Irish Macro-Algal Cultivation Strategy to 2030

BIM Ireland's Seafood Development Agency

REVIEW OF THE IRISH SEAWEED AQUACULTURE SECTOR **AND STRATEGY FOR ITS DEVELOPMENT TO 2030**

Rialtas na hÉireann
Government of Ireland

Có-mhaoinithe ag an Aontas Eorpach

Co-funded by the European Union

Funding:
This study is part of the Seaweed Development Programme funded through the Knowledge Gateway Scheme which is established under Union Priority 2 of Ireland's Operational Programme under the EMFF and is co-funded by the Irish Government and the EU.

Commissioned By:
Seafood Technical Services Bord Iascaigh Mhara (BIM)

Researched & Written By:
Steelesrock Strategy Consulting

Enquiries:
info@bim.ie

BIM Ireland's Seafood Development Agency

Steelestock Strategy Consulting

Executive Summary

This report presents an overview of the current state of seaweed aquaculture in Ireland and outlines a strategy for the sector in Ireland to 2030. The strategy was developed following a review of the sector by Steelesrock Strategy Consulting on behalf of BIM.

The strategic review reveals that production of seaweed is rising rapidly worldwide, increasing by 46% between 2012 and 2019. While production has historically and remains to be dominated by Asian countries, production elsewhere is now rapidly rising. Most of the global seaweed output is cultivated (97% by volume), mostly in Asia. Elsewhere seaweed production is dominated by wild harvest practices, although cultivation is rising. Despite the rise in production, global demand for seaweed exceeds supply, driven by its increased use in a wide range of industries including food and ingredients, animal health, cosmetics and pharmaceuticals, and many others. In a European context, this demand is reflected in, and increasingly driven by European Union policies. These policies reflect the potential of seaweed to play a significant role in the transition to a green economy, with seaweed biomass well positioned to displace some of the carbon producing terrestrial sources of biomass.

An analysis of seaweed output in other EU member states demonstrates that despite a track record in seaweed research, as well as a rich cultural tradition of seaweed use, Ireland has not matched the growth of production seen elsewhere. This is particularly the case in relation to cultivated seaweed. There are many reasons for this relatively slow development including the relatively small size of the aquaculture industry in Ireland generally, an absence of capital investment, and a small domestic market.

Despite the exploding market for seaweed internationally, the cultivation sector in Ireland remains small and in a nascent state. During the strategic review, industry participants were revealed to be optimistic and ambitious, but face challenges in realising their goals which are often based on the production of sophisticated value added products that require significant processing facilities. Such facilities are capital intensive and require the availability of large quantities of biomass. A key outcome of the review highlights this apparent dilemma – to grow the sector requires additional processing capabilities which in turn require significant growth in volume to justify the investment.

The strategic review also reveals that while there is a clearly growing market, the nature and location of that market is poorly understood. While there is availability of licenced sites, and the prospect of more to come, growers are frequently producing on the basis of grow it first and then find a buyer. By contrast, market share would be better served by identifying market demand first, and growing species to meet this demand. This issue is compounded by the absence of commercial hatchery facilities and capabilities beyond a limited number of species.

To address these and other issues, the strategic analysis has led to the identification of seventy-four actions which are detailed in this strategy. The actions, fall under 12 strategic themes grouped in three pillars are designed to be put in place in the lifetime of the strategy, that is to 2030, but in some instances will run beyond that date. Some actions are prioritised, specifically to address the issues outlined above; that is to ensure access to hatchery facilities; provide accurate market data; and boost production with an initial focus on seaweed the food and ingredients market thereby increasing the volume of biomass produced nationally.

Table of Contents

Introduction

BIM have commissioned a strategic review of the Irish Seaweed aquaculture sector, including the production of this strategy for the sector to 2030. In doing so, BIM perceived that there are significant opportunities for the expansion of the sector in terms of functional foods, nutraceuticals, cosmetics, biostimulants (by means of biorefinery), bioremediation, feed and a possible use for seaweed as an anti-methanogenic of interest of the dairy and beef sectors.

The strategic review took place between October and December of 2021, and involved consultation with a range of stakeholders, a review of literature of relevance to the sector (including market reports, EU and national policies, outputs of recent EU projects, and academic publications), and a profile of the performance of three other EU countries. These are summarised in this strategy, together with the results of several analyses that led to the development of the strategy presented in the document.

The full strategic review is available in a separate report – A *Strategic Review of Irish Macro Algae Cultivation 2021-2030*, which is available from BIM. The information and data presented in this strategy is derived from that report, and the reader is directed to it for further detail and citation purposes.

Strategic Analysis

This report presents 12 strategic themes with associated actions, grouped into three pillars: viz; **building and sustaining the sector**; **establishing and growing the market**; and **securing and safeguarding the future**. To arrive at these, several recognised strategic analysis tools were used to investigate external and internal factors to the sector. These included consideration of the landscape the sector operates in, including the Political, Economic, Social, Technological, Environmental, Legal (PESTEL) factors. Building on this, consideration was given to the five main competitive forces that are typically found in an industry sector: the threat of entry; the threat of substitutes; the power of buyers; the power of suppliers and the extent of rivalry between competitors.

These, together with the wider strategic review and stakeholder consultation, informed the development of a detailed Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis. Actions needed to overcome the threats and weaknesses and capitalise on the strengths and opportunities were identified using the so-called TOWS approach. Once identified, these actions were grouped organised into the three strategy pillars and their associated thematic areas.

Stakeholder consultation

A key element in the formulation of this strategy was feedback in interviews with thirty-eight consultees. These interviewees were drawn from industry participants including growers, processors, relevant state agency and Government Department employees, and researchers active in areas relevant to the sector. Interviews followed a semi-structured interview approach, and were conducted on the basis of non-attribution of views to any one individual. Appendix 1 lists the interview participants.

Context

For millennia, people living in coastal communities have used seaweed in raw, dried and composted forms; providing a source of food, food ingredients, medicine, animal feed and fertiliser for the land. The extent of seaweed harvesting and use by Ireland's coastal communities, particularly those living along the western seaboard, contributes to folklore and remains visible in traditional practices. Such is the strength of Ireland's connection with seaweed, traditional harvesting continues in parallel with the emergence and growth of an indigenous seaweed cultivation industry.

Global seaweed production

Seaweed production is increasing globally and dominated by the output from Asian countries. The United Nations Food and Agriculture Organisation in 2020 reported world seaweed output in 2012 was 23,776,499 tonnes, increasing by 46 percent to 34,697,134 tonnes by 2019. Although the share of global production by Asian countries continues to increase; production is also increasing in other regions. In contrast to Asia, where seaweed cultivation developed in response to overharvesting of wild Nori species ,wild harvested seaweed is the dominant source of European seaweed. Seaweeds harvested in Ireland in the year ending 2019 total 29,542 tonnes (wet weight) inclusive of 42 tonnes of cultured stock.

Table 1 - European seaweed output 2019

Country/region	Total seaweed production		Cultivated seaweed	
	Tonnes (wet)	*Share of global production (%)*	*Tonnes (wet)*	*Share of cultivated biomas in total production (%)*
World	**35,762,504**	**100**	**34,697,134**	**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)

The commercial potential of seaweeds is recognised by many industries including human and animal health, biomaterials, pharmaceuticals, cosmetics and biofuels and in reports of other uses for seaweeds and seaweed derived compounds, as fertilizers and soil conditioners, animal feed, fish feed and in bioremediation. Most of the 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. This positive outlook on the use of seaweeds is reflected in a recent commercial market report (Markets and Markets), which indicated a global market value for cultivated seaweeds of US$16.7 billion in 2020 and set to increase to US$30.2 by 2025; a compound growth rate of 12.6 % over the period 2020 to 2025. Behind this projected growth is the increasing interest and demand for seaweed-based products in the consumer foods, industrial, agriculture and feed sectors.

European seaweed related policy

The European Commission has reinforced its position on the economic and environmental potential of cultivated seaweeds. In its communication to the other Institutions of the European Union in December 2019 on **The European Green Deal**, the Commission profiled algae as an example of new innovative food and feed that could reduce the impact of food processing on the environment. Seaweeds feature within the EU's Farm to Fork Strategy; a strategy that 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. The strength of the EU's commitment on seaweed is clear in new European Maritime and Fisheries Fund.

This mechanism is 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.

Tangible actions in relation the EU's approach to seaweed production emerge from within 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.** In it, the Commission highlights the role of algae production as an alternative to agriculture, and as a source of new biobased products, committing the EU to adopt a dedicated initiative on algae in 2022 to support the development of the EU's algae industry.

Seaweed is prominent within the EC and Joint Research centre reports on the **Blue Economy** both cultivated and wild harvested, and inclusive of micro-algae production, positioned as an emerging sub-sector of the blue bioeconomy. Against this background various EU initiatives both highlight and support new technological developments to increase the environmental sustainability and economic feasibility of industrial processes including offshore aquaculture techniques, Integrated Multi-Trophic Aquaculture (IMTA) and biorefineries.

National seaweed related policy

Successive national food and agriculture strategies from 2015 have emphasised the economic potential of both harvested wild and farmed seaweeds to Ireland's bioeconomy. Specific actions included support for research on the use of seaweeds as food ingredients, functional foods and as high value sources of novel ingredients for use in pharmaceuticals and cosmetics products. Food Vision 2030 identifies the strategic importance of the development of new biobased value chains: including the contribution of bio resources from Ireland's oceans and seas to Ireland's bioeconomy. The Food Vision strategy draws attention to the actions needed to realise this potential, including algal biorefineries and seaweed farming, together with the multi-use of marine space in offshore platforms.

This recognition of the strategic importance of seaweeds also features in national sectoral reports. Ireland's recent Seafood Task Force calls for specific actions to further the development of the seaweed sector. Some of these aim to address the unique needs of Ireland, such as a commercial seaweed hatchery to support seaweed aquaculture; supports for knowledge and innovation to add value to raw seaweed (including extraction of bioactives), combined with knowledge transfer to product generation and commercialisation. Other actions coincide with EU views concerning the co-location of seaweed aquaculture with offshore wind energy sites, the use of Integrated Multi-trophic Aquaculture (IMTA), and the roles of seaweeds in bioremediation for heavy metals and carbon sequestration. Similarly, the National Strategic Plan for Sustainable Aquaculture Development (2021-2030) draws attention to knowledge gaps around seaweed cultivation; where an enhanced scientific understanding of seaweed species and cultivation know-how will contribute to its future development; as will a road map for seaweed related Research, Technological Development and Innovation and the associated investment in innovation and support for knowledge transfer to the sector.

Legal and regulatory systems and seaweed

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

Separate regulations exist for different categories of seaweed based products in the European Union. These include regulations for foods, food supplements, food additives, cosmetics, feed and feed additives, cosmetics, packaging, fertilizers, bio stimulants and biofuels. In the case of foods, seaweeds fall within the scope of a Directive concerning novel foods. The novel food regulation (regulation [EU] 2015/2283) recognises several species of macro-algae as having been in common use before its introduction. These can be placed on market subject to national guidelines. Other species are subject to the directive, and the process it lays down for national food safety regulatory authorities to authorise their introduction to the market. Table 2 lists the European Directives applicable to seaweed related products.

The main EU legislation relevant to seaweed aquaculture production 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 Alien 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 licencing system is administered by the Department of Agriculture, Food and the Marine. This system is designed to ensure any aquaculture activity in Ireland 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.

Table 2 - Main European legislation relevant for macroalgae end uses

Macroalgae end-use	**Main EU regulations**	**Bottlenecks, uncertainties, and need for development**
Medicine	Human Medicinal Products Directive 2001/82/EC Veterinary Medicinal Products Directive 2001/83/EC	Categorization (e.g., herbal medicine vs. traditional medicine, medicine vs. food) is unharmonized between member states.
Food (incl. food supplements and food additives)	Novel Food Regulation (EU) 2015/2283 Food Additive Regulation (EC) 1333/2008 Food Contaminants Regulation (EC) 1881/2006 Pesticide Residues Regulation (EC) 396/2005 Seaweed Contaminants Recommendation COM 2018/464 Fishery and Agriculture Products Labelling Regulation (EU) 1379/2013 Nutrition and Health Claim Regulation (EC) No 1924/2006	The novel food status of some edible seaweed species has not yet been evaluated. Uniform safety rules are lacking as regards heavy metals and toxins in foods. Antibiotic residues are not regulated but should be considered in IMTA. Fishery product labelling rules seem unfeasible for macroalgae products Health claim substantiation is very demanding.

Macroalgae end-use	Main EU regulations	Bottlenecks, uncertainties, and need for development
Feed	Feed Materials Regulation (EU) 68/2013 Feed Additive Regulation (EC) 1831/2003 Feed Contaminants Directive 2002/32/EC Pesticide Residues Regulation (EC) 396/2005	
Cosmetic product	Cosmetics Regulation 1223/2009/EC Regulation on Claims 655/2013	
Packaging material	Food Contact Materials Regulation (EC) 1935/2004	Stricter regulation is anticipated in the future.
Fertilizer or biostimulant		The positive lists and standards for claims are still in the process of being developed.
Biogas and bioethanol	Renewable Energy Directive (EU) 2018/2001 Delegated Regulation on Indirect Land-Use Change (EU) 2019/807	

Source: Reproduced from *European Union legislation on macroalgae products.* A. Lähteenmäki-Uutela et al (2021)

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.

The status of seaweed cultivation in Ireland

Ireland's seaweed sector is dominated by the harvest and processing of wild stock, mostly A*scophyllum nodosum*. Until very recently, any consideration of the role and potential of cultured seaweeds required acknowledgement of this dominance as processing, marketing and public perception were driven by the capabilities of the wild harvest sector. In recent years, the emergence of differing species from cultivated sources has seen some divergence between the sectors, but wild harvest continues to dominate in the discussion of seaweed in Ireland.

Species cultivated

Of the 500 or so different seaweeds species found in Irish waters less than 20 are relevant in terms of commercial cultivation. BIM has identified seaweed species in each of the three phyla – Phaeophyta (brown), Rhodophyta (red) and Chlorophyta (green) that offer commercial potential. The type of cultivation method (at sea or on land in tanks or ponds), climate and regulatory systems all influence the selection of species. Irish growers cultivate five species; three brown species – *Alaria esculenta, Laminaria digitata* and *Saccharina latissima (*formerly *Laminaria saccharina)* and two red species – *Palmaria palmata* and *Asparagopsis armata.* Table 3 and Table 4 identify cultivated species and species offering potential for cultivation in Ireland.

Table 3 - 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	Land, 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
Fucus serratus	No	DE DK SE	Land, Sea
Ascophyllum nodosum	No‡		
Pelvetia canaliculata	No		
Rhodophyta – red seaweeds			
Palmaria palmata	Yes/trial	DK FO FR NO PT UK	Land, Sea
Porphyra spp	Trials	FR NO PT	Land
Chondrus crispus	Yes/trial	FR PT	Land
Mastocarpus stellatus	No‡	DE PT	IMTA Land, Sea
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

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

Table 4 - 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
Sacchoriza polyschides	UK	Trial @ sea	Native to Ireland
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
Rhodophyta – red seaweeds			
Furcellaria lumbricalis	Baltic	Trial	Source of furcellaran (gelling agent) and pigments, native to Ireland
Gracilaria spp	DE ES PT	Land	High value food crop, agar containing, native species occur in Ireland
Osmundea pinnatifida[ǂ]	PT	Trial	High value food crop, identified for future potential in Scotland, native to Ireland

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

Scale and distribution of seaweed cultivation

The most reliable indication of the extent of seaweed cultivation is the number of aquaculture licences issued by the Department of Agriculture, Food and the Marine. However, these data do not provide a full picture of actual cultivation, since licence grantees may not always commence cultivation. DAFM and BIM indicate a total of 25 licenced sites in counties Clare, Cork, Donegal, Galway, Kerry, Mayo and Sligo covering a combined area of 254.5 ha.

Difficulties arise in respect of identifying employment levels at the licenced sites; some sites are licenced to cultivate other aquaculture 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.

Data from BIM indicate there are 9 active seaweed growers and one trial cultivation site the state, which in 2020 harvested a total of 44 wet tonnes, rising to 50.5 tonnes to date in 2021.

At the time of preparing this report DAFM was processing 13 applications for aquaculture licences. Together, these applications related to the culture of seaweed in a total sea area of 522 ha.

Seaweed biomass yield

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. Based on a generally accepted ratio for kelp species of 6.5 to 1 for converting wet to dry biomass, a dry weight equivalent for each of the years 2018, 2019 and 2020 is 6.06, 9.55 and 6.67 tonnes respectively. Significant variation exist in reports of biomass production for species of kelp on long-lines ranging from 5 kg/m up to 12kg/m, increasing to 18kg/m where seaweed is cultivated close to nutrient sources such as salmon farms.

Seaweed processing activity

There is a minimal level of processing of seaweeds in Ireland today. Most harvested stock is dried; either naturally on the shore or by forced drying. Few producers have facilities to force dry harvested seaweed. Other processing includes the weighing, milling, packing and distribution of seaweeds. Some growers have started to consider various other processes to add value to their harvest including drying, milling, extraction, ensiling and biorefining, though this is largely at the early investigative stage. The cost of drying equates to approximately 80 percent of the cost of production. Contract drying by others, including wild harvest seaweed processors, is common.

Enterprise performance

Given the small scale of the cultivation sector there are few publicly available insights concerning costs of production, capital investments, sales revenue and pricing. This makes projections about sector performance difficult to produce. There is considerable variation in selling price with significant price elasticity depending on end use of the species.

Employment is generally seasonal in nature, corresponding to setting growing lines at sea (October/November) and harvesting stock (April/May). Growers employed an average of 3.8 full-time equivalent staff per annum over the period 2017 to 2020. 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.

Markets and product applications

Two broad geographic markets exist. The domestic market is dominated by the sale of dried and wet seaweed to artisan food producers and the producers of cosmetic products. The export market typically sees seaweed sold directly to customers or via a wholesaler to foreign markets.

Direct engagement by growers with the end user remains at an early stage. Accordingly, except where a grower has an established seaweed product range, many growers know little about how customers process or use seaweeds. Cultivated stock competes directly with hand harvested wild stock. Processors of wild stock maintain a lower cost of production; higher volume output and greater numbers of customers than the seaweed growers. 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 of cultivated seaweed from wild harvested sources and both sectors describe their product as sustainably harvested.

Domestic markets

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.

Export markets

Irish growers export *Alaria esculenta, Saccharina latissima, Asparagopsis armata* and *Palmaria palmata.* The principal route for growers to export markets is via wholesalers. Rarely do growers know the 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, to be used as a source of polysaccharides and proteins.

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 compared to 2019 (€0.14 million). Key trading partners were France (2,300 tonnes), UK (900 tonnes), China (17 tonnes) and Switzerland (4 tonnes).

These data from EUROSTAT do not differentiate the trade of cultivated seaweeds from that of wild harvest, but the average price was more than €20/kg.

Support for seaweed cultivation in Ireland

Ireland has an extensive research infrastructure comprising public sector research centres and higher education institutions (HEIs) that supports Ireland's marine bioeconomy. These are a major source of research expertise. Some players such as University of Galway (formally NUIG) have a long-standing history and international reputation in algal, and specifically, macroalgal research spanning the entire value chain, whilst others such as Teagasc and some of the HEIs target individual elements of the value chain. Most of the HEIs have engaged to some extent in seaweed related research. Public funds (including EU sources) for seaweed related research awarded 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; cultivation and the processing of seaweeds. 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 Marine Institute, many institutions had developed expertise and infrastructure relevant to the seaweed sector by accessing public funds, including EU funds administered by BIM.

RTDI capabilities

Ireland's seaweed sector is well served by an extensive and responsive research infrastructure built around public sector organisations such as the Marine Institute, Teagasc and the HEIs. Many Irish HEIs and other research institutions have a long history of involvement in seaweed and seaweed related research generating new knowledge in projects involving the human food applications for seaweed, animal nutrition, feed cosmetics. Some possess the knowledge needed to explore the potential of microorganisms from seaweeds to extract compounds of value to the food and health sectors and to contribute to bioprocessing. Extensive research capabilities exist 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. Specific expertise exists regarding the use of seaweed proteins as an alternative to other protein sources; the nutritional benefits and their contribution to human health. Institutions can also isolate and characterise compounds in seaweeds, and use of bioprocessing to convert biomass into useable fractions. Seaweed research is supported by expertise in molecular biology and genetics and an extensive infrastructure, including pilot facilities for the cultivation and processing of seaweeds relevant to product development.

Agencies funding seaweed related RTDI activities

Multiple sources of public sector funds for seaweed related research exist. These include BIM, Department of Agriculture Food and the Marine, Department of Enterprise Trade and Employment, Department of Rural and Community Development, Department of the Environment, Climate and Communications, Enterprise Ireland, the Environmental Protection Agency, the Marine Institute, Science Foundation Ireland and Teagasc.

European seaweed cultivation – a comparison

There is an expansion of seaweed cultivation globally, with increasing output reported on all continents. European countries, particularly those with an Atlantic coastline such as Ireland, France and Norway have a long history of using wild harvested seaweeds as food, feed and fertilisers. Over time new industries developed to process these seaweeds into increasingly sophisticated products. Changing consumer preferences, the emergence of new applications for seaweed derived products that demand traceability, and concerns over the sustainability of wild harvested stocks, have brought about changes in outlook on the part of the traditional seaweed processors. There has also been increased engagement with seaweeds by the other European countries with coastlines. Three European regions, each of which has a different level of engagement with seaweed, yield insights to the nature of these changes. Norway, France and a North Sea collaboration between the Netherlands, Belgium and Germany provide examples of different development routes from established to new entrants as below.

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

Figure 1 is a summary comparison of the seaweed industry activity in each of the three regions above and insights from Ireland.

France

France is Europe's second largest producer of seaweed with an estimated value of over €400 million. The industry is still largely based on the harvest of wild biomass although cultivation activity is increasing. 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 largely 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 biopackaging. Companies range from large multinationals (cosmetics, speciality ingredients) to SME/ artisanal producers and processors. The industry is well organised with several clusters and industry associations to support and drive the industry forward.

	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 develooment	• 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 1 – Summary comparison of key European seaweed industries

Norway

Norway is Europe's largest producer of seaweed (by volume) and 9th largest global producer. 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.

The thriving Norwegian aquaculture industry benefits a developing seaweed sector, providing expertise in cultivation, processing technology, storage and logistics; marine ingredients businesses, and a high public/ consumer awareness and acceptance of aquaculture products. 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.

The coastline of Norway is highly suited to aquaculture including seaweed cultivation. Production in 2020 was around 185 wet tonnes with a value of NOK 8.6 million (ca. €850,000). This represents the largest annual crop from cultivated biomass in Europe to date. The key species cultivated were *Saccharina latissima* and *Alaria esculenta,* in almost equal volumes. 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).

Cultivators generally operate mostly at small scale (10-100 wet tonnes). Industry associations support smaller seaweed producers to work together for their collective benefit, and to develop and promote the industry. Several larger companies with connections to multinational corporations also exist. These have the capacity to farm hundreds of wet tonnes over extensive areas. These firms have aggressive production goals. Seaweed Solutions AS has concessions in place for 65 hectares with potential to grow > 3,000 wet tonnes, and in 2020 announced the completion of a 19 ha farm with the capacity to produce 500 wet tonnes of kelp. Norway plans to cultivate an estimated 4 million wet tonnes by 2030, increasing to 20 million wet tonnes at a value of US$ 4 billion by 2050.

North Sea Community

The North Sea seaweed community comprising the Netherlands, Belgium and Germany share a common vision to develop large scale, offshore, multi-use seaweed farming activity for the future development of a sustainable seaweed economy.

North Sea farmers, a Netherlands based international foundation for the seaweed sector, is coordinating the development of an inter-regional and cross-sectoral seaweed industry with the ambition to be the largest in Europe. The Dutch industry is planning development of a 500 km^2 sea area that will produce 10 million wet tonnes of seaweed with a revenue of €1 million. 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.

The consortium is directing considerable effort towards joint investment projects and knowledge exchange on all aspects of sustainable seaweed cultivation. The group has an offshore test site comprising six one km^2 and licenced for seaweed cultivation and IMTA trials. Growers have started to cultivate and harvest small amounts of seaweed including *Alaria esculenta, Saccharina latissima* and *Ulva ssp.* at scales ranging from experimental, to 10's of tonnes/annum (wet weight).

A cluster of seaweed-oriented support services is developing in parallel with the development of the cultivation industry. Companies that supply juvenile seaweeds, seeded substrate, and growing systems, including automated line deployment, harvesting and cleaning systems have emerged. Some such as the Dutch company Hortimare and the Belgian, At Sea Nova have established themselves in export markets and serve several Norwegian growers.

Seaweed cultivation and processing

Internationally, the cultivation of most seaweed occurs at inshore or off-shore locations, though there is an increasing use of land-based systems using tanks, ponds/ lagoons or raceways for some high-value species. Several successful pilot projects involving seaweed cultivation in multi-species growing systems has stimulated increased interest in Integrated Multi Trophic Aquaculture (IMTA) systems. Coping with the predicted increased demand for cultivated seaweed requires considerable expansion of sea and land based growing systems. The recent *Seaweed for Europe* modelling exercise presented a vision of the European industry in 2030, in which sea-based cultivation will range from range 7,000 to 26,000 ha and land-based systems between 300 to 1000 ha. A range of factors influence the choice of cultivation systems including species type, intended use, costs, logistics. These and the increasing availability of new knowledge and technologies will influence choices of production systems.

The role of a seaweed hatchery

Apart from a few individual growers who have developed or are developing their own in-house capability, Ireland's cultivated seaweed sector has relied on trial hatchery facilities, some of which was supported by BIM on a research and development basis. These facilities have limited supply capacity and currently only able to supply juvenile *Alaria esculenta*, *Saccharina latissima* and *Laminaria digitata*. There is only limited evidence of growers sourcing juvenile supply from beyond the island of Ireland.

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 a hatchery or hatcheries 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.

Supporting knowledge acquisition

Despite the societal and economic importance of seaweed, the rate of knowledge acquisition about seaweeds is slower than for some other aquaculture species.

The increased demand from markets for seaweeds with high-potential in food and other applications, requires new approaches to juvenile production and new species. Many species of commercial interest have failed to respond to traditional protocols. Hence new standardised cultivation and preservation protocols for these species will be required.

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. This 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 of high value seaweeds fell by 15 percent. The decline is reported to stem from diseases and pests resulting from the intensification of aquaculture activity.

Automated production systems

Meeting the demand for large scale cultivation will need new approaches to seeding growth substrates. Large scale seaweed cultivation requires new, standardised approaches to seedling production, improved quality, predictable biomass output and increased use of automation. The traditional hatchery is a labour intensive operation; reliable and consistent supply of seedlings for large scale cultivation is outside their supply capabilities.

A commercial focus

Hatchery facilities established at a scale that can respond to the growth of a new aquaculture sector must 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 or juveniles for use in direct seeding methods. Adding a research dimension to the venture needs careful evaluation and justification in light of the anticipated lengthy timescales involved in establishing new species. In this regard there is likely to be an ongoing development role for state bodies.

Inshore cultivation

European seaweed cultivation is primarily an inshore activity involving the growth of seaweed on various configurations of growing systems. These systems typically comprise vertical and/or horizontal growing structures maintained in the surface waters (around 1-3m) using buoys and moored to the seabed. Some systems are adjustable and allow for growth at different depths. Growing structures include ropes (long-lines), nets, cages or grids depending on species under cultivation and site location. Environmental factors and the choice of growing system influence biomass yield. The use of two-dimensional (as opposed to single growing lines) grid/frame systems is better suited to large-scale sites and offer scope for using mechanised systems at all steps in the cultivation process, and these systems may offer larger yields.

The use of long-lines for kelp is the standard set-up on most Irish seaweed farms. Long-line systems are relatively cheap to deploy and easy to lift for inspection, harvest etc. These systems involve the use of parallel growing lines (ropes) spaced optimal distances apart, anchored at each end and supported by buoys to keep the lines near to the surface. The seaweed grows on pre-seeded twine wrapped around individual growing lines.

Offshore (open water) cultivation

In “offshore” or “open water” seaweed cultivation, the growing systems experience exposure to significant mechanical forces from wave and wind. The installation and operation of these systems can be costly, presenting a challenge in maintaining a competitive cost of production. As the European cultivation industry develops, and the number and size of farms increases, it is inevitable that cultivation will move offshore, though this is likely some years away from commercial viability. In doing so, it will become mechanised, and increasing reliant on innovative seaweed farming practices.

Several test sites of offshore systems exist in the northern Atlantic and in the North Sea using similar concepts of sub-surface structures able to operate at depths ranging from 6 to 200 m. Such structures are flexible to enable free movement in high energy environments. Typically such systems comprise a main structure that is heavily anchored and buoyed to the surface, with multiple vertical growing lines that are individually buoyed to the surface. Each rig can have more than 250 individual growing lines.

On shore/land-based cultivation

Onshore seaweed cultivation include growing seaweed in tanks, ponds/lagoons or 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. The use of aeration or paddle wheels keeps the seaweeds afloat/moving in the water column. Land-based cultivation typically involves considerable construction and energy costs.

A land-based cultivation system is the only way to grow some species; whilst others perform better in these systems than in open water. The use of land-based systems is 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 supports 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 in proximity to each other. 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.

IMTA is not yet widely used at a commercial level in Europe, though a small number of commercial sites and test sites exist in which kelp species are successfully cultivated alongside finfish, mussels and oysters in sea-based systems and various red and green seaweeds with fish in land-based systems.

Comparison of cultivation methods

Multiple factors, ranging from the species to be grown, to requirements for seaweed with specific traits and even the proposed use of the harvested biomass influence the choice of cultivation methods. Figure 2 lists some of the reported benefits and challenges of different cultivation approaches.

	Benefits	Challenges
Inshore	• Well established in some regions • Regional best practice exists • Possibilities for linear, 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 2 - Comparison of cultivation techniques

Post-harvest processing seaweed biomass

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 is a major influence the level of processing. However, it is the end-use for the seaweed that dictates the processing steps.

Figure 3 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, preservation 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.

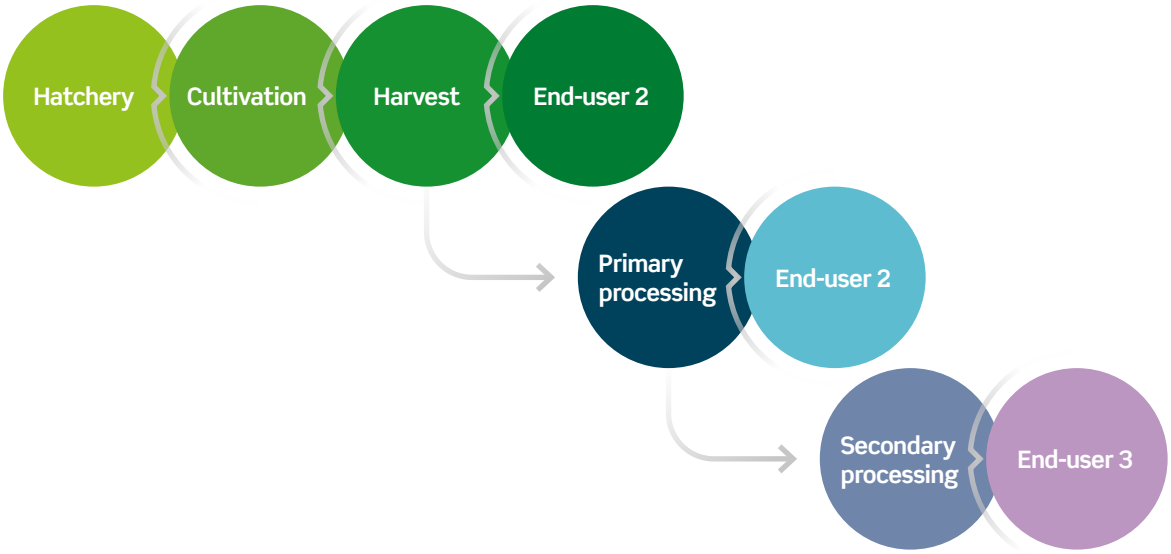

Figure 3 - Different end users in the cultivation value chain

Primary processing

Value chains typically involve an initial primary processing step, e.g., washing; chopping and grinding; de-watering; drying; ensiling; freezing or other stabilisation methods. 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. Preserving seaweed by fermentation has been successful and is increasingly used by seaweed producers, where larger volumes of biomass are being handled in a short space of time. However, challenges exist in controlling the fermentation process leading to unpredictable product quality, which may limit its use in food and feed applications. The increasing demand for seaweed extracts in food applications draws attention to role of preservation by fermentation. Freezing is an alternative but costly option.

Secondary processing

Traditional seaweed value chains have targeted the production of a refined material for a single application. The pre-treatments or primary processing steps mentioned above 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.

Processing capabilities influence choice around compounds to be extracted. With limited processing capabilities as currently exist in Ireland, 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.

Biorefinery for cultivated seaweed

Biorefineries convert biomass/organic matter into a variety of end products for use as food, feed, chemicals, biomaterials, and fuel. They employ multiple technologies to deliver ranges of product streams in a cascading and/or integrated approach. An 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.

The challenge to realise a concept of seaweed biorefining is quite substantial, since these biorefineries are less advanced than those using terrestrial sources of biomass, pointing to need for more study on the design of efficient processes. Despite the global commitment of funds totalling €49.8 million over the past 10 years to seaweed biorefining, biorefineries remain in their infancy; and whilst they show promise, they are slow to move from laboratory scale to industrial scale.

A EU funded study commissioned by BIM on scoping a biorefinery concept for Ireland provides a detailed overview of various biorefinery models and potential product streams for key market sectors. 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.

Seaweed biomass availability

Seaweed cultivation at a scale that justifies cascade type biorefining requires high volume material input. Figure 4 indicates the potential 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 15 tonne/ha (as reported for *Saccharina latissima*). Increasing the current licenced sea area of 254 ha by 25 percent/annum over 10 years to an area of 2,365 ha could support the production of 35,500 tonnes of biomass.

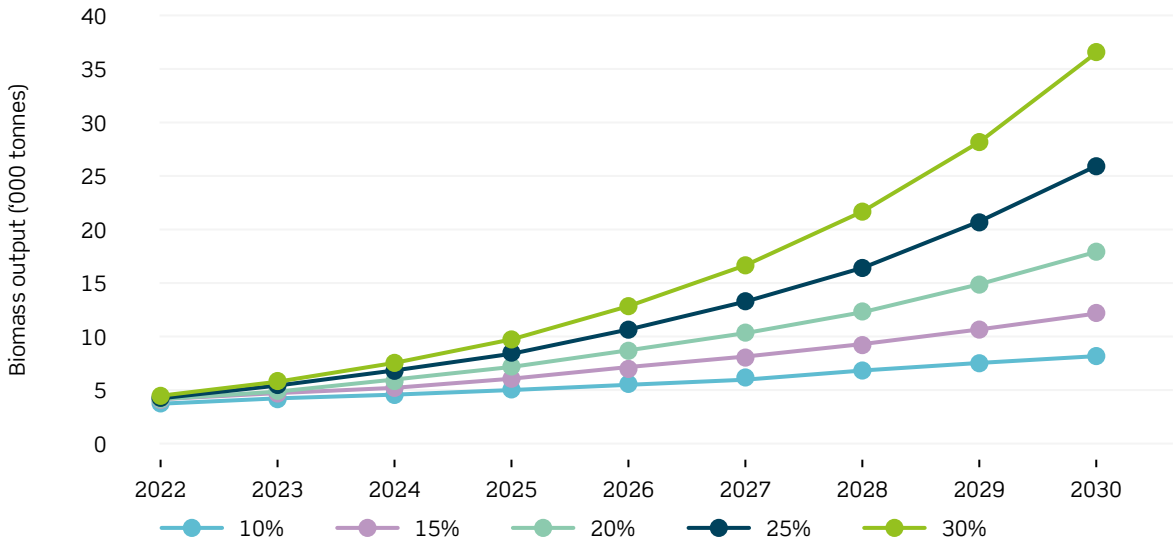

Figure 4 - Projected cultivated biomass output

Markets for cultivated seaweeds

European consumer demand for seaweed is increasing. The European seaweed market is worth €840 million, compared to a global value of €8.4 billion. Seaweed aquaculture has emerged as the prime response to this increased demand, providing traceable, high quality and predictable yields, whilst at the same time avoiding any over exploitation of wild stock.

The current supply of seaweed does not meet European demand and Europe (as a whole) imports 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 5. Europe consumes 10 percent of the global seaweed output.

Table 5 - Import and export of seaweed and microalgae in Europe in 2020. Volumes in 1000's tonne (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

The focus of European seaweed aquaculture activity 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.

Seaweed market segments

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.

Many skin care, cosmetics and health and wellness products incorporate seaweed derived compounds. 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.

Figure 5 shows the 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 support the production of cheap biomass to supply very high -volume, low-value markets like biofuels and platform chemicals.

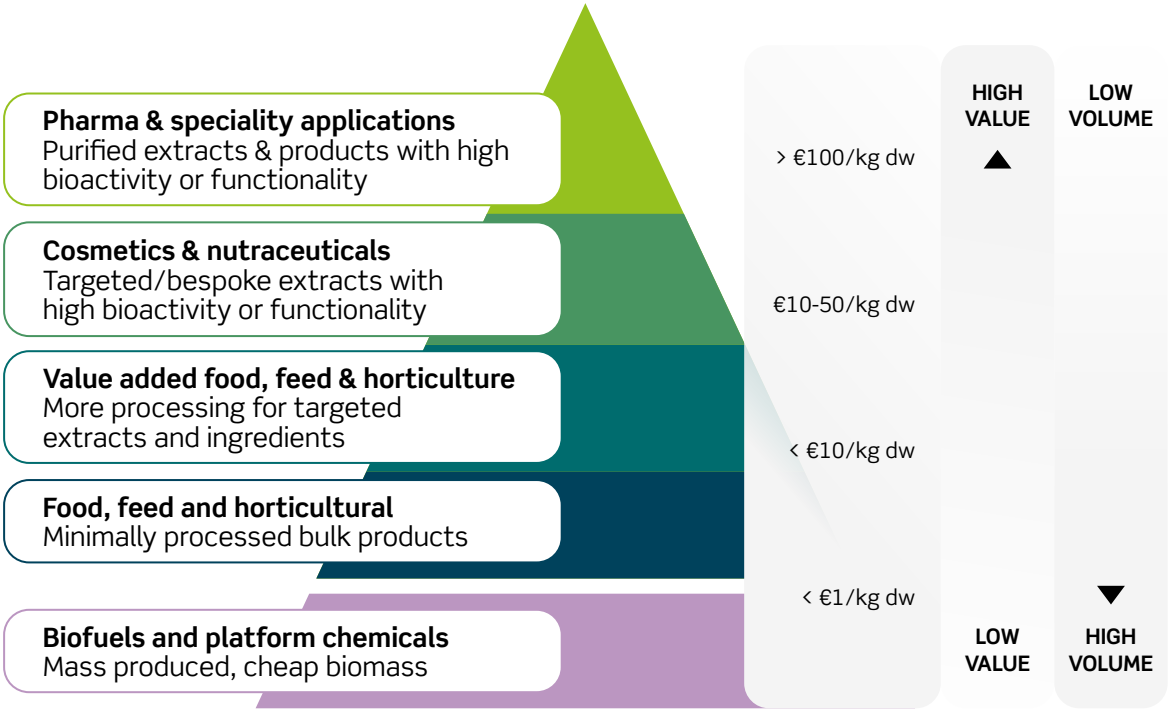

Figure 5 - Value pyramid for seaweed derived products

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 for seaweeds are not widely available. There is a critical need for more sector specific analysis to profile the demand, drive the industry forward, and build confidence. Global market reports provide an insight to seaweed product areas and broad estimates of their potential market value. A summary of major market areas/applications is provided below.

Biostimulants and liquid extracts

Estimates of a global market for biostimulants of €2.66 billion by 2022 exist, with seaweed-based products accounting for over 30% of that market by value (i.e. around €900 million). Europe will remain as the major market for biostimulants in general (>€1 billion) and for seaweed-based products (€369 million).

Animal nutrition (feed, aquatic and pets)

Kelps constitute the main source seaweed based feed supplements/additives for cattle, sheep, pigs and poultry. The global market for animal feed is projected to reach US$460 billion by 2026. Feed additives valued around €30 billion in 2021 is set to reach US$49.6 billion by 2026. Global pet food sales in 2017 dominated by the US market were €100 billion. There is a rapid growth in the use of seaweed supplements for other animals including horses, dogs and cats. Growth in global market for aquatic feed will continue to rise, reaching €50 billion by 2025. However, 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.

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. There are calls for more detailed studies to fully understand the impact of seaweeds in animals and through the food chain.

Biomaterials and packaging

Increased consumer demand and government policies to reduce the dependency of industry synthetic for packaging materials, are behind the increased worldwide demand for biobased packaging. The global bioplastics market is valued at of €30 billion, inclusive of a global edible packaging market worth US$ 527 million in 2019. Manufacturing capacity, algal biomass supply, technology development and product performance continue to be factors limiting market growth. However, Europe is set to be the main source of films and coatings for use in a variety of food and non-food applications in a market worth €180 million by 2030.

Pharma, health and nutrition

The marine derived drugs market as a sub-set of the total pharmaceutical market could account for sales of US$ 2763.8 million by 2025. Market data relating specifically to seaweed derived compounds are not publicly available. Of the approved drugs, only Carragelose® (Iota-carrageenan) an anti-viral agent for the treatment of respiratory diseases is derived from a seaweed. The use of seaweeds and seaweed derived extracts as supplements and functional ingredients is a growing market. The market is 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. Global markets were estimated to reach US$37 billion and US$25 billion, respectively, in the next five to six years.

Cosmetics

The global cosmetic market inclusive of skincare (42%), haircare (22%) and makeup (16%) – each of which incorporate various seaweed extracts 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. Increased consumer demand for environmentally sustainable products and products that fit within life-style aspirations drive growth in the sector. Analysts suggests that the cosmetic industry is a market in expansion in which product innovation around natural based products is a priority. as consumers seek out. Notable developments in the sector relevant to the use of seaweeds, include research designed to identify novel compounds, including from seaweeds, to replace the use of synthetic materials in cosmetics.

Food, food ingredients and hydrocolloids.

Food use is the largest market for cultivated and wild harvested seaweeds. The global seaweed market for human consumption, including hydrocolloids, was €8 billion in 2018, with most (89% by value) used as food; with the remainder (11% by value) destined for hydrocolloids production
The European seaweed market for food (excluding hydrocolloids) could reach €2 billion by 2030. The nutritional properties of seaweeds – fibre, proteins, fatty acids, vitamins, and minerals make them attractive to the food sector as an alternative food source. The food market is set to dominate future seaweed consumption, with demand from Europe for seaweed-based products outperforming growth in other regions. Europe is unlikely to satisfy local market demand for seaweed products due to limited supply; this constraint will lead to increased imports and higher prices in the European market. At best, European production may satisfy 30% of the market demand by 2030.

Findings from the strategic review

Multiple sources, including most of the Irish seaweed growers, processors and customers of seaweeds, including processors of wild harvested seaweed, government departments, state agencies and the research community, contributed to a strategic review of the cultivated seaweed sector. Feedback from this wide constituency and an extensive literature review informed the major conclusions, and hence the framework of a strategic plan.

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; food use being the most dynamic seaweed segment in Europe. Compared to competing European regions such as Norway, where production has increased each year from 2015 to reach 336 tonnes in 2021, Ireland's output lacks scale. Ireland has a licenced area capable of supporting an output of at least 3,810 tonnes.

The strategic review defines multiple actions over the next 10 years relevant to an industry that wants to compete internationally. However, taking immediate action to retain the current growers, attract new growers and to help them to become more productive is a priority. Such actions are needed to enable an incremental growth of the sector, whereby capacity to grow sufficient biomass (through an initial focus on the food and ingredients market) is developed to justify investment in higher value processing capabilities. Immediate actions include;

- Stimulating non-productive licence holders to commence cultivating seaweed;
- Maximising the production output from licensed areas;
- 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 hatchery facilities capable of operating to international best practices, to reliably culture *Alaria esculenta, Saccharina latissima and Laminaria digitata* on behalf of growers and having the competences to develop methods to breed species in demand such as *Palmaria palmata* and other high-value red seaweeds.

Major conclusions from the strategic review fall within seven areas as summarised below.

Structure

The increased interest in seaweed cultivation in Europe created challenges for sector to add value to raw materials. Increasingly, its immediate future is defined as a provider of biomass for high-value added products, differentiated from the wild harvest sector. Doing so however, demands the introduction of new species and processing methods. Above all, the sector must expand its production capability and become more industrialised and competitive within a rapidly developing global industry.

Infrastructure

Significant infrastructural change is needed to enable the sector to develop from what is a largely a collection of artisan producers. Being globally competitive demands a systems approach to deliver changes at all stages in the value chain. Meeting demand for increased seaweed biomass and larger scale cultivation will only be met by adopting new breeding, deployment and harvesting, landing, storage and processing methods.

Market insight

There are many positive trends within global markets for cultivated seaweeds; e.g. market growth, consumer acceptance but exaggerated claims about seaweeds pose a threat. Demand for red seaweeds for use in food and cosmetics, offers greater value-added opportunity than cultivating kelps. The lack of precise market knowledge is a barrier to the development of the sector, this and constraints in biomass production will inhibit the development of new markets and access to supply chains.

Knowledge and research

Growers recognise the existence of multiple scientific and knowledge gaps and that these inhibit development. High on their agenda is a need for access to new species, greater understanding of the properties of species from different sites, different naturally occurring strains and seasonal variation.; all of which is dependent on research effort to develop reliable breeding methods. Collaboration within Ireland's research community under expert leadership can develop the knowledge required to enable growth in the sector, however a precise research agenda must drive future research. 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. A draft research agenda based on these sources is included in Appendix 2.

Regulation

Favourable national and EU policy environments support seaweed cultivation with clear insight to regulations for seaweed derived products. Whereas the national licensing process was once perceived as unresponsive to potential growers, this is no longer the case.

Biomass production

The rate of biomass production in Ireland lags that in other European countries. Unless biomass output is increased Irish growers will not be able to compete. The low level biomass output reflects involvement of new entrants and failure to maximise growing sites by incumbents. Land-based tank cultivation offers scope to deliver "customised" product, with variations in composition and year-round cultivation possible.

Processing

The cultivation of seaweed is a separate activity from large-scale seaweed processing. Except in the case of food use, processing seaweed into high-value products typically relies on dedicated processing facilities. Ireland's cultivated seaweed volumes do not justify such facilities. Introducing new processing technology requires high-volume biomass and clarity on market opportunity to justify the investment. Biorefineries require large scale, reliable and consistent supply of biomass to justify the levels of investment required.

A strategy for the Irish Seaweed Aquaculture sector

As part of the analysis carried out in the *Strategic Review of Irish Macro Algae Cultivation*, a range of actions were identified. These were informed by the findings from an extensive desk study, feedback from the stakeholder engagement, and the analyses as outlined earlier.

The actions fall into three pillar areas, each of which comprises four strategy themes as shown in Figure 6 - Emerging thematic areas grouped within strategy pillars.

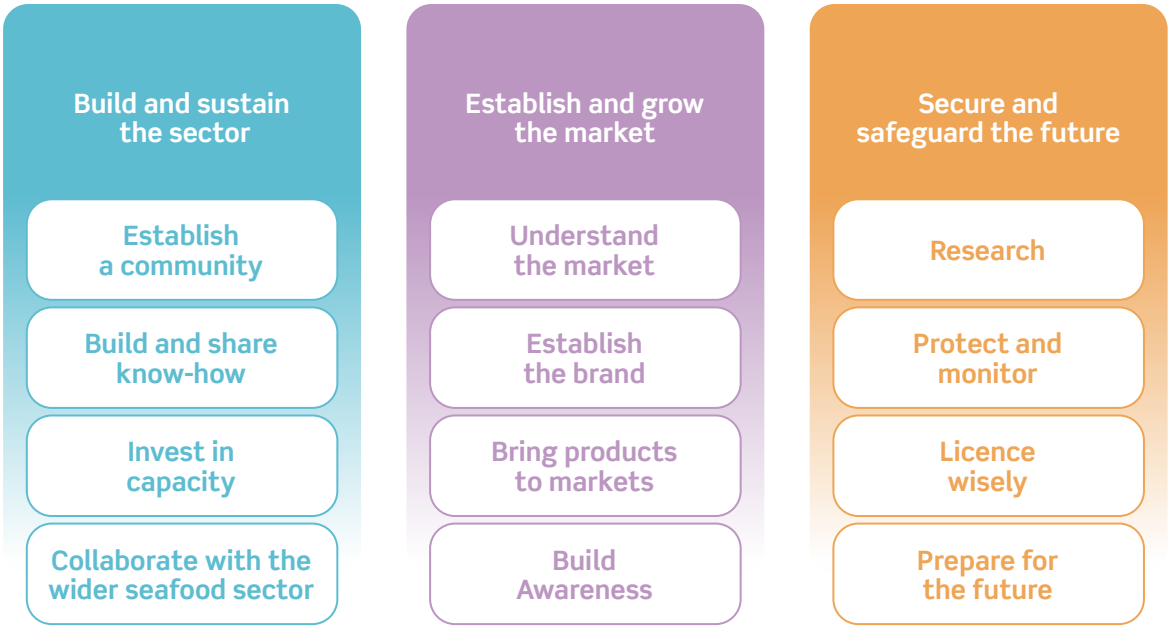

Figure 6 - Emerging thematic areas grouped within strategy pillars

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 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 (nutrients and or actives) 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.
5. Carry out pilot studies into the co-location of seaweed aquaculture with established sea food production.

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* and *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 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 whole seaweeds, processed 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 involving seaweed cultivation include those such as such as bio remediation and carbon capture. These are not mutually exclusive from commercial projects which grow crops for harvesting – 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.

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 of the Strategic Review as a draft *Research Agenda for the Irish Seaweed Aquaculture Sector*; under the research themes of cultivation, composition, biomass production, biosecurity, processing, environment and consumer/community attitudes.

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. Recognise 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.

Licencing 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 licencing of activities must ensure achieving the best possible public-good is achieved. As such, licencing 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 licenced sites are sustainable in both environmental and business terms. Ultimately, a robust licencing 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. Some can be considered relevant to the pre-application stage where potential growers interact with the Department before submitting a licence.

Actions in this area may include:

1. Provide a mechanism to ensure that applicants for new licences have business plans and that consideration of the quality of business plans forms a substantial part of the licence evaluation process.
2. Provide mechanisms to allow active growers seeking more licenced 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.
4. Ensure there is strict adherence to a principal of “use it or lose it” to discourage prospecting and ensure area is available for active growers.
5. Strictly enforce the requirement to accurately identify and name all species to be cultivated in licence applications, using scientific nomenclature.
6. Ensure that a justification is provided for the inclusion of a species, the prospects for successful growth and the market it is intended to serve. Require a risk assessment for novel or exotic species.
7. Include licence conditions designed to mitigate the risks (if any are determined to exist) of novel or exotic species cultivation.
8. Promote applications in sheltered areas “an 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).

Timing and implementation

Three levels of maturity for the seaweed aquaculture industry exist: 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). The growth curve in Figure 7 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.

This implies that by 2032, Ireland should be in a position to produce 1,000 tonnes per annum, assuming an annual growth rate of 30%. More aggressive growth would enable these levels of production to be achieved in a shorter timeframe.

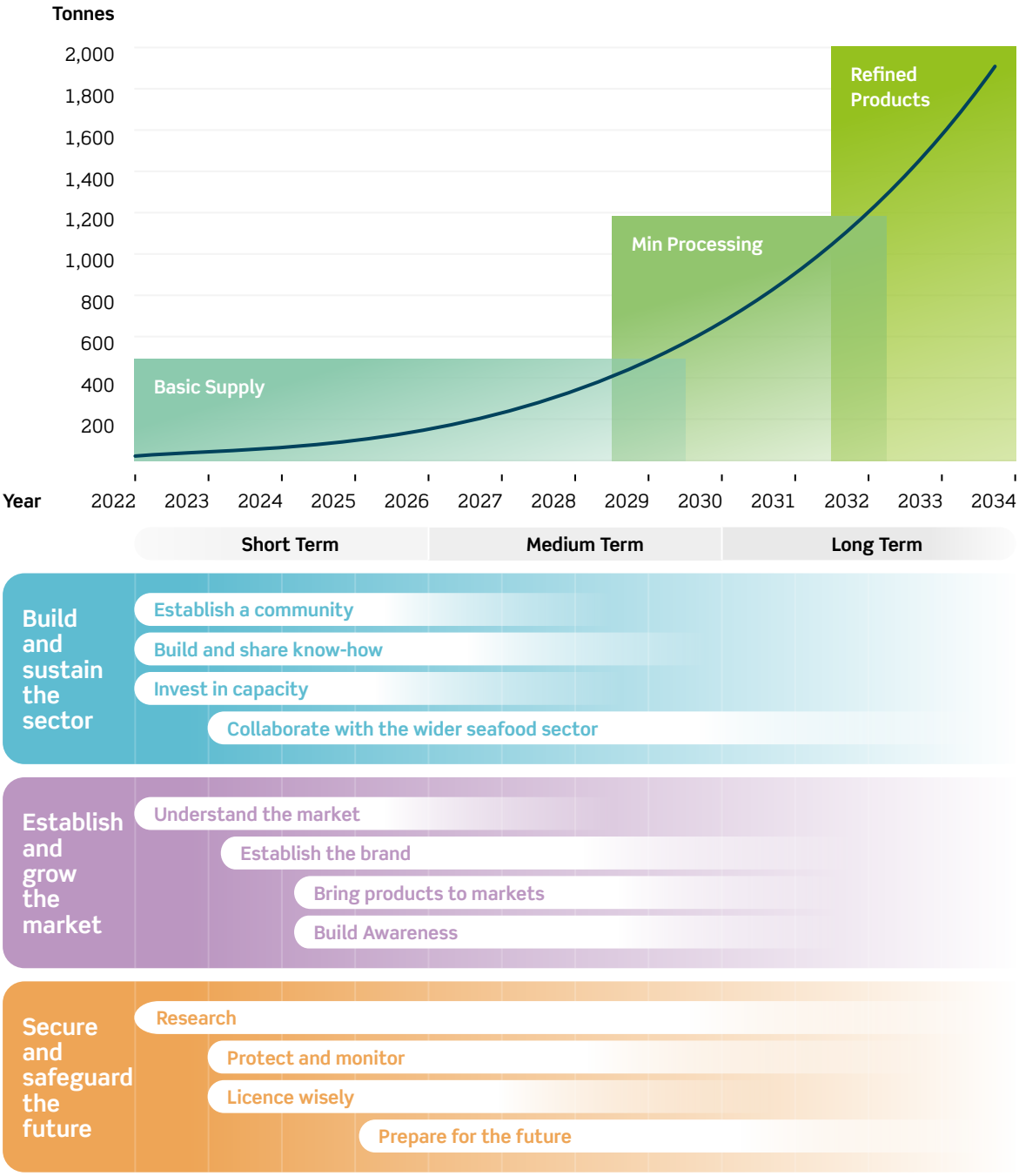

Figure 7 - Actions compared to desired growth

The actions proposed under each of the strategic areas fall within the short-term (1-4 years), medium-term (4-8) years and long-term (8-12 years). Figure 7 illustrates how time frames map to the maturity levels; and shows that each of the proposed actions need to start sooner rather than later.

Appendix 1
List of consultees

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.

Name	Organisation
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
Seamus Sheridan	Sheridan's Cheesemongers
Dagmar Stengel	National University of Ireland, Galway

Appendix 2
A draft research agenda for the seaweed aquaculture sector

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.

E info@bim.ie
W www.bim.ie
T 01 2144100
@bordiascmhara