specifically, the report states that there is a need for a commercial hatchery to provide seeded string to the sector, and for development agencies to support and innovate existing and new production techniques. The opportunities of anti-methanogenic animal feed additives are noted, though caution on the challenges associated with realising these opportunities is advised. Co-location of seaweed aquaculture with offshore wind energy sites, Integrated Multi-trophic Aquaculture (IMTA), bioremediation for heavy metals and carbon sequestration are also mooted as areas for further consideration. There is a specific need identified for increasing knowledge and innovation in mechanisms to add value to the raw seaweed, including extraction of bioactives, combined with knowledge transfer to product generation and commercialisation.

Appendix 6 of that report includes sectoral analyses of a number of aquaculture sectors, including Seaweed. This provides an overview of the sector (including wild harvest). Given the small size of the sector, which is characterised in the analysis as accessing local and niche markets, little impact or challenges are identified as arising from Brexit.

Industry perspectives provided include the need for multi-stakeholder collaboration in an innovative development programme, and innovation policy which is challenge orientated. A strengthen R&D capacity is stated as being required. The sectoral analysis also includes a SWOT analysis for the Seaweed sector sourced from IFA.

At the time of preparation of this report, the National Strategic Plan for Sustainable Aquaculture Development (2021-2030) was being prepared on behalf of government by BIM. In parallel, DAFM have commenced preparation of an Aquaculture Scheme as part of a forthcoming Operational Programme for Ireland's implementation of the EMFAF.

Both these documents are likely to be updated to reflect the recommendations of the Seafood Task Force, with publication expected in 2022. The two documents are closely related, representing strategy and implementation respectively.

Based on discussions with multiple stakeholders, the National Strategic Plan for Sustainable Aquaculture is expected to include four objective areas:

- **Building the resilience and competitiveness of Irish aquaculture.** This will include actions relating to: Access to space and water; Regulatory and administrative framework; Animal and public health; Climate change adaptation and mitigation; Producers and market organisations; Control of aquaculture products; and Diversification and adding value.
- **Participating in the Green Transition.** This will include actions relating to: Environmental performance; and Animal welfare.
- **Ensuring social acceptance and consumer information.** This will include actions relating to: Integration of aquaculture in the local economy; and Data and monitoring.
- **Increasing knowledge and innovation.** This will include actions relating to: Innovation; and Human capacity-building and training.

A significant number of the expected actions relating to the first objective area (Building the resilience and competitiveness of Irish aquaculture), while not directly related to seaweed cultivation, will have relevance to the development of the sector. These include actions relating marine planning activities and the administrative and regulatory framework. In keeping with the status of seaweed products as Novel Foods, no specific actions relating to seaweed are expected in relation to animal and public health.

As part of climate change adaptation and mitigation, it is expected that actions to encourage opportunities for low trophic aquaculture will be included, in particular seaweeds. These actions are expected to primarily focus on how such species can contribute to the replacement of high carbon items such as animal feeds, packaging and fuels. Actions may also examine the role of seaweeds in carbon sequestration.

The positive role seaweed aquaculture can play in supporting ecosystem services and positively contributing to the marine environment is expected to be highlighted in relation to the second objective area (Participating in the Green transition). Actions under this goal are likely to support the development of societal understanding of this role, and these will also support the third objective area.

The third objective area (Ensuring social acceptance and consumer information) will itself focus on direct consumer understanding of the benefits of seaweed (and aquaculture generally) to consumers, both directly as a food product and indirectly as an environmentally sustainable and beneficial activity. This is likely to include actions that support the development of synergies of aquaculture to other coastal economic activities.

Much of the seaweed cultivation sector is at an early stage of development, both in terms of scientific understanding of species, and in terms of cultivation know-how. With this in mind, the fourth objective area (Increasing knowledge and innovation) is likely then to be highly beneficial to the seaweed sector.

Actions that support basic understanding of individual species, the role of IMTA, put in place a road map for Research, Technological Development and Innovation (RTDI), promote investment in innovation and support knowledge transfer to industry are expected under this objective area. So too are actions that identify training need and take steps to promote the aquaculture sector as a sector for employment.

Projects to support each of the objectives of the National Strategic Plan for Sustainable Development, and which are aligned with the priorities of the European Maritime, Fisheries and Aquaculture Fund (EMFAF), are likely to be supported under the national Operational Plan Aquaculture Scheme. The support rate of 50% attached to seaweed cultivation projects that was in place for the EMFF is expected to be continued. Funding for the scheme is likely to come from both the Brexit Adjustment Fund (focusing on projects in the in the early part of the programme) and from the EMFAF.

4.2.3 Legislative setting

Two regulatory systems, one European and the other Irish, ultimately provide the legal framework for the operation of all seaweed aquaculture activities. However, at a European (EU) level, specific regulations concerning seaweed aquaculture have yet to be formulated. Despite this lacuna, a raft of other EU regulations is relevant to, and hence influences how all stages in the seaweed cultivation process, including hatcheries, operate.

The main EU legislation relevant to seaweed aquaculture includes the following directives and regulations, the Maritime Spatial Planning Directive 2014/89/EU, the Marine Strategy Framework Directive 2008/56/EC, the Water Framework Directive 2000/60/EC, the Alien Species Regulation 2014/1143/EU and Regulation on Aliens Species in Aquaculture 2007/708/EC, the Habitats Directive 92/43/EEC, and the Regulation on Organic Production 2018/848/EU. Other legislation relating to employment, workplace safety etc. also apply.

Ireland's national aquaculture licensing system is administered by the Department of Agriculture, Food and the Marine. This system is designed to ensure any aquaculture activity in Ireland (defined as) "the culture or farming of fish, aquatic invertebrates, aquatic plants or any aquatic form of food suitable for the nutrition of fish" complies with Section 6 of the Fisheries (Amendment) Act, 1997 (as amended). Any land-based aquaculture may require planning permission and permits for the discharge or abstraction of waters from the relevant authorities.

The Marine Spatial Planning Directive is transposed into Irish Law by Part 5 of the Planning and Development (Amendment) Act 2018. This has established a legal basis for Ireland's National Marine Planning Framework (NMPF). The Framework, which has been published, sets out the basis for 'Overarching Marine Planning Policies' (OMPPs) and 'Sectoral Marine Planning Policies' (SMPPs). The NMPF will not replace existing regulatory regimes such as that outlined above for aquaculture but will provide an overarching framework for their continued operation. At the time of preparation of this report, The Maritime Area Planning Bill 2021 is before the Houses of the Oireachtas, and once enacted will provide a legal imperative for the consideration of OMPPs and SMPPs.

4.3 Production profile

4.3.1 Commercially relevant seaweed species

Few of the many Irish seaweeds (~500) have been exploited commercially, with an even smaller number accounting for the majority of seaweed biomass in Irish waters [126]. A greater research effort to profile all indigenous species, would most likely identify further species with properties that are of interest to the expanding number of commercial sectors seeking novel compounds.

This research could also determine the feasibility of culturing these species in a commercial setting. The BIM guide identifies seaweed species in each of the three phyla – Phaeophyta (brown), Rhodophyta (red) and Chlorophyta (green) as commercially important. The 20 species described as important are listed below in Table 8.

Table 8 – Seaweed species identified as commercially important in Ireland. Showing current cultivation status in Ireland and elsewhere in Europe.

Species	**Ireland**	**Europe**	**Cultivation system**
Phaeophyta – brown seaweeds			
Alaria esculenta	Yes	DK FO FR NL NO UK	Sea
Laminaria hyperborea	No‡		
Laminaria digitata	Yes	FO FR NO SE UK	Sea
Saccharina latissima (formerly Laminaria saccharina)	Yes	DE DK ES FO FR NO NL PT SE UK	Sea
Himanthalia elongata	No‡		
Fucus vesiculosus	No‡	DE DK SE	Land, Sea [127, 128, 129]
Fucus serratus	No	DE DK SE	Land, Sea [128, 129]
Ascophyllum nodosum	No‡		
Pelvetia canaliculata	No		
Rhodophyta – red seaweeds			
Palmaria palmata	Yes/trial	DK FO FR NO PT UK	Sea, Land [13]
Porphyra spp	Trials	FR NO PT	Land [13]
Chondrus crispus	Yes/trial	FR PT	Land [13]
Mastocarpus stellatus	No‡	DE PT	IMTA, Land, Sea [95, 130]
Asparagopsis armata	Yes	DK,PT SE	Sea, Land Trial
Phymatolithon calcareum	No		
Llthothamnion corallioides	No		
Chlorophyta – green seaweeds			
Ulva rigida	Trials	Regional *Ulva spp.* ES FR NL PT SE UK	Land, Sea
Ulva Intestinalis (formerly Enteromorpha intestinalis)	No‡		
Ulva compressa (formerly Enteromorpha compressa)	No‡		
Codium fragile	No	*C. tomentosum* PT	Land [13]

‡ Information provided by the Department of Agriculture, Food and the Marine indicate that applications have been received for licences to cultivate these species.

Of the 20 species listed, 8 are currently cultivated in Ireland, albeit some are at trial scale. Of the 12 species that are currently not cultivated, it is very unlikely that *Phymatolithon* and *Lithothamnion* would be cultivated as they are extremely slow growing species and no records have been found to indicate any activity in relation to the cultivation of *Ascophyllum nodosum* (again a relatively slow growing species), though information received from DAFM indicate that licence applications for the cultivation of this species have been received.

However, cultivation of most of the remaining species (or similar regional species) is occurring elsewhere in Europe. Table 9 details some species that are cultivated elsewhere in Europe and may be of potential to Ireland in the future.

Table 9 – Other seaweed species identified as commercially important in Europe, showing current cultivation status and potential for future cultivation in Ireland.

Species	Cultivated elsewhere in Europe	Cultivation system	Potential for Ireland
Phaeophyta – brown seaweeds			
Laminaria ochroleuca	PT	Trial	European species shifting northwards in response to climate change. Now present in Ireland [131]
Sacchoriza polyschides	UK	Trial at sea	Native to Ireland [132]
Undaria pinnatifida	FR ES	Sea	High value food crop, source of fucoidan and pigments, non-native to Europe but cultivation permitted in some countries, present in Ireland [133]
Rhodophyta – red seaweeds			
Furcellaria lumbricalis	Baltic	Trial	Source of furcellaran (gelling agent) and pigments [127], native to Ireland [132]
Gracilaria spp	DE ES PT	Land	High value food crop, agar containing, native species occur in Ireland [132]
Osmundea pinnatifida‡	PT	Trial	High value food crop, Identified for future potential in Scotland [41], native to Ireland [132]

‡ Information provided by the Department of Agriculture, Food and the Marine indicate that applications have been received for licences to cultivate this species.

4.3.2 Scale and distribution of culture activity

There is a scarcity of reliable data relating to the structure and performance of Ireland's seaweed culture sector, reflecting its nascent stage of development. National trade (import and export) statistics do not differentiate between wild harvested and cultured stock. Growers are the source of information on the species being cultivated and biomass production rates, however, for reasons of commercial confidentiality, growers are reluctant to provide any data.

Until recently applications for licences to culture seaweed did not always indicate the botanical names of species to be cultured; with some licences appear to have been granted for the cultivation of species based on common names. They indicate the total sea area within which the cultivation is to be established, and the cultivation method, however, the projected biomass production, or the source of seaweed for on-growing, are not.

At least two seaweed hatcheries operate in Ireland, one in Bantry Bay, the other in Allihies Co. Cork. These hatcheries can produce a range of species for on-growing, including *Alaria esculenta, Laminaria digitata, Saccharina latissima* and *Palmaria palmata*. Other species in trial cultivation include *Asparagopsis armata* and *Porphyra umbilicalis* [134]. The National University of Ireland, Galway maintain a hatchery for research purposes at Carna, Co Galway. None of the hatcheries operate on a fully commercial scale. The topic of hatcheries is discussed more fully in Section 5 of this report ("Hatchery Requirements of the Irish Seaweed Industry").

Scale of enterprise activity

The only indication of the extent of seaweed cultivation is the number of aquaculture licences issued by the Department of Agriculture, Food and the Marine. Even these data do not provide a full picture of actual cultivation, since licence grantees may not always commence cultivation. Data provided by BIM indicate a total of 25 licenced sites in counties Clare, Cork, Donegal, Galway, Kerry, Mayo and Sligo. Difficulties arise in respect of identifying employment levels at the licenced sites; some sites propose to cultivate other species as well as seaweed, whilst others may not have commenced seaweed cultivation. Similarly, the area for which the licence is granted, even though seaweed is being cultivated, may not be fully operational.

The total area of all licenced sites approved to grow seaweed is 254.5 ha, however, this also includes areas used to cultivate other species. Data from BIM indicate there are 9 active seaweed growers in and one trial cultivation site the state, which in 2020 harvested a total of 44 tonnes, rising to 50.5 tonnes to date in 2021. The same source indicated the employment in the sector is 3.8 full-time equivalents (FTE's) per annum.

The increased global interest in seaweed for applications in a variety of commercial activities is replicated in rising interest in the species in Ireland. There are reports of the sector attracting new entrants involved in farming seaweeds, utilising seaweeds for human food, in horticulture, animal health and nutrition, and cosmetics [135]. However, the proportion of the 43 companies growing seaweed or using cultured seaweed, or a breakdown of the numbers involved in each of the application areas are not reported.

Geographic distribution of cultivation activity

Data provided by BIM [108] indicate the distribution of licences granted for seaweed cultivation and species by county are shown in Table 10.

Table 10 – Distribution of licenced seaweed cultivation sites

County	No of licenced sites	Area (ha)	Active growers (2021)
Clare	1	2.4	1
Cork	13	125.4	4
Donegal	3	51.9	1
Galway	1	0.7	1
Kerry	1	18.1	1
Mayo	5	45.9	2
Sligo	1	10.1	
Totals	25	254.5	

Source: BIM

Applicants for aquaculture licences are now required to include the botanical names of the target species in their licence application. Table 11 provides the scientific name for those species previously applied for under a common name.

Table 11 – Species mentioned in licence applications

Species name used by applicant	Phylum	Scientific name
Alaria	Phaeophyta (brown)	*Alaria esculenta*
Palmaria, Dulse	Rhodophyta (red)	*Palmaria palmata*
Porphyra, Nori*, Kelp Laver,	Rhodophyta (red)	*Porphyra umbilicalis*
Winged Kelp	Phaeophyta (brown)	*Alaria marginata*
Carageen Moss(sic)	Rhodophyta (red)	*Chrondrus crispus*
Oarweed, Sea Belt Devils Apron**	Phaeophyta (brown)	*Saccharina latissimi (formerly Laminaria saccharina)*
Wrack	Phaeophyta (brown)	*Fucus vesiculosus*
Asparagopsis	Rhodophyta (red)	*Asparagopsis armata*
Royal kombu	Phaeophyta (brown)	*Saccharina japonica (formerly Laminaria japonica)*

Source of botanical names and region: Guiry, M.D. & Guiry, G.M. 2021 [136]

Notes: * This is not the same variety of Nori that grows in Japan.

**Devils Apron is not listed as a common name in Algaebase but is used by several on-line shops offering seaweeds for sale when referring to Laminaria saccharina.

Licence applications, status and approvals

As of the 10th November 2021, the Department of Agriculture, Food and the Marine was processing 13 applications for aquaculture licences. Together these applications related to the culture of seaweed in a total sea area of 522 ha. Of the 13 licence applications, one applicant included another species, mussels, with application for seaweed cultivation. Table 12 lists the applications by county, together with the approximate areas.

Table 12 – Summary of applications being processed

County	Total applications	Approx Area (ha)
Donegal	1	20.03
Galway	5	148.45
Kerry	1	110.00
Mayo	4	73.75
Waterford	1	23.04
Wicklow	1	146.76
Totals	13	522.03

Source: DAFM [137]

Recent applications listed above included the species listed in Table 13.

Table 13 – Species included in recent licence applications

Species	Juveniles available in Ireland	Cultivated in Ireland	Cultivated in Europe	Included in Novel food list
Laminaria Hyperborea (Forest Kelp)	no		yes	
Saccarina Latissima (Sugar Kelp)	yes	yes	yes	yes
Alaria Esculenta (Wing Kelp)	yes	yes	yes	yes
Saccorhiza Polyschides (Sea Hedgehog)	no			
Chrondus Crispus (Carrageen Moss)	no		yes	
Palmaria Palmata (Dulse)	no	yes (T)	yes	yes
Porphyra Species; *Linearis, Umbilicalis, Dioica* (Sloke/Nori)	no	yes (T)	yes	yes
Asparagopsis Armata (Harpoon Weed)	no	yes (T)	yes	
Asparagopsus	no			
Laminaria Digitata (Kelp)	yes	yes	yes	yes
Asparagopsis Armata (red Weed)	no			
Ulva Lactuca (Sea Lettuce)	no		yes	yes
Fucus vesiculosus (Bladder wrack)				yes
Ascophyllum nodosum (Asco)				yes
Himanthalia elongata (Sea Spaghetti)	5 y to maturity			yes
Laminaria hyperborean (Kelp)	no			
Osmundia Pinnatifida (Pepper Dulse)	no			
Ulva Compressa / Intestinalis (Sea Grass)	no		yes	
Codium Fragile (Velvet Horn)	no			
Mastocarpus stellatus (Carrageen Moss)	no			

Source: DAFM, modified by Steelesrock Consulting to include locations where the species are grown and if the species is included in the EFSA list of novel foods [137]

Production output

Species

Seven species of seaweed are considered commercially relevant in Ireland, viz; *Alaria esculenta, Asparagopsis armata, Laminaria digitata, Palmaria palmata* and *Porphyra umbilicalis, Saccharina latissima* and *Chondrus crispus* [138]. Species known to be currently cultivated in Ireland include *Alaria esculenta, Asparagopsis armata, Laminaria digitata, Palmaria palmata* and *Saccharina latissima.* Two additional species, *Porphyra umbilicalis* and *Ulva spp*. remain the subject of trials to determine the feasibility of producing immature seaweed for on-growing.

No reliable data profiling the biomass yield from each cultured species were sourced. The total reported biomass (wet weight) from cultivated seaweeds over the period 2011 to date in 2021 is ca. 482 tonnes. Biomass production in the three years 2018, 2019 and 2020 was 40, 63 and 44 tonnes, respectively [139].

Challenges exist in estimating the dry biomass obtained from wet seaweeds. These stem from factors such as e.g., species, age, season [13]. Multiple ratios to convert wet to dry exist in the scientific literature ranging from less than 10:1 to more than 10:1 [47, 140, 34]. Using a typical ratio used to convert seaweed biomass (kelp species) from wet weight to dry weight is 6.5:1[based on feedback from processors contacted as part of this review] a dry weight equivalent for each of the years 2018, 2019 and 2020 is 6.06, 9.55 and 6.67 tonnes respectively.

According to growers, biomass production for species of kelp on long-lines ranges from 5 kg/m up to 12kg/m, though where seaweed is cultivated when salmon farms operate close by, the yield increases to 18kg/m. BIM indicated 8 kg/m as a typical yield.

Processing activities

Minimal processing of cultivated seaweeds occurs at growing sites. Producers indicated most harvested stock is dried; either naturally on the shore or by forced drying. Few producers have the facility to force dry harvested materials. Instead, they rely on the services of a small number of growers with drying capacity and occasionally wild harvest seaweed processors. Other processing reported as performed by growers is the weighing, packing and distribution of seaweeds. Some growers have started to consider various other processes to add value to their harvest including drying, extraction, ensiling and biorefining, though this is largely at the early investigative stage. Growers indicate the cost of drying equates to 80 percent of the cost of production.

Cultivation of seaweed in conjunction with other species

Thirteen of the 25 licences granted to cultivate seaweeds include permission to cultivate other species at the same site [137]. The species mentioned in licences include Scallops, Mussels, Sea urchin, Oysters, Aquatic plants and Abalone. Few growers contacted in the course of this work indicated they cultivate other species on the licenced site, where they did, Mussel was the only species mentioned. Several growers mentioned the close proximity of salmon farms to their seaweed sites and their belief that salmon farms make a positive contribution to growth rates.

Enterprise performance

During interviews conducted for this study, growers carefully avoided providing anything other than general information about the performance of their business. Specific data about costs of production, capital investments and sales revenue and pricing were not provided. Whilst acknowledging price differentials exist between species, there was a general reluctance on the part of growers to provide even examples of approximate selling price. All growers expressed a common view that considerable variation in selling price exist and buyers acknowledge significant price elasticity depending on end use of the species. One grower cited the selling price for an unidentified dried kelp was €35/kg FOB for a biomass of less than one tonne.

Employment in seaweed cultivation

Employment on the majority of sites is seasonal corresponding to setting lines at sea (October/November and harvesting (April/May). Data provided by BIM indicate an average of 3.8 full-time equivalent staff per annum over the period 2017 to 2020 [139].. During this period the number of operational harvesting units varied; there was 4 sites in 2017; 3 sites; 2018; 4 sites in 2019; and 7 sites in 2020.

4.3.3 Biosecurity

The National Biodiversity Data Centre maintains a database of, and reports, on invasive and non-native species. This includes species of macro-algae which are currently cultivated, such as *Aparagopsis armata* (Harpoon weed) which is classified by the centre as a non-native/low risk of impact species, of which the centre has 138 records. Of more concern are records of species classified as Invasive/High risk of impact such as *Undaria pinnatifida* (Wakame) of which the centre records four locations.

Species such as this are subject to restrictions under Regulations 49 and 50 of SI 477/2011 – European Communities (Birds and Natural Habitats) Regulations 2011. However, there are other non-native and potentially invasive species that have been recorded in Ireland which are not subject to these restrictions which have been observed in Irish waters such as *Laminaria ochroleuca* (Golden kelp) [131].

There are uncomfirmed reports of the cultivation in Co. Donegal of *Asparagopsis armata*, a marine red algal genus *Asparagopsis* (Bonnemaisoniales, Rhodophyta) both at sea and on-land in Co. Cork [141]. Described variously as a naturalised or invasive this species was first identified in 1941 and is described as widespread and found in the South and West of Ireland (Carnsore Point, Co. Wexford; Magharees Lagoon, Co. Kerry; and from Finavarra, Co. Clare north to Clare Island., Co. Mayo) [136].

The National Parks and Wildlife Service are a statutory consultee to the aquaculture licensing process in Ireland where such licensing is in, or may impact, on habitats designated under the Habitats and Birds Directives. Where such licence applications are for non-native species appropriate caution is exercised by the NPWS according to the sensitivity of the site and the nature of species which is the subject of an application. It is notable that in many licence applications non-specific or common species names are used. While licensing of macro-algae has been low in recent years, increased licence activity is likely to lead to increased scrutiny of applications necessitating a move to a more precise specification of species.

Unlike fish and shellfish species, there is no specific legislation in Ireland in relation to the movement of seaweed within the state. Importation of seaweed products from outside the state for the purposes of further cultivation may be the subject of a number of regulations; in the case of aquatic species that are alien, or locally absent Council Regulation (EC) No 708/2007 applies. In effect this means that anyone bringing a non-native species in the state requires a permit issued by the Department of Agriculture, Food and the Marine [142].

Apart from the legal requirements connected with the importation and movement of macroalgae at various points in the lifecycle, a concern for those in the industry relates to the viability of seed stock both in the short and long term. The KelpRes[46] project examined populations of *Laminaria hyperborea* and identified several distinct genetic populations in the Southwest, West, Midwest and northwest of Ireland [143]. It is reasonable to speculate that similar distinct populations exist in other macro-algae species, and that cultivars native to a particular area will thrive when cultured in that area. The introduction of cultivars from other areas may destabilise local populations and are less likely to produce yields equivalent to local populations.

4.4 Markets

Full consideration of the extent and nature of the European and worldwide market for macroalgae is presented in Section 3 ("Macroalgae Markets") of this report. In this section we briefly consider the existing markets served by the Irish seaweed aquaculture industry.

A feature of much of the stakeholder consultation carried out as part of this work was a tendency on the part of participants towards vagueness and extreme optimism about markets and actual end-use. While this is reflective of the nascent nature of the seaweed cultivation industry in Ireland, it presents a difficulty in developing a reliable and coherent profile. It is clear two broad geographic markets exist; one domestic; dominated by the sale of dried and wet seaweed to artisan food producers and the producers of cosmetic products. The other export – directly to Europe or via a wholesaler supplying foreign markets.

Except where the grower has developed a product range that includes "seaweed", little is known about cultivated seaweed processing and end use by customers in Ireland. Knowledge of how the seaweed is processed or used in specific products in the case of exported seaweed is largely hearsay.

Cultivated stock, competes directly with hand harvested wild stock on the basis of cost of production, volume and number of companies using wild sourced so-called sustainable harvested materials. Sadly, the demand for all seaweed is such that some growers care little about product differentiation. Leading one grower to comment "I don't have to think about what I'm growing or how to sell it; it sells itself". Direct engagement with the end user remains at an early stage.

46. See: http://www.nuigalway.ie/zoology/research/kelpres/

Growers generally have little choice when deciding what species to grow, they grow whatever is available from the hatchery. A single source of supply for seeded strings means all growers either win or lose depending on the quality of the material they receive. There are few choices other than to grow varieties of kelp and frustration that more red seaweed species are not available for on-growing in any significant scale. This has prompted some growers to source seedlings from outside the state; and to give serious consideration to establishing their own hatcheries.

4.4.1 Domestic market

A recent socio-economic study of Ireland seaweed industry identified 85 businesses as processors of seaweeds. Processors in this case included all businesses harvesting, cultivating, or using seaweeds or materials derived from seaweed in product applications, and companies that process seaweeds – drying, milling, packaging or refining seaweed via mechanical or chemical means. The results of further analysis of the scale and structure of the different industry sectors will not be available until late 2021. The number of companies involved in hard-harvesting seaweeds is as yet unknown. The first price sale of wet seaweed from the hand harvest and growers range from €55 per tonne to €90 per tonne [139].

Three clearly identifiable segments exist in the domestic seaweed market – human food and ingredients; cosmetics/life-style products and agricultural – animal and plant feed and stimulants. There is no obvious differentiation between wild harvested and cultivated seaweeds.

The domestic market for cultivated seaweeds comprises two main segments, fresh seaweed for human consumption used principally by restaurants and few consumers; minimally processed (normally dried, macerated and milled) for sale as "business to business" and incorporated in bakery or other food products (e.g. cheese, processed meat) or packaged for sale to consumers, for use as a food ingredient. Personal care is the other main sector, with seaweed sold wet or minimally processed for use in skin, bath, hair, soap and other cosmetic products. *Alaria esculenta, Palmaria palmata (and undefined "kelp")* are the only cultivated seaweeds identified as used in these products. Growers were unable to provide data relating to sales into these segments.

Purchasers do not generally buy against any specification. Some seek "organic certification" which has prompted a minority of growers to obtain organic certification from the Organic Trust or Irish Organic Association. Growers stress they produce "quality" product, though this is not described by reference to specific quality attributes. Against this background there is a belief that cultivated product is a higher quality than wild harvest, because of its farmed growth. Occasionally, growers have been asked by customers to provide a chemical analysis of their product; whilst some customers send the results of their own analysis to the grower.

4.4.2 Export market

Irish growers reported the export of *Alaria esculenta, Laminaria saccharina, Asparagopsis armata* and *Palmaria palmata.* The principal route to export markets is through wholesalers buying Irish seaweed, rarely do growers know the final destination, or eventual use when selling via wholesalers. Some seaweed is sold directly to customers in Scotland, Denmark and France.

In the case of sales for Denmark and France the product is sold for use by food ingredients and cosmetics companies respectively. Other than wet and dried seaweed is exported, no insights to the volume, value, or specific end use of these exports were provided. Polysaccharides and proteins were the compounds of interest to the customers.

EUROSTAT data indicates that Ireland exported around 3,000 tonnes of food grade seaweeds and microalgae to over 100 countries in 2020. The estimated market value was €0.8 million. Key trading partners were France (2, 300 tonnes), UK (900 tonnes), China (17 tonnes) and Switzerland (4 tonnes). It is not possible to differentiate the trade of cultivated seaweeds from that of wild harvest, but the average price was more than €20/kg. Of particular interest is that exports were up considerably from 2019 (€0.14 million).

4.5 Research capability

A review of the various Irish research, development and innovation projects and initiatives identified the existence of an extensive research infrastructure, elements of which support the marine bioeconomy to some extent. Drawing from publicly available material, mostly from the web-sites of individual organisations, the scope of their involvement/contribution in the seaweed sector is outlined below.

Some players have a long-standing history and international reputation in algal, and specifically, macroalgal research spanning the entire value chain, whilst others target individual elements of the value chain. The organisations in this review include Irish higher education institutions, nationally funded research centres, state agencies and private initiatives.

Other sections include a listing of Irish funding agencies and a summary of an independent review of Ireland's National Marine Research and Innovation Strategy ('MRIS') 2017-2021 [144]. The Marine Institute National Marine Research [145] database provided insights to the level of public sector research funds supporting seaweed and seaweed related research spanning the period 2013 to 2021.

4.5.1 Funding for seaweed related research in the HEIs and research centres

The National Marine Research Database [146] provided data about the public sector (national and EU sources) funds, managed by a range of agencies, and dedicated to seaweed and seaweed related research. Seaweed research was not identified in the database as a thematic area; overcoming this required the review of individual research projects in three thematic areas Bioresources Aquaculture: Bioresources Processing for Food and Other Use: and Bioresources High Value Products to identify seaweed projects.

Funds for seaweed research awarded to the lead institution between 2013 and 2021 amounted to €12.6 million. The majority of these funds supported research into the composition and use of seaweeds in food, food Ingredients (inc. nutraceuticals), human and animal health, and animal feed and the processing of seaweeds, and were awarded to 12 institutions. The average award per project was €360,253. Table 14 summarises the research awards to institutions.

Table 14 – Seaweed research grants awarded over the period 2013 to 2021

Institution	Grants awarded to project leader	No of Projects
WIT	€1,101,148.00	1
CIT	€105,000.00	1
DCU	€638,415.00	2
UL	€706,122.00	2
LIT	€359,514.00	1
UCD	€493,064.00	3
UCC	€1,248,956.00	8
NUIG	€4,134,068.00	10
Teagasc	€1,196,171.00	2
BMRS	€295,953.00	2
MI	€1,248,270.00	2
TCD	€1,082,176.00	1
Totals	€12,608,857.00	35

Source: National Marine Research Database

4.5.2 Higher education institutions (HEIs)

Ireland's higher education sector is a major source of research expertise that continues to engage in research related to Ireland's seaweed sector. Most of the universities and some of the former institutes of technology have engaged to some extent in seaweed related research. Many continue an involvement in the area, focusing on specific aspects of seaweed.

Much of this involvement stems from the support provided by the Marine Institute in enabling the formation of the NutraMara marine functional foods research initiative that started in 2008 and the Marine Biodiscovery project. Even prior to the major funds provided to these projects by the MI, many institutions had developed expertise and infrastructure relevant to the seaweed sector. It is beyond the scope of this section to cover the full range of expertise available in the HEI sector and instead it highlights examples of seaweed related activity and projects.

UCD

Much of the seaweed connected involvement of UCD relates to the extraction, purification and characterisation of compounds from marine sources and other agri-food by-products for functional food, nutraceutical and animal feed applications and its major role in Ireland's agri-food research and various national and international collaborations. It is a major research performer in animal nutrition and has partnered with industry and research providers in exploring the role of seaweeds in animal feed.

Relevance to the cultivated seaweed sector

With the increased interest in the use of seaweed in the formulation of animal feed, UCD expertise in this area is directly relevant to the sector's ambitions to develop new products. The experiences of UCD in working with seaweed processors and in projects involving the human food applications for seaweed is particularly useful to the future of the sector.

TCD

Trinity College Dublin, Centre for Environmental Humanities is involved in seaweed related research, through its work on an Irish Research Council funded project COALESCE that built a framework of knowledge exchange and action that addresses the global and topical issue of sustainable food from the oceans responding to the EU report on Food from the Oceans (2017) that discussed how food and biomass can be obtained from the oceans in a sustainable way. TCD has also collaborated on research that investigated the potential of some red algal species as biomaterials. More recently, through an SFI funded project Beyond biofuel, TCD has started a project to discover new methods of cultivating seaweed specifically grown to produce high value products, while also harnessing their associated biofuel potential.

Relevance to the cultivated seaweed sector

The knowledge and experience developed through the Beyond biofuel project is anticipated to generate new insights to how best to cultivate seaweeds, particularly seaweed species known to offer potential to be used in the production of high-value products.

UCC

University College Cork has a long history of involvement in seaweed and seaweed related research. It has developed specific competences in the study of microorganisms in either natural or artificial environments and their potential biotechnological exploitation. This expertise continues to be deployed in investigating the survival and interact on microbes on seaweed, and the potential to use these organisms to extract compounds of value to the food and health sectors and their role in bioprocessing.

UCC was a major partner in the MI funded Marine Biodiscovery and Marine Functional Foods projects providing leadership to aspects of molecular biology and genetics research. Both these projects involved extensive research into the human health and food potential inherent in Irish seaweeds, and in the development of novel foods.

UCC continues to be a key player in EU and national funded research projects investigating new applications for seaweed derived compounds. UCC is also active in aquaculture research that has investigated the potential of seaweeds in aquaculture feed. Further expertise related to seaweed is available at UCC through the SFI MaREI centre. The extensive research infrastructure including a network of laboratories, test sites and off-site facilities at various Irish marine locations supports on-going seaweed and other marine related research.

Relevance to the cultivated seaweed sector

UCC, through its capabilities in microbiology, brings a unique research perspective to the potential of seaweed as a source of new enzymes and proteins with applications in the health, food and processing sectors. These capabilities already contribute to national and international research outputs in several projects, many of which include leading Irish and international companies as collaborators. On a wider front and reflecting the multi-disciplinary capabilities of UCC, its expertise in marine coastal planning and off-shore technologies are immediately relevant to a developing seaweed cultivation sector.

University of Galway (Formally NUIG)

The seaweed related research output from the University of Galway is internationally recognised. The institution has a long history in all aspects of algae related research and is home to the country’s only academic research team dedicated to Algal BioSciences research. This group brings together full-time academic Principal Investigators with research interest in algae, seaweed (macroalgae) and microalgae, as well as other aquatic organisms including cyanobacteria, seagrasses, lichens and the wider marine environment. It maintains a leading role in several national and internationally funded seaweed related projects both as co-ordinator and project partner, and is a frequent collaborator with other Irish universities in seaweed research.

University of Galway has a strong educational and training record and specific research knowledge and expertise in algal cultivation for optimised biomass production; the production and optimisation of primary and secondary metabolites and bioactives in algae with industrial potential; algal productivity and the sustainable exploitation of seaweed resources including climate change impacts; contaminants in algae of economic importance; and invasive algal species. It is also the home to the Carna marine research laboratory, a research infrastructure that can support seaweed cultivation.

Seaweed related research at the University of Galway has received funds from Science Foundation Ireland; Teagasc; Department of Agriculture, Food and the Marine; Enterprise Ireland; EU Horizon2020; Marine Institute; Environmental Protection Agency; and the Irish Research Council.

Relevance to the cultivated seaweed sector

The research capabilities and infrastructure at this University is relevant to the needs of the seaweed sector for fundamental knowledge on which to base its future development. In addition to being a focal point for applied research in the area, through an involvement in multiple international projects, is a conduit to international expertise and project partners. Knowledge developed in a multitude of research projects such as e.g., NutraMara, NEPTUNA, MINERVA, EnAlgae, and others involving seaweeds and both national and international partnerships, is highly relevant to the on-going development of the cultivation sector.

University of Limerick

Over many years, UL has successfully applied and expanded its dairy processing and protein knowledge to seaweeds. In doing so, it has become recognised for its extensive research on seaweed derived bioactive peptides as functional food ingredients, nutraceuticals and food protein. Scientific expertise includes chemistry/biochemistry; food enzymology and extraction/purification.

As a major partner in the NutraMara project UL perfected techniques to identify and evaluate compounds isolated for seaweeds e.g., proteins, polyphenols, carotenoids and polysaccharides etc that offer potential for used in the formulation of functional foods. UL has developed specific expertise on seaweed proteins; investigating how seaweed protein can be used as an alternative to other protein sources; and assessing their role in human health. UL has access to multiple extraction processing equipment, all of which is used in the extraction of compounds from seaweeds.

UL maintains a close working relationship with the Algal Biosciences Group at NUI Galway, and is a frequent collaborator with this group, and with others, in national and international funded projects. UL maintains collaborations with the food ingredients and pharmaceuticals sectors on the use of seaweeds and compounds derived from seaweeds as functional ingredients. Other areas of expertise and knowledge relevant to the seaweed sector include food safety, human and animal nutrition, sensory science and the role of food ingredients in control of cardiac and inflammatory disease.

Relevance to the cultivated seaweed sector

UL has the capabilities to apply a wide range of analytical and processing methods to seaweeds to investigate and assess the potential of seaweed compounds in food and health applications. Current work in UL on Palmaria palmata on industry project, supported by the Disruptive Technologies Innovation Fund, is a prime example of where UL can contribute to the cultivated seaweed sector.

Dublin City University

DCU maintain an extensive multi-disciplinary outlook in its priority research areas. This is clearly visible in the focus of the DCU Water Institute on marine related research, and health. The four marine research areas include Monitoring and Decision Support Systems; Biotechnology and Discovery; Aquaculture and Biomass; and Invasive Species. Specific research competencies in Bioprocess Engineering, Biochemistry, Microbiology, Genetics, Bioinformatics, Immunology, Virology and Molecular Cell Biology support research in the marine areas.

Marine related projects completed by DUC include Sensors for monitoring marine algal toxins, mining marine species for anti-inflammatory drugs, and the development of specialised sensors for the marine environment. There is a strong emphasis at DCU in bioprocessing methods for food, agri-food and drug production that is supported by an infrastructure to increase outputs from bench to pilot-scale bioprocesses.

Relevance to the cultivated seaweed sector

Capabilities at DCU can support the sector in three areas, the isolation and characterisation of compounds in seaweeds, the use of bioprocessing to convert biomass into useable fractions and the application of sensors to monitor the marine environment in the immediate vicinity of the cultivation site.

4.5.3 Research and development centres

APC Microbiome Ireland

APC Microbiome Ireland is described as "a world leading SFI research centre, with over 300 researchers and clinicians based in headquarters University College Cork and Teagasc as well as partner institutes MTU, NUIG, UCD, NIBRT, UL and TCD". Additionally it maintains strategic partnerships with companies from the food, pharma and biotech sectors and a strong network of international academic and industry collaborators.

The core scientific competences of this SFI funded research centre support its work on gut health, particularly the influence of intestinal microbiota in maintaining health and in developing therapies for a various common gut-health conditions.

APC Microbiome maintain an extensive involvement with industry sectors, including pharma, food, diagnostics and veterinary, all of which produce high-value added products based on different sources of biological materials. Speciality areas include the "development of functional foods, medical foods and live biotherapeutics to improve human (and animal) health, the development of microbiome solutions to microbiome-based challenges such as antimicrobial resistance (AMR), pathogen persistence and methane production".

Relevance to the cultivated seaweed sector

The APC has worked on several major functional food research projects, which involved seaweed origin ingredients. Their dedicated research platforms are directly relevant to a vision of the seaweed sector to develop high-value health related products; including provision of scientific and clinical evidence needed to support the identification of bioactive ingredients and approvals required for e.g., feed additives, materials in contact with food, nutrition and novel foods.

Shannon ABC

Shannon ABC describe the facility as "well equipped for analytical work and small-scale process development". Its laboratories are co-located at Munster Technological University and Technological University of the Shannon and available to industry to assist with extraction, purification and concentration; and analysis of a variety of living cells, and derived compounds. The centre describes working within a number of industry sectors e.g., food, cosmetics, marine, agriculture, nutraceutical and bio/pharma, developing/applying biotechnological based processes to add value and/or extract high-value products. Shannon ABC in their lengthy client list identify four companies that process seaweed –Voya, Nutramara, BeoBio Teo and Brandon Bioscience Ltd. Industry engagement over the past 10 years involved working with Irish seaweed processing companies involved with food, feed, cosmetics, agriculture and healthcare.

Relevance to the cultivated seaweed sector

The Centre has worked with projects that have involved the processing of wild harvested seaweed for various applications. This processing experience may be relevant to the processing of cultivated seaweeds, following harvesting. It is not apparent that Shannon ABC has direct experience of relevance to the propagation, cultivation or harvesting of seaweeds; however, the processing expertise may be of interest to growers seeking to move their operations further along the value chain.

BiOrbic Bioeconomy

Ireland's national bioeconomy research centre, BiOrbic, is an SFI funded Research Centre built around collaboration with Teagasc, University College Dublin, Trinity College Dublin, NUI Galway and the University of Limerick. This collaboration brings together more than 100 researchers, all of whom work in areas related to the sustainable circular bioeconomy. The focus of the research is upon "selectively separating and extracting valued compounds from renewable materials, converting those resources into novel bio-based products and processes" including marine biomass. The centre has fostered links between industry and academia nationally and internationally.

A key theme within the work of BiOrbic is the development of biorefineries and refining processes. They participate, through their institutional partners, as collaborators in several EU and nationally funded projects funded that involved algae as an input to the refining process. Including SpiralG where they have a role in life-cycle assessment of a micro-algae input; the demonstration project BiorefineryGlas which aims to deliver a small-scale biorefinery, and the SFI funded project at Trinity College, Dublin – Beyond biofuel: Advanced seaweed cultivation for marine biodiscovery and climate change mitigation.

Teagasc and collaborators have started to focus on refining processes for use in the "Blue Bioeconomy" including processes for the transformation of seaweeds into human health, animal feed and biochemicals, where the research is targeting TRL levels 4 to 7 spanning experimental pilot plants to the first implementation in an industrial setting. Hence their work commences once the basic scientific principals are established and the concept validated.

Relevance to the cultivated seaweed sector

This is a relatively recent initiative which includes an interest in bioprocessing marine origin materials, including macroalgae. Through the various bioprocessing projects, the processes being developed could have applications for transforming cultivated and wild harvested seaweeds. The TCD based project "Beyond biofuel" whilst it is just at the start-up stage targets the cultivation of seaweeds and "will discover new methods of cultivating seaweed specifically grown to produce high value products, while also harnessing their associated biofuels, thus, developing a novel circular economy model aligned with strategies identified to support our bioeconomy".

MaREI

MaREI is the SFI funded Research Centre for Energy, Climate and Marine research and innovation co-ordinated by the Environmental Research Institute (ERI) at University College Cork. The Centre comprises over 220 researchers focusing on defined global challenges such as the Energy Transition, Climate Action and the Blue Economy and involves partners from most of Ireland's universities, institutes of technology, research centres and the Dublin Institute of Advanced Studies. The Blue Economy is one of three research platforms hosted by MaREI.

The centre has specific expertise in in the areas of the management of coastal and marine areas, marine policy and the impact of marine based activity on the health of marine ecosystems. It is also has expertise in marine structures, remote observation and in marine renewable energies. Participation in major EU funded projects broadens its knowledge base and offers scope to access specialise knowledge from other regions.

Relevance to the cultivated seaweed sector

Marine spatial planning and marine policy directly impact the seaweed cultivation sector. An array of assessment and observations tools available at MaREI can play a key role in aquaculture site location decision making. Establishing large-scale seaweed cultivation and locating them off-shore requires knowledge and expertise in marine structures that can withstand year-round open ocean conditions. MaREI has experience in structural systems design and modelling, including capabilities to carry out full-scale structural testing in MaREI, all of which are relevant to aquaculture.

4.5.4 State agencies

Teagasc

Teagasc the national agriculture and food development authority has a lengthy association with seaweed related research relating to Ireland's the agri-food sector. The organisation coordinated the NutraMara functional food programme, and played a key role in defining extraction processes and exploring seaweeds for bioactive compounds with food potential. Teagasc continued an involvement in food and feed related seaweed research through its involvement in various European research projects, where its skills in chemical profiling and identification of bioactive compounds were employed.

The organisation has applied its food processing technologies to seaweeds and explored potential of seaweed biomass in agriculture. Teagasc has also funded seaweed research through its Walsh Scholarship Programme; working Irish universities in investigating the properties of seaweed derived compounds and processing methods and the potential of seaweed compounds on gut health.

As a participant in the BioOrbic initiative, Teagasc is investigating methods for processing seaweed biomass, including bioprocessing and the application of various extraction methods. As a partner in several ERU projects, Teagasc has access to an international network of researchers involved in the use of seaweeds in the agri-food sector, including in food supplements and nutraceuticals. Amongst its recent seaweed research collaboration with companies in Ireland's food sector, it has developed "green" processing methods to extract dietary fibres from a species of seaweed.

Through the EU funded Seasolutions project Teagasc and other partners plan to evaluate the effects of native, sustainable seaweeds on total methane gas production by characterising seaweeds and their actives and using different in vitro rumen fluid models and animal trials in sheep, cattle and dairy cows. The project also looks at how processing of seaweeds impacts on bioactivity and ability to reduce methane and the impact of feeding seaweeds on meat and milk quality.

Relevance to the cultivated seaweed sector

Experience in extracting and profiling bioactive compounds and working with researchers with an extensive knowledge of the biology of Irish seaweeds continues to be relevant to the seaweed sector, including cultivated seaweeds. This expertise and the access of Teagasc researchers to extensive in-house analytical and processing facilities at its Ashtown and Moorepark facilities enable laboratory outputs to be scaled up to pilot stage.

Marine Institute

The Marine Institute operates a range of services related to various aspects of aquaculture in Ireland. In addition to its regulatory role, which that ensures the sector operates to international best practice standards and in accordance with national and European legislation, it is an active research performer in seaweed related projects supported by national and European funds.

It operates a coastal research site in Cashel in Connemara, in Bertraghboy Bay, known as Lehanagh Pool; Ireland's only licenced multi-species marine research site. Recent seaweed related projects include a major investigation of iodine content in species of kelp and an IMTA project based at the Lehanagh Pool that investigated the design and implement new/emerging efficient and cost-effective technologies in monitoring and management systems for IMTA production. Its work on mapping the marine environment, particularly its role in mapping wild seaweed stocks is helpful to entrants to seaweed aquaculture.

Relevance to the cultivated seaweed sector

This is a major national facility with statutory responsibility for aquaculture food safety and is an active research performer in collaborative research projects including seaweeds. It maintains an extensive research network involving Irish and international research institutions relevant to seaweed cultivation.

4.5.5 Other

Moorepark Technology Ltd (MTL)

This joint venture between Teagasc and Irish dairy companies provides pilot manufacturing facilities for companies in the food industry. Service offerings include the rental of specialised processing equipment, contract research and development, pre-commercial manufacturing support and the provision of technical advice. Many of the processing capabilities can support the processing of seaweeds, from post-harvest to product formulation.

Specific areas with this potential include the processing of liquid food and ingredients; separation technology; evaporation and drying; a fermentation unit and a dedicated Bio Functional Food Engineering Unit for the isolation, fractionation and preservation of bioactive food ingredients. The beauty of the Moorepark facility is the support it can provide to early stage and pilot production – a process involving the transfer of ideas from the laboratory to pre-production. Companies can use the facilities to produce product for performance evaluation and market trials.

Relevance to the cultivated seaweed sector

MTL is ideally positioned to work with cultivated seaweeds from the point of harvesting through various stages of processing up to and including finished product. The location of MTL within the Moorepark campus positions it close to Teagasc's scientific expertise working on food products, functional foods and food ingredients.

Bantry Marine Research Station (BMRS)

BMRS is a Limited company that engages in a wide variety of aquaculture and climate change related projects funded by national and international public research programmes and the private sector. Located on the shore of Bantry Bay, its facilities support fish, shellfish and seaweed aquaculture development.
It is also a licenced aquaculture site, that cultivates seaweed, producing *Alaria esculenta, Saccharina latissima* for export and other marine species.

With a staff of 15, the laboratory's facilities include "salt water ambient and controlled environment tank infrastructure, a range of tank sizes and experimental design, capacity 100m^3. Water filtration, sterilisation and treatment systems. Environmental monitoring and emergency systems for stock and site security". There is also a macroalgal hatchery, on-growing units and a marine site to cultivate seaweeds.

BMRS embarked on a major investment programme to upgrade its facilities during 2019 and 2020 aided by "funds from the Irish Government and the European Maritime and Fisheries Fund under the Sustainable Aquaculture Development Scheme and was administered by Bord Iascaigh Mhara (BIM),Ireland's Seafood Development Agency".

The BIM funded seaweed hatchery managed by Cartron Point Shellfish Ltd operates under a lease arrangement funded by BIM and is based at the BMRS. The Centre led several seaweed projects funded by BIM, which in 2020 included funds of €258,000 to investigate, extract and test anti-methanogenic compounds from Irish seaweeds to identify candidates demonstrating any anti-methanogenic properties: addressing the resulting seaweed product as a potential feed additive, particularly for ruminants including cattle.

Relevance to the cultivated seaweed sector

The BMRS is directly involved in seaweed aquaculture related projects. It operates as a research provider; and cultivates seaweeds for commercial markets. A strong connection exists between the BMRS and Ireland's seaweed sector. Trial facilities are particularly relevant to the seaweed cultivation sector.

The Irish Bioeconomy Foundation (IBF)

The IBF is an industry association with members from industry, academia and policy areas linked with Ireland's bioeconomy. Its main roles are connected to the development of Ireland's bioeconomy through:

Promoting opportunities to use natural resources in developing the bioeconomy;

- Facilitating the formation of networks between its membership and elements of bioeconomy related support infrastructure e.g., research centres, innovation clusters and pilot facilities; and
- The provision of services, including waste reduction and the adoption of new environmentally sustainable practices, identifying scale-up opportunities; and the analysis of production processes.
- Identifying sources of finance and participation in bioeconomy related projects.

Relevance to the cultivated seaweed sector

No direct connection exists, none of the projects listed include reference to the algal sector. Directing seaweed growers to potential partners and end-users are possible roles for the IBF, other organisations offer the same.

4.5.6 National Marine Research and Innovation Strategy ('MRIS') 2017-2021 external review

The National Marine Research and Innovation Strategy 2017-2021 provided an assessment of the maturity level of Irish algal cultivation research with reference to three dimensions, human capacity; infrastructures; and networks and relationships. The status of research on algal biomass cultivation was defined as below in Table 15 and assigned an overall ranking of Ad Hoc.

Table 15 – Algal biomass research maturity ranking 2017

	Human Capacity	Infrastructures	Networks and relationships
Ranking	**Established (3)**	**Established (3)**	**Ad Hoc (1)**
Criteria	*Dedicated research facilities exist and there is evidence of collaboration nationally and internationally, with industry participation.* • Established Principal Investigator Position(s) • PI Led Research Teams with Postdoctoral Researchers	*Dedicated research facilities exist and there is evidence of collaboration nationally and internationally, with industry participation.* • Purpose built lab space/purpose bought equipment. • Dedicated data infrastructures or repositories. • Postgraduate teaching	*Research is based on individual research interests with no institutional support or facilities.* • No nationally organised/ hosted workshops. • No associations, networks of interest. • Collaboration is based entirely on one-to-one or personal relationships.

Source: National Marine Research and Innovation Strategy 2017-2021

The external review of research progress in algal cultivation, included algal cultivation within a composite report, grouping the performance of all aquaculture and biomass production – finfish, shellfish and algae (macro – and micro-algae) together. The result of this amalgamation of the sector led the reviewers to assign rankings as indicated in Table 16.

The amalgamation three different aquaculture and biomass areas together prevents a close examination of the change in performance in algal cultivation and biomass production research maturity during the period 2017 to 2021. Table 16 infers the research maturity level of human capacity and infrastructure in algal cultivation has declined; whilst networks and relationships have increased, compared to the 2017 evaluation.

Table 16 – Aquaculture and biomass production

	Human Capacity	Infrastructures	Networks and relationships
Ranking	**Defined/Established (2/3)**	**Defined (2)**	**Established (3)**
Criteria	*Communities of interest exist with some access to facilities and active research projects.* *and* *Dedicated research facilities exist and there is evidence of collaboration nationally and internationally, with industry participation* • Multiple Project Based PI Appointments. • Active PhD Level Research Projects. • Undergraduate courses with established lecturers. • Established Principal Investigator Position(s) • PI Led Research Teams with Postdoctoral Researchers	*Communities of interest exist with some access to facilities and active research projects.* • Purpose built lab space/purpose bought equipment. • Dedicated data infrastructures or repositories. • Postgraduate teaching	*Dedicated research facilities exist and there is evidence of collaboration nationally and internationally, with industry participation* • Multiple teams concurrently participating in Framework/H2020 projects. • Industry or sectoral policy-maker led research themes. • Regular national conferences/workshops with some international participation.

Source: National Marine Research and Innovation Strategy ('MRIS') 2017-2021 external review [144].

4.5.7 Funding agencies

Ireland's seaweed sector is recognised as a major potential source of biomass in Ireland's blossoming marine bioeconomy – the Blue Bioeconomy. Table 17 below lists some of the major sources of public funds that can support initiatives in Ireland's bioeconomy.

Some of the organisations mentioned below may only provide periodic funding and parties seeking support should make direct contact with the organisation managing the funding programme.

Table 17 – Sources of funds for initiatives in the Blue Bioeconomy

Organisation	Funding programme
Department of Enterprise Trade and Employment	• Disruptive Technologies Innovation Fund
Enterprise Ireland	• Technology Centres • Technology Gateway Programme • Small Business Innovation Research • High-Potential Start-Up Feasibility Study Grant • Exploring Innovation • Innovation vouchers
Science Foundation Ireland	• Programme for Industry • Research Centres • Research Spokes • Strategic partnerships
InterTradeIreland	• Acumen • Innovation Boost • Elevate
Department of Agriculture Food and the Marine	• National Competitive research calls
Department of the Environment, Climate and Communications	• Climate Action Fund
Environmental Protection Agency	• Green Enterprise Scheme • Circular Economy Programme
Department of Rural and Community Development	• Rural Regeneration and Development Fund • LEADER Programme
BIM	• Sustainable Aquaculture Scheme • Knowledge Gateway Scheme • Seafood Processing Capital Investment Scheme • Seafood Processing Innovation Scheme
Marine Institute	• Ship-time Call • Cullen Research Fellowships Programme • Networking and Travel Awards
Teagasc	• Walsh Scholarship Programme

Source: based on The Irish Bioeconomy Foundation Funding Brochure 2012

4.6 Perspectives on seaweed aquaculture (from interviews)

During the preparation of this report, Steelesrock conducted a series of interviews with a wide range of stakeholders in the Irish seaweed aquaculture sector. A total of 38 individuals were consulted, to capture the perspectives of seaweed growers, processors, researchers and state agency personnel. A full list of those consulted is included in Appendix 1.

Mostly, interviews were conducted using desktop video conferencing, lasted approximately one hour, and followed a semi-structured format; the exception being interviews by telephone. Participation in the interviews were on the basis that comments would not be directly attributed to individuals, and in some instances specific information was provided (such as market prices and production volumes) on the basis that it would not be directly reproduced in this report.

Several broad themes emerged during these conversations, and these are summarised below.

4.6.1 Prospects for the seaweed aquaculture industry.

All those operating directly in the industry were optimistic about the future, though in many cases this optimism was founded on instinct and anecdote, rather than on any specific data or projections. The food and unrefined food ingredients markets were a particular source of optimism for these participants. There was general satisfaction expressed in relation to the licensing of seaweed aquaculture, with several stakeholders drawing attention to improvements in the response time of the Department of Agriculture, Food and the Marine in processing applications.

In some instances, the view was expressed that a licence to grow seaweed was more likely to succeed and to be processed in a timelier manner, than other forms of aquaculture. Amongst state agency consultees, this optimism concerning the future of seaweed aquaculture was more tempered and less consistent. Several noted the positive impact that job creation arising from seaweed aquaculture could have on coastal communities. In contrast, others observed that for it to be an attractive job option for younger people, there was a need for greater certainty about its future. Some respondents also noted the manual nature of the work and suggested there was need for a focus on mechanisation for harvesting and deployment.

4.6.2 Hatchery requirements

There is a strong perception within state agencies that a national hatchery or similar facility is a pre-requisite for a successful Irish seaweed aquaculture industry. By contrast, this view is not universally shared by industry actors both in the growing and processing areas. Some expressed the view that the current provision of seeded string is a research and development activity that cannot be expected to support the entire industry and expressed an expectation of its discontinuation.

This has led a number of seaweed growers and others about to commence cultivation, to consider developing their own hatchery facilities. A view offered by these growers is that many applying for licences to cultivate seaweeds, view seaweed cultivation as a way to top-up their income. Established growers envisage taking the lead in hatchery operations. They would provide small growers with seeded string, and ultimately buy back the mature seaweed from them.

A small, but notable, number of participants expressed the view that there is ultimately a danger to the industry in the current situation where seeded string is available as a by-product of a research and development programme. This view stemmed from the risk faced by growers in making investments based on a business model where a significant future cost (seeded string) is absent; and on the view that encouraged growers to focus on particular species for no other reason than the availability of seeded string.

A number of growers cited the example of the availability of *Saccharina latissima* being an easier crop to sell than *Alaria esculenta* but growing the latter because of the availability of seeded string. There is wide variation on the question what constitutes a sustainable cost per meter for seeded string. For some, €2 per metre was a maximum, whilst others mentioned €6 per metre as acceptable.

Interviewees in both industry and in state agencies drew a distinction between a hatchery facility providing seeded string nationally on a commercial basis, and the research effort associated with understanding the lifecycle of individual species. Those making this distinction placed an emphasis on the need for applied research on the deployment and growth of species, once an understanding of its lifecycle was at a point where seeded string could be reliably produced.

There was a strong call from growers for increased research effort to produce seeded string for other species. The capacity to grow multiple species and have multiple harvests in a year was seen as a key objective for some growers. This would enable growth in terms of employment, guard against market fluctuation, and provide some protection against catastrophic weather events or contamination, which currently can destroy a year's income.

Despite the widespread acceptance that the current situation whereby seeded string is being made available at no cost is unlikely to continue, several growers cautioned against a sudden cessation of the supply. The sector was described by these growers as being at the very early stages of development, and in the absence of any significant technology transfer or development of the growers' own hatcheries, any removal of the source of seed would be to "blow the candle out".

4.6.3 Markets and marketing

Active seaweeds growers are confident that there is a expanding market for seaweed, and that any product produced will find a buyer. In a few cases, growers have themselves developed food products, typically (but not exclusively) in the form of dried and flaked ingredients for direct sale to consumers or the catering industry. Unsurprisingly, where product is not being sold directly by the grower, there was reluctance to share market information.

With few exceptions, growers not selling product directly remain unsure as to the ultimate destination of their crop. This reflects a low-level of awareness across the industry as to the scale, nature, and potential of the markets for cultivated seaweed. On the part of state agencies, current market knowledge is focused on the output of wild-harvest and its associated species – there is acknowledgement that this understanding needs to be further improved.

State actors tended to focus more on higher value potential extracts from seaweed aquaculture rather than on the direct food product or lower value processing. This view was often informed in the first instance by familiarity with results from research projects that identified the composition and range of compounds in seaweeds.

However, this familiarity with what is typically low Technology Readiness Level (TRL) stages of research is not matched with an understanding or acknowledgement of the realities of reliable breeding, deployment, harvesting, processing and the development of seaweed-based product applications. Some growers expressed frustration with a perception that state actors are focused on hypothetical global markets for compounds that may be extracted from seaweed in the future, without having any clear picture of when or how this capability will be in place, and what the routes to those markets might be.

These growers expressed a view that their efforts are best placed in the short to medium term, in developing the know-how to successfully produce product for the consumer and unrefined ingredients market, coupled with collaboration with research institutes to explore new product applications. This direction was identified as being pursued by a minority of growers.

There was broad consensus concerning the low-level of awareness generally about seaweed, and seaweed products. This was coupled with views about how Irish seaweed products should be marketed: a focus on the "green and blue" image of the country and the use of terms like "pristine Atlantic Ocean". One interviewee observed that Ireland is known as being "good at growing food in a green manner", and that the seaweed aquaculture industry would be foolish to take any other approach.

A number of those interviewed added to this that there is an element of a "forgotten cultural heritage" in relation to Irish seaweed, that is to say there is an ancient tradition of seaweed use in Ireland that could be rekindled. This was evidenced by these interviewees in the fact that many of the common terms for seaweed, such as Dulse or Dilisk, and Carrageen are used all round the world but originate in Ireland and a reported increase in the use of seaweeds by elements of Ireland's restaurant sector.

The key challenge identified by most interviewed relates to consumer understanding of the nature of seaweeds. In more processed forms, such as noodles, consumers are willing to accept that the ingredients include seaweed product. But as a basic ingredient, there is poor understanding of the tastes and properties that seaweed can bring to recipes and cooking.

4.6.4 Processing and biorefining

There was a widespread, inconsistent and often interchangeable use of terms such as biorefining and processing in the interviews. Some participants spoke of the need for a national biorefinery as a destination for biomass created by the seaweed aquaculture sector; however, without having any understanding of what that biorefinery would produce, how its outputs would be used, or what the required costs and volumes would be. Others were of the view that biorefineries should be located close to the sources of production and had a defined set of outputs in mind, including but not limited to alginates and lipids, but with little or no insight to the biorefining process or its scale.

Two industry interviewees expressed the opinion that a biorefinery – in the sense of a true cascading biorefinery, would require a level of biomass that Ireland could potentially achieve, but only if the state embarked in a large scale and off-shore programme of seaweed farms. These participants were of the view that Ireland's capacity to produce sufficient biomass in coastal bays would be insufficient to meet the needs of a national biorefinery. Their view was that such an offshore endeavour would represent a different seaweed aquaculture industry to the existing nascent one.

Existing processors, who in the main are sourcing biomass from wild-harvest sources were clearer about what, for them, constitutes processing. This is mainly taking wild harvest species such as *Ascophyllum nodosum*, applying conventional mechanical deformation and thermal treatments to extract a concentrate comprising alginic acids and polysaccharides and a fibre residue. Some processors observed that their activities are seen as "low-value" but expressed a view that they have a growing market and achieving a return from their products.

Some did express a view that continuity of supply was an issue they faced in the long term, and that in this context seaweed aquaculture was a likely long-term path for their industry. In the short-term however, seaweed aquaculture does not offer the prospect of the culturing of any of the species of interest. Several processors expressed frustration at the lack of government support and lack of direct agency involvement with the wild harvest sector, asserting that only Údarás na Gaeltachta had an official remit to support wild harvesters, on whom the processors depend.

One key area where the existing seaweed aquaculture industry is currently dependent on the wild harvest industry is for access to drying facilities. Several growers referenced using the drying facilities of wild harvest gatherers and processors. A number of growers indicated that they are either in the process of, or have plans to, develop their own drying facilities.

4.6.5 Research and innovation

In keeping with the positive optimism of many of those interviewed, there is a high degree of interest in product applied research and innovation in the sector. A significant number of the industry participants were involved in research partnerships with other industry players, food companies and research institutions. Several saw their long-term future as producers of value-added product, derived from seaweeds grown by farmers with whom they would have deep and long-lasting relationships.

According to participants, achieving this position required innovation and the development and marketing of new innovative products. For these participants, their current involvement in seaweed aquaculture was as much about developing know-how, credibility, and brand identity, as much as cultivation.

Research partnerships were often described as being instigated by the industry itself – with relationships established through chance meetings or cold-calling of researchers. Such an approach reflects opportunism, rather than a strategic research outlook. There was a widespread view that much of the current research effort is built on researchers chasing funding for basic scientific research. Some growers mentioned being asked by reseachers to join a consortium. There was a strong view that opportunities exist for greater collaboration between the research community and industry.

They believe greater effort should be placed on new product development and the development of innovative engineering solutions to the specific challenges of operating in the Irish coastal environment, rather than basic research. This view, however, must be tempered by feedback from the research community in pointing out the multiple challenges that persist regarding the breeding, culture and processing seaweeds; expanding the range of species; the use of seaweed extracts as the basis for food /feed related products and regarding the variability of composition of seaweeds. The research community also cautioned what they identified as exaggerated claims often made without scientific evidence, regarding the use of seaweeds in food, feed and health products.

In several interviews, the topic of research and development (including new product development) was strongly related to the issue of market definition. Interviewees commented that ideally, a market would be identified that needed a particular ingredient or compound; research would occur as to what algal species could provide that compound, and seaweed producers would then grow a seaweed to service that market. By contrast, the current situation is that licence holders grow seaweed (often on the basis of the availability of seeded string), and then chase a market for the biomass. This situation appears to work at the moment, where demand exceeds supply, but it does not encourage product innovation, differentiation and the development of niche products required to build lasting value chains.

Several of those interviewed were involved in various production innovations, ranging from the development of new mechanisms on which to grow seaweed, micro-processing facilities, to new harvesting techniques. Several of those observed that there is a lack of available know-how, and that much of the innovation taking place is of necessity. It was observed by several interviewees that trial-and-error was a feature of most operations, and that reaching a productive harvest could require several years. Growers recognised the potential for greater involvement of research institutions in overcoming the many technical challenges facing the sector.

4.6.6 Food safety and other standards

Few of those interviewed regarded food safety or other regulations as a significant impediment. Most of those involved in the harvesting of seaweeds destined for consumer food product were familiar with the Novel Foods Directive and the requirements for new products. A number of those interviewed noted that a number of seaweeds are designated as “in common use” by the Directive, and as a result there is no impediment to their being placed on the market. Where product was being used to produce cosmetics or health supplements, there was awareness by those involved of the requirements of the Health Product Regulatory Authority. These were regarded as straight forward and clear, and the associated costs were regarded as a cost of doing business.

Only a small number of those interviewed were concerned with, or had plans for to supply product for pharmaceutical applications/ use. Some of these growers had not fully appreciated the significant technical and temporal challenges associated of developing health care products.

4.6.7 Bioremediation and carbon sequestration

There was some scepticism amongst industry participants about the view of some government entities positioning seaweed aquaculture as a mechanism to provide remediation of polluted waters and acting as a form of carbon sequestration. Industry interviewees pointed out that seaweed grown to mitigate the effects of heavy metals, or to capture carbon, cannot be then used as a commercial crop.

Heavy metals taken up by the seaweed cannot make their way into the food chain, and any carbon sequestered during growth would be released on harvesting and processing. Those expressing this view did not dispute that seaweed would be an effective mechanism to improve the environment but positioned such activities as needing to be government led, or subsidised in the same way as environmental schemes are on land.

A positive view exists about the prospects of Integrated Multi-Trophic Aquaculture (IMTA). Several contributors noted that locating seaweed aquaculture in areas proximate to, for instance, salmon farms, resulted in significantly higher seaweed yields. That the salmon industry did not embrace the positive environmental image of seaweed was a source of frustration for some. This hesitation on the part of the salmon industry was attributed to fears that seaweed aquaculture could act as a reservoir for pathogens, resulting in disease such as amoebic gill disease.

This was seen by many growers as being an overstated risk. The growing of seaweed in conjunction with all forms of aquaculture was seen as a positive – though those with experience in the industry sounded some notes of caution. These related to, for instance, the differences required in line lengths for growing seaweed to those required for mussel production and site location.

Similarly, some expressed a view that the prospect of seaweed being grown at floating offshore platforms was unlikely on a commercial basis. Several blocks to such developments were identified by participants – these included the practicalities of harvesting at some of the exposed offshore wind sites, the complexity of moorings and the complications that seaweed might bring, and the question of ownership. A further question raised by some participants was how such mixed use installations could be enabled given the separate licencing processes for aquaculture and offshore energy.

4.6.8 Biosecurity and non-native species

A number of participants, including growers, raised concerns relating to biosecurity and the use of non-native species in seaweed aquaculture. Some went as far to express concern in relation to the movement of cultivars around the coast of Ireland. Concern was expressed in relation to the importation of juvenile algae and/or seeded string from hatcheries outside the state.

The absence of specific legislation governing such importation was identified by participants as a particular shortcoming. Reasons for concern on this topic varied, with some citing the need to learn from experiences in the shellfish industry following the introduction of pacific oysters. Others were concerned about the potential for reputational damage to an industry at the very early stages of its development.

The question of when a species becomes naturalised as opposed to invasive was also an area of some confusion – the example of *Asparagopis armata* being a case in point. While there was some discomfort expressed about the cultivation of that species, several participants expressed the view that the species was now naturalised. Others expressed some concern around the potential for the spread of non-native species, citing the rapid proliferation of *Sargassum muticum* since it was first observed in Ireland in 1995.

4.6.9 Wild harvest

Consideration of the wild harvest is outside the terms of reference of this report. Inevitably however, during conversation with many of those involved in multiple aspects of the seaweed aquaculture industry (including growing, processing and research) the topic arose. A picture arose of a complex relationship between the two streams of seaweed production.

On the one hand there is a recognition that for the seaweed aquaculture industry to grow, it must utilise the strengths of the wild harvest sector. This was evident in areas relating to some aspects of processing (such as drying), and marketing. Some participants noted that from a consumer point of view, there is little to distinguish the two sectors. Product placed on the market as food is presented in much the same way, with reference to the natural environment, freshness and perceived health benefits. Similarly, some processors dealing with biomass observed, that in the long term, current gathering practices are unlikely to be unsustainable in the context of demand that is expected to be vastly higher than day. This, coupled with social issues such as the age profile of those typically gathering seaweed today, was seen to give rise to a need for such processors to at least become active in research and development in seaweed aquaculture. Frustration was expressed by some that there is little or no state support for the wild harvest sector, other than in areas that fall within the remit of Údarás na Gaeltachta. This was seen as an impediment to the maintenance of sustainable harvest practices practiced by older gatherers, and an impediment to market development which was seen as being ultimately to the benefit of the seaweed aquaculture sector.

However, on the other hand, there is also recognition that the seaweed aquaculture sector may become a competitor, or substitute, for wild harvest. This is particularly apparent in the ready to eat food market. There is recognition that the Irish, and European situation, whereby aquaculture is a minority source of macroalgal biomass, is not reflective of the global situation. Despite this, amongst those sourcing seaweed on a volume basis (such as those processing for bio-actives etc), there is an understanding that the species in question are very different, with the aquaculture industry today producing kelps, and the wild harvest gathering inter-tidal red algae species. The substitute threat was therefore seen as a long term issue, and one which can be dealt with through research and development into the culture of red algae species.

Section 5

Hatchery requirements in the Irish Seaweed Industry

5.1 Introduction

There is no commercial hatchery in Ireland, that is to say, no hatchery selling juvenile seaweeds for grow out at sea to another party. At least one company is understood to be currently self sufficient in producing their own juvenile stock of kelps in the form of seeded string, while a small number of seaweed cultivation companies have reported that they have commenced preparations to produce their own seeded strings to support the growth of kelps. Some companies may source seeded string from abroad, there is no prohibition to the importation of juvenile seaweeds within the European Union. Some growers in Ireland have sourced juvenile stock from Northern Ireland.

In the main, Ireland's cultivated seaweed sector is currently reliant on a single hatchery facility, established on research and development basis rather than a commercial one. As the source of seaweed juveniles, a hatchery is critical infrastructure in enabling the development of seaweed aquaculture activities. The capabilities of the hatchery to initiate and maintain the growth of seedlings are fundamental to the sector.

Their role has become more than the provider of seedlings; positioned at the beginning of the aquaculture value chain, they must provide growers with seedlings with predictable growth properties and which are compatible with different growing systems. In doing so, hatcheries contribute to the overall competitiveness of the sector. The BIM trial hatchery is only able to supply juvenile *Alaria esculenta, Saccharina latissima* and *Laminaria digitata*. This section therefore concentrates on hatchery development opportunities for species currently provided by this hatchery.

5.2 Development of hatchery capabilities to date

5.2.1 Species

Few of the species of interest to Irish growers are available as juveniles for on-growing. Only the kelps *Alaria esculenta, Saccharina latissima* and *Laminaria digitata* are at present capable of hatchery propagation with any degree of consistency in Ireland. However, the current EMFF funded R&D process whereby growers source seeded lines does not have the production capacity to meet the demand for all of these species. Although the hatchery has successfully propagated *Palmaria palmata*, the process only exists at a pilot/laboratory scale. This limitation has prompted one grower to commission a development project to define a process that can be transferred to an industrial scale facility. Work on this project is believed to be currently on-going.

Currently, with a single source of R&D supply, Irish growers are unable to make decisions about what species to grow based on market needs. Despite the market demand for e.g., *Palmaria palmata* and *Porphyra spp.* growers can only access seedlings for varieties of kelp. One grower indicated performing growing trials of *Palmaria palmata* at sea.

5.2.2 Previous hatchery projects

Hatchery methods, tank and sea-based cultivation of *Alaria esculenta, Palmaria palmata, Chondrus crispus, Ulva spp.* and *Porphyra spp.* were tested in 2001 in a BIM supported project involving the then Irish Seaweed Centre and later by the Roaringwater Bay Co-op. Both *Alaria esculenta* and *Palmaria palmata* were subsequently transferred on long-lines to a 1.75 ha sea-site. Success was described a "partial" due largely to poor weather and other factors relating to growth. Around the same time, Enterprise Ireland supported the Irish Seaweed Centre and Roaringwater Bay Co-op to investigate the culture of *Chrondus crispus*; the results of which appear to be unavailable [138].

With financial support from the Marine Institute under the Marine Research Sub-programme of the National Development Plan, 2007-2013 BIM initiated and led a project to develop and trial an industry-scale hatchery and growing methodologies for three seaweed species — *Palmaria palmata, Porphyra umbilicalis* and the kelp *Laminaria digitata*— and to transfer know-how to create new business opportunities in seaweed aquaculture. The consortium included Queen's University Belfast, the National University of Ireland, Galway, and industrial participation from — Cartron Point Shellfish Ltd., Tower Aqua Products Ltd., Dolphin Sea Vegetable Co., G and B Barge Operators Ltd., Roaringwater Bay Seaweed Cooperative Society Ltd. and Cleggan Seaweeds.

The results from this project indicated that the hatchery and on-growing methods for *Laminaria digitata* were reliable and productive, though in need of further research for improvement. Results from work on *Palmaria palmata* and *Porphyra umbilicalis* was less successful; delivering a land-tank based culture method only for *Palmaria palmata* [147, 148].

Prior to the 2010 trials mentioned above, *Alaria esculenta* was successfully cultivated in Roaringwater Bay Co Cork for sale as a sea vegetable [138]. Since then, BIM has contracted Cartron Point Shellfish Ltd following an open tender as part of the Seaweed Development Programme through the Knowledge Gateways scheme. Under this contract, Cartron Point have produced seeded lines for *Alaria esculenta* and *Saccharina latissima* and to continue trials to increase the scale of culturing *Palmaria palmata* in tanks and at sea to commercial levels. Since 2018 BIM expenditure with Cartron Point Shellfish Ltd amounts to €755,713 up to 2021. Only seeded strings for *Alaria esculenta* and to a lesser extent, *Saccharina latissima* have been available to commercial growers over this period, [139, 149].

The Cartron Point Hatchery received orders for 16 km of *Alaria esculenta* and 11.2 km of *Saccharina latissima* strings in 2021. A contamination of *Saccharina latissima* cultures resulted in the hatchery being unable to supply seeded strings to growers. Capacity constraints resulted in the hatchery delivering 10km of seeded strings [139].

There are already indications that hatchery systems will become more process oriented to meet with growers' demands for greater volumes, diversity of species, traceability, security of supply and operational flexibility. To comply with these requirements, hatcheries need to maintain a detailed knowledge of culturable seaweeds from biological, biochemical and ecophysiological perspective; coupled with knowledge of their life-cycles, propagation methods, nutritional and growth requirements. Faced with likely demands from growers for new species, hatcheries will need to be able to exercise control over the growing conditions to ensure the seedlings mature in optimised growing conditions prior to on-growing.

5.2.3 Existing hatcheries and their capacity

The R&D hatchery established under the Seaweed Development Programme mentioned above is based in premises leased by BIM at the Bantry Marine Research Station, and is a pilot facility where Cartron Point Shellfish Ltd. carryout their programme of work under contract to BIM. It has a limited capacity to develop seedling production, produce seeded lines of more than 10,000m per annum and advance techniques to expand the range of new species it can culture.

The Carna, Co Galway based laboratory of the National University of Ireland, Galway is a research facility. Its speciality is large-scale, exploratory aquatic investigations on existing and novel species for aquaculture. The facility was a participant in previous BIM seaweed hatchery projects for *Laminaria digitata* and *Palmaria palmata* supported by the Marine Institute.

As indicated in the introduction, at least one company has the capacity to source and produce its own juvenile stock, while two seaweed cultivation companies have started to prepare their own seeded strings to support the growth of kelps, one of which also commenced a project to establish the production of *Palmaria palmata*. Neither company currently have the capacity to engage in the large-scale production of seeded string.

5.3 Capabilities and characteristics required of a hatchery

A hatchery is a facility used to start the reproduction of species and support the early growth of young seaweeds prior to on-growing them at sea. The capacity to supply seedlings of proven, consistent quality and in sufficient volume to match the demand from growers for reliability in supply, is essential for any commercial hatchery. Hatcheries also need to possess knowledge of how to manipulate the life cycle of the species and the experience to maintain them.

The complexity and differences in the reproductive life cycles of seaweeds, demands that hatcheries can access the necessary scientific knowledge and experience required for seedling propagation [150].

It is equally important, given the challenge of delivering growers productive high-yielding varieties, for hatcheries to be cognisant of factors that influence growth and yields. The adaptive behaviours of seaweeds to their environment can present the hatchery with obstacles when attempting to maintain and grow them. Seaweeds are known to be problematic at all stages from reproduction, early growth stages; growers need reliability of supply, including healthy seedlings at a commercial scale [150].

Hatcheries must be able to exercise a high-level of control over the growing environment. An awareness of the sea-site where the seedlings will grow, and the environmental stressors they face, is essential. The selection of the species, propagation and the cultivation process all influence the level of control required in the hatchery [150]. The key function of any seaweed hatchery is to support the reproduction process of each species, replicate and maintain the environmental conditions as found in the natural environment, and to control contamination at all stages of the cultivation cycle [151].

5.3.1 Best practice characteristics

In Ireland a hatchery needs an aquaculture licence to operate, a process that must be recognised in planning any hatchery. The summary of best practices presented below draws from the experiences of several recently published sources [41, 13, 152, 150].. Together they identify a set of generic requirements that hatcheries should meet to cultivate seedlings. The use of new analytical tools in the selection of species and strains to culture is expanding and beginning to influence the operational capabilities of hatcheries. The importance of specialist knowledge and expertise in using many of these tools is a challenge that hatcheries must overcome to remain competitive.

Knowledge of the environment at the growing site(s)

An understanding of the characteristics of each site where the seedlings will grow is required to ensure adequate survival rates. This includes the site's suitability for the intended species, e.g., water and environmental conditions, climate, environmental quality and diversity at the sites. Prior knowledge of the growing sites is essential if the species selected is to develop the compositional profile that matches the intended application(s).

Infrastructure and facilities

The scale and design of the facility should be such that it is suitable to cultivate seaweeds at levels to meet the demand for seedlings. A hatchery is a laboratory "type" facility, hence requires a basic standard of building and services as found in a general biological laboratory setting. Selecting the site of the hatchery should acknowledge its demand for fresh seawater.

The critical elements of the hatchery, light, temperature and water supply must be controllable to ensure optimal growing conditions for each intended species. Fresh water should be distilled and deionized for cleaning purposes and available at flow rates that match the hatchery output. Seawater is a potential source of contamination and needs to be sterilised prior to use. The supply must be reliable and capable of dosing with nutrients to meet the needs of the seedlings.

As with the fresh water supply, pH must be measured and controlled. Air is needed to aerate the seawater in growing tanks and should be filtered to remove any contaminants. A range of different sized growing tanks is required and provided with supply and discharge pipework and the means of monitoring and controlling the growing environment. In anticipation of quality certification and requirements for traceability, growing conditions should be measured and recorded.

Currently, establishing immature *Palmaria palmata* or any other species of red seaweed typically involves vegetative propagation in tanks. This involves the gradual transfer of seedlings into larger and larger cultivation tanks according to rate of growth. Cultivation tanks are fitted with agitators to ensure the biomass does not stagnate, a means of delivering nutrition and equipment to control the growing environment. Tanks are sized to suit seaweed stocking densities (kg/m^3) corresponding to stage of growth.

Collection and maintenance of reproductive materials

Hatcheries must understand the life-cycle of each of the target species to collect, isolate and grow the appropriate reproductive material e.g., spores or gametophytes. These materials may only available on a seasonal basis and for a few months each year. This means the hatchery must have access to sites where there is an abundance of species of interest. Marine environmental conditions are known to vary greatly even over short distances resulting in the development of different populations of the species in response to the differing conditions.

Only by monitoring coastal sites will the hatchery be sure of timing collection to correspond to peak reproductive period. Some degree of flexibility is possible in controlling the growth cycle. Hatcheries with the required infrastructure and expertise can maintain cultures over long periods in a non-reproductive stage, thus allowing the hatchery to start production at times when fertile material may not be available in the wild.

Inoculation "seeding" techniques

The processes involved in the production of seedlings and seeded string for the cultivation of relevant seaweeds are well known [152, 151, 41, 49], albeit some systems need optimising for Irish waters. Various methods are used in cultivation of seaweeds, depending on their reproductive life history. Hatcheries should be capable exercising control over the various life cycles whether through sexual reproduction or vegetative propagation. For example, in kelp culture systems (only systems for kelp culture are considered) that use seeded twine (as is typical in Ireland), inoculation can be achieved in 2 ways, using wild collected spores or via propagation using lab raised gametophytes. The latter method is also referred to as "the European method". There are pros and cons for each.

For the first method, reproductive tissue is excised from fertile sporophytes collected from wild populations and spore release is induced in the laboratory. Solutions containing the motile spores are then used to inoculate spools of twine (i.e. collectors). Once settled, the spores germinate into male and female gametophytes. The gametophytes grow and become reproductive. Female gametophytes are fertilised *in situ* and juvenile sporophytes develop on the twine.

Alternatively, cultures of male and female gametophytes can be produced (essentially as above) or harvested from wild populations and maintained in vegetative culture rather than being seeded on to twine. These cultures are then used to prepare an inoculum. Mixtures of male and female gametophytes are blended to produce fragments and the solution of fragments is used to seed the spools of twine. As above, the gametophytes grow, fertilisation occurs in situ and juvenile sporophytes develop. This approach cycle cuts out the necessity to induce asexual sporulation and is more controlled.

Many challenges exist in attempting to broaden the range of species that can be cultured and to improve levels of biomass production. With market demand increasing and becoming reliant on the domestication of more species, hatcheries must demonstrate competencies in managing the diversity and complexity the seaweed life cycle. This is an area that relies on expertise not only in cultivation processes but also in the use of analytical and genetic profiling tools to assist hatcheries to choose the best strains.

Support and maintain growth

This lengthy process starts once inoculation has been carried out. Seeded materials need to be maintained under controlled laboratory conditions until the juveniles have reached an optimal size and sea conditions are appropriate for out-planting. For cultivation systems that utilise a “direct-seeding” or “binder-seeding” approach, juveniles are maintained in bubble culture or tumble culture in free-floating form. When they reach optimal size, they are mixed with bio-glue/binder and used as the inoculum for direct seeding of ropes and 2D growing structures.

It is a time dependent process that relies on the hatchery being able to monitor and control temperature, light, pH, nutrients, aeration, and contamination. Hatcheries must be able to exercise tight control over these environmental parameters to sustain growth. This demands that the hatchery has the competence to develop management protocols for each species.

5.3.2 Future challenges for hatcheries

Hatcheries are an essential infrastructure supporting the growth of cultivated seaweeds. Any response to the demand for increased biomass production relies on the abilities of the hatchery to provide juveniles for on-growing. Some growers may choose to develop an in-house capability, whilst others decide to rely on independent sources. Hatcheries may choose to undertake the production of juveniles and perform research into the cultivation of new species. In doing so, they will have recognised the different competences needed to fulfil both roles. The challenges in establishing what in effect is the next generation hatchery are many, as summarised below.

Use of new tools and techniques

The sustainable management of seaweed aquaculture requires fundamental understanding of the underlying biological mechanisms controlling all stages of macroalgal life cycles by using diverse approaches that require a broad range of technological tools [153].

Supporting knowledge acquisition

Despite the societal and economic importance of seaweed, the rate of knowledge acquisition about seaweeds is slower than for some other species. A range of protocols to cultivate seaweeds exist. However, the increased demand from markets for seaweeds with high-potential in food and other applications, requires new approaches to production. Many species of commercial interest have failed to respond to traditional protocols. Hence new standardised cultivation and preservation protocols for these species are needed. Hatcheries need maintain an awareness of research in this and other related areas, and to find ways to contribute to the development of new protocols.

Enhanced awareness of diseases

The increased interest in seaweed for commercial purposes is a global phenomenon. This contributes to an increased demand for this resource for use in a myriad of applications; leading to increased farming activity. The dominance of eastern Asian countries as a source seaweed presents seaweed cultivators in the western world with a competitive challenge. To date, the scale, production methods and costs of Asian producers have remained outside the grasp of western farmers.

However, the demand for seaweeds has caused problems for some major growing regions to meet this demand due to a decline in the yield. In some cases, the production value fell by 15 percent. The decline is reported to stem from diseases and pests resulting from the intensification of aquaculture activity [154].

Automated production systems

Realising any plans for large scale cultivation as planned e.g. in Norway by Alginor capable of producing 100,000 tonnes per annum of kelp, will require new approaches to seeding growth substrates. It is likely therefore, as proposed by Solvang *et al*, that hatcheries and other stages in the cultivation and harvesting of biomass will have to employ new automated technologies to maintain a continuity of supply [42].

Current hatcheries are largely labour intensive: supplying sites covering 100's of hectare with seedlings would be outside their supply capacity. Large scale seaweed cultivation requires new, standardised approaches to seedling production, improved quality and predictable biomass output [155].

A commercial focus

Establishing a hatchery with the scale to respond to the growth of a new aquaculture sector has to be commercially focused. Although the projected growth for seaweed cultivation is significant, large scale growers, if they follow models of Norway and the Faroe Islands would be likely to create an in-house hatchery capability. In doing so, they recruit the necessary technical and scientific expertise. An *ad initio* hatchery venture is a significant capital project, particularly when it aims to eventually operate at a scale able to meet the demands for hundreds of kilometres of string. Adding a research dimension to the venture needs careful evaluation and justification in light of the anticipated lengthy timescales involved in establishing new species.

5.4 Future hatchery options and associated factors

Ireland's seaweed culture sector, comprising nine growers and one trial licence predominantly located along the western seaboard, has access to 254 ha of licenced sites. These growers fit within three broad geographic/regional clusters: a southern cluster of growers in counties Cork and Kerry, a western cluster within county Galway and Clare and a northwest cluster within counties Mayo, Sligo and Donegal.

They share several common characteristics: the scale of operations – most do not farm the full extent of their licenced area and employ few full-time staff; they grow essentially the same species of brown seaweed; engage in minimal post-harvest processing; and with few exceptions sell bulk volume to intermediaries.

5.4.1 Current situation

The current production capacity of Ireland's licenced area is not fully utilized. Typical wet weight yield per hectare for *Saccharina latissima* ranges from 15 tonne/ha (6 kg/m of line) to 20 tonne/ha (8 kg/m of line) [156, 41, 139]. BIM estimates the annual cultivated biomass output as between 40 to 60 wet tonnes: equating to a cultivated area of between 2 ha to 3 ha based on a yield of 8 kg/m. The total length of seeded line in a typical open sea cultivation system configured as 25 seeded lines per hectare (100 m line, spaced 4 m apart) is 2,500 metre.

Two constraints affect the scale of seaweed cultivation: firstly, seeded string is available for only two species – *Alaria esculenta* and *Saccharina latissima*, and secondly, the output of seeded sting is a maximum of approximately 10,500 m/annum. If fully utilised, this length of string could support growth in an area of 4.2 ha. Some growers have an in-house capability to produce seeded string, however, accurate data on production are not available.

When the hatchery cultivation stalls or fails, as happened in 2021 with *Saccharina latissima*, growers receive a reduced quantity of seeded string, or none. In such situations, growers have few options other than consider buying seeded string from outside the state, cultivating another species or not growing anything.

Faced with on-going constraints in the supply of seeded string and access to new species, some growers started to explore the possibility to bring the breeding and string production in-house.

Most licences allow the holder to cultivate other species in addition to seaweed. Licence applications from existing and potential growers continue, despite the presence of underutilised sites.

Work is on-going to deliver a stable supply of *Palmaria palmata* seedlings in a project, involving one grower, funded under the the Disruptive Technologies Innovation Fund (DTIF) operated by the Department of Enterprise, Trade and Employment. This is reflective of the wider demand from growers for access to high-value species other than those currently available, including cultivars with specific high-growth traits. Specific detail concerning the methods used to establish a reliable source of juvenile *Palmaria palmata* is not available for reasons of commercial confidentiality.

5.4.2 Factors influencing the hatchery concept

Scale of future seaweed cultivation

Despite the support received by the sector from BIM, DAFM and other agencies the current scale of seaweed cultivation output at around 40 wet tonnes/annum remains low compared to that from wild harvest (~30,000 wet tonnes) and comprises mostly three species of kelp – *Alaria esculenta, Saccharina latissima* and *Laminaria digitata*. Annual biomass production of *Palmaria palmata, Porphyra ssp.* or *Chondrus crispus* is unknown.

Growers have access to licenced sites that are yet to operate at full capacity at a time when applications for new licences continue. Even a modest annual increase in licenced sites over the current 254 ha would likely result in seed supply capacity issues. Global forecasts for cultivated seaweed indicate constant growth for the near future.

A high level of optimism exists amongst growers concerning their ability to sell whatever seaweed they can produce. Moving from the current output to one where all 254 ha becomes operational, would create a potential demand for 635 km of seeded string: more than 50 times the current supply capacity. However, a scenario whereby the sector increases the area under cultivation by 15% to 20%, per annum may not be unrealistic. Feedback from growers included the lack of available string as a limiting factor in increasing biomass output.

Supply must meet demand

The sector will not experience growth without a hatchery to meet the demand for seedlings and to cultivate different species. A restriction in the current limited supply of seedlings would force growers to consider sourcing strings from elsewhere, cease or limit production, or as some have already done, to develop an in-house hatchery capacity. Demand for seeded strings is related to the stocking density in the area under cultivation. Table 18 below summarises the requirement for seeded strings for three different stocking densities and area under cultivation, with an assumed single line length of 100m.

Table 18 – Seeded line output required for different areas under cultivation

Area cultivated nationally	4ha			10ha			20ha		
Line spacing at sea	3m	4m	5m	3m	4m	5m	3m	4m	5m
Hatchery line output (km/yr)	13.3	10	8	33.3	25	20	66.3	50	40

Source: Calculated based on data from SAMS [41]

The cost of supply of seeded string

The current situation, where seedlings are available as a by-product of a research and development activity is not a basis for commercial, fully functional, sector. Current market prices for seeded string vary enormously. Large scale hatcheries such as SeaSolutions and Hortimare advertise between €6 to €8 per metre.

SAMs indicate the cost of production of seeded string as between as between €1.9 to €4.3 per metre, depending on total length of string per hectare, whilst a grower outside the state was quoted as charging €7.2 per metre [41]. One Irish grower claimed any price above €2 per metre reduces their competitive position.

Demand for new species and cultivars

There is a clear demand from growers for access to a wider range of high-value species than those currently available, including cultivars with specific high-growth traits. This call for new species stems from the recognition of the high-value of red species including *Palmaria palmata, Porphyra spp.* and *Chrondus crispus* and an emerging interest in the green species *Ulva spp*. Ireland has yet to meet a long-term goal to establish a reliable breeding and seeding regime for the red species. Another more long-term, slowly emerging demand, surprisingly comes from the wild-harvest industry.

There is a nascent recognition of a long-term threat to the wild harvest supply chain from various sources including e.g., the loss of hand harvesters, the EU policy on wild resources, and the possible impact of climate change. These factors, coupled with an increased awareness of the commercial potential of species not readily accessible in the wild, has placed seaweed cultivation on the long-term development agenda for some processors.

Allied to the search for new species, is an increased recognition of the potential offered through identifying wild strains with growth and biochemical characteristics that could enhance the competitiveness of the seaweed sector. Closely linked to this is the role of hybrids; species bred/cultivated to produce specific compounds by close management and control of the growth environment, though this could pose a biosecurity threat.

Biosecurity

The movement of materials into or from a hatchery, biological or otherwise, poses a potential threat to the stock and the environment. Examples of such threats include – releasing non-native species; importing or realising disease; collecting stock from different regions; release of untreated water; and chemical spills. This is not an exhaustive list; each hatchery must establish and maintain its own risk management procedure.

The concept and practice of biosecurity in managing pathogens, including diseases and pests on aquaculture sites is well established. Disease and other environmental threats can negatively impact farm productivity and production. Biosecurity is a key element of successfully managing shellfish and finfish aquaculture activities. Responding to the threat of disease in fish aquaculture resulted in requirements for bio-secure hatcheries supported by national legislation.

The seaweed aquaculture will inevitably face tighter controls as biomass output intensifies and new species introduced. The 2016 joint report by SAMs and the UN [157] concerning safeguarding the future of seaweed aquaculture concluded…

> *"As the seaweed aquaculture industry grows and diversifies into new species and geographical areas, new diseases are likely to emerge, and the risk will intensify of introducing non-indigenous pathogens and pests to the new regions."*

Any future hatchery must anticipate threats and establish biosecurity systems to minimise and deal with any breaches to ensure continuity of supply.

Investments required

Multiple factors influence hatchery investment decisions. Typically, these include the demand for seedlings – its anticipated output, the selection of species and the extent that the hatchery is integrated in the cultivation supply chain, i.e., customised to the needs of an individual or small group of growers; or serving all growers. Irrespective of its output, the hatchery must maintain an environment conducive to the growth of the alga; achieved by controlling temperature, light, salinity, nutrients to mirror its natural habitat and to do so whilst minimising any risk of contamination [151].

An issue of overriding concern is the scale of the facility, particularly when considering any future developments leading to its expansion, and the associated building and requirements for services. Ultimately the market price for seeded string or other juvenile stock and the hatchery's cost of production determines its viability. As with the production of any product, manufacturing costs comprise labour, materials and manufacturing overhead. A major component of manufacturing overhead is the depreciation of buildings and equipment.

Excluding the building, other major investment items include seawater supply system – comprising pumps, storage, treatment and associated pipework; water sterilisation unit, environmental chamber(s); temperature and lighting control and alarms; deionised water system; growth tanks; aeration for tanks; freezer; laboratory grade microscope, scales; assorted glassware; instrumentation – pH metre, light metre; racking, benches and storage; fire protection and security; spool winding machine and IT equipment [156, 151]..

Any hatchery would need prior licence approval from the Department of Agriculture Food and the Marine and since it would also draw/discharge seawater, a separate licence in addition to possibly needing planning approval, from the relevant local authority.

Access to expertise

Despite the successes of the past in establishing breeding and seeding programmes for *Alaria esculenta, Saccharina latissima* and *Laminaria digitata*, species of red seaweed have so far, largely eluded attempts establish reliable cultivation in hatcheries. The skills required to manage and operate a hatchery, differ greatly from the skills needed to establish breeding programmes for new species. Support from EMFF funded projects BIM has enabled individuals to be trained in hatchery techniques.

Establishing new breeding programmes involves considerable scientific knowledge of seaweed life cycles and demonstrated research expertise. Ireland is not well resourced in these areas, with knowledge and expertise resting with few scientists. This expertise, however, could provide the leadership to develop hatchery methods and operational protocols needed for hatcheries to operate competitively.

5.4.3 Hatchery development options

The processes involved in the production of seedlings and seeded string for the cultivation of relevant seaweeds are well known [152, 151, 41, 49], albeit some systems need optimising for Irish waters. They comprise an initial nursery/hatchery phase, which uses controlled and optimised growth conditions to maximise growth from spores to macroscopic juveniles, followed by their transfer to a growth substrate such as rope or cord. Another more direct process, is to spray immature seaweed onto a growth substrate for immediate deployment at sea. This process is more complex and relies on specialist expertise and facilities to maintain cultures in a non-reproductive state. However, despite the technological challenges, this process can deliver fertile sori at times when they may not be available in the wild.

Consideration must be given to establishing new breeding programmes for specific species and investigating cultivars that display traits of interest. This creates new roles for hatcheries to maintain these cultivars in culture, creating biobanks to ensure their long-term survival for use by growers.

Ireland's seaweed growers do not yet have access to a fully operational industrial scale hatchery facility. Such a facility must have the capacity to meet the demands of growers for the consistent supply of high-quality seedlings and strings (as appropriate). A number of options for how this might be brought about in the future, are considered below.

Encourage growers to set up their own hatchery

The Bantry Bay trial hatchery provided basic training courses for persons interested in cultivating macroalgal gametophyte cultures and producing seeded collectors for deployment at sea. The extent that these courses stimulated growers to consider establishing in-house hatcheries is unknown.

It is unrealistic to expect that growers will continue to receive direct support by way of the free issue strings or other seeded material. Some growers have moved ahead to ensure supply or have plans at varying levels of development, to establish their own hatchery facility. The extent that these plans include the supply of materials to other growers is unknown. The motivation for this planning is the constraint they face in obtaining the quantity of strings they need, limited access to different species and concerns over security of supply.

Incentives to assist growers to establish a basic hatchery facility may encourage more growers to become self-sufficient on either an individual basis or in collaboration with other growers in their region.

Establish a national hatchery

Several Irish reports concerning the future of aquaculture draw attention to the need for a seaweed hatchery. This implies support for a facility to meet the demand for seeded string and for new species from Irish seaweed growers. By its nature, such a facility would need to be able to expand its operations in response to increased demand from growers. With a potential demand for string increasing to more than 500 km per annum in meeting the projected cultivation area of 254 ha, the hatchery would operate at a commercial scale.

This would mean adopting novel technological solutions, including automated processing systems; employ specialised staff, forge links to expert scientific expertise and develop competences relevant to biobanking seaweed cultures. Business models that include investments from growers or private sector finance may qualify the development to receive EMFAF or other grant support.

Source seeded string and immature seaweed from specialist hatcheries

Several organisations can supply seeded strings including SAMS, Scotland; Seaweed Solutions, Norway; Hortimare, Netherlands and Islander Kelp, Co Antrim. Indicative costs for the supply of seeded string range from €6/m to €8/m, which 3 to 4 times the price needed for Irish growers to remain competitive. The possibility remains to negotiate a price to supply all Irish growers with seeded string for one of these sources. However, this would leave Ireland's fledgling sector vulnerable strategically, reliant on species that may or may not reach optimal performance or constitute a biosecurity risk.

5.4.4 Evolving hatchery methods

In Norway, a country recognised as a leader in European seaweed cultivation, growers have already demonstrated their commitment to large scale production, reporting a 100 % year on year increase in biomass from 2017 to reach 117 wet tonnes in 2019, en route to their goal to produce 1,000 tonnes [158]. Plans for the large-scale cultivation of seaweeds as in Norway and the North Sea stimulated research into cultivation and hatchery methods [160]. Results from these efforts have not yet reached the public domain, possibly because of an understandable reluctance on the part of organisations to disclose proprietary knowledge.

Irrespective of the system used to grow seaweeds at sea or in land-based tanks, cultivation of European species typically requires land-based hatchery facilities to initiate and maintain the early growth stages. The traditional methods for seeding and cultivating are labour intensive and time consuming, and increasingly incompatible with plans to increase the scale of cultivation operations [159]. Traditional growing and harvesting methods in large-scale operations is no longer practical, as is borne out by the financial modelling completed within this project and presented in the following section. This highlights the substantial increase in the scale (and investment) of the traditional hatchery concept to support even modest increases in biomass production.

Different strategies exist to transfer seaweed culture to a growth substrate. Two transfer methods typify these strategies; spraying a culture solution onto a substrate, and submerging substrate in a tank containing culture medium [155]. Both methods occupy significant hatchery space to support large-scale on-growing as occurs in areas such as Norway. In a modification to the seeding process, the substrate is coated with a mixture of culture and bio-adhesive, typically referred to as binder. This allows the seeded substrate to be maintained in a hatchery environment to stimulate further growth prior to deployment, or deployment immediately after being coated. These modified methods provide scope to significantly reduce the space demanded by a conventional hatchery.

The use of bio-adhesive to bind the culture onto the substrate is reported to be particularly attractive to large-scale growers, [161, 155]. It offers a clear advantage over the use of traditional seeded string; eliminating the use of string wound collectors, thereby reducing hatchery space; and speeding up the deployment since there is no need to wind the string onto ropes. This direct seeding method is suited to being automated [42].

The demand for more competitive seeding and deployment methods by large scale growers appears to have stimulated further innovations in seeding. At least two firms now provide bulk cultures to allow growers to directly seed growing ropes. One of these is the Dutch company Hortimare, the other is the Norway based Eukaryo [162]. The Hortimare website reports providing customised cultures to growers in the Netherlands, Norway, England, Scotland, Faroe Islands, Belgium and France.

Growers can accrue a significant competitive advantage in choosing to use cultures and in taking responsibility for seeding growing substrate. They do not have to establish in-house hatcheries, eliminating the need for space, specialised infrastructure, and specialised personnel to operate the hatchery. Growers have greater security of supply, and access to species that otherwise may not be within their capability to culture. Sourcing from a culture bank that engages in selective breeding, allows growers to obtain cultivars from within specific regions. This potentially provides greater yield, stability and improved overall quality, than available from wild species. Importantly, from the perspective of a grower seeking to significantly expand biomass production, the direct seeding of culture is compatible with using automated systems to seed ropes.

5.4.5 Economics of hatchery set-up and operation

Multiple variables such as species, production methods, geographic location, environmental conditions influence any approach to evaluating the economics seaweed production. The impact of these factors on output make any attempt to compare the economic performance of different growing units unreliable. A scarcity of literature on the subject adds further to this challenge [163]. A similar gap exists concerning the economic performance of seaweed hatcheries.

Previous work by BIM emphasised the dependency of seaweed cultivation activities on an operational seaweed hatchery. In follow-on work, BIM established the basic requirements and performance characteristics of a hatchery to culture *Laminaria digitata* and other kelp species. The hatchery concept exploited the cultivation protocols and methods designed to stimulate seaweed reproductive cycles in an artificial environment. This approach led to hatcheries inoculating growing strings with a culture for supply to growers.

A BIM initiated trial hatchery demonstrated the successful deployment of the various processes in supplying *Laminaria digitata* and *Alaria esculenta* seeded string to commercial growers. However, the supply of *Saccharina latissima* seeded string was not as reliable; requiring further work to prevent/minimise post-culture contamination. Once competed, this work will support *Saccharina latissima* production in same trial hatchery configuration.

Examples of international hatcheries closely resemble hatchery concepts developed in Ireland: retaining their essential elements, whilst customising infrastructures to suit local requirements for species and services, [151, 164, 165, 49] [47]. Each international example, through their successful operation, has validated the early Irish research work in different commercial settings.

It is obvious from these examples that “seeded string” is not a feasible solution for high volume growers. The alternative is a direct seeding of the rope on which the biomass will grow. Despite evidence pointing to the use of direct seeding resulting in similar or higher biomass yield, differences in the seeding method can impact on the crop’s biochemical composition, suggesting growing methods should take account of how the biomass is to be used [166].

47. See also the website of Hortimare and Greenwave (www.greenwave.org)

5.4.6 Scenarios for Hatchery Development

The starting point in modelling the economic feasibility of different hatchery configurations is the model hatchery infrastructure and cultivation process as initiated by BIM. Below five high-level scenarios are presented. Each models different types of hatchery configuration and their performance in responding to broad scale and commercial objectives of growers over a 10 year time frame.

The scenarios presented are:

- **Scenario 1:** Production of a seeded line to meet the requirements for an individual grower or dedicated hatchery supplying string for an area of 3 ha increasing to 5 ha in five years.
- **Scenario 2:** This scenario involves collaboration by a group of growers or dedicated hatchery supplying string for their own use or sale to others. The group produce string to support the cultivation of kelp in a combined total area of 6 ha, increasing at a rate of 26 % per annum to a maximum of 15 ha over 5 years. Any unused string may be sold to other growers, with sales revenue retained by the hatchery.
- **Scenario 3:** Collaboration by a group of growers to provide seeded string for their own use. The group plan to cultivate species of kelp in a combined total area of 6 ha, increasing at a rate of 26 % per annum to a maximum of 15 ha over 5 years. Any unused string could be sold to other growers, with sales revenue retained by the hatchery.
- **Scenario 4:** Production of seeded line over a five-year period 2022 to 2026 to match an annual compound growth of area under cultivation of 30% from a starting point of 10 h. The 30% compound growth is the rate required to provide sufficient string to meet the needs of an industry utilising 50% (115ha) of the current sea-area licenced for seaweed cultivation by 2031.
- **Scenario 5:** The production of seeded line for cultivation from 2026 to 2031 at a volume corresponding to an annual compound growth of area under cultivation of 30% as described in Scenario 4

The modelling does not consider any of the anticipated technological developments in cultivation and hatchery management that will undoubtably emerge and influence competitiveness as outlined in the previous section. Nor do they aim to predict the nature of the inevitable automation that hatcheries will need to support large scale biomass cultivation. Ireland's seaweed growers want to extend the range of species they grow. Reliable and robust protocols that hatcheries need to cultivate species other than kelps do not yet exist. The modelling only includes consideration of the facilities need to cultivate kelp.

It is abundantly clear that hatchery equipment alone does not determine its success, but rather the tacit knowledge of the technicians operating it. This indicates any plan to develop a hatchery, should go hand in hand with the transfer of technological know-how from a knowledge source to the hatchery technician. This can be through formal technology transfer agreements, training or the recruitment of technical staff with proven specialist knowledge.

Considerable uncertainty surrounds the motivation and response of growers to align with National goals to establish a cultivated seaweed sector: especially the major expansion of seaweed biomass production. This has implications for future hatchery configurations and performance. Varying the scale of possible performance by introducing different scenarios helps to overcome this challenge.

This modelling exercise is not an investment appraisal – that is a task confined to the hatchery promotor(s). The modelling provides insights to the economics of scenarios to inform individual growers, regional collectives or groups of growers and others about likely hatchery performance. The modelling evaluates the results of scenarios that bridge short to medium, to five-year time horizons; using the results to highlight the longer-term challenges and implications for hatcheries in responding the BIM vision of growth.

Operating costs and investments

Hatchery operating costs and investment includes the following categories: capital investments, salaries, materials and consumables. Except where indicated otherwise, all future costs include for 10% annual increases.

Capital investment

The BIM model suggested the use of shipping containers to house the cultivation tanks but excluded their cost from their analysis. The modelling presented below includes the use of second-hand shipping containers (12.180m x 2.440m x 2.590m). Other capital items are as detailed in Table 19.

Table 19 – Capital equipment costs for Scenarios 1 to 5

Item	Unit price (€)	Scenario 1		Scenario2		Scenario 3		Scenario 4 &5		Comment
		Quantity	*Total (€)*	*Quantity*	*Total (€)*	*Quantity*	*Total (€)*	*Quantity*	*Total (€)*	
Insulated room	€9,775	1	9,775	1	9,775	1	9,775	1	9,775	
Housing	€4,000	2(Y1)	8,000	2 (Y1)	8,000	2(Y1) 2(Y3) 3(Y5)	28,000	2 increasing to 11	44,000	12m shipping container
Tanks	€671	48 (Y1)	32,200	48 (Y1)	32,200	48(Y1) 48(Y3) 96(Y5))	112,560	48 increasing to 168	177,100	Tank volume 0.675m³ each
Autoclave	€16,100	1	16,100	1	16,100	1	16,100	1	16,100	
Instrumentation	€3,450	1	3,450	1	3,450	1	3,450	1	3,450	Microscope, scales, sensors
Pipework	€2,300	1	4,600	1	4,600	1	16,100	1	25,300	Water supply/ discharge for tanks
UV steriliser	€1,150	1	1,150	1	1,150	1	1,150	1	1,150	
Filtration	€2,000	1	2,000	1	2,000	1	2,000	1	2,000	
Water distribution	€5,000	1	5,000	1	5,000	1	5,000	1	5,000	Seawater intake/ discharge
Furniture	€1,600	1	1,600	1	1,600	1	1,600	1	1,600	
PCs, printers	€3,500	0		0		1	3,500	1	3,500	Assume already available in scenarios 1 and 2
Benches/racking	€2,000	1	2,000	1	2,000	1	6,000	1	5,500	
Totals			**€85,875**		**€85,875**		**€205,375**		**€294,475**	Excluding any grants

Salaries

Starting salaries are those recommended by the Irish Universities Association for technical staff and research assistant. They include employer PRSI and pension contributions. An annual increase of 3% is applied.

Materials

Materials are ex-VAT costs for collectors and the nutrients needed for culture. Collectors include cost of twine.

Consumables

These include costs of assorted glassware, replacement lighting, and items of stationery.

Utilities

Electricity is the only utility service included in the analysis. The cost is an estimate based on €600/tank per annum (as per BIM model) and electricity costs increasing at 5 % per annum.

Sales

Each scenario uses the same selling price from hatcheries of €5.0/m for seeded string in calculating the revenue. Where a grower(s) produce seeded string for their own use the selling price is a cost saving.

Configuration

In each scenario, kelp is cultivated on long-lines in individual sites of 1 ha. Lines are 100 m in length spaced 4 m apart, resulting in demand for a total line length of 2.5 km/ha. It is assumed all the seeded string is sold by the hatchery, or in the case of the individual grower, fully utilised thus eliminating the need to purchase strings. Depending on market demand, the hatchery operator has the option of introducing a two season growing cycle, thus increasing the production of seeded string.

Total line length is major factor influencing the scale of the hatchery. It determines space requirements, the number of cultivation tanks and staffing levels. The length of seeded line is proportional to the area under cultivation, similarly the number of cultivation tanks and number of containers in which to house the tanks are also proportional to the cultivation area. Table 20 shows the line length, number of tanks and number of containers.

Table 20 – Seed line length for different cultivation areas

Area under cultivation	5 ha	10 ha	50 ha	150 ha	200 ha	250 ha	300 ha	350 ha	400 ha	500 ha
Line length (m)	12,500	25,000	125,000	375,000	500,000	625,000	750,000	875,000	1,00,0000	1,250,000
Number of tanks	41.67	83.33	416.67	1,250.00	1,666.67	2,083.33	2,500.00	2,916.67	3,333.33	4,166.67
Number of containers	1.74	3.47	17.36	52.08	69.44	86.81	104.17	121.53	138.89	173.61

The modelling presented does not include the costs associated with the construction of a specialised facility or facilities. While such an exercise would undoubtably be worthwhile, it is beyond the scope of this strategic review. The scenarios presented rely on the use of containers to house the hatchery facilities. This is in line with the previous BIM model exercise, but in the larger scenarios is likely no a feasible approach. Nevertheless, it provide a useful mental model to illustrate the differences in scale between the scenarios and highlights the practical challenges likely to arise in their implementation at higher production volumes.

Other assumptions

Other basic assumptions include;

- Cultivation of a single species within a growing season of 6 month.
- Equipment required matches that defined in the BIM hatchery plan 2010.
- The analysis does not include site preparation costs e.g., design and planning, foundations, seawater abstraction and discharge etc.
- Hatcheries rely on the use of second-hand shipping containers instead of new buildings;
- Revenue results from the sale of seeded strings, or in the case of an individual grower is a cost saving, the analysis does not include revenue from the sale of seaweed.
- The selling price seeded string used in the cash flow projection is €5/m. This corresponds to an average of the maximum price Irish growers can pay to maintain competitiveness (€2)[48] and the highest price charged by a commercial hatchery, Hortimare BV (€8).
- Equipment and costs based on the BIM report and adjusted to reflect the current purchasing power of the Euro applying a factor of 1.3 to the 2010 cost estimates.
- The cost of electricity includes price changes to industrial users from 2012 as indicated by The Commission for Energy Regulation[49] and Sustainable Energy Ireland[50]. Future costs include a price inflation factor of 5 % per annum.
- Variables such as number of tanks, pipe work etc subject to increase because of greater output are adjusted on a scaled basis to match output.
- The holding capacity of tanks is 10 collectors (30m line per collector)
- The capacity of the 5m container is 24 tanks; allowing for the inoculation 240 collectors.
- The volume of culture tanks is 0.675 m^3, as per the original BIM design.
- Collectors will not be recycled.
- No consideration given to the redesign of collectors to reduce their cost.
- No consideration of any automated equipment e.g., string winding, spraying etc.
- No consideration of grant eligibility.
- The analysis does not include depreciation since it is a non-cash item, or taxation.

The analysis of each scenario is based on a seeded string selling price of €5/m. Each scenario shows the annual cash flow without grant aid and with grant aid of 50% for capital investments. A separate table indicates the cumulative cash flow at different string selling prices.

48. The grower setting the €2/m maximum also indicated having previously paid €7.00/m for material from outside the state
49. See: https://www.cru.ie/wp-content/uploads/2013/07/cer13120.pdf
50. See: https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/prices/

Scenario 1

Production of a seeded line to meet the requirements for an individual grower or dedicated hatchery, supplying string for an area of 3 ha increasing to 5 ha in five years. The main items of capital equipment and estimated cost of each are as presented in Table 19.

Table 21 is an indication of projected cash flow over the five-year period at a price per meter of €5. Table 22 shows the cumulative cash flow based on different selling prices for seeded string. This scenario assumes hatchery operation is a part-time activity demanding the participation of 0.25 FTE per annum. All investments occur at year 1.

Table 21 – Cash flow – Scenario 1

Area cultivated (ha)		3.0	3.4	3.9	4.4	4.9
String length (km)		7.5	8.6	9.7	10.9	12.3
		€	**€**	**€**	**€**	**€**
String sales/saving on purchase of string	€ 5.00	37,500	42,750	48,308	54,587	61,684
Costs	Collectors	1,238	1,411	1,594	1,801	2,036
	Nutrients	600	684	773	873	987
	Consumables	1,100	1,210	1,331	1,464	1,611
	Electricty	15,000	15,750	16,538	17,364	18,233
	Staff costs	8,882	9,059	9,240	9,425	9,614
Total costs		23,882	24,809	25,778	26,790	27,846
Profit/loss		**13,618**	**17,941**	**22,530**	**27,798**	**33,838**
Investment		85,875	0	0	0	0
Cash flow		-72,257	17,941	22,530	27,798	33,838
C/F cum			-54,316	-31,786	-3,988	29,849
With 50% cap grant	Investment	42,938	0	0	0	0
Cash flow		-29,319	17,941	22,530	27,798	33,838
Cummulative c/f			-11,378	11,151	38,949	72,787

Table 22 – Cumulative cash flow at different selling prices excluding grants – Scenario 1

Price per m	2022	2023	2024	2025	2026
€4	€-79,757	€-70,366	€-57,498	€-40,617	€-19,117
€5	€-72,257	€-54,316	€-31,786	€-3,988	€29,849
€6	€-64,757	€-38,266	€-6,075	€32,641	€78,815
€7	€-57,257	€-22,216	€19,637	€69,270	€127,781
€8	€-49,757	€-6,166	€45,348	€105,899	€176,747

Scenario 2

Production of a seeded line to meet the requirements for an individual grower or dedicated hatchery supplying string for an area of 5 ha for five years. The main items of capital equipment and estimated cost of each are as presented in Table 19. Table 23 is an indication of projected cash flow over the five-year period at a price per meter of €5.

Table 24 shows the cumulative cash flow based on different selling prices for seeded string. As with Scenario 1, this scenario assumes hatchery operation is a part-time activity demanding the participation of 0.25 FTE per annum and the investment made at year 1.

Table 23 – Cash flow – Scenario 2

		2022	2023	2024	2025	2026
Area cultivated (ha)		5	5	5	5	5
String length (km)		12.5	12.5	12.5	12.5	12.5
	Selling price/m	€	€	€	€	€
String sales/ saving on purchase of string	€ 5.00	62,500	62,500	62,500	62,500	62,500
Costs	Collectors	2,063	2,063	2,063	2,063	2,063
	Nutrients	1,000	1,100	1,210	1,331	1,464
	Consumables	1,100	1,210	1,331	1,464	1,611
	Electricty	30,000	31,500	33,075	34,729	36,465
	Staff costs	8,882	9,059	9,240	9,425	9,614
Total costs		38,882	40,559	42,315	44,154	46,079
Profit/loss		**23,618**	**21,941**	**20,185**	**18,346**	**16,421**
Investment		85,875	0	0	0	0
Cash flow		-62,257	21,941	20,185	18,346	16,421
C/F cum			-40,316	-20,131	-1,785	14,636
With 50% cap grant	Investment	42,938	0	0	0	0
Cash flow		-19,319	21,941	20,185	18,346	16,421
Cummulative c/f			2,622	22,806	41,152	57,573

Table 24 – Cumulative cash flow at different selling prices excluding grants – Scenario 2

Price	2022	2023	2024	2025	2026
€4	€-74,757	€-65,316	€-57,631	€-51,785	€-47,864
€5	€-62,257	€-40,316	€-20,131	€-1,785	€14,636
€6	€-49,757	€-15,316	€17,369	€48,215	€77,136
€7	€-37,257	€9,684	€54,869	€98,215	€139,636
€8	€-24,757	€34,684	€92,369	€148,215	€202,136

Scenario 3

This scenario involves collaboration by a group of growers to provide seeded string for their own use or sale to others. The group produce string to support the cultivation of kelp in a combined total area of 6 ha, increasing at a rate of 26 % per annum to a maximum of 15 ha over 5 years. Any unused string may be sold to other growers, with sales revenue retained by the hatchery. The main items of capital equipment and estimated cost of each are as presented in Table 19.

Table 25 is an indication of projected cash flow over a five year period at a price per meter of €5. Table 26 shows the cumulative cash flow based on different selling prices for seeded string. This scenario assumes hatchery operation is a full-time activity, initially demanding the participation of 1 FTE per annum and rising to 1.5 FTE per annum from 2026. Investments are made at year 1,3 and 5 to cope with projected increase in area under cultivation.

Table 25 – Cash flow – Scenario 3

		2022	2023	2024	2025	2026
Area cultivated (ha)		6	8	9	12	35
String length (km)		15	19	24	30	37
	Selling price/m	€	€	€	€	€
String sales/ saving on purchase of string	€ 5.00	75,000	94,500	118,598	148,840	186,794
Costs	Collectors	2,475	3,119	3,914	4,912	6,164
	Nutrients	1,200	1,800	2,700	4,050	6,075
	Consumables	1,100	1,210	1,331	1,464	1,611
	Electricty	30,240	31,752	63,504	66,679	116,689
	Staff costs	35,526	36,237	46,202	47,126	57,682
Total costs		65,766	67,989	109,706	113,805	174,371
Profit/loss		**9,234**	**26,511**	**8,891**	**35,035**	**12,423**
Investment		89,375	0	46,800	0	69,200
Cash flow		-80,141	26,511	-37,909	35,035	-56,777
C/F cum			-53,630	-91,539	-56,504	-113,281
With 50% cap grant	Investment	44,688	0	23,400	0	34,600
Cash flow		-35,454	26,511	-14,509	35,035	-22,177
Cummulative c/f			-8,943	-23,451	11,583	-10,593

Table 26 – Cumulative cash flow at different selling prices excluding grants – Scenario 3

Price	2022	2023	2024	2025	2026
€4	€-95,141	€-87,530	€-149,158	€-143,892	€-238,027
€5	€-80,141	€-53,630	€-91,539	€-56,504	€-113,281
€6	€-65,141	€-19,730	€-33,919	€30,883	€11,465
€7	€-50,141	€14,170	€23,700	€118,271	€136,212
€8	€-35,141	€48,070	€81,320	€205,658	€260,958

Scenario 4

Production of seeded line over a five-year period 2022 to 2026 to match an annual compound growth of area under cultivation of 30% from a starting point of 10 h. The 30% compound growth is the rate required to provide sufficient string to meet the needs of an industry utilising 50% (115ha) of the current sea-area licenced for seaweed cultivation by 2031.

The main items of capital equipment and estimated cost of each are as presented in Table 19. Table 27 is an indication of projected cash flow over the five-year period at a price per meter of €5. Table 28 shows the cumulative cash flow based on different selling prices for seeded string. This scenario assumes hatchery operation is a full-time activity, initially demanding the participation of 1.5 FTE, rising to 4 FTE per annum from 2026.

Table 27 – Cash flow – Scenario 4

		2022	2023	2024	2025	2026
Area cultivated (ha)		10	13	17	22	30
String length (km)		25	32.5	42.5	55	75
	Selling price/m	€	€	€	€	€
String sales/ saving on purchase of string	€ 5.00	125,000	162,500	212,500	275,000	375,000
Costs	Collectors	4,125	5,363	7,013	9,075	12,375
	Nutrients	2,000	2,600	3,400	4,400	6,000
	Consumables	1,600	1,760	1,936	2,130	2,343
	Electricty	57,600	75,600	95,256	133,358	192,536
	Staff costs	77,927	123,361	159,933	196,527	197,615
Total costs		135,527	198,961	255,189	329,885	390,151
Profit/loss		**-10,527**	**-36,461**	**-42,689**	**-54,885**	**-15,151**
Investment		134,175	22,900	22,900	45,800	68,700
Cash flow		-144,702	-59,361	-65,589	-100,685	-83,851
C/F cum			-204,063	-269,652	-370,338	-454,189
With 50% cap grant	Investment	67,088	11,450	11,450	22,900	34,350
Cash flow		-77,615	-47,911	-54,139	-77,785	-49,501
C/F cum			-125,526	-179,665	-257,450	-306,951

Table 28 – Cumulative cash flow at different selling prices excluding grants – Scenario 4

Price	2022	2023	2024	2025	2026
€4	€-169,702	€-261,563	€-369,652	€-525,338	€-684,189
€5	€-144,702	€-204,063	€-269,652	€-370,338	€-454,189
€6	€-119,702	€-146,563	€-169,652	€-215,338	€-224,189
€7	€-94,702	€-89,063	€-69,652	€-60,338	€5,811
€8	€-69,702	€-31,563	€30,348	€94,662	€235,811

Scenario 5

The production of seeded line for cultivation from 2026 to 2031 at a volume corresponding to an annual compound growth of area under cultivation of 30% as described in Scenario 4.

Once seeded line production exceeds that required for a cultivation area of 8 ha (20 km), the hatchery faces challenges in processing lines using traditional methods for seeding and cultivating strings. The number of culture tanks increase, as does the number of containers. Additional staff is needed in what is a labour-intensive process. Winding string into collectors can be mechanised, even automated, but at a cost; as can spraying collectors with cultures. A hatchery site using the current seeding process to supply string for 126 ha – half the total sea area licenced for seaweed; requires more than 43 containers and 1050 tanks, to supply 315 km of seeded line. Such a facility, even with some level of automation, is impractical and unrealistic.

5.5 Hatchery discussion

Any expansion of the cultivated seaweed sector is reliant on expanding the output of current growers or by attracting new entrants. The absence of a hatchery with the capacity to support increased output is a barrier to aspiring new entrants and limits performance of existing growers. A further hurdle faced by both groups aiming to circumvent the hatchery problem, by setting up their own facility, is the level of investment and the risks faced in operating a hatchery. The absence of scientific and technical knowledge required to operate a hatchery is a major component of the total risk.

Investments by the state via BIM in research to develop breeding methods for new species have yet to fully deliver reliable culture. Disease temporally thwarted efforts to deliver a reliable breeding programme of Saccharina latissima. Reliable breeding methods for any of the highly valued red seaweed species remain to be fully proven. It would be unrealistic to expect that individual hatchery operators could unlock the breeding cycle, or undertake the research required to introduce new species. Apart from the technical challenge they would face, doing so, may lead to duplication of effort and rivalry between growers. Developing breeding methods for new species would not be enabled by training growers. This requires scientific knowledge, technical know-how and experience; competences which remain embedded within a small pool of individuals in research community.

The modelling exercise completed during this project highlights the hatchery investment challenge and the practicality of developing a hatchery to service any large scale-cultivation. Realising the BIM vision to cultivate the 254 ha of sea area currently licenced for seaweed aquaculture would be unlikely. Unless that is, the sector adopts new hatchery and cultivation systems. An area of 254 ha would have a requirement for 635 km of seeded string. A further expansion in cultivation if current licence applications (522 ha) receive approval, would create a potential demand for 1,880 km of seeded string.

The justification for a grower owned hatchery, is to reduce the cost of buying seeded string and improve reliability of supply. Where a grower plans to cultivate 3ha rising to 5ha over 5 years and can maintain a hatchery using temporary staff, payback on the initial investment (€85,875) would be less than 5 years, but only when the cost of seeded string is at least €6/m. A grower would need training to establish cultures from the wild, implementing hatchery protocols and monitoring early growth.

Growers would need access, via technology transfer agreement to the knowledge required to cultivate new species, otherwise they may only be able to cultivate Alaria esculenta. This limitation applies to all growers unable to develop or acquire knowledge needed to cultivate new species. A hatchery investment of €85,875 to support a grower to cultivate 5 ha of seaweed (as in Scenario 2) would have to pay more than €4.50/m for string to obtain a pay-back the initial investment in less than 5 years. Both these scenarios do not include grant aid.

Once a hatchery has to produce string to support a cultivation area greater than 8 ha (20 km of string), investments and overheads rise; there is also a need for greater space to accommodate up to 7 containers to house the cultivation tanks. A combination of practical challenges and the scale of investments, is unlikely to be attractive to growers, even with grant-aid support.

Any expansion in biomass output requires a degree of confidence in the supply of string coupled with access to new species. Uncertainties exist around growers adopting the current hatchery model to provide that confidence or expand the range of species.

The current hatchery model does not support large scale cultivation activity. Insights to large scale international culture operations (>15 ha), point to a separation of breeding from on- growing. They also indicate preparations are underway to introduce mechanisation and eventually automation in attaching culture to growing lines and deployment at sea. The steps being taken to support large scale cultivation in European waters include the development of an integrated systems approach to biomass cultivation.

This new approach extends from species development through all downstream cultivation stages, including deployment, harvesting and processing. The production of a seaweed culture by specialist breeders is at the heart of this system and is an area where Ireland has relevent expertise.This innovation removes the main risks associated with breeding programmes and early-stage culture from the grower, or the need for growers' to build hatcheries.

Table 29 illustrates the numbers of hatcheries described in each of the hatchery scenarios presented earlier that would be required to meet such demand at the end of year 5 in each case.

Table 29 – Numbers of hatcheries to service Scenarios 1 to 5

	Seed string production Year 5 (km)	Currently licenced 254ha	With further expansion of 522ha
Scenario 1	12.3	52	153
Scenario 2	12.5	51	150
Scenario 3	37	17	51
Scenario 4	75	8	25
Scenario 5	315	2	6

The table highlights the point that supporting the growth of an entire industry needs a new approach to seed supply. Scenario 5, though included above, is impractical as it necessitates the use of ca. 1050 tanks. The table also illustrates that the concept of a national hatchery, as advocated as some participants in this strategic review, is infeasible using established seeded string techniques. If such techniques are utilised into the future (as is likely in the near to medium term), a distributed approach is required.

Adopting a culture bank approach, built around proven breeding and culture capabilities is the first step in introducing a new hatchery model in Ireland, to support future growth aspirations. The benefits for growers from this model regarding cultures, include access to cultures based on regional cultivars; retention of grower specific cultures; enhanced reliability of supply; new species; traceability; quality assurance; biosecurity and technical support.

In this approach, significant space savings over the traditional hatchery process would result due to the elimination of the need for a lengthy hatchery incubation period, when using a direct seeding method [155]. However, a dedicated culture room to maintain would be required. The cost of a small culture room (6m^2) incorporating lighting and temperature control is estimated to be around €120,000 [167].

On a broader front, such a model would eliminate the need for growers to make major investments in infrastructure; incur increased costs or the added overheads associated with employing technical staff. The state would indirectly benefit from the introduction of this model; it could prevent any hybridisation of species in the wild; maintain diversity of indigenous species; and eliminate the importation of non-native cultivars.

Establishing large-scale seaweed cultivation in Ireland needs barriers to be removed and the introduction of new methods. Leading biomass producers in countries such as Norway have already taken such steps, including forming collaborations with companies in the Netherlands and Belgium that specialise in culture supply, and turnkey cultivation systems respectively.

Section 6
Towards a strategy for the Irish Macroalgal Industry to 2030

6.1 Introduction

This report reviewed the state of seaweed aquaculture today as follows:

- **Section 2:** The state of the art in macroalgal cultivation in Europe and beyond.
- **Section 3:** Macroalgal markets
- **Section 4:** A profile of the Irish macroalgal industry
- **Section 5:** Hatchery requirements the Irish macroalgal industry

This section addressing the future of the seaweed cultivation sector to 2030 draws on information presented in other sections of our report. We completed several analyses in developing three strategic pillars, each with 4 thematic areas, and suggest a series of actions to enable the further development of the sector.

6.2 Commentary

Ireland's cultivation sector is at an early stage of evolution, populated by new entrants with ambitions to cultivate seaweed, and a cohort of individuals with significant experience in cultivating shellfish, fishing and other experiences in the marine sector. A recent increase in the number of licences granted for seaweed cultivation as reported by BIM, reflects a rise in interest in seaweed cultivation to a level where there are 254 ha of licenced sites. Additionally, there is a high expectation that current applications for an additional 522 ha may soon come on stream. Most licences also allow shellfish cultivation, hence there is no certainty that all 776 ha will only cultivate seaweed. BIM cite current biomass output as around 40 to 60 tonnes/annum (wet weight); equating approximately to a sea area under cultivation of 4 ha.

Growers are attracted to seaweed cultivation by reports of market growth potential, increased demand for seaweed and seaweed-based products in consumer and industrial sectors, consumer concerns about environmental sustainability and the increased public profile of seaweed as something that is natural, and therefore "good". The wild harvest and cultivation sectors make similar claims of sustainability and the growth of seaweeds in "clean" Irish waters.

Many of the individuals involved in growing or using seaweed have only recently identified the multiple challenges they face in working with the resource. Increasingly, they recognise seaweeds as a complex natural material with little or no consistency in composition; variable growth rates – even within the same species; possessing life-cycles that make some species difficult to replicate outside their natural environment; and include species which are hard to easily identify.

There is an assumption that all species of seaweed can be cultivated in Irish waters. This is visible in some licence applications which include e.g., *Codium fragile* – a species described as invasive [168]; *Ascophyllum nodosum*, which although processed in Ireland is not suited to cultivation and is only harvested from the wild; and *Osmundea Pinnatifida* or other species that are not yet able to be successfully cultivated.

Only a few of the many hundreds of seaweed species found in Irish waters lend themselves to reliable cultivation at present. *Laminaria digitata* was once alone as the only species that could be cultivated, however, now *Alaria esculenta* and *Saccharina latissima* stand out as the mainstay of Irish cultivated seaweeds. Other species including *Palmaria palmata, Chrondrus crispus* and *Asparagopsis armata* are the focus of laboratory trials.

Though there are exceptions, Irish growers typically prioritise biomass production; the challenge being to generate revenue from increased output, over cultivation for a specific market application. This stems from the demand for dried product from a small number of international buyers acting on behalf of companies in three sectors viz. the human food, personal care and nutraceuticals[51]. These are consumer-oriented sectors known to be responsive to increased consumer awareness of environmental and humanitarian issues. As a result companies seek natural, high-quality, and environmentally-friendly ingredients with traceable provenance.

51. In interviews conducted as part of the preparation of this report, growers were reluctant to identify specific buyers for reasons of perceived commercial sensitivity.

A review of global seaweed value chains identified major differences in terms of innovation, geographic scale and governance in high-profile sectors of pharmaceuticals, bioplastics, biostimulants, alginate and cosmetics [71]. Frequently, these industry sectors and others such as animal nutrition and biofuels feature as targets for high-value added seaweed-based products. Much of the optimism surrounding the use of seaweeds in these sectors stems from the positive laboratory scale performance of various seaweed extracts, [74, 169].

In a European context, any seaweeds used in these industries are more likely to come from wild harvested species within the next 10 to 20 years at least, due to far greater diversity and available biomass, as opposed to cultivated biomass from a small number of kelps. Opportunities for very high volume, low value markets such as biofuels and packaging may only be viable if, and when, very large-scale cultivation is realised. Wild harvest stock cannot support the volumes required by these sectors.

Current demand for seaweed outstrips supply both internationally and in Ireland; and applies equally to biomass sourced from wild and cultured stock. Most Irish growers have not yet developed to the stage of being able to add significant value to what they grow. Growers cultivate the same species resulting in each becoming locked into producing a commodity. Perhaps counter intuitively, the growth of the sector to a point where growers and processors can add significant added value depends, in the short term, on continue to grow these species but at significantly higher volumes. Doing so will enable the development of markets and sales channels, and crucially will enable the achievement of turnover.

The development of a community within the sector will be central to this, as will the adoption by some of a leadership position. Those that take on a leadership position will assume responsibility for taking on certain costs (such as those associated with producing or sourcing seed string, drying facilities) in return for guaranteed supply of product from other smaller producers. The authors of this report informally refer to this as the "Chateau Model", drawing a similarity to wine producers who in addition to growing their own grapes, purchase from local vineyards and produce a product which they market benefiting the wider community.

6.2.1 Involvement in the value-chain

BIM identified nine commercial seaweed growers, with access to a total of 254 ha of licenced sites and a further 522 ha as the subject of 13 licence applications. By farming the 776 ha, total biomass output could reach 15,320 tonnes/annum (wet weight)[52]. The current farmed area is less than 10 ha, producing around 40 tonnes/annum. Cultivating 776 ha in 10 years would require a compound annual growth rate of 54% per annum (approx.) Most licences allow the cultivation of shellfish and seaweed on the same site, hence there is no certainty that seaweed will be cultivated on any site.

Establishing large-scale biomass cultivation is dependent on having the capacity to produce the high-quality cultures and seeding substrates for on-growing into to a harvestable biomass. Increasing biomass output requires that Irish growers access seedlings. Few of the active growers can produce seeded string, having relied on supplies from a trial hatchery. This hatchery may sustain current production levels, but is unlikely to support any major expansion of the sector. It has limited capacity for both string production and the introduction of new species beyond what is currently available.

52. Based on a yield of 20 t/ha

Few growers control the major value adding elements of the seaweed value chain. Most Irish growers focus on the cultivation and harvesting of seaweed. The potential for major added value is at the processing stage. By extending their engagement within the value chain, growers may be able to add value. However, exercising successful control of individual elements in the value chain or the entire chain, demands a clear market understanding and focus; and significant financial and technical resources, all of which may be outside the capacity of traditional growers to secure. Overcoming this type of constraint may need the adoption of new ownership models such as mergers of companies, community ownership or co-operatives.

Growers must take ownership of what and how much seaweed they grow. The first step to achieving this level of control is to overcome the seeded string supply chain issue to support an expansion of the area under cultivation. Without a significant expansion of biomass output the basis for competing is limited.

6.2.2 Species selection

Any plans to expand biomass production must be informed by the selection of species suitable for cultivation. The reality is only the kelps Saccharina latissima, *Alaria esculenta* and *Laminaria digitata* have been cultivated with any degree of consistency: *Alaria esculenta* being the most reliable performer in the hatchery. In recent times, *Saccharina latissima* suffered early stage growth issues that still need to be resolved; whereas there is little current demand for *Laminaria digitata*, the first species to be successfully cultured in Ireland.

Other European seaweed species are the subject of continued interest because of the high value they command in food and cosmetic markets. Amongst these *Porphyra/Pyropia spp., Palmaria palmata* and *Chrondus crispus* stand out as potential candidates for product diversification. However, overcoming the complexity and achieving control over their life-cycles, is the key to reliable cultivation [165]. Irish research on these species, having started in 2011 has only recently recommenced with trials to establish stable methods for *Palmaria palmata* and *Porphyra/Pyropia spp.* There are no reports of similar effort to develop *Chrondus crispus.*

The possibility exists, as practiced in countries such as Canada, to cultivate high-value species in land-based tanks [170]. This approach offers significant advantages over sea-based cultivation, including e.g., control over the growth environment, avoidance of contaminants, and the possibility of all-year cultivation. This approach is also showing success in Spain and Portugal where *Ulva spp.* are cultivated in tanks and in raceways [18].

6.2.3 Scale of cultivation

Ireland's macroalgal biomass production lags the output reported in other European regions, accounting for approximately 12% of Norwegian output of 336 wet tonnes *Saccharina latissima* and *Alaria esculenta*. in 2020 [35]. Biomass production in France in 2019 was 77% greater than Ireland's output at 176 wet tonnes. The scale of biomass cultivation influences processing options and targeted markets. Ireland's licenced area of 254 ha has a potential yield of 5,080 wet tonnes/annum, whereas Norway's licenced area is more than 900 ha [35, 37] with a potential output of 13,500 wet tonnes/annum[53], though some reports from Norway suggest higher yields locally depending on growing conditions. Currently, an estimated 2.5% of Norway's licenced area is productive, compared to 1.74% of Ireland's licenced area.

53. This output is based on a yield of 15t/ha/annum.

Ireland's low-level of seaweed biomass output reflects the performance of a sector predominantly comprising new entrants. The absence of access to more productive cultivation and harvesting methods and hence greater output, restricts growers to rudimentary processes such as drying, freezing, milling and packaging. They could however, justify moving to more efficient processing technologies, by increasing biomass production. The effect of such a move would be to open the way to more customised processing for specific markets and with it possibly greater added-value.

6.2.4 Harvesting

Major expansions in areas under cultivation requires different approaches to harvesting the biomass. On sites capable of producing biomass at levels approaching the volumes needed to begin move up the value chain, growers must consider adopting mechanised harvesting. Typically, farms of 1ha or more may need to employ some degree of mechanisation, which becomes even more necessary when using more productive growing systems [106]. This equipment provides a semi-automated approach to harvesting large areas, cleaning the growing substrate and reseeding growing lines whilst at sea.

Increased volume production also presents growers with the post-harvesting challenge of preventing the harvest from natural decay at the pre-processing stage. This occurs once the seaweeds are removed from the water, during landing and transport from the growing site to a processing facility. Various options exist to minimise biomass decay ranging from drying, freezing, fermentation (ensiling), however, deciding which method to use, as with decision making about processing of seaweeds, must consider the end-use or uses and the necessary logistics for onward transport and/or storage.

6.2.5 Processing

Methods used to process seaweed biomass must be compatible with the product application, end-use and product market requirements. Currently, the major markets for most of the Irish grown seaweed are food related and to a lesser extent, cosmetics. Some growers supply minimally processed seaweed to niche food markets, whilst others sell in bulk to food ingredients and cosmetic companies.

Each of these markets is highly regulated to ensure consumer safety, and whilst most seaweeds are generally considered as safe, seaweeds can also absorb and accumulate toxins, both naturally occurring or of anthropogenic origin. Suppliers of seaweed in any form must be aware at a minimum of EU regulations covering food and feed; including General Food Law (Regulation (EC) No 178/2002 and Regulation EC 767/2009 concerning animal feed; Regulation (EC) 1881/2006 about food contaminants; and Recommendation (EU) 2018/464 relating to metals: and iodine in seaweed.

The biochemical profile of seaweed is known vary depending on species, where it grows, the effect of seasonal change and age/reproductive status [46, 171]. This instability must be acknowledged in processing, because processing methods are also known to alter the properties of the raw seaweed and therefore end-use. These changes in composition may not always suit every market application. It is necessary for processing methods to be optimised to suit the seaweed species, and specification/requirements of the end product [37]. The key to achieving this balance from a processing perspective, is to ensure each process step is capable of operating consistently. Indeed, sustainable and profitable processes are now recognised as key in meeting industry requirements for high-quality products and as a prerequisite for future industrial developments of the sector.

Biorefining is often cited as the solution to producing high-value compounds. However, a common caveat, even if seaweed biorefineries can progress beyond laboratory scale [59], is that their financial justification relies on a continuous supply of raw materials in volumes exceeding 65,000 frozen tonnes/year [62]. Large scale, integrated biorefineries with biofuel as a target output and based on cultivated biomass of *Saccharina latissima* or *Ulva spp* are reported to be feasible but only at a scale requiring feedstocks of 1 dry t per hr [56] or upwards of 200,000 dry tonnes per year [63]. Smaller scale production based on at 2,000 dry t of *Saccharina latissima* or *Ulva spp* per year was not feasible.

6.2.6 End-use applications

The production of seaweed biomass through cultivation is growing rapidly in Europe, and is a goal in Ireland's plans to develop a sustainable bioeconomy. There is a long history of people using seaweeds in various applications and in different formats for human food, animal feed, cosmetics and as fertilisers and soil conditioners in horticulture. More recently, interest in seaweeds as sources of materials with potential applications in other areas has emerged.

There are multiple references in grey literature, project reports and peer reviewed publications to the potential of seaweed derived compounds in pharmaceutical, food, food ingredients, functional food, animal feed, nutraceuticals, cosmetics and cosmeceuticals, biomaterials, specialised human and animal diets, pet food, bioplastics, fine chemicals and many other product applications. Additionally, there is widespread reference to seaweed compositional properties associated with antioxidant, anti-inflammatory, antitumor, anticoagulant and other effects and so-called "health benefits" of consuming seaweeds.

In moving through the value chain into higher value-added product applications, growers and processors must have a clear understanding of the end application and of the role of individual seaweeds' primary and secondary metabolites, since it is these compounds that determines the potential bioactivity of seaweed derived material [172].

One application which has been the focus of much speculation and consumed countless millions of public and private funds is biofuel. However, there has yet to be any commercialisation of seaweed derived fuel. There are also concerns about the social acceptability of cultivation at a scale that demands such enormous sea-area to be dedicated to fuel production, when society faces so many other challenges [74].

6.3 Key conclusions

Multiple sources contributing to this consideration of a strategy for Ireland's cultivated seaweed sector informed and shaped our conclusions about its future. Our conclusions are organised under the headings of structure, infrastructure, market insight, regulation, processing and biomass production below. Prior to presenting the individual conclusions, we provide a high-level overview informed by the main findings about Ireland's seaweed cultivation activities.

6.3.1 Conclusions – an overview

Ireland's seaweed industry is dominated by companies that process seaweed harvested from the wild. The majority of this is from one species – *Ascophyllum nodosum*, which is processed to produce biostimulants and fertiliser. The other activity within the industry is seaweed cultivation. It is difficult to define the individual seaweed growers as a sector, due to the erratic nature of their activities, variable numbers and the lack of reliable performance data around markets, costs, scale etc.

The first significant cultivation activity started around 2010 and supported by various BIM initiatives, producing 12 tonnes in the first two years. Since then, the maximum annual production was 70 wet tonnes, in 2015. Biomass output has fallen since then.

Some seaweed licences data back to 2011, however, the majority of the current 25 seaweed licences were granted between 2016 and 2020, and most include species other than seaweeds. In 2021 six production units operating the licenced area of 254 ha produced 50 wet tonnes.

Developing a cultivation sector demands a clear vision and targets for biomass production at a scale to allow Ireland to capture a share of the expanding markets. Compared to competing European regions such as Norway, where production has increased each year from 2015 to reach 336 tonnes in 2021 [35], Ireland's output lacks scale. Delays in the issue of licences cannot be held up as the reason for low biomass production, Ireland has a licenced area capable of supporting an output of 3,810 tonnes.

Ambitions to develop high-value seaweed-based products will not be realised unless biomass production is increased. This increase can result from licences holders cultivating more of the current licenced area or attracting more growers. It is clear, that most of area licenced for seaweed is not productive.

Ireland has little or no infrastructure which directly supports the development of a cultivated seaweed section or industry. A largely opportunistic research community responds to EU calls for research proposals and occasional national calls where macroalgae is included in the brief. Unlike leading countries, Ireland does not have seaweed strategic research agenda, hence knowledge gaps concerning the cultivation of native species exist.

Access to juvenile seaweed for on-growing at sea is restricted by the limited capacity of a trial hatchery to supply seeded lines, currently around 10.5 km per annum; sufficient to support a productive farm of around 4 ha. Such a facility cannot support the growth of an industry. Some growers have started to develop their own hatcheries; however, little is known about their seeded string production capacity, other than it meets their requirements.

Growers generally struggle to obtain market information. Those producing seaweed for food products, typically have better insight to the national markets than international markets. Some growers just do not consider the need for such insight, claiming they sell all the seaweed they can produce – since it's a seller's market. Few realise, they produce a commodity, and that the increasing output of other European countries will lead to price reductions.

The strategic review defines multiple actions over the next 10 years relevant to an industry that wants to compete internationally. However, immediate action is needed to retain the current growers, attract new growers and to help them overcome the barriers they face. These priorities include,

- Stimulating non-productive licence holders to commence cultivating seaweed;
- Boosting the sector by attracting new growers;
- Obtaining relevant market information on seaweed for food use;
- Confirming and funding a national seaweed research agenda;
- Encouraging collaboration between growers to share information, know-how and equipment; and

- Establishing a hatchery facility capable of operating to international best practices, to reliably culture *Alaria esculenta, Saccharina latissima* and *Laminaria digitata* on behalf of growers and possessing the competences to develop methods to breed species in demand such as *Palmaria palmata* and other red seaweeds.

6.3.2 Conclusions regarding the current status and future of cultivated seaweed activity in Ireland

Structure

1. The increased interest in seaweed cultivation in Europe has brought about a change in how the sector is perceived. Increasingly, its immediate future is defined as a provider of biomass for high value added products. In the longer term, there is likely to be more focus on bulk markets.
2. Accurate data on the overall performance of the sector are not readily available.
3. Three distinct regional clusters comprising growers in the south west, west and north west exist.
4. The scale of seaweed growers in Ireland corresponds to the scale of growers elsewhere in the EU; predominantly micro-enterprises.
5. There is a realisation that eventual success of the sector will be determined by how it adapts to become more industrialised and competitive within a global industry.
6. Unless biomass output can increase Irish growers will not be able to compete.
7. Seaweed growers are different to seaweed processors.
8. Large scale processers of seaweeds rely on networks of growers to provide raw materials.
9. Growers currently have a low level of control over species cultivated resulting from a single source of supply for seedlings.
10. The seaweed sector is generally restrained in discussing factors relevant to its growth.
11. Value-added activity in the cultivated sector is minimal compared to the wild harvest sector.
12. New players will encounter few barriers in entering the cultivated seaweed sector, leaving incumbents vulnerable to predatory activity by overseas firms seeking to take advantage of Ireland's favourable growing conditions.
13. The cultivated seaweed sector faces threats from the wild harvest sector, which offers a greater range of species and higher volumes.
14. High demand for seaweeds neutralises threats from buyers, but this will change with increasing availability of biomass
15. A single source for reproductive cultures or juveniles is a threat to growers, a possible response from growers is to source materials for seeding outside the state. This is reported as having already happened.
16. Ireland's position as a leader in seaweed cultivation has diminished by failing to capitalise on early success in breeding species
17. There is a low level of seaweed cultivation in licenced areas
18. Intercompany rivalry is absent in the marketplace, but this does not translate to cooperation.

Infrastructure

19. There is a need for a systems approach to the development of the sector. This will ensure that essential infrastructure exists to match the demand for breeding, deployment and harvesting, landing, storage and processing.

20. Any development of the sector depends on the ability to produce seedlings but there is a capacity constraint in the production of seeded strings.

21. There is an imperative to consider future hatchery options for the sector.

22. Strings available to growers from the EMFF funded R&D programme is unlikely to continue and growers will be threatened without a temporary solution to string supply.

23. There is a need for a practical solution to the hatchery issue built upon a new hatchery concept.

24. Large scale cultivation (> 1 to1.5 ha) is unlikely to be competitive without the introduction of mechanised harvesting methods, including automated systems and other essential infrastructure.

25. Any consideration of future hatchery configurations need to take a whole systems approach into account e.g. matching hatchery requirements to seeding methods, particularly the costs of buildings to house any hatchery and other infrastructure to meet the demand for increased biomass production and growing systems.

Market insight

26. Cultivated seaweed must be differentiated from wild harvested to justify any premium price.

27. Species in demand for food and cosmetic use such as *Palmaria palmata*, *Porphyra/Pyropia*, *Chrondus crispus* offer greater added value opportunities than any of the kelps.

28. Market knowledge remains a barrier to development.

29. Limited biomass output is a barrier to developing new markets and access to supply chains.

30. Exaggerated claims about the potential of seaweeds pose a threat to the sector.

31. Food products for artisan products is a current opportunity but requires more precise market definition, extended supply chains and new product development.

32. Public acceptance of seaweed aquaculture is generally positive compared to that of finfish aquaculture.

33. Major market opportunities exist because of increasing demand for seaweed biomass and seaweed products in Ireland and Europe as a whole.

Knowledge and research

34. Access to new species is uncertain, requiring research effort to develop reliable breeding methods.

35. Greater knowledge of the properties of species from different sites and different natural occurring strains and seasonal variation is required to optimise processing with end user requirements.

36. Growers recognise the existence of multiple scientific and knowledge gaps and that these inhibit development.

37. Greater collaboration within Ireland's research community under expert leadership can develop the knowledge required to enable growth in the sector.

38. Results from Irish participation in EU funded research projects appears not to have found their way to seaweed cultivators and processors.

Regulation

39. Favourable national and EU policy environments support seaweed cultivation.

40. Licencing is no longer a barrier to the development of increased scale in the sector.

41. Minimal regulations exist for seaweed-based food products.

Processing

42. Producing low levels of biomass, and with limited processing capabilities restricts opportunities for growers to move up the value chain.

43. Introducing new processing technology requires high-volume biomass and clarity on market opportunity to justify the investment.

44. Large scale cultivation will only be achieved via a gradual evolution that matches processing capabilities to biomass output.

45. Seaweed processing activity is generally confined to drying, milling etc.

46. The current low-level availability of biomass does not justify biorefining.

47. Other than growers processing seaweed as a food, the majority of biomass is sold without significant processing – hence value added is low.

Biomass production

48. The rate of biomass production in Ireland lags that in other European countries

49. Land-based tank cultivation offers scope to deliver "customised" product, with variations in composition and year-round cultivation possible.

50. Low biomass output reflects involvement of new entrants and failure to maximise growing sites by incumbents

51. Unless biomass output can increase Irish growers will not be able to compete

52. Site availability is not a barrier to short to medium term growth however, to support biomass output at rates found in e.g., Norway may result in operations shifting off shore into more exposed sites

6.4 Scenarios for developing seaweed cultivation

Ireland's current seaweed cultivation activities clearly position participants, despite the presence of some long-established growers, in a nascent sector on the edge of an expanding market for seaweed and seaweed derived materials. Individual growers, and the sector as whole, face multiple constraints in developing sufficient scale to allow them to become internationally competitive.

Though there continues to be reference to a licencing barrier, it is quite clear with a licenced area of 254 ha and more than 500 ha included in current applications, the licencing process is no longer a barrier. Other barriers persist, including access to juvenile seaweeds, limited availability of a range of seaweed species; and access to knowledge or technical know-how, including market insights. Together these barriers limit any expansion of cultivation activity and hence biomass output. Many licence holders do not fully utilise their sites to cultivate seaweed. Most growers have minimal infrastructure for cultivation, harvesting and processing, relying instead on services provided by others.

Only growers cultivating seaweed for use in minimally processed food products have an insight to market opportunities or consumer requirements. Generally, seaweed is sold in bulk as dried biomass. Knowledge about the use of this bulk material is largely, on the part of the grower speculative. Since *Alaria esculenta* accounts for the majority of seaweed biomass produced, and without reliable access to other species, the sector produces a commodity; it is lacking in an economy of scale to enable a shift from this position in the near future. Unless the sector develops critical mass and scale it will remain vulnerable to external price competition.

Increasing the level of biomass production, with a clear insight to potential end-use, is an essential priority. However, many knowledge-gaps exist, ranging from reliable control of species life-cycles, to species specific site selection, linking harvesting times to seaweed compositional profiles, cultivation and harvesting methods, the effect of processing on biochemical composition, and processing methods optimised for specific end use. Filling these gaps is essential, as is developing a lasting knowledge infrastructure to ensure the sector has access to core scientific disciplines and competences on which its development and survival is reliant, and to counter misinformation about seaweeds.

6.5 A scaled development

The rate of development of the sector depends on its access to seaweed biomass in sufficient volume to allow it to achieve a competitive position. This is possible by following one or more of four possible routes;

- developing the scale required to become a leading supplier of seaweed biomass;
- establishing a processing infrastructure to provide refined seaweed extracts to high value-added markets;
- establishing the capacity to cultivate and process high-value seaweeds e.g., *Palmaria palmata* and other red algal species; or by
- focusing on the cultivation species for a specific end-use, e.g., minimally processed food under a brand.

The sector is currently locked into a situation that constrains biomass cultivation. Without access to greater biomass, its capacity to take advantage of opportunities in the expanding global market for seaweed and seaweed-based products, is severely limited.

From the extensive review of international cultivated seaweed activities and stakeholder feedback, the opportunities for Ireland's seaweed cultivation sector fit within one of three levels of industry maturity as described in Table 30 below.

Current growers fit the profile of the "Basic Supply" level with biomass production in the range 40 tonnes wet weight/annum to 60 tonnes wet weight/annum. On drying this could yield between 3 tonnes to 6 tonnes dry weight (dry weight) depending on drying methods and initial water content; an average output of between 300kg to 600kg per enterprise [173]. There are few options to move to higher value products without increasing biomass production.

A focus on food products by some growers is emerging in response to a reported increase in consumer awareness of seaweeds. However, any new product development activity to build on this trend requires growers to have access to new species. In the absence of any major increase of biomass, or new business models, the introduction of additional processing capabilities is unlikely. Some growers have sought to lessen their dependency on a common source of seeded string by developing an in-house capability. These growers will have an on-going need for know-how and robust scientific knowledge transfer to establish any culture facilities.

No grower appears to currently operate at a scale that positions them at the level of "minimal processing" or "refined products". Though a small number display signs of progress towards the "minimal processing" stage. Operating at these levels demands significant increases in biomass output, and developing access to supply chains.

Increasingly, there is a realisation amongst growers that contributions from multi-disciplinary scientific collaborations are needed to fill the many knowledge gaps that exist regarding the cultivation, harvesting, processing and development of seaweed-based products. Without this knowledge, and concomitant increases in biomass output, progress along the value chain is unlikely.

Table 30 – Development models

Maturity Level	Scope	Products	Market focus	Processing	Enablers
Basic supply	• No or minimal increase in biomass • Growers take responsibility to cultivate seedlings • Attract more growers	• Whole, flaked or ground seaweeds • Fresh, frozen or dried	• Sea vegetables and ingredients • Artisan type food • High-end restaurants • Undifferentiated bulk supply of kelp to buyers	• Air drying • Milling • Packaging	• Create awareness of seaweed • Tech transfer for seedlings, cultivation • Expand knowledge base of cultivation • Market insight
Minimal processing	• Increase biomass to 500 t/y wet • Expanded range of species • Attract more growers	• Powders with targeted particle size • Crude extracts (liquid, dried)	• Cosmetics • Food ingredients • Functional food & supplements • Pet food • Biostimulants	• Stabilising • Drying • Freezing • Targeted milling • Extraction • Separation	• Expand knowledge base of cultivation • Processing and product formulation knowledge • Investments in research and infrastructure • Market insight • Develop supply chains
Refined products	• Increase biomass to >1000 t/y wet • Expanded range of species • Attract more growers • National and international collaborations	• Extracts with targeted composition and/or activity (dried, liquid)	• Cosmetics • Food ingredients • Functional food • Nutraceuticals • Dietary supplements • Pet food • Biostimulants	• Stabilising • Drying • Freezing • Milling • Extraction • Separation • Purification	• Expand knowledge base of cultivation • Processing and product formulation knowledge • Investments in research and infrastructure • Market insight • Develop supply chains

6.6 Strategic direction

The large-scale cultivation of seaweed in Ireland is not yet a reality. The feasibility of establishing processing activities above those presently available hinges on significant increases in biomass production. Enhancing the support infrastructure is likely to help growers to expand cultivation [13]. However, any expansion in output is likely to create challenges for production and processing due to the investments required in developing these capabilities [3]. This is also a view shared by several stakeholders with long-standing involvement in national and international seaweed sectors consulted during this project and several Irish growers.

In the short to medium term, the options for the strategic development of the cultivated seaweed sector appear limited. Two priorities stand out; firstly, to cope with and overcome the current constraints, and secondly, anticipate a future scenario inclusive of a gradual increase in biomass output. Unless there is an early breakthrough in controlling the cultivation of *Palmaria palmata*, any such increase will come from *Alaria esculenta, Saccharina latissima* or *Laminaria digitata*; being species that lend themselves to reliable cultivation.

Each area of market maturity identified above in Table 32 offers product development opportunities. These range from extending existing product lines to creating entirely new products in new markets. Product line extensions do not generally lead to any significant long-term increase in demand. This typically results from the development of new products, finding new uses for current processes or identifying new supply chains.

An analysis of global seaweed value-chains identified differences in both the role and influence of lead-firms in high-value sectors using seaweeds [71]. Companies producing high-value added products based on seaweeds do not describe themselves as "seaweed companies", they identify themselves as processing companies. This separation is clearly visible in Ireland with wild harvesters supplying seaweeds to processing companies. These companies typically rely on growers and harvesters to provide raw materials that they convert to meet specific end-use applications.

This is an activity supported by extensive knowledge of the raw material and of the performance requirements of their customers. Their business model relies on access to high-volume raw materials; they buy seaweeds at lowest total cost, adding value via though processing for specific applications. The cultivation sector therefore must find ways to differentiate their product offering, by identifying ways to add value.

Ireland's seaweed sector is dominated by wild harvesting activity providing a wide range of seaweeds. These are used by some artisan food, restaurants and cosmetic companies, but harvesters mostly supply *Ascophyllum nodosum* to processing companies for use in animal feed and horticulture products. There is no apparent differentiation between wild-harvest and cultivated seaweed, with the virtues of the so called "pristine waters" of the Atlantic attached to products derived from both sources. In the absence of obvious product differentiation, the cultivation sector must aim to distance itself from wild-harvest, and from other global regions such as the Asia Pacific which dominates seaweed cultivation output.

The likelihood of any major infrastructural development of the sector in the short-term is low. Growth, therefore must come from maximising the use of current species and available processes in the absence of new species. This requires a clear focus on high-quality production, compliant with regulatory standards and customer requirement regarding environmental sustainability, safety and traceability.

6.7 Analysis

The situational analysis presented in this section draws from and makes use of several widely recognised strategic analysis tools to investigate external and internal (to the cultivation sector) factors, including Political, Economic, Social, Technological, Environmental, Legal factors, termed PESTEL; a consideration of the five main competitive forces of the threat of entry: the threat of substitutes; the power of buyers; the power of suppliers and the extent of rivalry between competitors, often described as Porters 5-Forces; identifying the Strengths, Weaknesses, Opportunities, Threats of the sector – commonly termed a SWOT analysis; and finally, identifying actions needed overcome the threats and weaknesses and capitalise on the strengths and opportunities using the TOWS approach.

Through not strictly a strategic analysis tool, consideration of the Hype Cycle to illustrate the market situations of several potential seaweed products.

6.7.1 PESTEL Analysis

Political and Policy Environment

National and EU policy is positive toward seaweed aquaculture, based on societal needs to reduce a dependency on terrestrial crops that result in carbon emissions and are damaging to biodiversity. In addition to the displacement of unsustainable terrestrial crops, much of the policy commentary on seaweed aquaculture is based on anticipated benefits that may arise from the ability of seaweed cultivation to provide opportunities for carbon sequestration and remediation of contaminants, together with anticipated anti-methanogenic properties.

Behind this positivity there remains an absence of clear guidance reflecting an acceptance that seaweed aquaculture is an immature industry, which requires ongoing research and the development of best practices to enable its growth This is visible in the outputs of several large EU projects, such as the Phycomorph project that identifies the requirement for action in areas such as:

- The harmonisation of EU regulation and simplifying procedures across Member States.
- The use of risk assessment approach to the cultivation of non-native species.
- The standardisation and of food frameworks and the improvement of traceability.
- The adaptation of food security monitoring programmes for seaweeds.
- Dedicated research to support market claims.

Actions such as these are likely to take several years to reach conclusion.

There is specific mention of the role of seaweed in European policies such as The European Green Deal, the Farm to Fork Strategy and the EU Circular Economy Action Plan. These are primarily focused on seaweed's potential for food production. Despite these, while the EU Commission has published a communication on strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021-2030, which explicitly excludes seaweed aquaculture. This is to be dealt with in an, as yet unpublished, separate and specific initiative to support the production, safe consumption and innovative use of algae.

At a national level, public policy is also favourable toward seaweed aquaculture, but is also lacking in specifics. Seaweed aquaculture is mentioned in Food Vision 2020 for the reasons outlined above, and features in the recommendations of the report of Seafood Task Force. The forthcoming National Plan for Sustainable Aquaculture is expected to include actions to support for seaweed aquaculture, with financing likely to be made available via the European Maritime, Fisheries and Aquaculture Fund (EMFAF) and the Brexit Adjustment Fund. It is expected that seaweed aquaculture projects will continue to attract funding at a rate of 50% as was the case under the EMFF.

Environmental situation

Despite the strong demand for new species to cultivate, growers only have access to *Laminaria digitata, Saccharina Latissima* and *Alaria esculenta*. Three supply problems exist – reliability of supply, only *Alaria esculenta* is generally available; supply constraints – capacity to produce seeded string output is limited to around 10,000 m/annum; and the inability to propagate successfully and reliably any of the red seaweeds.

In the short to medium term there is little likelihood of temperature changes ascribable to climate change having a significant impact on the range of species available to Irish growers, however changes to water salinity and the possibility of temporary but sustained increases in water temperatures over a period of days or even weeks may impact on productivity.

Few barriers prevent the introduction of exotic species to Irish waters. Licence applications to areas within Special Areas of Conservation are subject to comment by the National Parks and Wildlife Service, while the Marine Institute also may offer advice to DAFM in making licence decisions. Nevertheless, there is no specific legislative prohibition.

Social Environment

Employment associated with Ireland's seaweed aquaculture activity is minimal. In common with other aquaculture activities, employment in the sector could have a significant positive impact on local communities that are associated with peripheral economies with low employment prospects.

The sector remains small-scale comprising micro-enterprises and casual growers. It exists in three geographic clusters; south – counties Cork and Kerry; west – counties Clare and Galway; and growers in Sligo and Donegal forming the northwest cluster. Data to enable the profile of total biomass output by region, species, or end application is either non-existent or unreliable. There is a small group of individual growers that typically are involved in other aquaculture businesses.

Anecdotally, relative to other forms of aquaculture, there is high acceptance of seaweed aquaculture among the public, both those living adjacent to seaweed aquaculture sites, and the wider population. Recent media attention to the opportunities for carbon capture, bioremediation and feed stock benefits have influenced public opinion [174].

Technological profile

All biomass production in Ireland is at sea using various configurations of long lines and some nets, with two exceptions. Two growers indicated the use of on-shore tank-based systems as well as long-lines at sea. Biomass harvesting is a manual, labour intensive task. It appears that little consideration is given to mechanisation or the use automation at any stage.

The current source of seeded string is a pilot hatchery located in leased premises in Bantry county Cork. Licensed operators, with a track record are considered as candidates for seeded collector string from the EMFF funded R&D programme, however it is not always possible to supply all the string required to each operator' providing free issue seeded string to growers based on "first come first served". Several growers and companies indicated an interest in establishing their own hatchery.

Seaweed processing capabilities are currently rudimentary for the most part. Many growers do not have the means to process what they produce. Most seaweed is dried, in many cases by another grower or processing plant (in which case often associated with wild-harvest streams of biomass). Forced and airdrying are common processes. Some growers have started to investigate ensiling as a preservation method and a means of reducing the bulk of the biomass.

Typical processing for human food products involves cleaning/separation, drying, milling and packaging. All growers mention biorefining, most without any clear understanding of what this involves. There is a general misapprehension about bioprocessing and biorefining – both used interchangeably, with limited obvious insight to the various stages or the need to consider the species, its end use in advance of deciding on processing methods. There is also confusion about extraction: some viewing extraction as biorefining.

Justification for large-scale cascading type biorefining in the short to medium term is difficult. Biomass volume is too low, and there are no defined processing requirements for any product. Processing capability must be compatible with the product requirements; currently, in most cases these lack clear definition.

Economic profile

There are three clearly identifiable supply chains for Irish cultivated seaweed; human consumption, including food ingredients; wholesale markets and bulk supply to a processor.

Growers are guarded in speaking about markets in any specific way, referring to generic markets – food, pharmaceuticals, functional foods, food ingredients, nutraceuticals and supplements, animal feed, bio-stimulants, cosmetics, energy etc. Most growers are yet to develop a clear understanding of the market for the seaweed they cultivate. The growers selling product into the food retail know far more about its use and the end-user. Few have any direct contact with the end-user, or insight to where the seaweed will be processed. Selling seaweed to an intermediary is common, though no grower was willing to identify them other than as a wholesaler. Destinations mentioned for product include Scotland, Denmark and France.

The vagueness encountered in respect of markets and applications also exist regarding the cost of production and first-sale price. A minority of growers provided an indicative price, but given the variation in responses from multiple sources, these cannot be regarded as reliable.

There were few instances where any significant value was added to the seaweed by the growers. However, expectations and aspirations remained high that they would eventually add value without being specific. Growers were reluctant, and at times evasive about specific applications for their seaweed. Specific reference was made to food markets -sold as minimally processed, packaged for food retail. These products were designed for use as ingredients in soups, stews for flavour and as salt substitutes. Others were sold as dried snacks. Other growers mentioned projects to develop functional food and therapeutics based on extracts from seaweed they grow, without mentioning specific compounds. It was common for growers to admit they did not care about market applications; they were satisfied that they could sell everything they produce to an agent.

Legal Framework

A licenced area of 254 ha is reported as available for the cultivation of seaweed. However, the area currently used to cultivate is significantly less. Based on an estimated yield of 20 tonnes/ha/annum we estimate an area of no more than 3 ha is being cultivated based on total biomass output of 60 tonnes/annum.

No specific regulations apply to seaweed aquaculture products. From a cultivation perspective, while there is an overall positive attitude towards the licencing of seaweed cultivation, it is managed under a common process with other forms of aquaculture.

No specific food standards are in place for cultivated seaweeds; all species in Ireland being managed as commonly used foods under the EC Novel Foods Directive, complemented using national food standards. While there are suggestions that limits will be set regarding heavy metals such as arsenic, and iodine in seaweeds, early indications from the institutions of the European Union point to a continued reliance on existing process and standards. In the case of animal feeds, European Union wide regulations are in place which govern the levels of certain compounds and elements found in seaweed including arsenic and iodine.

Table 31 – PESTEL analysis for the seaweed aquaculture sector

	Factors	Effect on the seaweed aquaculture sector	Certainty of situation	Importance to strategic development
Political/Policy	*Favourable view of industry*	Positive investment and funding environment (including governmental) in light of climate and biodiversity emergencies.	**High;** unlikely to be significant change.	**High;** there is positive environment but need to remain guarded against hype.
	Specific position of EU Policy remains unarticulated.	Little effect, as changes are likely to be benign or positive.	**Medium;** changes can be inferred from Commission consultation.	**Low;** in the short to medium term EU policy changes will not affect market; and changes are only likely to bring increased certainty.
Economic	*Identifiable markets: human consumption (including ingredients), wholesale markets, bulk supply).*	Informs species selection and type of processing.	**Low;** beyond human consumption, the exact nature of markets is poorly understood. In the human consumption market, there is currently demand that exceeds supply, but the size and extent of the market is unquantified.	**Medium;** growers currently subject to a buyers' market, selling to the first available buyer based on quantity rather than on properties of species type.
	Competition from wild harvest.	Affects market selection (food consumption vs bulk supply) based on price per tonne, and also informs need to differentiate based on e.g., quality.	**High;** the price differential between wild harvest for bulk markets is substantial.	**High;** without the generation of significantly higher volumes, certain markets are not viable.

	Factors	Effect on the seaweed aquaculture sector	Certainty of situation	Importance to strategic development
Social	*Low employment*	A key factor in the social acceptability of aquaculture activities is related to the public's perception of benefits accruing from the activity. There is as yet an unestablished employment benefit.	**Medium;** employment is not reported as a constraining factor on the industry; however, employment costs are significant element of the price differential with e.g., wild harvest.	**Medium;** the attractiveness of seaweed aquaculture to future employees may act as a constrain to growth.
	Public acceptance	Indications are that there is relatively high acceptance of seaweed aquaculture, with public perceptions that it is a "public good" activity.	**Low;** current acceptance may be related to low levels of activity and to public perceptions that seaweed production is associated with carbon capture, environmental remediation. This positive image may not sustain.	**Medium;** while there is positive investment and licencing environment, these may be interrupted by objections to individual sites.
Technological	*Automation*	There are low levels of automation in the European Seaweed aquaculture industry generally, and in Ireland in particular.	**High;** evidence from publicly available information and anecdotal evidence points to an industry that utilises either manual labour, or bespoke engineering solutions. There is little evidence of standard equipment.	**High;** Increased mechanisation will ultimately be required to produce the volumes of production required for anything other than direct food markets.
	Hatcheries	There are limited options for seed juvenile stock. A single supplier dominates the European market, with smaller scale commercial hatcheries focusing on a few species. Hatcheries are typically heavily dependent on sourcing propagation material from the wild and have low levels of automation.	**High;** the current industry is wholly dependent on a few hatcheries in Europe and particularly so in Ireland.	**High;** the current hatchery model is typically predicated on the production of seeded string for a few species. Hatcheries are choke point for the industry which is dependent on their output for growth.
	Processing	Access to basic processing resources, such as cold rooms and dryers is limited. In Ireland there is significant reliance on dryers owned by a few individuals, in some cases strongly associated with wild harvesting activities.	**Medium;** anecdotal evidence indicates suggests bottlenecks associated with drying facilities, however some producers have been guarded about their capabilities in this regard.	**High:** Expansion of the sector from its current low production base is wholly dependent on the sector's ability to meet current demand.

	Factors	Effect on the seaweed aquaculture sector	Certainty of situation	Importance to strategic development
Environmental	*Species availability*	At most, producers have access to only three species, with only *Alaria esculenta* generally available.	**Medium;** there have been anecdotal reports of production of other species such as *Asparagopsis armata*; but there is little evidence of such species being grown commercially.	**Medium;** in the short term, production of available species is sufficient to support the direct food market. Longer term development, where species are grown to serve other specific markets, is likely to be constrained if the current situation continues.
	Climate Change	Changing water conditions may threaten the viability of certain species.	**Medium;** The Marine Institute has produced robust models of likely future temperature change scenarios.	**Low;** impacts on production may arise from changes in water salinity and marine “heat waves”, but in the medium-term impacts on production are unlikely.
	Invasive Species	Introduction of exotic species may damage the image of Seaweed Aquaculture.	**High;** there are little to no direct restrictions currently on the importation of exotic species.	**High:** experience with invasive species already present in Ireland, such as *Sargassum muticum* have attracted much media attention.
Legal	*Licensing*	There are currently adequate licenced sites to allow production growth; with a pipeline of licence applications that are likely to add to this capacity. The licencing regime is such that it is reasonable to assume that this availability of licenced sites will continue in the long term.	**High;** Data provided by DAFM shows the availability of licenced sites; and a pipeline of licence applications.	**Medium;** given the current licenced capacity, availability sites will not be a limiting factor in the short to medium term. In the long term, high volumes of production may require a move to more exposed sites, and this presents a more uncertain licencing scenario.
	Regulation	Increased regulation may limit the growth of the industry by creating constraints on how and where material can be marketed.	**Low;** indications are that the EU commission is not contemplating more restrictive regulation. However individual member states are likely to move to more rigorous standards.	**High;** Changes would directly impact the direct food market, which is currently the most accessible for growers.

6.7.2 Competitive analysis

This considers the five generic competitive forces – entry, exit, buyers, suppliers and rivalry within of faced by the cultivated seaweed sector.

In the analysis below, we focus on the Irish industry with an emphasis on the position of growers. Each force is examined in turn, using sub-headings to guide the analysis [175].

Threat of entry

Table 32 – Threat of entry summary for 5-Forces analysis

Scale and Experience	Medium	Those wishing to enter the seaweed aquaculture industry face few barriers. The licencing regime is such that applications for small areas are accepted. There are some capital requirements associated with deploying lines or nets, and a requirement for access to a suitable boat for harvest. At present drying of material can be achieved, although for significant growth a grower is likely to have to make investments. Access to know-how is an area where some growers have indicated challenges, having had to rely on a trial-and-error approach.
Distribution channels	Low	In the current environment demand for seaweed exceeds supply, especially for the direct food and ingredients market. While an individual grower may not have distribution channels in place, there are established distributors and emerging growers willing to collaborate with smaller growers.
Access to supply	High	Access to juvenile stock is a significant potentially lasting bottleneck. Most growers in Ireland rely on access to seed stock from a R&D source. Other options are limited.
Expected Retaliation	Low	There is minimal threat of retaliation from existing operators in the industry; the market is such that there is little scope for retaliation in the form of price competitiveness.
Legislation	Low	There are few if any legislative barriers to entry or to placing product on the market.
Differentiation	Low	There are no obvious brands within the industry; meaning that new entrants to not need to overcome established players. On international markets, European products are viewed as higher quality than those of other countries.
Summary Finding	**Low**	**Relatively few impediments to entry to the seaweed aquaculture in Ireland, and this does not particularly threaten existing players. The principal areas requiring actions relate to provision of access to seed material; access to know how and access to capital investment funds.**

Threat of substitutes

Table 33 – Threat of substitutes summary for 5-Forces analysis

Price/ Performance ratio	Medium	In a European context, there is little evidence that growers can differentiate their product from other growers based on specific qualities. The exception to this is where growers can produce specific species that their competitors cannot.
Extra-industry effects	High	There remains a significant price differential between wild-harvested seaweed. From that industry's perspective, seaweed aquaculture represents a low threat on the basis of price and performance. Conversely, for those working in seaweed aquaculture, there is little advantage currently offered by their product that will justify the price differential. In time this advantage may emerge from an ability to provide more certainty in relation to supply and quality. Similarly, for end users (e.g., cosmetics producers), there is a wide availability of ingredients derived from terrestrial sources with specific properties that provide more certainty and price advantage than seaweed-based products.
Summary Finding	**Medium to High**	**As a nascent industry, the seaweed aquaculture faces significant threats from wild seaweed harvesting and other substitute sources. There is a need to valorise the seaweed aquaculture product by differentiating the product through defined qualities and data.**

Power of buyers

Table 34 – Power of buyers summary for 5-Forces analysis

Concentrated buyers	Low	There do not appear to be any buyers of seaweed aquaculture biomass who are dominating the market.
Low Switching costs	Medium	Low buyer switching costs in moving from one supplier of cultured seaweed to another. From the grower's perspective, this represents a threat as it can mean that expected sales may fail to materialise. This risk is somewhat mitigated at present due to the high demand for product.
Buyer competition threat	Medium	Given the low threat of entry detailed above, there is little to stop a buyer of product deciding to grow biomass themselves. This threat is mitigated at present due to the high demand for product.
Summary Finding	**Medium**	**High levels of demand at present mitigate against the power of buyers. As production rises internationally this is will diminish.**

Power of suppliers

Table 35 – Power of suppliers summary for 5-Forces analysis

Concentrated suppliers	High	There are few suppliers of seed stock in the Irish context. The current situation, where limited stock is available as a by-product of a research and development programme, is unlikely to sustain. As a consequence, those in a position to supply seed stock will have significant power and will be able to attract a premium for the product.
High Switching costs	Medium	Despite the strong position of suppliers of seed stock outlined above, there are few costs for a grower associated with switching to another supplier – the main cost here is likely to be simply securing supply, as suppliers will naturally supply growers with whom they have established relationships.
Supplier competition threat	Low	While there is evidence of growers considering producing their own seed stock, there is little evidence that any of the established seed stock suppliers moving towards growing seaweed at a scale that would threaten the position of growers.
Summary Finding	**Medium**	**The concentrated nature of seed stock suppliers is an overall risk to the Irish seaweed aquaculture sector.**

Competitive rivalry

Table 36 – Competitive rivalry summary for 5-Forces analysis

Competitive balance	High	There are no dominant growing entities in the Irish market. The industry is at present typified by several low volume producers. Given the current high demand for product, it is unlikely that an entity will emerge of a size that will impact on others.
Industry growth rate	Low	Despite high demand, there has been low growth in the sector. This is likely due to bottlenecks such as access to seed stock and specialist equipment.
Fixed costs	Low	There are high capital costs associated with Seaweed Aquaculture, but once established, fixed costs are modest.
Exit barriers	Low	There are few barriers to exit.
Differentiation	Low	Differentiation of product is low, and this would normally be countered by price. Current market demand is masking this.
Summary Finding	**Low**	**At present there is low competitive rivalry between those in the Seaweed Aquaculture industry.**

Commentary on the competitive analysis.

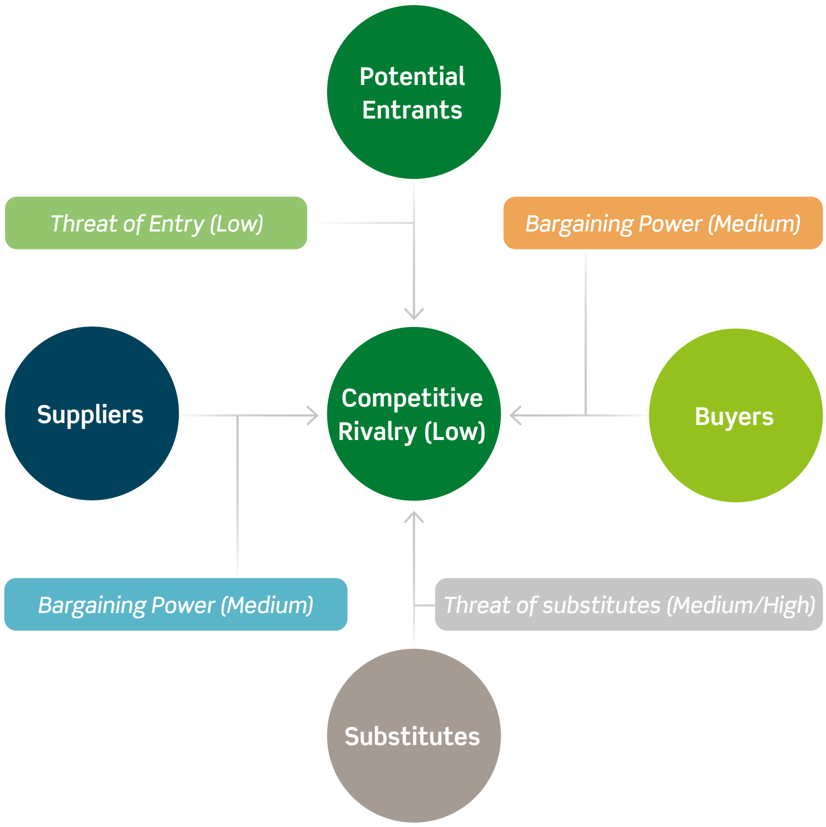
Given the industry's nascent nature it would be expected to have low threats, however this is not uniformly the case as illustrated in Figure 9, which shows the nature and magnitude of the forces as indicated by green/orange/red colouration. In those areas where threats are other than low, specific state actions are likely to be required to counter these threats.

The analysis shows that, the sector is exposed to alternative substitutes; specifically, biomass sourced from the wild harvest sector, but also from terrestrial crops. To counter this, differentiation is required through marketing and clearer definition of the properties associated with culture (such as consistency of supply and properties).

Structural issues with the sector are also highlighted regarding both suppliers and buyers. In terms of suppliers, this relates to hatchery capability and the provision of seed stock. In relation to buyers, the issue relates to the potential ability of buyers to either switch growers or indeed enter the production arena themselves.

Competitive rivalry between participants in the sector is low, largely because of the low levels of production combined with the high demand for product. As production increases to meet demand, competition within the sector will most likely grow.

Figure 9 – Overview of Competitive Forces model applied to the Irish Seaweed Aquaculture sector



6.7.3 The Hype Cycle

A hype cycle is a subjective representation of a technology, product or market relative to its promotion. The most common representation of such a cycle is that presented by technology research and consulting company Gartner[54] and shown below in Figure 10 to illustrate elements of the seaweed sector [176].

In assessing where in the cycle an industry is located, the following milestones are identified:

- **Innovation Trigger:** A potential product, technology or innovation kicks things off. Early proof-of-concept stories and media interest trigger significant publicity. Often no usable products exist and commercial viability is unproven.
- **Peak of Inflated Expectations:** Early publicity produces several success stories — but these are often accompanied by scores of less-reported failures. Some companies act; many do not.

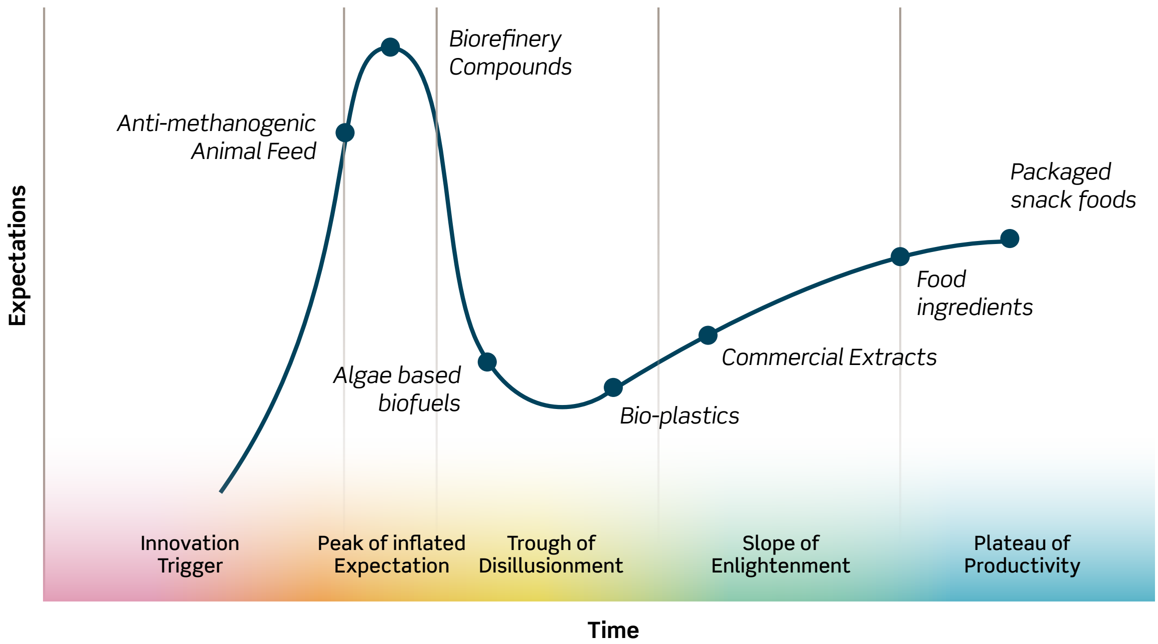
54. See www.gartner.com

- **Trough of Disillusionment:** Interest wanes as experiments and anticipated products fail to deliver. Producers of the technology shake out or fail. Investments continue only if the surviving providers improve their products to the satisfaction of early adopters.
- **Slope of Enlightenment:** More instances of how the product can benefit particular customers start to crystallize and become more widely understood. Second- and third-generation products appear from providers. More enterprises fund pilots; conservative companies remain cautious.
- **Plateau of Productivity:** Mainstream acceptance occurs. Criteria for assessing provider viability are more clearly defined. The products broad market applicability and relevance are clearly paying off.

Based on the review of markets, and the situation in relation to seaweed aquaculture in Ireland, Europe and beyond. Figure 10 is an estimate of approximate position of several algae-based product types on the hype cycle.

The further along the cycle a product or technology is placed, the more certain is the market situation. It is possible that certain product types will not progress to a stable market. Some will become highly niche products, while others may stall temporarily or completely, as some technical or other issue becomes an impediment to progress. Where this happens in the "disillusionment" phase, lack of interest, investment, or innovation attention can leave the product or technology permanently stalled.

Figure 10 – Algae based product types placed on the hype cycle



Commentary on the Hype cycle.

Use of the Hype Cycle when considering a product or technology area requires a degree of caution. Its use is subjective and does not use firm indicators. Nevertheless, the simple descriptors of each of the phase cycles provides a useful means of "reality checking" much of the commentary that surrounds various products.

Where products or product types exist within a single sector, as is the case in this analysis, the hype cycle provides a means of determining how far individual products sets are from a stable market. In the case of the seaweed sector, the hype cycle presents the opportunity to state what may seem obvious: food products are the closest to market, while some highly publicised product types such as biofuels and anti-methanogenic animal feeds remain at an early stage of product development.

6.7.4 SWOT Analysis

A Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis captures internal strength and weaknesses of the industry and sets them against the opportunities and threats as shown in Figure 11. Many sources have informed SWOT analysis, including the interviews with multiple industry and other stakeholders, previous SWOT analyses carried out on Irish Seaweed Aquaculture such as that in the report of the Task Force on Seafood; the findings from the PESTEL and from the competitive force analysis.

Figure 11 – Overview of a SWOT analysis

Strengths

Table 37 – SWOT Analysis -Strengths

Structural	1. BIM knowledge and accepted role as an honest broker. 2. Favourable yet exacting licencing regime. 3. Access to scientific research expertise, particularly research at low TRLs. 4. Increasingly confident aquaculture sector with ambition for growth, e.g., plans for Pairc na Mara. 5. Broadly supportive EU and national policy environment 6. A track record of participation in EU funded research programs with a seaweed focus
Brand and Image	7. Good national food brand – "Clean, sustainable, food". 8. Positive public acceptance of seaweed aquaculture. 9. Ireland's seaweed heritage. 10. Long research history and maintains a reputation in the field
Sustainability	11. Long-term sustainability versus wild harvest. 12. Can contribute to environmental targets e.g., water quality in multi-trophic settings. 13. Ireland's marine environment. 14. Activity is located along a coastline with sheltered bays. 15. Low input form of aquaculture.
Product and Market	16. Attributes of seaweeds: e.g., an array of different compounds, – proteins, polysaccharides etc. 17. Identifiable markets (e.g., ingredients, wholesale, bulk etc.). 18. Part of the EU single market.

Weaknesses

Table 38 – SWOT Analysis – Weaknesses

Structural	1. Sector comprises small number of growers lacking in scale 2. Low access to supply chains 3. Uncertainty around seed supply/No commercial hatchery(ies) and limited alternative sources. 4. Weak industry cohesion, over reliance on informal networks 5. Fragmented and uncoordinated production and weak market position for producers. 6. Low level of integration of state supports– who does what? What is primary production? 7. Dependency on a single crop. 8. Limited number of species available for cultivation 9. Small size of sectors creates limited capacity to attract talent at every level. 10. Lack of engagement with algal research community 11. Low translation of licenced area to production.
Infrastructure and Support	12. Limited access to dedicated pilot facilities. 13. Weak processing infrastructure leading to bottlenecks in existing facilities. 14. Weak technical support for product and process development. 15. Low support levels for "in the field" development activities. 16. Failure to recognise major gaps in seaweed research – breeding, diversity, composition, temporal and geographic variability. 17. As yet unclear policy articulation at European level, reflected in national policy. 18. Cost of infrastructure and sceptical financing environment.
Product and Markets	19. Poor understanding of market needs. 20. Restricted to cultivation of low-value species 21. No coordinated market development. 22. Little differentiation from other European countries in terms of species grown. 23. Absence of reliable data on scale, structure and output of the sector 24. No differentiation of cultivated species from wild species 25. Reliance on low value brown seaweeds. 26. Low level of consumer awareness, perception and knowledge of seaweed in Ireland and Europe, and consequent lack of trust in product offerings 27. Poor understanding of the specific needs of processors in different industry sectors
Knowledge and awareness	28. Poor understanding of "biorefining" and bio processing 29. Lack of availability/know how in relation to hatchery facilities and cultivation methods. 30. Low levels of experience and "know-how" in the industry. 31. Over optimistic view of the potential of seaweeds – views not based on scientific evidence. 32. Absence of a clear research agenda. 33. An ongoing inability to reliably manage the life cycle of most species.

Opportunities

Table 39 – SWOT Analysis – Opportunities

Structural	1. Relatively small industry with existing participants known to each other. 2. Underutilised licence capacity with scope to add more. 3. Advantageous funding rates for seaweed aquaculture compared to other maritime activities. 4. Availability of "marine savvy" workforce as other marine industries decline.
Levers	5. Co-location of seaweed aquaculture with other marine activities (IMTA), e.g., floating wind, mussel growing. 6. Existing seafood processing capability and facilities providing the possibility of co-location 7. Existing positive internal & export markets established through wild harvest industry (feed, cosmetics, bio stimulants) 8. Existing seafood supply chains to access international markets. 9. Available capacity and capability in other marine sectors, e.g., availability of technical know-how in fishing gear and technology. 10. Established Irish food research capability
Standards	11. Likely increased food safety requirements in European markets will lead to displacement of Asian imports. 12. Recognition of European food safety standards in Far East. 13. Availability of international best practice (e.g., New England in US, Norway)
Markets	14. As yet unmet demand for food ingredients 15. Demand in established markets (e.g., Far East) for higher quality product. 16. Under exploited domestic market. 17. Growing consensus that the food market will be the key driver for the European industry
Technology & Science	18. Scope for increased automation. 19. Alternative culture methods – tank-based located on land, genetic cultivars 20. Seasonality allows for wide range of compounds to be extracted. 21. Mobilisation of expertise throughout Europe. 22. Emerging blue-biotech industry with cross-sectoral industry network association

Threats

Table 40 – SWOT Analysis – Threats

Environmental	1. Reputational risk from poor environmental management, e.g., wastewater discharges as reported by EPA. 2. Extreme weather events. 3. Novel disease threats – spores still collected from the wild. 4. Inadvertent introduction of invasive species. 5. Biological and physical challenges related to climate change.
Regulatory	6. Iodine and heavy metal contamination in species of food interest. 7. Potential regulatory hurdles for new products (e.g., extracts, supplements, protein) and new food safety standards in key markets. 8. Shortage of suitable sites due to competition for space within seaweed growers, other forms of aquaculture and other marine users. 9. “Licence prospecting”, resulting in stagnant licenced areas. 10. Competition for space within seaweed aquaculture growers, and with other forms of aquaculture and marine uses.
Commercial and logistic	11. Unpredictable annual production and quality 12. Price differential with bulk low value wild harvests. 13. Uncertain and evolving cost base, e.g., seed costs, drying (energy) costs. 14. “Pinch points” in the supply chain, e.g., juveniles, low availability of basic processing infrastructure such as drying facilities. 15. Short harvesting window
Message	16. Maintaining an emotional rather than a rational view of the potential of seaweed applications is a threat. (*) 17. Unrealistic expectations regarding the positive environmental impact and confusing messaging to public (“how can I eat seaweed – they use it to soak up heavy metals”).

Commentary on the SWOT Analysis.

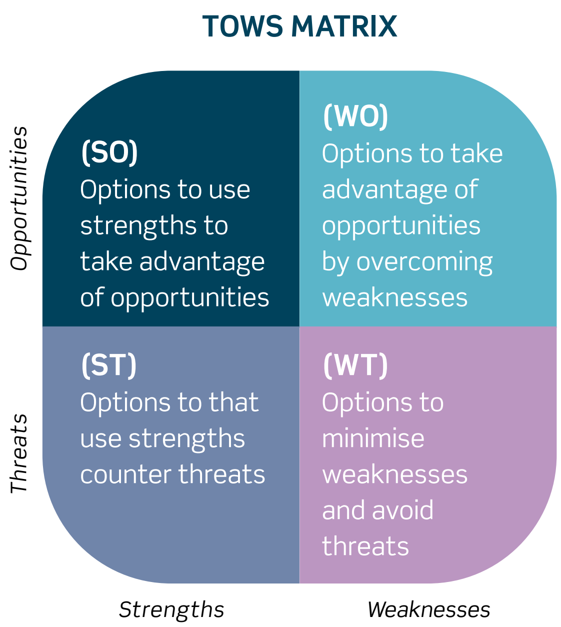
A challenge, and a danger, in carrying out a SWOT analysis is that it can become an exercise in generating passive lists. As illustrated in each of the SWOT categories above, the highest number of items relates to weaknesses in the sector. This is not unsurprising given the nascent nature of the industry. Similarly, this young sector has yet to fully establish itself, consequently there are as yet few industry strengths to be exploited.

By grouping each of the items under subheadings as above, it is clear that there are various “themes” at work in the industry. These are useful in carrying out the TOWS analysis detailed below.

6.7.5 TOWS analysis.

A TOWS Analysis (the name comes simply from SWOT backwards) is a useful mechanism to move beyond the passive list generation nature of a SWOT analysis [177]. The technique is based on considering, (in turn) the items listed under Strength against Opportunities, items under Weaknesses against Opportunities, and so on, to generate options for action. This is illustrated in Figure 12.

Figure 12 – Overview of the TOWS model



The actions generated are non-exhaustive and may at time be repetitive between (and within) each of the quadrants of the above model. The intention is to generate actions that can be used to identify thematic areas forming the basis of strategic pillars.

Following removal of similar and duplicate actions, 84 actions remain, these actions and the matrices used to generate them are presented in Appendix 3. Subsequently, a further analysis of the actions led to the identification of 12 thematic areas. The allocation of actions within themes is shown in Appendix 4.

Section 7
Emerging Strategy Themes

The TOWS analysis identified a non-exhaustive list of potential actions to further develop the seaweed aquaculture industry in Ireland. The TOWS analysis, and the SWOT analysis on which it is based, were informed by the findings from the extensive desk study, and feedback from the stakeholder engagement. Consequently, these actions reflect a strategic direction shaped by the various industry participants and the reviews of the competitive and environmental landscapes within which seaweed cultivation rests.

Ultimately, existing budgetary, legislative and organisational constraints will limit the extent that actions can be implemented. However, the analysis of the many actions led to the identification of 12 thematic areas that need attention in further developing the sector. Similarly, having established the themes, further actions may emerge following stakeholder consultations. These themes fit within strategy pillars, as shown in Figure 13.

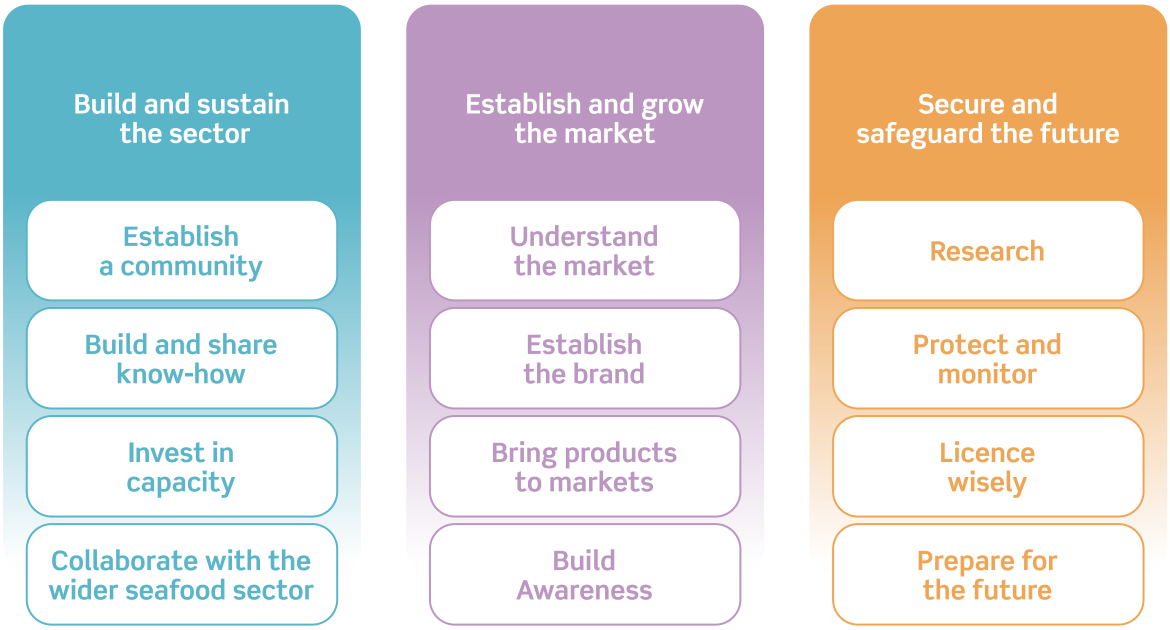


Figure 13 – Emerging thematic areas grouped within strategy pillars

7.1 Pillar 1 – Build and sustain the sector.

Several conclusions point to the need to build the Irish seaweed aquaculture in terms of production volumes, infrastructure and knowledge. The actions emerging under the strategy themes presented below reflect these needs, pointing to primarily short-term actions.

Thematic area 1 – Establish a community.

Ireland has a nascent seaweed aquaculture industry or sector, with low levels of production compared to other European countries. Despite this, individuals within the sector have built up considerable personal expertise and know-how on certain aspects of seaweed production. This includes expertise on species cultivation, growing at sea, harvesting and simple processing.

There is also early-stage knowledge of product development and marketing. These experiences are not spread evenly across the existing industry, and there are instances of multiple individuals going through the same learning experience. Despite market demand for products such as food and food ingredients, growers have difficulty connecting with consumers, and are wary of sharing market knowledge with others.

There is pressing need to quickly increase the volume of biomass production and increase the area under cultivation for the Irish seaweed aquaculture industry to grow in the short term. Doing so will enable growers increase turnover and enable the industry to consider higher value products. Such rapid expansion will require a collective shortening of the learning curve on several fronts, and an acceleration in developing new products and markets.

Establishing a sense of community and encouraging knowledge sharing among current and new participants in the sector is key to this. Supporting sector participants who wish to take on a leadership position is to be encouraged, following the "Chateau model" where a single actor supports other, smaller, growers to the benefit of all.

Possible actions falling under this theme include:

1. Establishing a trade organisation to facilitate information sharing, branding and to lobby for support to develop the industry. There may be existing organisations that can take on this role.
2. Sharing knowledge on cultivation methods of existing and new species.
3. Sharing the cost burden associated with certain aspects of the production cycle, such as producing and accessing supply for seeded string, access to drying facilities etc.
4. Supporting individual sector participants to take on leadership positions through mentoring and enhanced business support.
5. Entering joint supply arrangements to protect against and share the risk burden arising from adverse weather events and crop failures.
6. Collaborating on product development, in particular aspects of product development that require regulatory approval.
7. Establish a brand identity for cultivated Irish Seaweed that support individual growers to differentiate from other European suppliers.

From the above actions, it can be inferred that the coming together of groups of growers and processors to provide each other with support is a development to be encouraged. While such groups may well be regionally based, Ireland is small enough to sustain consortia arrangements nationally.

Thematic area 2 – Acquire and share know-how.

Strengthening the seaweed aquaculture community, will enable to the sharing of knowledge across the sector. Given the nascent nature of the sector, not just Ireland but internationally, there are multiple areas of uncertainty that growers and processors must overcome. Developing and making use of international best practice, availing of opportunities to trial new techniques and refine existing practice, and translating the outputs of research to practical implementation will be key to overcoming these uncertainties.

This knowledge sharing requirement extends to all aspects of the value chain, including cultivation, harvesting, product development and marketing. To achieve this, participants in the sector will need to be provided with mechanisms such as training and access to information resources to enable rapid growth.

Actions to enable this include:

1. Encourage the sector in the short term to focus on cultivating species currently available to increase biomass production and to perfect growing techniques.
2. Encouraging new entrants to the sector to initially focus on established markets and market channels, with a particular emphasis on markets where there is a focus on quality, such European and Far East consumer markets.
3. Develop a knowledge transfer programme that features:
   - **a.** Prioritisation of activities designed to improve production and product development outcomes.
   - **b.** Implementing best international practice (e.g., New England in the US, Norway etc.) in cultivation, harvesting and primary processing.
   - **c.** Best national practice.

4. A programme of gear development based on designs that meet challenges of the Irish environment and to increase volumes of biomass production.
5. Coach the licence holders that have not commenced seaweed production to do so as a matter of urgency, and all other growers to increase production. To do this, provide guides to industry on the capital and current costs associated with seaweed aquaculture.
6. Establish a basic research programme to develop a knowledge bank of:
   a. Key compounds in demand that can be potentially be provided by cultivated Irish species.
   b. Details of when such compounds may be extracted at different points in season and from where.
   c. Details of food safety limits and other regulatory constraints on ingredients and compounds in key target markets.
7. Promote engagement with agencies supporting export product development to source funds for testing and accreditation of seaweeds in accordance with national and international regulations.
8. Support access to testing facilities where growing and processing techniques can be trialled. This may include:
   a. Supporting funded access to existing industry pilot facilities such as e.g., Teagasc Moorepark Technology.
   b. Promotion of, and funding to access, state supported sites such as the Marine Institute Lehanagh Pool site and marine test sites developed for other marine sectors.
9. Establish good practice guidelines for cultivation. Those used in the Forestry and similar sectors may provide a useful model.

Thematic area 3 – Invest in capacity

Conclusions relating to infrastructure point to the need for investment in and support for the sector. This includes support using funding streams that may be available for the wider aquaculture sector, generally from sources such as the European Maritime, Fisheries and Aquaculture Fund, and targeted support to the seaweed aquaculture sector.

Examples of actions in this thematic area include:

1. Targeted funding for capital infrastructure and capacity development. This could include specialist hatchery facilities, drying and other processing equipment, deployment and harvesting gear and other facilities associated with culture, growing and harvesting.
2. Funding for knowledge transfer and the implementation of research outputs, such as the funding of proof-of-concept and demonstration type projects.
3. Training, including both direct training associated with the sector, and marketing and business development supports.
4. Funding and financing options that enable established growers to increase the scale of production and to encourage licence holders that are yet to exercise seaweed cultivation rights to do so.
5. Funding market research investigations and market development.

Thematic area 4- Collaborate with the wider seafood sector

A striking feature of Ireland's seaweed aquaculture sector is with a few exceptions, most of those involved have previous experience with the wider seafood industry. Given the early stage of development of the sector, there are multiple opportunities for the sector to leverage the experience and markets that the seafood sector has already established. This would benefit the seaweed aquaculture sector, and benefit the seafood sector, which as highlighted by the report of the Task Force on Irish Seafood, needs to diversify.

A further opportunity exists in the utilisation of seaweed aquaculture in conjunction with other primary production seafood activities. This can be by way of shared sites, co-location, or the use of seaweed to offset the negative impacts of other forms of aquaculture (real or perceived).

Actions that could lead to synergies with the wider seafood sector include:

1. Utilising existing seafood market channels to carry out market research and to introduce Irish seaweed products to established markets and customers.
2. Adding seaweed products to the portfolios of existing seafood exporters.
3. Utilising existing seafood processing equipment and facilities to process seaweed, e.g., freezing and chill storage etc.
4. Support innovation projects that repurpose existing marine and engineering capability to develop and produce gear suited for the Irish context.

Carry out pilot studies into the co-location of seaweed aquaculture with established sea food production.

7.2 Pillar 2 – Establish and grow the market

The seaweed aquaculture sector remains at an early stage of development. Recent developments, in the issue of licences by the Department of Agriculture, Food and the Marine and the positive environment created by recent European Union policy support the sector. Further, the heightened public awareness of threats to the environmental from cultivating carbon releasing terrestrial crops, is another opportunity to grow the industry.

Enabling growers to convert ambition into production is fundamental to achieving growth. This strategic pillar includes several strategy themes to enable this. These are aimed at establishing a market presence, initially in food and ingredients markets, that can be used to build future higher value processing activities and products opportunities.

Thematic area 5 – Understand the market.

A contradiction presented itself during our analysis of the sector. On the one hand growers reported being able to sell any biomass they produced. On the other, growers were often unclear as to the ultimate market destination of their crop, or if they were achieving the maximum value for their harvest. Often, competition with wild harvest sources appeared to set unrealistic market expectations in relation to price. This inability to maximise return on their crops is a constraint on growth, and such challenges must be overcome.

Product differentiation of Irish cultivated seaweed from wild harvest stock and other European suppliers is essential. Growers must have clear market opportunities, destinations and customers in mind at the time of deploying ropes. While there is a clear understanding that species such as *Palmaria Palmata* or *Porphyra/Pyropia* are likely to be in demand in the food and cosmetic and food markets, growers remain constrained in their ability to cultivate these species. Developing new products, supply chains and markets based on these species needs reliable biomass volumes.

Market related actions to overcome these challenges include;

1. A detailed market analysis, available to all in the sector, to include:
    a. Identifying different markets to those supplied by wild harvest resources, that value the attributes of cultivated species; e.g., traceability, environmental sustainability and stability of composition.
    b. An assessment of those European markets currently supplied from outside the EU, particularly from the Far East, to identify targets for substitution by cultivated species A particular focus should be on markets that have, or are likely to put in place, higher standards.
    c. An assessment of markets that are likely to see increased regulatory oversight in the near to medium term to ensure that future product development takes account of these requirements.
2. A market analysis of non-EU markets, where Irish product can achieve differentiation based on quality and standards-based attributes.
3. Identifying markets where cultivated seaweed can economically act as a substitute for wild harvest in the medium to long term.

Thematic area 6 – Establish the brand

In addition to the market assessment actions outlined above, a key issue for Irish growers is the differentiation cultivated biomass from other algae biomass sources. This includes both the wild seaweed harvest, and other European producers that can make similar claims in relation to quality and price of cultivated stock.

Differentiation based on price is likely to be difficult or impossible for the near future, since it requires significant increase in biomass output. The most reliable path to differentiation in the short to medium term is to take advantage of Ireland's global reputation as a producer of clean, wholesome foods and ingredients.

Actions to support the establishment of an "Irish Seaweed" brand may include:

1. Developing an Irish "brand". This may follow a product brand route (such as the "Kerrygold" brand for Irish butter), or the definition of a defined set of attributes that make products recognisably Irish and appealing for identifiable reasons. These reasons may include attributes such as quality, safety, and freshness (such as the Irish Beef campaigns operated by Bord Bia) or environmentally sustainable production as in the Origin Green initiative.
2. Identify and promote Irish cultural aspects of seaweed that may not be associated directly with Ireland and highlight them (e.g., the common name for *Palmaria palmata*, Dulse and Dillisk originate from Irish words).
3. Co-brand cultivated seaweed with recognised Irish brands such as the Wild Atlantic Way.
4. Create public information campaigns on the uses and benefits of seaweed-based products, ingredients, and derivatives in domestic and overseas markets.

There is a connection between some of the actions in this Strategic Theme with those in the **Build awareness and Protect and monitor themes.**

Thematic area 7 – Bring Products to markets

Central to the development of Ireland's seaweed aquaculture sector is to enable growers to increase turnover to sustain their ambitions to move to high value products. The most obvious opportunity, based on findings described in this report, is the production of artisan products and simple food ingredients.

While opportunities exist in these markets, they require access to extended supply chains and support for new product development. The actions identified in the **Collaborate with the wide seafood sector** and the **Acquire and share know how** strategy themes can support this, however additional support to develop new supply chains, markets and products will be required.

Furthermore, several actions will be required to overcome existing barriers to product acceptance. These include enabling the sector to provide accurate information on the composition of compounds, ingredients and extracts. Several actions in the **Research** strategy area will support this.

Specific actions to support the sector to bring products to market include:

1. Enable the rapid quantification of naturally occurring and anthropogenic contaminants to provide market reassurance.
2. Identify project opportunities arising from the market evaluations detailed under the **Understand the market** strategy area.
3. Produce products based on existing available species to establish market channels. Focus on products that can displace existing products based on perceived and actual quality attributes to strengthen differentiation.

Thematic area 8 – Build awareness

The public attitude to seaweed cultivation is one of benign acceptance. This corresponds to the low awareness relating to the use of seaweed as food and as a source of ingredients and other extracts. The recent commentary regarding the climate and biodiversity crisis has according to some stakeholders, confused consumers about the purpose and safety of seaweed products.

Although the Irish market for seaweed products is relatively small compared to the European market, it still provides an opportunity for Irish producers to sell product. Raising awareness on the uses of seaweed, and creating a distinction between seaweed grown for consumer purposes as distinct from public good purposes, can help to stimulate a response from local markets.

Public good projects to grow seaweed for purposes such as bio remediation and carbon capture are not mutually exclusive from growing commercial crops – but they are distinct activities that require further development and research. Nevertheless, seaweed growers can bring their experience to bear on these activities, and carry them out in parallel and benefit from the positive image they generate.

The positive image of seaweed can be further enhanced by drawing attention to those elements that make for a positive brand. These include a clean healthy and environment, high quality standards, sustainability, and positive nutritional qualities based on reliable evidence.

Examples of activities in awareness building include:

1. Campaigns to highlight the use of seaweed as a food.
2. Reinforcing public acceptance of seaweed aquaculture through the adoption and adaptation of international sustainability standards and certifications.
3. Highlighting public activities, such as Water Framework Directive monitoring, a rigorous licencing process to counter concerns about water quality.
4. Drawing attention to the economic benefits of seaweed aquaculture, while also emphasising the low input nature of the activity.
5. Generating accurate, robust and easy to understand data to support growers' engagement with local communities, particularly during the licence application process.
6. Public information campaigns on the role of eco-services aquaculture and the expertise seaweed growers bring to those activities.
7. Promotion of regular water quality testing by growers and publication of results.

7.3 Pillar 3 – Secure and safeguard the future

There is undeniable growth potential in the global seaweed aquaculture sector. However, the experience of the Irish sector demonstrates that demand on its own is not enough to enable sectoral growth, it must be matched by production capability and capacity, market definition and ongoing investment in research and development. Experiences in other sectors demonstrate that continued growth is dependent on continuing good will from the public, protection of the environment, and compatibility with national priorities.

The four closely related themes in this strategic pillar combine to ensure that the current growth trajectory of the sector.

Thematic area 9 – Research and innovation

Increased knowledge of seaweeds and seaweed aquaculture generated by research has improved the sectors understanding of the seaweed resource and how to cultivate it. Indeed, the achievements of Irish researchers have contributed greatly to expanding the international seaweed knowledge base. Irish research output is widely respected internationally, and in some jurisdictions, is behind the growth and development of the seaweed sectors, both cultivated and wild harvest.

Despite this progress, multiple knowledge gaps exist that inhibit the sectors development, closing them demands greater research effort and funding. New knowledge is needed to support innovations in cultivation, harvesting and processing native species to meet increasingly demanding market requirements and to help to differentiate cultivated biomass from wild harvested stock. There is also a need to draw from research findings to support investigations at higher Technology Readiness levels and in providing advice to growers to enhance their competitiveness. Discussions with stakeholders and from the reviews of the outputs from recently concluded EU funded projects (both with and without Irish participation), identified several research needs. These are presented in summary form in Appendix 5 as a draft *Research Agenda for the Irish Seaweed Aquaculture Sector.*

In addition to the research actions identified in that statement, the following actions should commence to ensure research driven growth in the sector.

1. Establish a combined industry/science partnership comprising internationally recognised seaweed expertise to review, expand on and finalise the research agenda.
2. Recognised the need for proven and relevant multi-disciplinary scientific collaborations in performing seaweed related research.
3. Secure multi-agency funding to support industry-led research partnerships awarded following open competition and international peer review of resulting research proposals.
4. Ensure that research projects include an effective communication and technology transfer component.
5. Ensure that research addresses regulatory compliance requirements, characterisation of ingredients and extracts, and market suitability.
6. Ensure participation by Irish experts in European Union initiatives developing and setting regulatory standards.
7. Promote further participation by Irish researchers and cultivation firms in EU research and innovation projects.
8. Ensure the availability of results from closed EU and nationally funded seaweed related research projects are accessible in formats relevant to the cultivation sector.
9. Promote partnerships between seaweed firms with existing food research experts in Ireland.
10. Ensure that research knowledge from lower TRL activities (e.g., lab-based activities) is applied to higher level activities involving product and process development and innovation.

Thematic area 10 – Protect and monitor

Some of the strategic themes of the Establish and grow the market pillar were focused on marketing, awareness and branding activities. Several of the actions identified within the themes of that pillar advocated communicating unique aspects of Irish cultivated seaweed including the quality of the water in which it is grown, the purity of the product and other attributes such as e.g., consistency.

To substantiate and sustain these claims there is a need for solid data. Both the state and individual growers have a role to play in monitoring and providing these data.

Similarly, building brand and public awareness around the attributes above means maintaining (and improving where possible) the environment; protecting it from degradation due to pollution: the introduction of invasive species; and from cultivation activities having any negative impact on marine species and habitats. Some of the actions needed to achieve this relate to licencing which are discussed in theme 11 – Licence wisely, while others are included below.

Actions to support protecting and monitoring the growing environment include:

1. Utilise existing, and where necessary establish new, monitoring to provide food safety and contaminant data that is easily accessible.
2. Ensure strict adherence to EU legislation and encourage Irish participation in future regulatory standard development and setting.
3. Discourage the introduction of non-native species in the absence of clear data on their ability or otherwise to naturally propagate in the wild.
4. Support growers to carry out monitoring of water quality.
5. Support participation in quality and sustainability certification schemes.
6. Encourage participation by growers in programmes to monitor the marine environment such as bird counts, cetacean observations etc.

Thematic area 11- Licence wisely

Despite being the subject of much comment in the wider aquaculture industry in recent years, the licencing process for seaweed aquaculture is recognised as appropriate and effective, albeit with some industry participants seeking shorter processing times.

Licensing seaweed aquaculture in Ireland is the responsibility of the Aquaculture and Foreshore management Division of the Department of Agriculture, Food and the Marine. The foreshore is a public resource, and licensing of activities must ensure achieving the best possible public-good is achieved. As such, licensing is an activity that must take a long view of an activity.

In the case of seaweed aquaculture, the process has a significant role to play in the acceleration of the amount of biomass being cultivated and ensuring that licened sites are sustainable in both environmental and business terms. Ultimately, a robust licensing process ensures the long-term viability of the sector and protects the sector from criticism of failures arising from environmental, safety and management failures.

The suggested actions below relate in the main to implementation rather than any specific aspects of the current process. A number of actions are of an informal nature, and could be dealt with through guidance or where potential growers interact with the Department before submitting a licence application.

Actions in this area may include:

1. Place an increased emphasis on ensuring that applicants for new licences have robust business plans.
2. Develop mechanisms to allow active growers seeking more licensed area, to engage with inactive licence holders.
3. Investigate mechanisms to allow existing licence holders (e.g., those in mussel aquaculture) to fast track the inclusion of seaweed species on a licence, recognising the need for appropriate environmental safeguards in line with EU and national legislation.
4. Ensure there is strict adherence to the principal of "use it or lose it" to discourage prospecting and ensure area is available for active growers.
5. Strictly enforce the requirement to include scientific names for species in licence applications.

6. Ensure that a justification is provided for the inclusion of a species, the prospects for successfull growth and the market it is intended to serve.
7. Include licence conditions designed to mitigate the risks (if any are determined to exist) of novel or exotic species cultivation. Existing regulations in relation to alien species offer significant protections to the natural environment.
8. Promote applications in sheltered areas, and exercise caution in relation offshore installations until gear technology is proven.

Some of the actions in the **Prepare for the future** strategy area are also relevant to the long-term direction of licencing.

Thematic area 12 – Prepare for the future

The general thrust of this report in the short term is towards encouraging the Irish seaweed aquaculture sector to move quickly to increasing the volume of biomass using existing species available for cultivation to establish markets, sales channels and turnover. In doing so the sector can establish a solid platform for itself to take advantage of the many opportunities that exist for the cultivation of seaweed and products derived from its production.

Even while focusing on this short-term objective for the sector, the time to prepare for some of these wider opportunities is now. Many of the actions identified in the **Research** strategy area are aimed at the longer view. There are institutional and structural actions that should also be undertaken.

For example, it would be unwise to assume that food products sold in the European Union will continue to be subject to the Novel Foods Directive alone – at a minimum individual member states are likely to introduce their own standards, some already have done so.

Similarly, while offshore seaweed cultivation, and co-location with other offshore activities are technically challenging now, those challenges will be overcome. It is necessary therefore to give thought as to how such installations would be licenced.

In preparing for the future, the following actions may be required:

1. Encourage early engagement by those in the sector with research and development being carried out for the development of other forms of aquaculture gear, e.g. mooring systems, environmental monitoring etc.
2. Investigate access to test site facilities for other marine activities (such as ocean-energy) to solve problems associated with the offshore wave regime.
3. Encourage Irish researchers to participate in EU projects focused on equipment development and consenting, and to gain access to test facilities in other member states.
4. Interagency engagement on future scenarios for the colocation of seaweed aquaculture with e.g., floating wind energy projects, including projects to demonstrate feasibility.
5. Engagement by those Departments with marine consenting responsibility on the options for co-located activity licensing, e.g., dual consents etc.
6. Ensure participation by relevant Irish agencies and researchers in EU standard setting activities.
7. Encourage participation in blue-biotech industry networks by Irish seaweed aquaculture sector (by individual participants in the sector, trade organisations or state agencies).

7.2 Timing and implementation

7.2.1 Timeframes

In section 6.5 *(A scaled development)* the concept of three levels of maturity for the seaweed aquaculture industry was introduced. These were: Basic Supply (producing products such as whole, flaked or ground seaweeds); Minimal Processing (producing products such as powders with targeted particle size), and Refined Products (Extracts with targeted composition and/or activity in dried or liquid form).

Table 32 indicated that 500 wet tonnes/year and 1,000 wet tonnes per year were approximate thresholds at which the sector might be in a position to transition between the first/second and second/third levels respectively. The growth curve in Figure 14 shows, based on a growth rate of 30% per annum from a baseline production of ca. 45 wet tonnes/year, these milestones may not occur until 2029 and 2033.

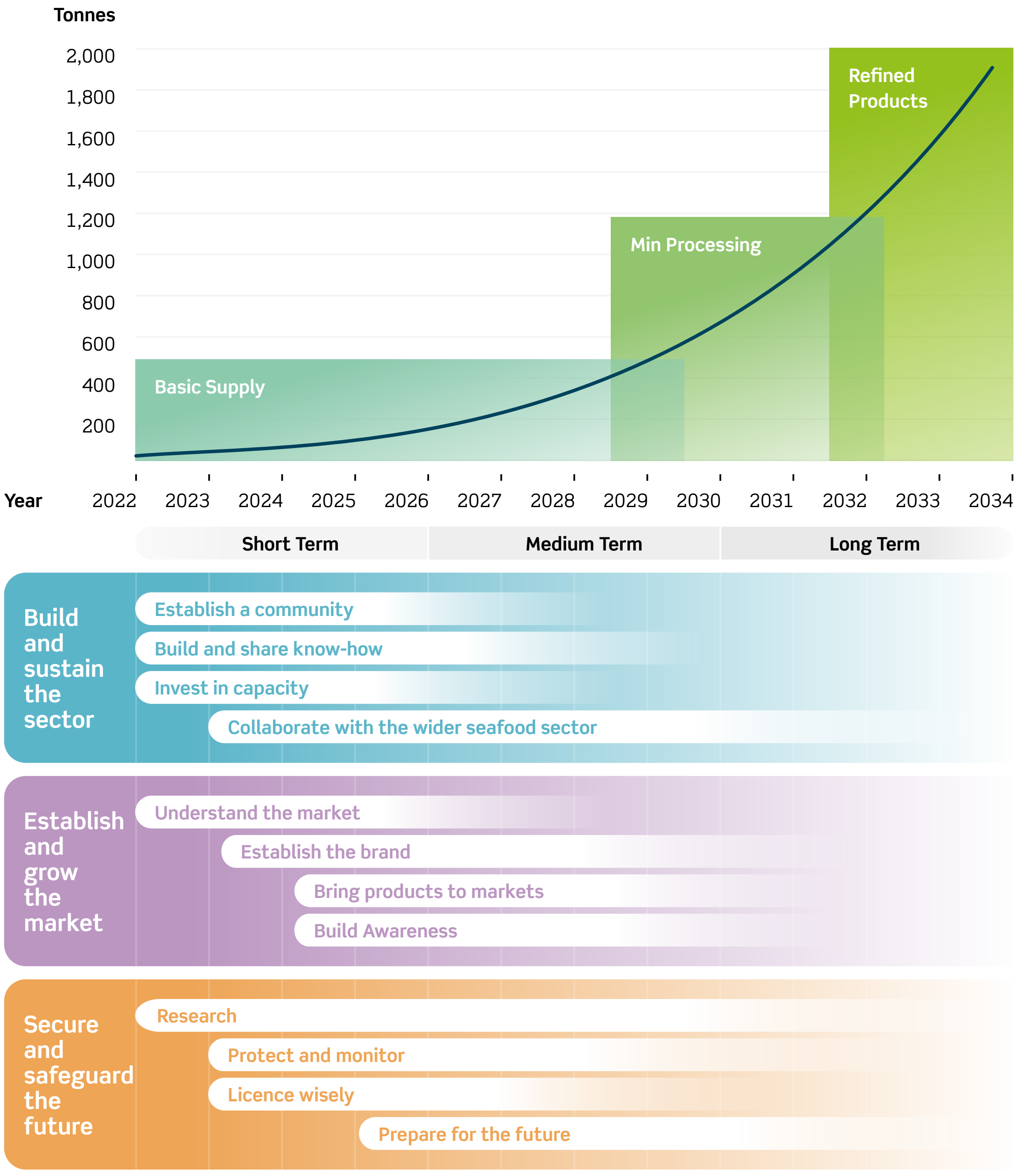


Figure 14 – Actions compared to desired growth

The actions proposed under each of the strategic areas described previously section are considered as short-term (1-4 years), medium-term (4-8) years and long-term (8-12 years). Figure 14 also illustrates how each time frame maps to the maturity levels; and shows that each of the proposed actions need commence in the short-term, i.e within the next four years, some need to start immediately. A number of the actions need to sustain over time, i.e. over next ten years, if not longer.

7.2.2 Responsibility

Acknowledging the role of state bodies and other entities, a successful implementation of a strategy demands the participation of the seaweed industry. Unless industry takes responsibility for its own future, any action of state bodies will have no effect.

A wide range of state bodies have a role to play:

- BIM is recognised and valued by those in the sector as a trusted party with a significant role to play in coordinating and driving the involvement of other state bodies.
- BIM and the Marine Institute each have a role with respect to marine related research and development. The Marine Institute has responsibilities and expertise in food safety, the marine environment and marine spatial planning. BIM has experience and expertise in gear development, providing industry advice, training and technology transfer.
- The Department of Agriculture, Food and the Marine have the primary responsibility with respect to licensing. In the longer term, that Department will need to engage with other marine consenting bodies do develop pragmatic processes for the licensing of multi-purpose marine sites.
- Fundamental to the economic development of the sector is an understanding of markets and building supply chains to service these markets. Bord Bia as the lead food marketing agency, has key role in both areas.
- There is significant ambition within the sector today to develop new products for overseas markets. These are not just confined to food products, but include amongst others cosmetic ingredients and nutraceuticals. Enterprise Ireland has significant role to play in supporting companies to develop these products, particularly supporting industry-based research and development.
- Finally, Ireland's broad research sector, comprising Higher Education Institutes, national research centres and network of applied industry centres each have a role to in research, development, education and training, and in providing expertise in the development of regulatory and other standards.

Appendices

Appendix 1 – List of Consultees

The following were interviewed as part of the preparation of this report. The authors also wish to thank Glen Nolan of the Marine Institute and Val Cummins of Simply Blue Group for their clarifications and insights. Thanks are also due to Helena Horan in DAFM who provided data on licensing. The views and conclusions expressed in this report are those of the authors, and do not necessarily reflect the views of those consulted.

Name	Organisation
Patrick Barrett	DAFM – Research, Food & Codex Division
Majbritt Bolton-Warberg	Marine Institute – Policy, Innovation & Research Support
Craig Benton	Benton eco-solutions
Kate Burns	Islander Kelp Ltd.
Damien Clarke	DAFM – Marine Agencies and Programmes Division
Iarfhlaith Connellan	Cartron Point Shellfish Ltd
Liam Curran	Enterprise Ireland
Maeve Edwards	Irish Seaweed Consultancy Ltd.
Mark de Faoite	Údarás na Gaeltachta
Richard FitzGerald	University of Limerick
Jerry Gallagher	Northwest Shellfish Ltd.
Lorraine Gallagher	Sea The Potential
Colum Gibson	Clean Technology centre, Munster Technological University
Aoife Glennon	Bord Bia
Maria Hayes	Teagasc
Anthony Irwin	Dúlra Iorras Teo.
Annette Kenny	Bord Bia
Jim Keogh	Arramara Teo.
Stefan Kraan	The Seaweed Company
Julie Maguire	Bantry Bay Research Station
Evin McGovern	Marine institute – Marine Environment & Food Safety Services
Helena McMahon	Nutramara Ltd.
JP McMahon	Restauranteur and Chef, Aniar Galway
Sinead McSherry	DAFM – Aquaculture and Foreshore Management Division
Michael Mulloy	Blackshell Farm Ltd.
Mike Murphy	Dingle Bay Seaweed Ltd.
David Murrin	Oilean Glas Teo.
Máire Ní Éinniú	Údarás na Gaeltachta
Francis O'Beirn	Marine Institute – Marine Environment & Food Safety Services
John O'Doherty	University College, Dublin
Freddie O'Mahoney	Cartron Point Shellfish Ltd
Michael O'Neill	Allihies Seafood Ltd.
Rosario Piseri	Algaran
Joanne Reilly	Kinvara Skincare Ltd.
Ann Ruddy	Redrose Developments Ltd.
J.T. O'Sullivan	BioAtlantis Ltd.
Joe Silke	Marine Institute – Marine Environment & Food Safety Services
Dagmar Stengel	National University of Ireland, Galway

Appendix 2 – Seaweed Food Market

Market analysts forecast a compound annual growth of 9.1 % in the global seaweed market between 2021 to 2028. During this period the value of the seaweed market is predicted to reach US$23.2 billion (~€20.4 billion). Major factors driving this growth consumer demand for plant-based products, an increase in the consumption of seaweed-based products, consumer recognition of seaweed as a source of nutrients and minerals, and government initiatives designed to encourage seaweed cultivation [178].

In 2013, BIM commissioned a report from Organic Monitor on the EU market prospects for sea vegetables [179]. This report valued the European market for sea vegetables in 2013 at €24 million and estimated volume output at 3,000 tonnes (472 tonnes dried). Projected market growth in the EU market ranged from 7% to 10% per annum. Since the publication of that report, there appears to have been no publicly accessible market forecasts for sea vegetables.

A review of Ireland's organic food sector and associated strategy for 2019 to 2025 valued the global market for organic foods at €106 billion rising to €224 billion by 2022. The projected value of the EU organic food market share by 2022 was €86 billion; (CAGR) of 14%.

In contrast to the projected increases in market share of meat, poultry and dairy and prepared foods segments, the share of organic vegetable was to remain quite stable at around 27% of the total EU market [180]. This share indicated a value for organic vegetables of €23.2 billion by 2022. Other market forecasts for the European organic food and beverages sector projected a CAGR of 8.34 % over the period 2020 to 2025 [178].

The report of the Seaweed for Europe Initiative includes projected EU market values for different seaweed segments, including food for 2030 [45]. These projections, based on interviews with industry experts, rather than any modelling exercise, reflect conservative, moderate and high growth scenarios for all segments.

The seaweed food segment projections range from €688 million – for the conservative scenario to €2,094 million for the high growth scenario. To reach €688 million by 2030 from the Organic Monitor baseline of €24 million in 2013, needs a CAGR of 21.8%. This rate is 3 times the conservative growth of 7% indicated by Organic Monitor; and 2.3 times greater than growth for the global seaweed market.

Previously, this report (by Steelesrock) mentioned concerns expressed elsewhere about data gaps and the absence of reliable data for seaweed. Further confirmation of this issue is the recognition of a global shortage of market insight to sea vegetables [181]. Without any specific insight to the European sea vegetables market, the only obvious mechanism is to consider using a proxy.

With "organic" often used in the promotion of seaweed products, the growth in the organic food sector may reflect a growth in sea vegetables. Recent data (above), combined with previous projections of the market share of organic vegetables in the total EU market, provide such a proxy. Table 43 gives a broad estimation of the value of sea vegetables in Europe in 2026 based on the use of a proxy compound annual growth rate of 8%.

Table 41 Estimated value and volume of sea vegetables in Europe [182]

European sea vegetables	2013 market volume	2013 market value	2026 market value
Proxy market growth of 8% CAGR from 2013 to 2026	3,000 tonnes	€24 million	€65 million

Market drivers, constraints and supply chains

Multiple factors drive sea vegetable market activity. The restaurant, retail and food processors influence growth, as does an increase in consumer awareness about possible health and nutritional benefits of consuming seaweeds. However, a low level of consumer awareness about sea vegetables exist; and attributed to an absence of knowledge amongst consumers about how to incorporate sea vegetables in their lives [183].

High-end restaurants in Europe, particularly in Spain, Ireland, UK and the Nordic region; predominantly Denmark, and Norway, were identified as advanced and innovative in the use of sea vegetables, albeit mostly from wild harvest. The same source associated an increased interest in sea vegetables as being stimulated by specialist food suppliers, and larger retailers stocking these products. A leading specialist Irish food retailer described a high general demand for organic food exists largely due to the increasing numbers of consumers adopting a healthy lifestyle and concerns around environmental sustainability [184, 181].

Restaurants use sea vegetables in different formats and many purposes including freshly harvested as a salad, decoration or texture; purees of seaweed to provide flavour, colour; dried to provide flavour or as a component in an infusion such as dashi; and in a dried milled or ground format used in bakery products – bread, confectionery [181]. Competition from Asian products offered at lower prices than Irish sourced products continues to be a significant threat, to local product offerings.

Distinct channels to markets exist for sea vegetables including retail – in store and internet based; specialist food shops and the so called “organic and health food shops”. High-end restaurants form a niche purchasing group, who generally source their supply from individual local harvesters. A wide variety of red, brown and green seaweeds are used by restaurants.

European seaweed growers provide seaweed in the format of seaweed products mentioned above. The Dutch Seaweed Group and some Norwegian growers provide Alaria esculenta and Saccharina latissima as fresh, freshly frozen, dried, flakes, salted, freshly frozen, cubes; dried, powder; dried, leaf; and as freshly frozen, flakes.

Appendix 3 – Identification of Actions as part of TOWS Analysis

Strengths/Opportunities

Opportunities	Strengths: *Structural*	*Brand & Image*	*Sustainability*	*Product & Market*
Structural	S1/O1- Support a trade organisation. S1/O2 –Coach existing licence holders on moving to production S2/O2/O3 – Provide mechanism to support new licence applicants who have good business plans. S3/O3 – Support product innovation products target towards defined markets. S3/O4 – Support innovation projects aimed at repurposing existing marine and engineering capability	S7/O1 – Establish a common national brand for export food products. S8/S9/O2 – Generate material that can be used by applicants for licences to support engagement with communities highlighting positive of seaweed aquaculture.	S12/O4 – Support projects to innovate in bioremediation and carbon capture.	
Levers	S1/O5 – BIM to engage with e.g., SEAI on future scenarios for colocation of seaweed aquaculture with wind energy projects. S2/O5 – DAFM, DHLGH. DECC to explore co-location licencing. S1/O6 – Assess the existing seafood processing industry with a view to brokering access. S6/O10 – Define a research agenda for seaweed aquaculture in Ireland and establish enablers required to ensure Irish participation in EU projects.	S9/O8 Investigate seaweed branding that positions seaweed as a "value add" to other aquaculture export products, focusing on "seaweed heritage". S10/O10 – Promote research collaborations between Irish seaweed researchers and food research (e.g., Teagasc). S10/O5 – Promote Irish researchers in European IMTA and co-location projects.	S11/O7/O8 – Support investigation of cultivated seaweed as a substitute for wild harvest species in products and markets. S12/S15/O5 – Support role of seaweed as a means of bioremediation for other activities. This also includes using positive image of seaweed aquaculture as an "offset". S14/O9 – support re-utilisation of expertise of coastal communities exiting other marine activities (see also S3/O4).	S16/O10 – Promote research into attributes of common Irish seaweeds to determine specific available compounds, proteins etc. S17/O8 – Promote seaweed products (e.g., food) through existing seafood markets.

	Strengths			
Opportunities	*Structural*	*Brand & Image*	*Sustainability*	*Product & Market*
Standards	S1/O13 – Build knowledge bank based on international best practice to be available to Irish growers and processors. S3/O11/O12 – Establish easy to access method for Irish growers to characterise the food safety profile of their product to support access to safety conscious markets. S6/O11 – Encourage Irish researchers to participate in EU studies relating to seaweed food safety.	S7/S9/O11/O12 – Establish food brand based on Ireland's "clean and sustainable food" and "seaweed heritage" image. S8/O13 – Reinforce public acceptance of seaweed aquaculture through adoption and adaptation of international sustainability standards and certifications. S10/O11 – Encourage Irish researchers to participate in EU studies relating to seaweed food safety.		S16/S18/O11- Encourage Irish participation in food safety standard setting at EU level.
Markets	S1/O14/O18 – Establish list of key ingredients currently in demand that can be potentially met from Irish species.	S7/S9/O14/O15/O16/O17– Establish food brand based on Ireland's "clean and sustainable food" and "seaweed heritage" image. S7/S8/S9/O16 – Establish public information campaign on use and benefits of seaweed as a food product.	S11/S17/O15 – Encourage cooperation amongst growers to supply foreign markets(in order to make continuity of supply more robust). S13/O14/O15/O16/O17– Establish food brand based on Ireland's "clean and sustainable food. S14/O16 – Promote a consumer/tourism "see it before you eat it" brand.	S16/O14/O17 – establish easy to access method for Irish growers to characterise the food safety profile of their product to support access to safety conscious markets. S17/O14/O18 – Establish list of key ingredients currently in demand that can be potentially met from Irish species.

	Strengths			
Opportunities	*Structural*	*Brand & Image*	*Sustainability*	*Product & Market*
Technology & Science	S1/O18 – establish programme focusing on gear development to support automation (e.g., seeded string winding, barge hoists, etc.). S3/O19 – Support research into practical cultivation issues, e.g., tank culture, cultivars, life cycle of additional species. S3/O20 – Establish list of key ingredients & compounds that may be extracted at different points in season. S4/O19 – Take advantage of existing and new research infrastructures to investigation cultivation methods such as tank culture.			S16/S17/O20 – Establish list of key ingredients & compounds that may be extracted at different points in season.

Weaknesses/Opportunities

	Weaknesses			
Opportunities	*Structural*	*Infrastructure & Support*	*Products and Markets*	*Knowledge and Awareness*
Structural	W1/W4/W5/O1 Support collaboration across the industry through trade organisation. W1/W2/W5/O1 – Support collaborative working arrangements between industry participants (e.g., sharing facilities, joint marketing etc). W1/W11/O2 Facilitate existing growers seeking more licenced area to engage with inactive licence holders. W1/O3 – Focus funding on established growers seeking to scale. W3/O1/O3 – Encourage shared hatchery facilities through funding focused on industry capacity growth. W6/O1 – Establish a commercially focused "seaweed industry development officer" post. W10/O1 – Establish industry/science partnership to define/refine research roadmap.	W12/O1/O4 – Promote and fund use of existing industry sites to pilot new techniques that are made available to whole industry. W13/O1 – Support collaborative working arrangements between industry participants (e.g., sharing facilities, joint marketing etc). W13/O3 – Target funding on infrastructure and capacity development.	W19/O1 – Commission market studies to be made available to all industry participants. W21/O1 – Support collaboration across the industry through trade organisation. Use as basis for market development. W20/W22/O1/O25 – Share knowledge on cultivation methods of new species.	W28/W29/O1 – Establish industry/ science partnership to define/refine research roadmap. W28/W29/O1 -. Develop programme of knowledge transfer to from scientific knowledge base to industry. W30/O2 –Coach existing licence holders on moving to production
Levers	W5/O8 – Support collaborative working arrangements between industry participants to broker product offerings that can utilise existing seafood producer market channels.	W5/O8 – W12/O5 – Promote and fund use of Marine Institute test site. W10/W16/O9/O10 -Establish industry/science partnership to define/refine research roadmap. W9/O9 – Support re-utilisation of expertise of coastal communities exiting other marine activities (see also S3/O4).	W19/O7/O8 – Utilise existing market channels for seaweed and other seafoods to carry out market research into Irish seaweed markets. W26/O8 – Utilise existing seafood channels to introduce Irish Seaweed aquaculture products to existing markets.	W32/W33/O10 – Establish industry/science partnership to define/refine research roadmap.

	Weaknesses			
Opportunities	*Structural*	*Infrastructure & Support*	*Products and Markets*	*Knowledge and Awareness*
Standards			W19/W21/O11 – Carry out study to understand current Far east imports to Europe and identify opportunities for displacement based on quality and standards. W19/W21/O12 – Carry out study of far east market based with focus on displacement of local product based on European quality standards and image. W21/W22/O12 – Establish food brand based on Ireland's "clean and sustainable food" and "seaweed heritage" image.	W30/O13 – Build knowledge bank based on international best practice to be available to Irish growers and processors.
Markets	W7/W8/O14/O15/O17 – Focus on growing capacity using existing available species to establish market channels to e.g., Far East and Europe markets focused on quality.		W19/W21/O15/O17 – Carry out study to understand current Far east imports to Europe and identify opportunities for displacement based on quality and standards. W20/W22/O14/O15/O17 – Focus on growing capacity using existing available species to establish market channels to e.g., Far East and Europe markets focused on quality. W26/O16 – Establish public information campaign on use and benefits of seaweed as a food product.	

	Weaknesses			
Opportunities	*Structural*	*Infrastructure & Support*	*Products and Markets*	*Knowledge and Awareness*
Technology & Science	W7/W8/O19 – Develop methods of tank culture for early stage growing or alternative species to mitigate against low numbers of cultivatable species currently available and to provide more harvest opportunities. W8/O20 – – Establish/research list of key ingredients & compounds that may be extracted at different points in season to maximise value from currently cultivatable species.	W16/O20 – Establish/ research list of key ingredients & compounds that may be extracted at different points in season to maximise value from currently cultivatable species. W12/O21 – Investigate access to pilot facilities in other EU member states. W17/O22 – Encourage participation in blue-biotech industry networks by Irish seaweed aquaculture sector (by individual participants in the sector, trade organisations or state agencies).		W32/O18/O19 – Ensure inclusion of applied topics such as hatchery refinement and automation in research agendas.

Strengths/Threats

	Strengths			
Threats	*Structural*	*Brand and Image*	*Sustainability*	*Product and Market*
Environmental	T1/S2 – Highlight rigorousness of licencing process to counter concerns about water quality. T3/T4/S2 – Ensure licence process places strict requirements on types of species to be cultivated and ensure licence conditions put constraints on seed sources. T2/T5/S3 – Utilise and promote existing state capacity in ocean modelling to understand climate and weather effects on seaweed aquaculture.	T1/S7 – Leverage branding elements of "safe, clean, Irish" food to counter possible concerns about water quality.	T1/S11 –Emphasise the fixed nature of seaweed aquaculture and promote the regular monitoring of water quality by growers to establish the long-term quality of product. T1/S13/S15 – Include detail of Ireland's clean coastal waters (as per WFD reporting) and low input nature of the activity marketing detail. T2/S14 – Encourage licencing in sheltered areas. Exercise caution in offshore installations until technology is proven.	T1/T4/S18 – Strictly adhere to EU legislation and encourage Irish participation in future standard setting.
Regulatory	T7/T8//S3/S6 – Quantify levels of iodine and other natural and anthropogenic contaminants to provide market reassurance, and to evidence Irish input to regulation formulation at EU level. T9/T10/S2 – Promote "use it or lose it" clauses in licencing and their enforcement. T9/T10/S2 – Investigate feasibility of a mechanism to allow existing licence holders (e.g., for mussel aquaculture) to fast-track inclusion of seaweed species.	T7/S7 – Leverage branding elements of "safe, clean, Irish" food to counter possible concerns about contaminants. Back up these branding elements with water and product monitoring. T8/S8/S9 – leverage positive public attitudes to seaweed aquaculture to promote co-location with other forms of aquaculture.	T1/S11 –Promote regular testing of seaweed aquaculture output for contaminants in order establish consumer confidence. T1/S11 –Encourage Irish participation in setting of regulatory standards at EU level. T8/S8/S12 – leverage positive public attitudes to seaweed aquaculture to promote co-location with other forms of aquaculture.	T1/S18 –Encourage Irish participation in setting of regulatory standards at EU level.
Commercial and Logistics	T14/S1 – Establish data on the capital and current costs associated with seaweed aquaculture and make these available industry-wide. T12/S4 – Scale production using collaboration between growers to provide more certainty of supply.	T13/S11 – Support investigation of cultivated seaweed as a substitute for wild harvest species in products and markets. Focus on positive continuity of supply aspects associated with aquaculture.		T13/S16 – focus on different markets to wild harvest based on attributes of cultivated species.

	Strengths			
Threats	*Structural*	*Brand and Image*	*Sustainability*	*Product and Market*
Message	T17/S1 – Focus entrants to the sector on quantifiable or established markets (e.g., food ingredients) as a means of establishing turnover before moving to other less defined markets. T18/S1/S2 – Establish eco-services aquaculture as a separate model for seaweed production. T18/S3/S4 – Through research establish benefits of eco-services seaweed aquaculture to other aspects of aquaculture (e.g., bio remediation, carbon capture offset, coastal protection).	T18/S7/S8 – Create distinct public perceptions of eco-service aquaculture and harvest aquaculture in relation to seaweed	T18/S12 – (see T18/S1/S2 and T18/S7/S8 in columns to left).	

Weaknesses/Threats

Threats	Weaknesses: *Structural*	*Infrastructure & Support*	*Products and Markets*	*Knowledge and Awareness*
Environmental	W1/W4/T2 – Promote mechanisms for growers to collaborate to minimise impact from natural events, e.g., co-op type arrangements where product is collectively sold and risk is shared. W1/T3/T4 – Establish good practice guides such as those used in the Forestry Sector (e.g., Code of Best Practice for Forests – Ireland, Forestry Standards Manual). W7/W8/W10/T3/T4/T5 – Promote engagement with national scientific capacity and develop a research agenda.	W12/W15/T2 – Engage with research and development being carried out for other forms of aquaculture gear development. Investigate access to test sites being used for other marine activities (e.g., ocean energy) at Galway Bay (Smartbay) and Belmullet (AMETS). W16/T2/T3/T4 – Promote engagement with national scientific capacity and develop a research agenda.		W31/T4 – Ensure licence applicants can justify inclusion of applied for species on basis of potential for growth and a risk assessment where non-native. W32/T3/T4/T5 – Include investigation into issues relating to bio security and climate change in a research agenda for the sector. W33/T3 – Further research into lifecycles of species and into possibility of asexual reproduction to reduce need for wild collection of spores.
Regulatory	W1/W5/W6T8 – Encourage cooperative product development to share costs of regulatory clearance. W1/T8 promote engagement with agencies supporting export product development to source funds for testing and accreditation. W11/T10/T11 – Promote “use it or lose it” clauses in licencing and their enforcement. W10/T7/T8 – Ensure issues relating to placing of product on market are addressed in a research agenda for the sector.		W19/T7/T8 – Carry out early market assessments to determine likely update of products that would be subject to regulatory approval, to ensure there is sufficient demand to justify product development. W20/T8 – Focus entrants to the sector on quantifiable or established markets using established species (e.g., food ingredients) as a means of establishing turnover before moving to other less defined markets.	

	Weaknesses			
Threats	*Structural*	*Infrastructure & Support*	*Products and Markets*	*Knowledge and Awareness*
Commercial and Logistics	W1/T12 – Scale production using collaboration between growers to provide more certainty of supply. W1/W2/W5/T12 – Support collaborative working arrangements between industry participants (e.g., sharing facilities, joint marketing etc). W7/W8/T16 – develop methods of tank culture for early stage growing or alternative species to mitigate against low numbers of cultivatable species currently available and to provide more harvest opportunities.		W24/S16 – focus on different markets to wild harvest based on attributes of cultivated species.	
Message	W5/T17 – Focus entrants to the sector on quantifiable or established markets (e.g., food ingredients) as a means of establishing turnover before moving to other less defined markets. W10/T18 – Through research establish benefits of eco-services seaweed aquaculture to other aspects of aquaculture (e.g., bio remediation, carbon capture offset, coastal protection).		W19/T17 – Commission market studies to be made available to all industry participants.	W31/T18– Through research establish benefits of eco-services seaweed aquaculture to other aspects of aquaculture (e.g., bio remediation, carbon capture offset, coastal protection).

Appendix 4 – Strategic Themes based on TOWS analysis actions

SWOT Reference	Theme 1	Theme 2	Theme 3	Consolidated Action
W19/07/08/W26	Collaborate	Assess The Markets	Markets and Products	Utilise existing seafood market channels for seaweed and other seafoods to carry out market research into Irish seaweed markets, and introduce product to existing seafood markets
S3/04	Collaborate	Know-how		Support innovation projects aimed at repurposing existing marine and engineering capability
S3/S14/04/09/W9	Collaborate	Know-how		support re-utilisation of expertise of coastal communities exiting other marine activities such as in marine engineering.
S1/06	Collaborate			Assess the existing seafood processing industry with a view to brokering access.
T13/W24/S16	Assess The Markets	Brand		focus on different markets to wild harvest based on attributes of cultivated species.
W19/T7/T8	Assess The Markets			Carry out early market assessments to determine likely update of products that would be subject to regulatory approval, to ensure there is sufficient demand to justify product development.
W19/W21/011/015/017	Assess The Markets			Carry out study to understand current Far east imports to Europe and identify opportunities for displacement based on quality and standards.
W19/01/T17	Assess The Markets			Commission market studies to be made available to all industry participants.
S3/03	Assess The Markets			Support product innovation products target towards defined markets.
S9/08	Brand	Collaborate		Investigate seaweed branding that positions seaweed as a "value add" to other aquaculture export products, focusing on "seaweed heritage".
S7/S8/S9/016/W26	Brand	Awareness		Establish public information campaign on use and benefits of seaweed as a food product.
T8/S8/S9/S12	Brand	Awareness		leverage positive public attitudes to seaweed aquaculture to promote co-location with other forms of aquaculture
S7/01	Brand	Markets and Products		Establish a common national brand for export food products.

SWOT Reference	Theme 1	Theme 2	Theme 3	Consolidated Action
S8/S9/O2	Awareness	Know-how		Generate material that can be used by applicants for licences to support engagement with communities highlighting positive of seaweed aquaculture.
W10/T18/S3/S4/S12/S15/O4/O5	Awareness	Prepare for the future	Collaborate	Through research establish benefits of eco-services seaweed aquaculture to other aspects of aquaculture (e.g. bio remediation, carbon capture offset, coastal protection).
T18/S1/S2	Awareness	Prepare for the future		Establish eco-services aquaculture as a separate model for seaweed production.
T1/S11	Awareness	Protect & Monitor	Brand	Emphasise the fixed nature of seaweed aquaculture and promote the regular monitoring of water quality by growers to establish the long term quality of product.
T18/S7/S8	Awareness			Create distinct public perceptions of eco-service aquaculture and harvest aquaculture in relation to seaweed
W6/O1	Invest	Community	Markets and Products	Establish a commercially focused “seaweed industry development officer” post.
W13/O3	Invest	Prepare for the future		Target funding on infrastructure and capacity development.
W1/O3	Invest			Focus funding on established growers seeking to scale.
W12/O1/O4	Know-how	Collaborate		Promote and fund use of existing industry sites to pilot new techniques that are made available to whole industry.
W5/W20/T8/T17/S1	Know-how	Assess The Markets		Focus entrants to the sector on quantifiable or established markets using established species (e.g. food ingredients) as a means of establishing turnover before moving to other less defined markets.
W7/W8/W20/W22/O14/O15/O17	Know-how	Assess The Markets		Focus on growing capacity using existing available species to establish market channels to e.g. Far East and Europe markets focused on quality.
W1/T3/T4	Know-how	Licence wisely		Establish good practice guides such as those used in the Forestry Sector (e.g. Code of Best Practice for Forests
S2/O2/O3	Know-how	Licence wisely		Provide mechanism to support new licence applicants who have good business plans.
S3/S16/O11/O12/O14/O17	Know-how	Markets and Products		Establish easy to access method for Irish growers to characterise the food safety profile of their product to support access to safety conscious markets.

SWOT Reference	Theme 1	Theme 2	Theme 3	Consolidated Action
T14/S1	Know-how	Prepare for the future		Establish data on the capital and current costs associated with seaweed aquaculture and make these available industry-wide.
S1/O18	Know-how	Prepare for the future		establish programme focusing on gear development to support automation (e.g. seeded string winding, barge hoists, etc.).
W1/T8	Know-how	Prepare for the future		promote engagement with agencies supporting export product development to source funds for testing and accreditation.
S4/O19	Know-how	Research	Prepare for the future	Take advantage of existing and new research infrastructures to investigation cultivation methods such as tank culture.
W28/W29/O1	Know-how	Research		Develop programme of knowledge transfer to from scientific knowledge base to industry.
S3/S16/S17/O20	Know-how	Research		Establish list of key ingredients & compounds that may be extracted at different points in season.
S1/S17/O14/O18	Know-how	Research		Establish list of key ingredients currently in demand that can be potentially met from Irish species.
W8/W16/O20	Know-how	Research		Establish/research list of key ingredients & compounds that may be extracted at different points in season to maximise value from currently cultivatable species.
W5/O8 - W12/O5	Know-how	Research		Promote and fund use of Marine Institute test site.
S3/O19	Know-how	Research		Support research (with a technology transfer components) into practical cultivation issues, e.g. tank culture, cultivars, life cycle of additional species.
S1/W30/O13	Know-how			Build knowledge bank based on international best practice to be available to Irish growers and processors.
S1/W30/O2	Know-how			Coach existing licence holders on moving to production
W1/W11/O2	Licence wisely	Community		Facilitate existing growers seeking more licenced area to engage with inactive licence holders.
S1/O5	Licence wisely	Prepare for the future		BIM to engage with e.g. SEAI on future scenarios for colocation of seaweed aquaculture with wind energy projects.
T9/T10/S2	Licence wisely	Prepare for the future		Investigate feasibility of a mechanism to allow existing licence holders (e.g. for mussel aquaculture) to fast track inclusion of seaweed species.
T2/S14	Licence wisely	Protect & Monitor		Encourage licencing in sheltered areas. Exercise caution in offshore installations until technology is proven.

SWOT Reference	Theme 1	Theme 2	Theme 3	Consolidated Action
W31/T4	Licence wisely	Protect & Monitor		Ensure licence applicants can justify inclusion of applied for species on basis of potential for growth and a risk assessment where non-native.
T3/T4/S2	Licence wisely	Protect & Monitor		Ensure licence process places strict requirements on types of species to be cultivated and ensure licence conditions put constraints on seed sources.
S2/W11/T10/T11	Licence wisely			Promote "use it or lose it" clauses in licencing and their enforcement.
S17/O8	Markets and Products			Promote seaweed products (e.g. food) through existing seafood markets.
W12/W15/T2	Prepare for the future	Know-how		Engage with research and development being carried out for other forms of aquaculture gear development. Investigate access to test sites being used for other marine activities (e.g. ocean energy) at Galway Bay (Smartbay) and Belmullet (AMETS).
T1/S16/S18/O11	Prepare for the future	Protect & Monitor		Encourage Irish participation in food safety standard setting at EU level.
S10/S6/O11	Prepare for the future	Protect & Monitor		Encourage Irish researchers to participate in EU studies relating to seaweed food safety.
W17/O22	Prepare for the future	Research		Encourage participation in blue-biotech industry networks by Irish seaweed aquaculture sector (by individual participants in the sector, trade organisations or state agencies).
S2/O5	Prepare for the future			DAFM, DHLGH. DECC to explore co-location licencing.
W12/O21	Prepare for the future			Investigate access to pilot facilities in other EU member states.
T1/T4/S18	Protect & Monitor	Prepare for the future	Research	Strictly adhere to EU legislation and encourage Irish participation in future standard setting
T1/S11	Protect & Monitor			Promote regular testing of seaweed aquaculture output for contaminants in order establish consumer confidence.
T13/S11/O7/O8	Research	Assess The Markets	Prepare for the future	Support investigation of cultivated seaweed as a substitute for wild harvest species in products and markets. Include focus on positive continuity of supply aspects associated with aquaculture.
W10/T7/T8	Research	Assess The Markets		Ensure issues relating to placing of product on market are addressed in a research agenda for the sector.

SWOT Reference	Theme 1	Theme 2	Theme 3	Consolidated Action
W10/W16/W28/W29/ W32/W33/09/O1/O10	Research	Community		Establish industry/science partnership to define/refine research roadmap
W7/W8/W10/W16/T3/ T4/T5	Research	Community		Promote engagement with national scientific capacity and develop a research agenda.
W32/O18/O19	Research	Know-how		Ensure inclusion of applied topics such as hatchery refinement and automation in research agendas.
T7/T8//S3/S6	Research	Markets and Products	Prepare for the future	Quantify levels of iodine and other natural and anthropogenic contaminants to provide market reassurance, and to evidence Irish input to regulation formulation at EU level.
W7/W8/O19/T16	Research	Prepare for the future		Develop methods of tank culture for early stage growing or alternative species in order to mitigate against low numbers of cultivatable species currently available and to provide more harvest opportunities.
W33/T3	Research	Prepare for the future		Further research into lifecycles of species and asexual reproduction to reduce need for wild collection of spores.
S10/O5	Research	Prepare for the future		Promote Irish researchers in European IMTA and co-location projects.
S10/O10	Research	Prepare for the future		Promote research collaborations between Irish seaweed researchers and food research (e.g. Teagasc).
S16/O10	Research	Prepare for the future		Promote research into attributes of common Irish seaweeds to determine specific available compounds, proteins etc.
T2/T5/S3	Research	Prepare for the future		utilise and promote existing state capacity in ocean modelling to understand climate and weather effects on seaweed aquaculture.
W32/T3/T4/T5	Research	Protect & Monitor		Include investigation into issues relating to bio security and climate change in a research agenda for the sector.
S6/O10	Research			Define a research agenda for seaweed aquaculture in Ireland and establish enablers required to ensure Irish participation in EU projects.
T1/T7/S7	Brand	Protect & Monitor		Leverage branding elements of "safe, clean, Irish" food to counter possible concerns about contaminants. Back up these branding elements with water and product monitoring.

SWOT Reference	Theme 1	Theme 2	Theme 3	Consolidated Action
S7/S9/S13/O11/O12/O14/O15/O16/O17/W21/W22	Brand			Establish food brand based on Ireland's "clean and sustainable food" and "seaweed heritage" image.
S14/O16	Brand			Promote a consumer/tourism "see it before you eat it" brand.
W1/W2/W5/W13/O1/O8/T12	Community	Know-how	Markets and Products	Support collaborative working arrangements between industry participants in order to e.g. broker product offerings that can utilise existing seafood producer market channels, sharing facilities, joint marketing etc
W20/W22/O1/O25	Community	Know-how		Share knowledge on cultivation methods of new species.
S11/S17/O15	Community	Markets and Products		Encourage cooperation amongst growers to supply foreign markets(in order to make continuity of supply more robust).
W1/W4/W5/W21/O1/S1	Community	Prepare for the future		Support collaboration across the industry through trade organisation. Use as basis for market development.
W1/W5/W6T8	Community			Encourage cooperative product development to share costs of regulatory clearance.
W1/W4/T2	Community			Promote mechanisms for growers to collaborate to minimise impact from natural events, e.g. co-op type arrangements where product is collectively sold and risk is shared.
W1/T12/S4	Community			Scale production using collaboration between growers to provide more certainty of supply.
W1/W2/W5/W13/O1/O8/T12	Community			Support collaborative working arrangements between industry participants (e.g., sharing facilities, joint marketing etc).
S8/O13	Awareness	Brand	Protect & monitor	Reinforce public acceptance of seaweed aquaculture through adoption and adaptation of international sustainability standards and certifications.
T1/S2	Awareness	Brand		Highlight rigorousness of licencing process to counter concerns about water quality.
T1/S13/S15	Awareness	Brand		Highlight detail of Ireland's clean coastal waters (as per WFD reporting) and low input nature of the activity

Appendix 5 – A research statement for the seaweed aquaculture sector

Ireland's Marine Research and Innovation Strategy 2017 to 2021 described a range of research areas linked to the cultivation and valorisation of seaweeds [185]. Undertaking research in these areas would contribute knowledge needed to increase Irish algal biomass output. Global demand for cultivated seaweed biomass for food and non-food use has continued to increase as mentioned in the national Strategy.

Many of the areas the strategy described as in need of improvement; and specific research challenges still exist regarding cultivated algal biomass. There was a clear focus by the strategy on biosecurity; breeding, cultivation and health at all stages of the life-cycle of commercially relevant species; large scale algal cultivation systems and the impact on the marine environment of cultivating seaweeds.

Feedback obtained from stakeholders contributing to this work on the future of seaweed cultivation in Ireland and insights obtained during the extensive review of research, policy and market related reports identified the need for research in multiple areas to become internationally competitive.

The successful processing of cultivated seaweeds is predicated on the availability of consistent supplies of biomass possessing clearly defined and consistent attributes. Knowledge gaps exist in key areas of seaweed cultivation that research can fill. The results will support growth in what is a nascent industry, helping it to contribute to the national goals to expand cultivated algal biomass output and utilisation.

Research in the following thematic areas is required to provide a foundation for the sectors continuous competitive growth.

However, greater involvement of stakeholders from the cultivation, processing and research community will be needed to finalise and prioritise specific research needs.

Cultivation

- Define strategies to use in identifying species best suited to cultivation and the conditions required to grow them at commercial scale.
- Develop an understanding of and control over the early stage life-cycle of all species of commercial interest to enable repeat breeding and the provision of a reliable supply of culture at a commercial scale from a hatchery.
- Identify factors that influence and contribute to the optimal successful growth of commercial species from initial fertilisation to the inoculation of growing substrates.
- Determine the impact of environmental conditions on growing and their impact on biomass production.
- Characterise biofouling and disease threats to cultivation at early life cycle stages and develop strategies to mitigate the threats and means of controlling them.
- Identify the existence of naturally occurring strains within wild populations and find strains that exhibit high-growth rates, disease resistance and other traits of commercial interest

Composition

- Understand the impact of environmental conditions, seasonal effect and location on compositional profile.
- Define optimal growing conditions required to maximise growth rates and compositional profile.

- Identify variation in composition, growth rates and genetic profiles between cultivated and wild species.
- Understand interaction between wild and cultured species and their effect on the growth and compositional profile of species.
- Identify how to predict the probable composition of seaweeds in advance of harvesting stock at maximum biomass production.
- Determine the extent that it is possible to control the composition of species grown in open waters such that the production of specific compounds is maximised.

Biomass production

- Understand the impact of seasons on growth rates and yield of biomass with a view to determining how growing seasons can be extended.
- Determine optimal time for the deployment of seedlings at sea and harvesting such that growth and compositional profiles are maximised.
- Define and understand the impact of environmental conditions and their contribution to optimal growth.
- Understand variations in growth conditions in areas earmarked for large scale cultivation.
- Establish best practice cultivation methods to enable optimal biomass production at an industrial scale for all commercially relevant species.
- Determine the impact of multi-species cultivation on biomass production and composition of species grown within the same area.
- Identify factors to support decision making in identifying growing sites that are best suited to specific species.
- Identify the impact of different growing and harvesting methods on overall productivity.

Biosecurity

- Identify potential biological and other threats to cultivated species, the likelihood of such events and the potential impact on biomass production levels.

Processing

- Characterisation of seaweed compositional, physical attributes and yield resulting from primary processing including e.g., storage, ensiling, drying, freezing, milling.
- Determine the feasibility of small -scale refining of seaweeds

Environmental

- Understanding the extent that seaweed cultivation will contribute to the formation of new marine habitats.
- Interaction between seaweed cultivation on other marine activities, e.g., fishing, aquaculture, shipping etc.
- The impact of seaweed cultivation on the marine ecosystem in the immediate vicinity of the farm.
- The impact of seaweed cultivation on finfish and shellfish aquaculture activity.
- Developing modelling methods to determine optimal location of cultivation sites to minimise any negative impacts on the environment stemming from cultivation.
- The role and nature of environmental monitoring methods on different growing systems and sites.

Consumer and community attitudes

- Identify factors that influence buyer behaviour and attitudes towards the consumption and use of seaweed as food and food ingredients.
- Understand the attitudes of coastal and other communities to seaweed cultivation.

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Notes

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