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Department of Agriculture, Food and the Marine

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Foras na Mara
Marine Institute

Socio-Economic Study of
Seaweed Harvesting in Ireland

This Report was prepared by:

The Clean Technology Centre and the Circular Bioeconomy Research Group, MTU and Benton Ecological Solutions and Technology

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The Marine Institute seeks to assess and realise the economic potential of Ireland's 220 million acre marine resource; promote the sustainable development of our marine resources through strategic funding programmes and essential scientific services; and safeguard our marine environment through research and environmental monitoring. The Marine Institute provides technical and scientific support to the Department of Housing, Local Government and Heritage (DHLGH) to develop Ireland National Marine Planning Framework (NMPF) and implement Directive 2014/89/EU - Establishing a Framework for Marine Spatial Planning.

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Acronyms

Included below are some of the most commonly used acronyms in this report:

ANPG	Ascophyllum Nodosum Processors Group *
DMAPs	Designated Maritime Area Plans
GES	Good Environmental Status
IMTA	Integrated Multi-Trophic Aquaculture
MAC	Marine Area Consents
MAP	Maritime Area Planning ACT
MARA	Maritime Area Regulatory Authority
MPA	Maritime Protected Areas
MI	Marine Institute
MSFD	Marine Strategy Framework Directive (EU)
NMPF	National Marine Planning Framework
NPF	National Planning Framework
SAC	Special Areas of Conservation
SPA	Special Protection Areas
SRA	Southern Regional Assembly

* ANPG is made up of the following national processors in Ireland: Arramara Teoranta, BioAtlantis Ltd., Brandon BioScience Ltd., Oileán Glas Teoranta and Ocean Knowledge Ltd.

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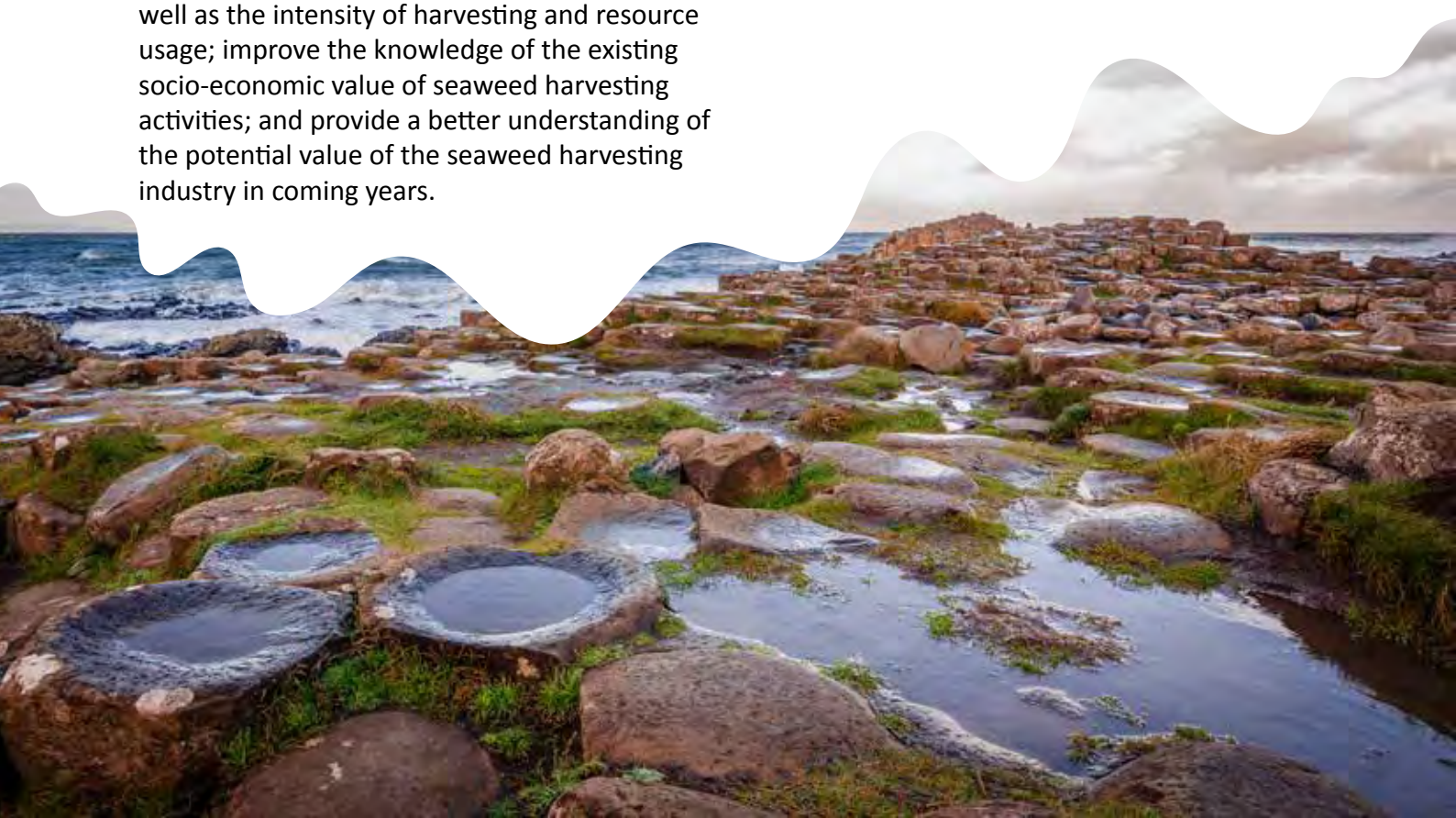
Executive Summary

This Socio-Economic Study of Seaweed Harvesting in Ireland aims to provide baseline socio- economic information regarding seaweed harvesting activity and product usage in Ireland today. This will inform the development of national policy for the sector through providing important background information to support Ireland's National Marine Planning Framework (NMPF). The NMPF highlights the increasing number of indigenous companies who are working in the seaweed sector developing and supplying high value products from harvested seaweed into international markets. Security of supply is important for the future production of high value products derived from the processing of seaweed, and this needs to be done with due regard for the resource while also ensuring that the rights of those who can harvest seaweed are respected. The NMPF also states that growth of the seaweed industry, which provides employment and a positive economic contribution to coastal communities in rural Ireland, must be balanced against ensuring that the level of seaweed harvesting is sustainable and is capable of continuing replenishment and availability of this natural resource for future generations. Therefore, this project aimed to provide information on the current and future spatial distribution of harvesting as well as the intensity of harvesting and resource usage; improve the knowledge of the existing socio-economic value of seaweed harvesting activities; and provide a better understanding of the potential value of the seaweed harvesting industry in coming years.

While there have been various studies and publications that provide estimates of the tonnages harvested, the number of people employed, the types of seaweed used and the extent of the processing involved, gathering this information can be challenging due to the fragmented nature of the sector. Initially, the project team compiled a detailed industry database that identified the main processors nationally. As these are a key link between raw material harvesting and the final seaweed based products, they are an invaluable source of information on all aspects of the sector. Though in-person interviews with harvesters and processors had been planned, due to the limitations imposed by COVID, and the difficulty in getting in contact with harvesters remotely, the project team identified the national processors as a key information source to explore. Through a structured surveying process, 36 national processors were interviewed and a range of socio, economic, spatial and sectoral data was gathered and collated. Subsequent interviews with a number of harvesters provided supplementary quantitative and qualitative information on the sector. The methodology employed for this data gathering exercise is outlined in Chapter 2.



Irish Seaweed Harvesting Sector

Chapter 3 outlines the findings regarding the harvesting of seaweed in Ireland. This includes information o`n the make up of the harvesting sector as well as the distribution of seaweed harvested, by volume and type. It is estimated that there are currently ~270 harvesters that are consistently involved in harvesting wild seaweed nationally, primarily on a part-time basis. Though there are many others that forage for personal use, or for local small scale commercial activities, these individuals do not contribute significantly to the tonnages collected.

,rofile of harvesters is mainly male, over 50, with those involved largely doing it to supplement household income (rather than it being a full-time commitment). Just under 35,000 tonnes are being collected annually with *Ascophyllum nodosum* accounting for 98% of this by weight. The majority of the volume harvested nationally is in the north and west with smaller volumes of a wider variety of seaweeds being collected in southern counties. Based on reported average costs per tonne, the value to those harvesting seaweeds is at least €2.7 million annually with the prices paid, per wet tonne equivalent, varying from €60 - €1,500. On an aggregate basis, the value of *Asco* to harvesters is about €2 million annually (or about 77% of the value for 98% of wild seaweed harvested by volume) while €700,000 was generated for all of the other wild seaweed species harvested nationally (23% of harvester revenue for 2% of the volume of seaweed annually harvested).

With the traditional handed-down nature of seaweed harvesting (with hand harvesting the main method used), it has been noted that the Irish harvesting industry already has in place many of the internationally recognised sustainable management practices that ensure the conservation of seaweed resources. However, with a dwindling number of experienced harvesters (due to age profile), the lack of tacit knowledge of new entrants (traditional techniques and information not being passed to the next generation) and an increased demand (leading to using less experienced harvesters from outside areas), there is a legitimate concern that the resource could become mis-managed quite quickly. Sustainability needs to be achieved through appropriate licensing regimes and associated licensing conditions by regulatory authorities under the Foreshore Act 1933, the Maritime Area Planning Act 2021 and by new Maritime Area Regulatory Authority.

Currently, no standards or register of seaweed harvesters exists in Ireland. While this is complicated by the unresolved issue of managing different rights, and the nature of harvesting in rural Ireland, it is an area that needs to be addressed urgently - for the sustainability of the resource, but also for the preservation of indigenous Irish harvesters. Ultimately, the mechanism by which any regulation is applied must protect the seaweed resources but also ensure security of supply, be equitable and ensure that those with existing harvesting rights can continue to harvest seaweed and that tradition is protected and preserved.

Irish Seaweed Processing Sector

Chapter 4 identifies that the number of businesses involved with processing seaweed into commercial products is between 40 (BIM, 2020) and 58 (this research). Though the sector is primarily made up of SMEs (based on absolute employee numbers), with most employing less than 10 people, there are also a number of larger businesses with the Ascoplyllum Nodosum Processors Group (ANPG) representing 5 of the largest businesses sourcing and processing the majority of brown seaweeds harvested in Ireland (ANPG is made up of Arramara Teoranta, BioAtlantis Ltd., Brandon BioScience Ltd., Oileán Glas Teoranta and Ocean Knowledge Ltd.). There is also one company, which processes almost 70,000 tonnes of imported, calcified seaweed called "maerl" (which is a form of dead seaweed), from Iceland, employing 70. Based on the input from those respondents that participated during this study, it is estimated that there are 359 people, from young professionals to older adults, involved in the Irish seaweed processing sector, with many of these involved in multiple roles which include harvesting, processing and other related work such as R&D, the natural sciences, engineering, skilled trades, quality control, accounting, administration, marketing and sales.

A wide range of products are produced here in Ireland for agriculture, animal and human markets. The largest volumes of seaweed, relating to *Ascophyllum nodosum*, are harvested in the north and west and are used primarily to produce intermediary ingredients for valorising within the state. Most are used to produce high value plant biostimulants[1] for agricultural use with the by-products from this process being sold as low value animal feed or organic fertiliser. The southern region businesses tend to use smaller volumes of a wider variety of seaweeds for the production of high value products for the human health food, cosmetics and beauty product markets.

The value of wet seaweed, which is related to both seaweed type and the final product, varies from less than €1 per kilo to in excess of €10 per kilo. While much of Irish harvested seaweed is already destined for higher value products such as plant biostimulants, there is certainly potential in the further expansion into other, more value-added production options. The current value of the Irish seaweed industry (based on seaweed harvested in Ireland) is estimated at over €45 million, though, when including the one processor using large volumes of imported maerl (calcified seaweed) from Iceland, the revenue is estimated at between €80-90 million.

1 Plant biostimulants are defined by the European Commission (Regulation (EU) 2019/1009) as inputs to stimulate a crop's natural nutrition processes, aimed solely at improving the crop's nutrient use efficiency, tolerance to abiotic stress, quality traits or increasing the availability of confined nutrients in the soil or rhizosphere

The use of cultivated seaweed is still, relative to the volume of wild harvested seaweed, very small (estimated at ~80 tonnes). While there is significant interest in exploring this area for growing a variety of seaweed species, including kelp, it is still under-resourced (in terms of research and direct support). It is also hindered by the lack of responsive licensing as well as with technical difficulties associated with the cultivation of seaweeds in exposed environments and limitations on species that are important to the existing processing sector, such as *Ascophyllum nodosum,* which cannot be easily grown in an aquaculture setting due to life-cycle or demographic characteristics.

That said, the processing of seaweed is a growing industry in Ireland and, with the benefits and different uses of various seaweed species being continually explored, it is anticipated that the sector will continue to evolve in the coming years. It is likely that this change will see a shift away from predominantly agricultural based products towards ingredients for human use and with this it is likely that the provenance of seaweed supplies will come into greater focus. Seaweed has traditionally been sourced in Ireland from wild sources and with the growing importance of sustainable supply chains, transparency in this regard will become an important aspect of premium seaweed-based products.

Similar to the case of harvesters, processors of Irish sourced seaweed (other than those cultivating it) are availing of a wild and public resource. Up to now, there has been no requirement for processors to apply an Irish quality standard to the seaweeds they accept or the seaweed based products they sell. However, most companies that produce extracts for animal feed or plant biostimulants already have quality and sustainability standards in place to comply with EU regulatory standards and requirements. Therefore, to ensure that our local supplies are protected, that the true value of sustainably sourced Irish seaweeds are achieved, and that businesses and local Irish communities can benefit from this emerging market, it is imperative that consistent standards are introduced.

Barriers to the Expansion of the Seaweed Industry in Ireland

From information received from surveying both individual harvesters and processing businesses, in combination with research conducted by the project team, the following barriers to growth have been identified and categorised within four broad areas. These are detailed in Chapter 5, and are summarised below:

Institutions & Policy

By far the most frequently mentioned barriers were those related to the difficulties with the current regulatory system associated with licences for harvesting, reporting of harvested seaweed and the lack of Irish product quality standards and regulation (though companies producing seaweed extracts for animal feed or plant biostimulants are already adhering to EU regulatory standards and requirements in relation to product quality and organic certification). The lack of a formal national policy on sustainable seaweed harvesting is also frequently mentioned as an impediment to the development of the industry and causes significant delays in the prioritisation and assessment of license applications. These barriers have hindered investment in the sector due to the uncertainty that they create in terms of supply security and consequently the ability to expand markets. Additionally, the current disjointed nature of institutional support and regulation hampers development and oversight of the sector.

Materials & Technology

This group of barriers consists of concerns about the lack of reliable and consistent supply of seaweed due to the declining number of harvesters, seasonality, climate change and sustainable management of existing wild seaweed areas, including the lack of oversight and regulation of existing seaweed harvesting. It also includes barriers related to harvesting methods and mechanical harvesting equipment as well as processing technology- from energy efficient drying to the extraction of various compounds or ingredients from cascading biorefinery systems. For businesses who have invested substantially in R&D, extraction technologies and facilities, including those of ANPG, the primary concern is having a guaranteed sustainable supply of seaweed to ensure further expansion, business development and job creation.

Economy & Growth

Barriers in this category include the economic viability of hand-harvesting of seaweed by individuals given the low prices paid for seaweed biomass; the ability to generate a profit, (especially for small or start-up businesses where processing or manufacturing costs are increasing lately due to higher energy costs); the difficulty in increasing seaweed supply from farmed sources, mainly related to the slow and onerous permitting process, and finally, a lack of guaranteed supply of seaweed for companies due to licensing issues.

Knowledge & Networks

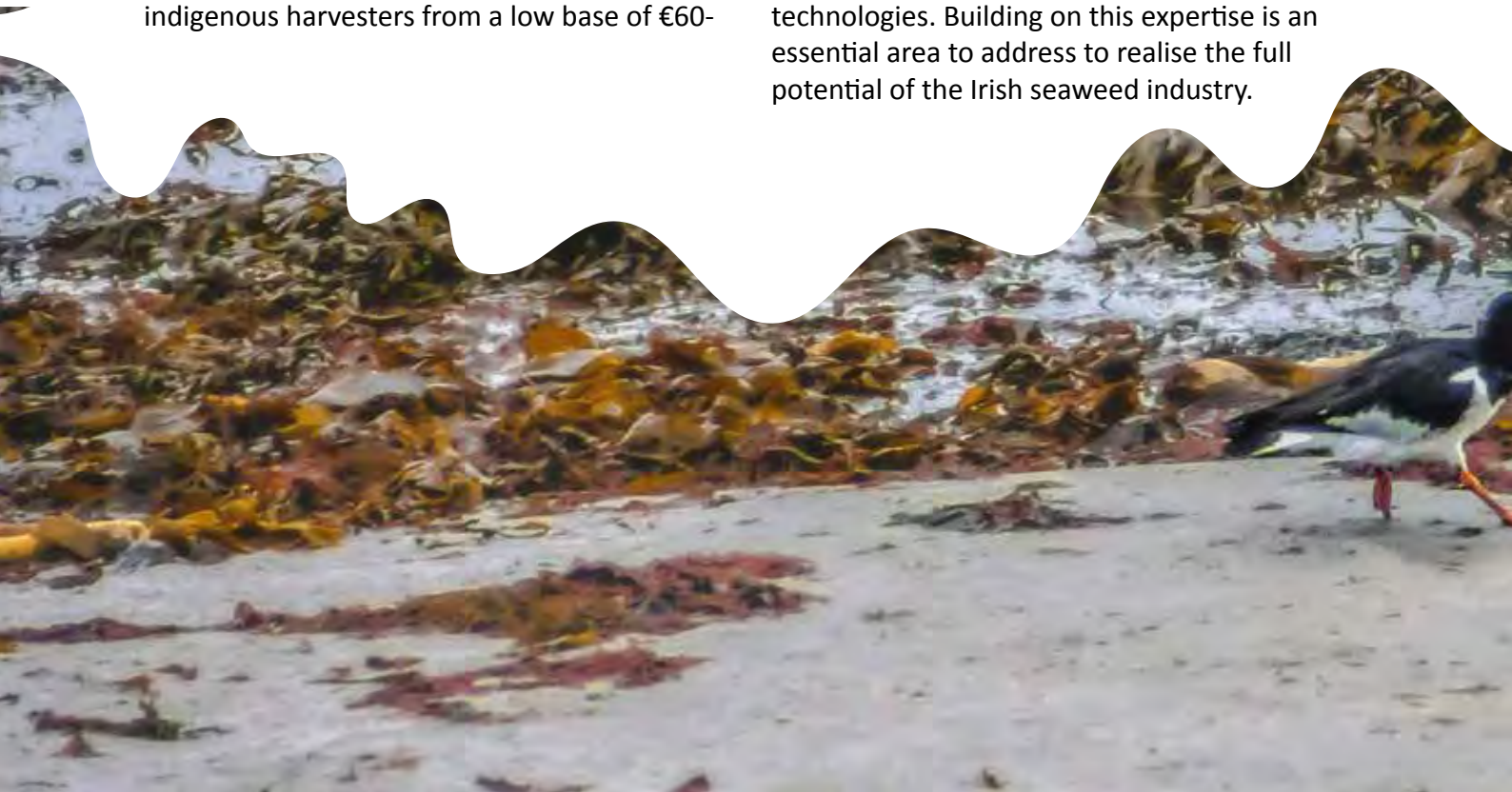
Barriers within this category included the lack of cooperative processing facilities or marketing organisations (for both individual harvesters and small processors) to reduce overhead and capital investment; the lack of a national seaweed forum for sharing information and R&D within the industry; a lack of knowledge regarding potential markets, other processors and prospective suppliers; and the lack of an industry or trade association for sharing expertise and providing training opportunities for continued professional development.

Potential Growth of the Irish Seaweed Industry

The opportunities for growing the Irish seaweed industry are also explored in Chapter 5. While Ireland's marine industry had an estimated turnover of €5.8 billion in 2018, providing employment of ~32,000, seaweed harvesting and processing is a relatively small overall contributor, for now. With the emerging technologies and business models of the circular bioeconomy, there is potential to unlock and transform Ireland's seaweed-based economy into a highly innovative diversified sector underpinned by new bio-based value chains. Potential opportunities identified include nutrition, cosmetics, pharmaceutical, biomaterials, agri-biotech and biostimulants, high value animal and human feed/food applications, and commercial application of seaweed based bioremediation.

Exploiting these options has the potential to further increase the value of seaweed use by processors in Ireland. By changing from current markets (e.g. such as selling dried seaweed meal for animal feed or organic fertiliser) to the higher value emerging markets (e.g. biostimulants, dietary supplements, animal and human health products, medicine and cosmetics) revenue per kilo processed could be increased significantly. This in turn would positively impact the income received by our indigenous harvesters from a low base of €60-200/wet tonne to €500-1,500/wet tonne. As prices for harvested seaweed are inevitably linked to the markets that companies sell in, a greater emphasis on high value uses and processing, and the markets targeted, would have a whole sector impact. This would provide opportunities in terms of the revenue generated for processors but also, and more importantly, generate more income for those involved in the harvesting sector.

The introduction of a national sustainability charter or standard would further increase the value of the seaweed biomass, whether harvested or cultivated, and further support the scaling of the Irish sector into the new value chains identified in this report. In addition to these options, this study identified a need for more research on the composition of all Irish seaweeds, enabling a comparison of the potential of different seaweeds in a consistent manner. This is particularly relevant for those components which have potential in the industrial applications outlined above, such as bioactive components. Irish industry, in collaboration with national and international research partners have conducted extensive R&D on the composition of Irish seaweeds in recent years and are among some of the leading experts in plant biostimulant and animal feed technologies. Building on this expertise is an essential area to address to realise the full potential of the Irish seaweed industry.



The future development of the industry must address the existing issues regarding stability of supply to all involved in the seaweed industry, whilst also remaining aware of the threats posed by over-exploitation of seaweed and habitat degradation due to harvesting activities, invasive species and climate change. In terms of supply, there are three main options, each of which will require consideration and investment. These are:

- Diversify the use of current supply – this builds on our existing supply but targets a shift from lower value products towards a greater emphasis on existing and emerging high value opportunities.
- Increase the supply of wild harvested seaweeds (both *Asco* and other species) – this is an area of undoubted opportunity. However, given the potential negative impacts for the broader ecosystem, this needs a considered and well researched approach. Additionally, this needs to be carefully regulated and managed to ensure sustainability of seaweed harvesting, in line with Irish policy, EU regulations and our international commitments.
- Significant expansion of seaweed cultivation – given the low relative volumes currently produced here, and the positive impacts that cultivation provides both as a stand-alone venture, and in conjunction with aquaculture or renewable energies, this should be an area of extensive investment. However, as with the other options, expansion needs to be done in a considered manner that allows targeted growth and development of a more resilient and diversified sector, notwithstanding the technical challenges that may exist for seaweed aquaculture in Ireland.

In reality, a combination of these three will most likely be required. Supporting the scaling and diversification of the industry requires development in the key areas outlined in the policy recommendations in Section 5.4 and the following framework provides a proposed holistic approach to the sustainable development of the sector.

A Proposed Framework to Support the Development of a Sustainable Seaweed Industry in Ireland

Based on the national and international best practice research on the sustainability of wild seaweed outlined in Chapter 6, it is clear that the creation of best management practice guidelines for wild seaweed harvesting is complex and specific to both the locality and the individual seaweed species. In Ireland, any such locality based approach is further complicated given the issues surrounding shoreline ownership and rights related to wild seaweed harvesting. Additionally, a "one size fits all" approach does not apply in relation to the different types of seaweed harvested and utilised by our growing national industry. Therefore, based on international best practice, and input from interviews with the sector, establishing an iterative framework for the oversight and regulation of wild seaweed harvesting appears to be the most appropriate way to ensure sustainability of the resource now and in future years.

Such a framework should include, as a minimum, the following essential elements:

1. A formal national sustainable seaweed harvesting policy

2. Establishment of geographically defined no-harvest seaweed zones around Ireland for scientific monitoring (both within and outside MPAs)

3. Creation of a transparent and responsive registration, licensing, reporting and regulation system

4. Development of an independent dedicated seaweed research centre

5. Fast tracking the development of a seaweed farming industry

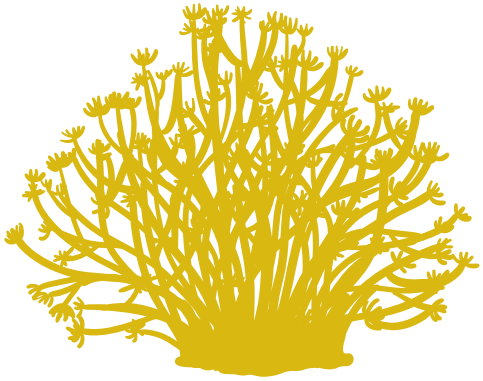
6. Coordination of business supports

These are discussed in detail in Chapter 7 and inform the recommendations outlined below and elaborated on in Chapter 8.

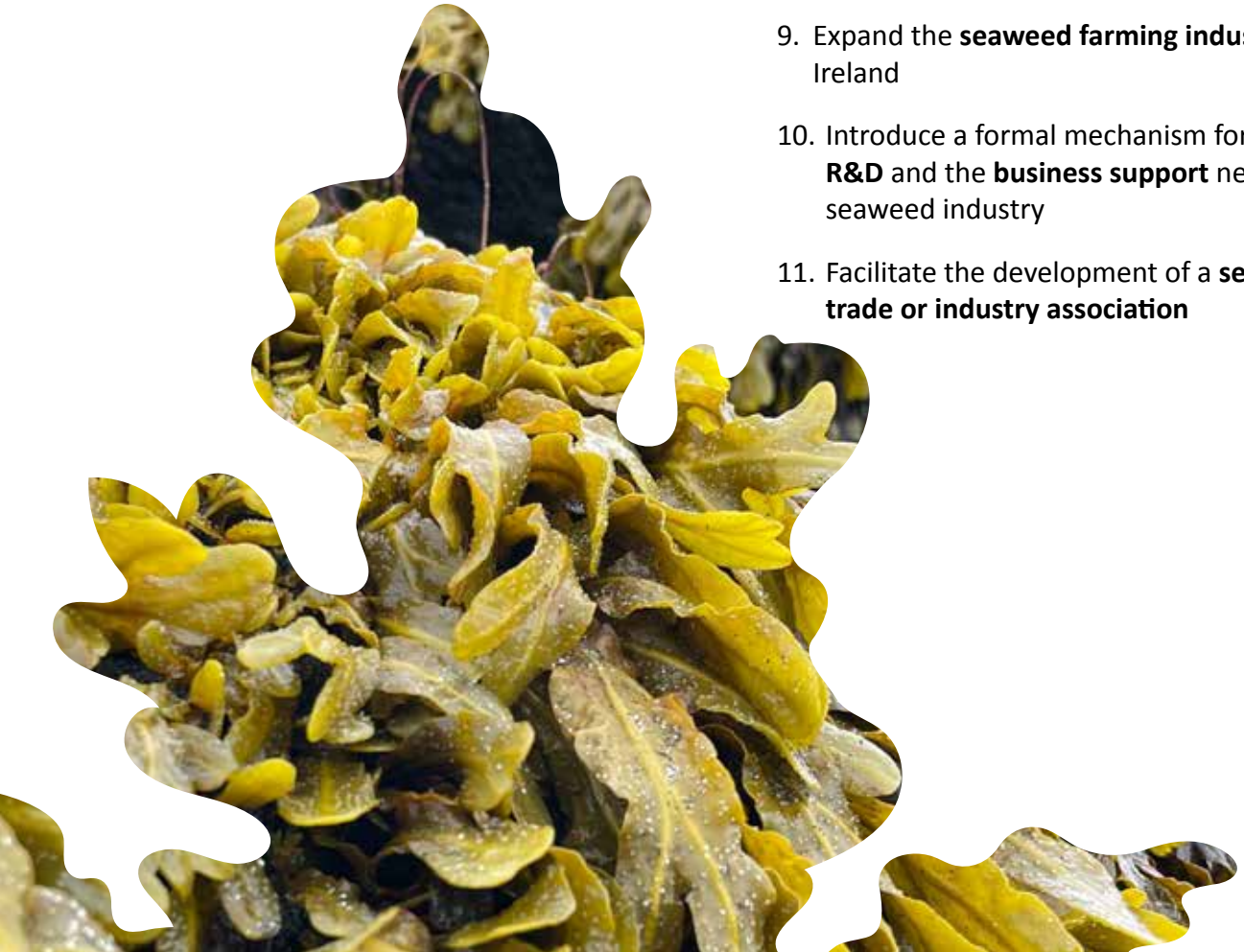
Recommendations for Sustainably Managing Seaweed Industry Growth in Ireland

From the research conducted by this report and the conclusion made about the state of the seaweed industry in Ireland, the following recommendations have been developed for consideration by the industry and policy makers. These are further detailed in Chapter 8 of this report.

1. Develop a formal national **sustainable seaweed harvesting policy**
2. Establish a **voluntary charter** for an agreed upon code of good practice for seaweed harvesting
3. Appoint an **overarching body** to oversee and coordinate all national seaweed industry development including research, business support, regulation and enforcement
4. Develop an ongoing and **consistent mapping** method and monitoring system for seaweed harvesting



5. Create a number of **no-harvest zones** around Ireland to act as seed banks and baseline areas of scientific reference
6. Introduce and establish an **integrated regulatory framework** and system for seaweed harvesting and processing in Ireland and expand the availability of seaweed harvesting licenses to companies that operate within the sector
7. Develop a set of **industry quality standards** and best management practice guidelines to support the development of the seaweed industry
8. Establish an **academic centre of excellence** to support a coordinated programme of targeted research and development (R&D)
9. Expand the **seaweed farming industry** in Ireland
10. Introduce a formal mechanism for **funding R&D** and the **business support** needs of the seaweed industry
11. Facilitate the development of a **seaweed trade or industry association**



Expanding the Potential of the Irish Seaweed Industry in 2022

Status of the sector in 2022

The seaweed industry contributes over €90 million annually to the Irish economy and employs about 700 people.
With the increasing national and international demand for sustainably sourced raw materials, there is great potential to grow this industry, increasing employment opportunities and contributing to local economic development in rural coastal communities. The challenge for Ireland will be to diversify and grow the industry in a sustainable manner. Given the critical roles seaweed plays in our marine ecosystem and fisheries, any expansion of the seaweed industry must be done in manner that ensures this precious public resource is protected for future generations.

The development and marketing of high-value seaweed based products can be achieved through:

Increasing the types and quantities of wild seaweed harvested

Cultivating more farmed seaweed both in-sea and on land

Incorporating seaweed into Integrated Multi-Trophic Aquaculture systems

Regardless of what combination of these occurs, there are a number of key underlying aspects to be considered

2. Potential Uses of Seaweed

A wide range of products are already produced here in Ireland for agriculture, animal and human markets. However, there are a multitude of potential uses for seaweed if support is provided to assess and develop the most valuable and viable markets.

Currently, the largest volumes of seaweed, relating to Ascophyllum nodosum, are used to produce high-value biostimulants for agricultural use with the by-products from this process being sold as low-value animal feed or organic fertiliser.

Smaller volumes of a wider variety of seaweeds are now used for the production of higher value products for the human and animal health, food, cosmetics and beauty product markets.

There is now a lot of investment in R&D developing potential products and markets.

These include:

3. Fostering Industry Growth

There is extensive knowledge and technological expertise in the Irish seaweed industry and, through surveying of seaweed industry representatives, the following areas were identified as being key to supporting industry growth:

An integrated regulatory system for licensing, reporting and enforcement of wild seaweed harvesting regulations as well as for seaweed farming

Product quality standards

Best management practice guidelines for sustainable harvesting and processing to assure a reliable and consistent supply of seaweed

Focused R&D in harvesting equipment, processing technology, potential benefits of use in higher value applications from bioenergy and bio-based materials to cosmetics, nutraceutical and pharmaceutical uses.

Coordinated business supports

Funding for start-ups and for commercialising biorefinery technology

An industry or trade association to share information and support continued professional development.

1. Components of Value

Seaweeds consist of a wide variety of compounds that can be used to create high-value products. Depending on the species, identifying the optimal extraction methods for the most value-added components needs to be supported.

Seaweeds contain a variety of valuable compounds including:

CELLULOSE, PROTEIN, LIPIDS, CARBOHYDRATES, MINERALS, VITAMINS, POLYSACCHARIDES, PEPTIDES, METABOLITES, PIGMENTS, MANNITOL, AGAR, ALGINATE, CARRAGEENAN, FUCOIDAN, LAMINARIN AND ULVANS.

4. Recommendations

To address these challenges and stimulate industry growth, the socio economic report of seaweed harvesting in Ireland suggested the following recommendations:

1. Establish a voluntary charter for an agreed upon code of good practice for seaweed harvesting
2. Appoint an overarching body to oversee and coordinate all national seaweed industry development including research, business support, regulation and enforcement
3. Develop an ongoing and consistent mapping method and monitoring system for seaweed harvesting
4. Create a number of no-harvest Protected Marine Areas around Ireland to act as a baseline for ongoing monitoring and management of seaweed harvesting areas
5. Establish and adequately resource an integrated regulatory framework and system for seaweed harvesting and processing
6. Develop a set of industry quality standards and best management practice guidelines to support the development of the seaweed industry
7. Establish an academic centre of excellence to support a coordinated programme of targeted research and development (R&D)
8. Expand the seaweed farming industry in Ireland
9. Introduce a formal mechanism for funding R&D and business supports needed by the seaweed industry
10. Facilitate the development of a seaweed trade or industry association

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A Snapshot of the Irish Seaweed Industry 2022

The seaweed industry in Ireland is well established and very much part of our national heritage. Protecting this resource is crucial for protecting indigenous harvesters, the local communities that rely on it, the businesses that are creating value-added products from it and, most importantly, the wide biodiversity seaweed sustains within our coastal ecosystems.

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Wild Seaweed Harvesting in Ireland

Seaweeds are mainly harvested by hand or harvested using a boat and rake method.

98% of the seaweed harvested is *Ascophyllum nodosum (Asco)*, a brown wrack type seaweed used for production of biostimulants, animal feed and organic fertiliser (about 33,700 tonnes in 2020). These are predominately harvested from western coasts of Galway, Mayo and Donegal.

15 other types of brown, green and red seaweeds, are harvested around Ireland for use in human food, nutrition, cosmetics and beauty products (about 687 tonnes in 2020). These are mostly harvested from western, SW and NW coastal areas

At least 270 people are harvesting seaweed on a part-time basis and supplying it to various seaweed processing businesses, mostly located along the west coast of Ireland.

These harvesters tend to be males over 50, who are using this work to supplement farm or household income.

Prices received for harvested seaweed ranges from €60/wet tonne for Asco to €1,500/wet tonne for edible seaweeds.

The national value of seaweed to harvesters is estimated to be €2.7 million, or an average of €10,000 per harvester.

Revenue from the harvesting of Asco, 98% of all seaweed harvested in Ireland, generated about €2 million for harvesters (74% of annual revenue), while harvesting of all other species or 2% of wild seaweed harvested, generated about €700,000 for harvesters (26% of annual revenue).

The Seaweed Processing Industry

Seaweed processing businesses range from **small artisanal** operations **to large multinational enterprises.**

By volume, **Asco is the most common seaweed** processed into agricultural products; from low-value fertilisers and animal feed, to high-value biostimulants used in horticultural applications.

Other seaweeds are used in beauty (bath leaves, lotions and soaps), cosmetic, dietary supplement, pet food and human food products.

All processors are classed as SMEs with **92%** identified as mico businesses (less than €2 million in annual revenue), 4% small businesses (less than €10 million) and 4% medium sized business enterprises (less than €50 million)

A majority of processors (**81%) focus on producing 1-2 product ranges**

Two-thirds of processors are making intermediary ingredients for other businesses to make into marketable products.

The most common type of seaweed processing consists of drying and milling. Other businesses are using biochemical techniques to extract beneficial compounds.

The processing industry **employs an estimated 429** employees, 84% on a full-time basis.

The value of products sold from Irish harvested seaweed is **estimated at €45 million per year**. When adding revenue from one Irish processing company importing 60-70,000 tonnes of maerl per year from Iceland, the value of products sold from Irish based processors doubles to €80-90 million per year.

The value of processed seaweed **ranges from €1 to €10+ per kilo** depending on the species and type of product produced.

THE SEAWEED INDUSTRY, BOTH HARVESTERS AND PROCESSORS, EMPLOY ABOUT 700 PEOPLE AND CONTRIBUTE AROUND €90 MILLION ANNUALLY TO THE IRISH ECONOMY

1. Introduction

The harvesting by hand of wild seaweed, and its use as a food, animal feed and soil enhancer has been ongoing for centuries in Ireland, and is an important part of the social, economic and cultural fabric of many coastal communities. The increasing demand for seaweed as a raw material in the production of high value products such as plant biostimulants, as well as emerging areas (animal and human health applications, cosmetic & beauty products, biochemical applications and pharmaceuticals), points to an area of great potential economic value. However, seaweed is of critical importance to the wider marine ecosystem so the challenge for the sector's future is to ensure this valuable resource is, first and foremost, protected, while exploring emerging opportunities that ensure continued coexistence with our traditional seaweed harvesting heritage and our indigenous seaweed industry.

Much of the commercial harvesting in Ireland is still done through relatively informal means, by individuals operating on a part-time, seasonal or casual employment basis supplying the Irish seaweed processing sector. Many individuals also engage in seaweed harvesting for personal or small-scale local use. Government policy and formal regulation of seaweed harvesting in Ireland is lacking, with little guidance on allowable species or quantities for harvest. Licences for harvesting are issued in the format of a foreshore licence, which allows the holder to remove 'beach material' from the shore. In addition, traditional rights to harvest seaweed are sometimes included as part of property rights. Given the existing practice of harvesting, the ambiguity in terms of legislation, and the slow pace of the licensing process, the full extent of seaweed harvesting in Ireland is not known – crucial information for developing a coherent overarching policy on the use of this national resource.

It has been estimated that 25,000 - 40,000 tonnes of seaweed are harvested annually in Ireland with the vast majority of this being from wild sources (Joint Oireachtas Committee, 2015,) in the west and north west of the country. Seaweed farming is still only a small contributor to the total harvested with an estimated 40 tonnes used in 2018 (BIM, 2020). However, there is a lack of detailed information and systematic reporting on national harvesting levels to corroborate these numbers and to compare them year on year. Though Irish coastal waters contain a comparatively large number of macroalgae species, commercial harvesting has been largely focused on *Ascophyllum nodosum* with the majority utilised in the manufacture of plant biostimulants and other agricultural products. The high value usage of *Ascophyllum nodosum* in the manufacture of plant biostimulants has provided an excellent basis to date for the development of the bioeconomy in Ireland, which can be expanded further to create new opportunities for Irish coastal communities and the wider development of the bioeconomy. To date, companies that manufacture high-value added biostimulants using Irish brown seaweeds as a raw material, represent the largest employers in the Irish seaweed sector.

Seaweed has significant potential in the animal feed sector, particularly in the development of technologies that modulate the immune system and gastrointestinal microbiome in animals. One of the biggest challenges animal husbandry faces is the overuse of antibiotics which is culminating in the emergence of drug-resistant diseases that infect humans. Irish industry and academic researchers have collaborated to identify bioactives in seaweed that modulate the immune system in animals. This has led to the development of a maternal

immunity transfer technology that can replace the need for in-feed antibiotics and zinc oxide in pig and poultry. This is a significant market both nationally and internationally.

The emerging food sector, while still a relatively small market, has a significant demand for the hydrocolloids present in seaweed, such as alginate which is used as a thickener and gelling agent. This is not an established activity in Ireland, with most alginate coming from red seaweeds harvested in Asia. The artisan food and culinary sectors in Ireland are a key market for edible seaweeds with use in cheeses, breads, haute cuisine ingredients and garnishes.

The use of seaweed extracts in the cosmetics sector is well established, with a number of Irish firms actively involved. The interest in marine ingredients for this sector is increasing significantly given the movement for clean and natural beauty products. Underpinning scientific efficacy data of marine actives such as fucoidan, laminarin and polyphenols are fuelling development of anti-inflammatory, antioxidant, anti-wrinkle, skin-soothing and anti-tyrosinase applications and products. This is creating significant interest in and demand for potential seaweed derived actives and ingredients.

There is also increasing interest in the potential use of macroalgal derived molecules in regenerative medicine applications, such as bioscaffolds for bone and cartilage repair. Research has also shown that seaweed is an important source for producing gums, alginates, agars, carrageenan and other compounds that can create animal probiotics, anticoagulants in blood products, and bio-active substances for human nutrition and regenerative medical treatments to improve immunity, treat skin disorders, stimulate bone repair and strengthening and ameliorate digestive functions. There is also growing interest in the use of seaweed compounds in creating biopharma products.

Seaweed has been assessed as a co-digestate in anaerobic digestion and research has also been carried out to assess the nutritional value of various macroalgae species in animal feed (Bikker et. al., 2020). Recent work on red algae in cattle feed has identified that the inclusion of *Asparagopsis spp.* in the diet of cattle may significantly reduce methane emissions from digestion (Brenna et al., 2019). However, bromoform, the active compound in *Asparagopsis spp.,* may face regulatory scrutiny before it is approved for use in animals.

In addition to harvesting for the production of products, seaweed provides indirect economic benefits through its inclusion in activities such as foraging walks, marine biology education programmes, seaweed baths and as ingredients used by local food businesses. These benefits contribute to employment but also to cultural richness of many small communities in the west of Ireland. However, regardless of where the future of the industry goes, and what progress is made in these areas, there are a number of factors that must be addressed.

Seaweed harvesting plays an important role in the culture and economies of many rural Irish communities with over 270 harvesters supplying seaweed processing businesses, from micro to SME scale operations throughout Ireland. However, the age profile of seaweed harvesters is heavily skewed towards older workers with only a small percentage of harvesters under the age of 30. The industry has experienced difficulty recruiting younger harvesters due to the challenging nature of the work and the draw of more lucrative opportunities in urban centres (DHLG, 2019). Without a re-think of the sector, the supply of seaweed (be it wild or cultivated),

through a lack of qualified harvesters, could limit any prospective growth areas. However, by adding value to the resource in Ireland and selling high value-added products on the world market, companies will be better positioned to pay a higher price for seaweed as a raw material and in turn, expand job creation in rural and coastal areas of Ireland.

Most notably though is the growing appreciation of the importance that seaweed plays in the totality of the marine ecosystem and its potential contribution to mitigating climate change. Macroalgae play numerous ecological roles that are vital to the health of the coastal ecosystem. Kelp forests, formed in Irish coastal waters primarily by *Laminaria digitata* and *Laminaria hyperborea*, are regarded as one of the most biodynamic and ecologically diverse habitats (Kelly et al., 2005). Similar to other marine areas, seaweed beds provide an essential habitat for a diverse range of organisms, including juveniles of many commercial fish species. Other marine areas that provide habitat for a marine species include: soft bottom areas, shallow open water, saltmarsh, seagrass, oyster reefs, mussel beds, rocky shores (Seitz et al., 2014) and deep water areas (>30m depth). It is imperative that marine habitats, including seaweed resources, are managed in a way that minimises impact to the coastal ecosystem and ensures the continuation of this vital natural resource.

It has been suggested previously that the tonnage of *Ascophyllum nodosum* harvested could be doubled or even tripled without compromising the sustainability of the resource into the future (ANPG 2019). This extra volume of seaweed could obviously support the expansion of existing businesses and create opportunities for new business ventures, both by creating jobs and adding to rural economic development and growth. To drive this expansion, there is an urgent requirement for the introduction of government policies on sustainable seaweed harvesting. However, any significant expansion of the harvesting of existing wild seaweed stocks should not take place without improved knowledge of existing seaweed stock, the extent of wild harvesting activities, the distribution of the processing sector, and consideration of international best practice in the management and protection of the resource. This will ensure that the sector can grow in a sustainable manner while also protecting this essential national marine resource.

1.1. Current Regulatory & Planning Framework

The harvesting of wild seaweed by hand, and its informal collection from coastal beaches, has been a part of rural living in Ireland for hundreds of years. Seaweed has been, and continues to be used, on a small-scale basis as animal feed, fertiliser/soil amendment and also as a source of food. However, with the development of commercial uses for seaweed, the dynamic of seaweed harvesting changed from a predominantly personal use to it also becoming a source of income. Arramara Teoranta was established in 1947 in Connemara to process *Ascophyllum nodosum* (*Asco*). It established a network of harvesters that it purchased *Asco* from and this became the main seaweed species processed in Ireland up until more recent times when the potential of other seaweeds has become more apparent. In all cases, *Ascophyllum nodosum* still remains the most commercially viable intertidal seaweed in Ireland today.

However, throughout the ongoing evolution of the seaweed harvesting/processing sector in Ireland, the underlying issues associated with historical rights and new licences have remained

challenging. An individual right to harvest seaweed may be related to a property (folio right) or built up through harvesting from the same area over a period of time (Profit à Prendre) and the process of registering such rights on a property folio is a matter for the Property Registration Authority (PRA). Where such existing formal or informal rights to harvest seaweed exist, there is no requirement to have a licence under the 1933 Foreshore Act and neither can any other entity be licensed to harvest in that area. Outside of these areas, a licence to harvest seaweed is required from the Department of Housing, Local Government and Heritage under the 1933 Foreshore Act. While there are over 9,500 registered folios that contain a reference to 'Seaweed' there is also the issue of local informal harvesting rights which remain unregistered but are very much seen by those involved as "legal" rights. Consequently, this is a complex and emotive area and this is reflected in the fact that, though a number of applications for the commercial harvesting of wild seaweed have been made, very few applications have been approved by the Minister (DHLGH) since March 2014.

While this ongoing licensing issue has recently been considered by the Attorney General, the Maritime Area Planning (MAP) Act of 2021 includes provisions to establish a separate agency to manage, among other things, the licensing of (traditional) seaweed harvesting. This is an important development which will, for the first time since the introduction of the 1933 Foreshore Act, shift oversight and responsibility for the harvesting of wild seaweed from DHLGH to an independent agency. This agency, the Maritime Area Regulatory Authority (MARA), is due to be operational in 2023. Also of interest in the recently published Maritime Area Planning Act is the provision for the establishment of "*Designated Maritime Area Plans*" (DMAPs). DMAPs are specific parts of the maritime area that are designated for particular *"maritime usages"*. Applications for Maritime Area Consents (MACs) (the equivalent of current foreshore leases in Ireland or the UK's Crown Estate Lease) within these DMAPs will be subject to a specific process for *"special MAC cases"* provided for under the MAP Bill. This legislative provision is a crucial aspect of the future protection and regulation of coastal activities. However, as DMAPs seem to be focused primarily on development (e.g. offshore renewables) rather than human activities, such as seaweed harvesting, it will be imperative to assess whether these are the most appropriate mechanism to oversee the sustainable development of seaweed harvesting.

Regardless of the historic rights and licensing issues that exist, the harvesting of wild seaweed requires those involved to comply with other legislation including the provisions relating to the EU Habitats and Birds Directives which is especially important as seaweed is often found in or near Special Areas of Conservation (SAC) or Special Protection Areas (SPA). Compliance with the provisions relating to the Habitats and Birds Directives is also likely to be required in future MPAs. Additionally, in 2021 the OSPAR Commission, representing 15 countries of the North-East Atlantic plus the European Union, took action to protect wild kelp forests which, it noted, are an important habitat for a range of marine species and is considered by some to play an important role in the sequestration of atmospheric carbon. Drastic losses of kelp forest habitat have already occurred in the southern part of the OSPAR Maritime Area, with significant declines at several locations elsewhere. The precipitous decline of these important elements of the Atlantic marine ecosystem has been attributed, in part, to destructive fishing practices and coastal pollution, with climate change foreseen to add to the multiple pressures already impacting kelp forests. Consequently, OSPAR has recommended a series of measures and programmes to protect, conserve and regenerate kelp forest habitats. It is possible that

these actions and recommendations by OSPAR may be an important consideration in the ongoing or future wild harvesting of kelp forest forming species in Ireland.

Also of relevance is the government's €116 billion National Development Plan, Project Ireland 2040. This plan, which is underpinned by a 20-year planning framework, highlights the potential of the circular bioeconomy in promoting the more efficient use of renewable resources such as seaweed while supporting economic development and employment in rural Ireland. In addition, the Government also published the first National Policy Statement on the Bioeconomy (March 2018) further highlighting and recognising the potential for the bioeconomy to achieve environmental and economic outcomes and mandated the establishment of an interdepartmental bio-economy implementation group to take forward a number of major actions, in close collaboration with bio-economy industries and other partners (Dept. of Taoiseach, 2018). The ambition outlined in the National Planning Framework (NPF) is now being seen through the Regional Spatial and Economic Plans. For example, the Southern Regional Assembly (SRA) identified that the Bioeconomy is a sector that is a key enabler in their ambition to become Europe's most creative and innovative, greenest and liveable regions (SRA, 2020). At the county level, an increasing number of Local Authorities are recognising the importance of the bioeconomy and its significance of creating economic development potential and are currently drafting their County Plans with identified bioeconomy actions (e.g. Tipperary and Kerry).

One of the key actions in the National Policy Statement on the Bioeconomy is to strengthen the development of promising bio-based products and grow the relevant markets for them. Feedstocks, like seaweed, through bioprocessing can be converted into bio-based chemicals, materials, bio-polymers, food, animal feed and other high-value products (e.g. biostimulants, animal and human health applications, ingredients for cosmetics, pharmaceuticals, and performance materials) especially if they contribute to the economic viability of the value chain and feature 'no waste' production and reduction in Scope 3 GHG emissions. This activity primarily takes place in rural regions, supporting economic and rural development, creating jobs as a result of investment attraction.

1.2. Remit of the Project

This Socio-Economic Study of Seaweed Harvesting in Ireland aims to provide baseline socio-economic information regarding seaweed harvesting activity and product usage in Ireland today. This study provides important background information for Ireland's National Marine Planning Framework (NMPF) and will inform the development of national policy for the sector. The NMPF highlights the increasing number of indigenous companies who are working in the seaweed sector, especially those involved in ANPG, who are developing and supplying high value products from harvested seaweed into international markets. The NMPF also states that continued growth in an industry that provides high value employment and a positive economic contribution to coastal communities in rural Ireland must be balanced against ensuring that the level of seaweed harvesting is sustainable and is capable of continuing replenishment and availability of this natural resource for future generations.

This project aims to provide information on the current and future spatial distribution of harvesting as well as the intensity of harvesting and resource usage; improve the knowledge of the existing socio-economic value of seaweed harvesting activities; and provide a better understanding of the potential value of the seaweed harvesting and processing industries in coming years.

Specifically, the project deliverables include:

- Investigation of the industry in Ireland to determine:
  - -the types and quantities of wild-harvested and farmed seaweed
  - -how it's processed and used
  - -what its value is to harvesters and processors
  - -the regulatory environment within which the industry operates
  - -the barriers to, and opportunities for, industry growth
- Spatial mapping of seaweed harvesting and farming activities to assess and value the seaweed supply chain
- A seaweed industry directory of harvesters and processors
- An overview of best practice on sustainable management of the resource as well as on the reporting of harvesting and farming activities
- Research on potential uses and value-added applications for seaweed
- Assessment of the present and future value, and potential demand for, products derived from Irish seaweeds.

2. Methodology for Data Collection & Assessment

In order to inform and support the development of national policy for the seaweed sector and provide important background information for Ireland's National Marine Planning Framework (NMPF), more information on the scope of the sector is required. Therefore, a core element of this project is to improve information on the sector and investigate:

-the types and quantities of wild-harvested and farmed seaweed

-how it's harvested, processed and used

-what its value is to harvesters and processors

-the regulatory environment within which the industry operates

-the barriers to, and opportunities for, industry growth

As an output of this investigation, in addition to this report and the spatial maps produced, an industry directory of those involved in the processing of seaweed has been compiled.

This section provides an overview of the methodology employed to

(a) develop the industry directory
(b) gather information from national processors on the extent and nature of the sector
(c) extract feedback from harvesters on the harvesting of wild seaweeds in Ireland.

2.1. Methodology

As noted previously, there is a relative paucity of detailed information regarding the scope of the seaweed sector in Ireland. While there have been a number of studies and publications that provide estimates of the tonnages harvested, the number of people employed, the types of seaweed used and the extent of the processing involved, gathering this information can be challenging due to the fragmented nature of the sector.

The initial project plan was to conduct a series of in-person interviews with both harvesters and processors throughout the country to gather as much information on the sector as possible. However, due to the limitations imposed by COVID, and the difficulty in getting in contact with harvesters, the project team identified the national processors as a key information source to explore. While small volumes of different seaweeds are harvested and used locally (including informal use by households), the majority of the seaweed mass harvested will go through the main processing and production businesses in Ireland. Consequently, these were targeted by the project team as a nexus between harvesters and the final market and probably the best source of consistent quantifiable information regarding the sector.

With input from the steering committee, the following sections outline the main steps involved in scoping the sector and the subsequent information gathering process.

2.2. Developing an Industry Database

At the outset of the project, the team set up a database to collate the details relating to all contacts and collaborators interacted with throughout the project. The fields for the processor and harvester datasets, the main focus for the work, were based on existing Marine Institute (MI) formats. This ensured that the outputs from this work align with, and are easily combined with, the existing MI data. These fields included: business name, address, county, Eircode, contact person, email, telephone number, website and business activity description.

In order to populate the database, an exhaustive internet search was initially carried out. This included searches of Google, Facebook and Linked-In. Once this initial database was complete, it was cross referenced with publicly available information from databases of a number of national agencies. Finally, members of the steering committee were invited to review the database to check for any businesses that may have been overlooked.

The database included **83 processors from throughout Ireland** and this was used as the basis for the subsequent qualitative and quantitative information gathering work.

2.2.1. Data Gathering

From the outset, there was an appreciation that this was a unique opportunity to gather a wide range of information regarding this important and developing sector of our economy. In order to ensure a comprehensive overview of the sector, a business survey was developed under the following broad areas:

Part 1. Information for Seaweed Business Directory (Publicly Available)

Part 2: Sectoral Information (including mapping) – Confidential

Part 3: Product Information – Confidential

Part 4. Environmental Information – Confidential

Part 5. Future Growth – Confidential

Part 1, which forms the business database produced through this work, allowed the team to corroborate the information gathered during the initial database development and get agreement from the businesses for their information to be disseminated through a public database. The other 4 sections of the survey were all confidential, with the information collected, anonymised and aggregated so that results would not link directly back to any businesses or individuals involved.

Part 2 focused on harvesting related activities and explored the economic and employment status of the businesses as well as the types and volumes harvested/used. In addition, information on the locations that the different seaweeds were harvested from was, where

possible, gathered. In order to achieve this, a free online mapping facility, http://map-me.org/ was used. This software allowed the project team to develop a dedicated seaweed mapping page. The page, which could be used by either the business or the interviewer, was developed to allow the areas along the coast where different seaweeds are harvested to be mapped according to the intensity of the estimated harvesting. The geographical information system (GIS) based information gathered was then used with the quantitative data supplied to develop the harvesting maps presented and discussed in Section 3.

Part 3 examined the outlets for the different seaweeds harvested. This included identifying any processing involved, the types of seaweed used, the products made and the sectors into which the final products were sold.

Part 4 explored the sector's attitudes to the sourcing of the seaweed raw materials and whether sustainable harvesting practices or requirements exist.

Part 5 provided an opportunity to elicit information regarding the future of the sector, the challenges and barriers that exist and the supports required to ensure the sustainable development of all aspects of the sector while also ensuring the preservation of the strong cultural and historical ties that seaweed harvesting has in local coastal communities.

Once the survey questionnaire was finalised, it was sent to the steering committee for input and comment. An updated version was then trialled with three businesses – of varying sizes and processing capacity – and based on this, the final version (see Appendix 1) was agreed.

2.2.2. Interview Format

In order to create consistency in the interview process, as well as ensuring that all data was managed in an appropriate manner (in line with GDPR requirements and the data management plan agreed with the Marine Institute), a standard interview procedure was drawn up. The following Table outlines the main steps involved.

Table 2.1: *Seaweed processor interview procedure*

Initial Contact 1. Send email note to company asking for interview (from our database) 2. Follow up by phone to identify person to interview 3. Contact appropriate person and set interview appointment- date and time 4. Send survey flow diagram ahead of interview 5. Prior to interview, view company website and our database to fill in parts of the survey, especially the contact details and nature of business sections

Survey Interview

6. Begin interview by explaining the flow chart
   Read privacy notice, explain how data will be used and emphasize confidentiality
7. Share screen if on Zoom and fill in survey online as person answers questions
8. Go to mapping section and work with person to identify areas where seaweed is harvested: species, quantities and locations
9. Fill in product range sheets
10. Return to main survey and complete

Post interview data management and follow up

11. Identify any missing information from survey, discuss how the information will be gathered and when it will be given to complete the survey process
12. Set follow up phone call or email response date
13. Complete and check survey and product range forms and save using the designated naming system
14. Password protect the files
15. Save all files to project database
16. Update "Status" on Seaweed Database

Wherever possible, standard templates were used to facilitate this process. This included standard emails for initial contact as well as the privacy notice that was read out at the beginning of the interview process. The following survey flow diagram was also sent out in advance to provide the participating businesses with a degree of advanced notice of the areas to be covered. This allowed them to prepare figures where required, though many ended up sending on information post interview. All of this allowed for a streamlined and consistent interview process.

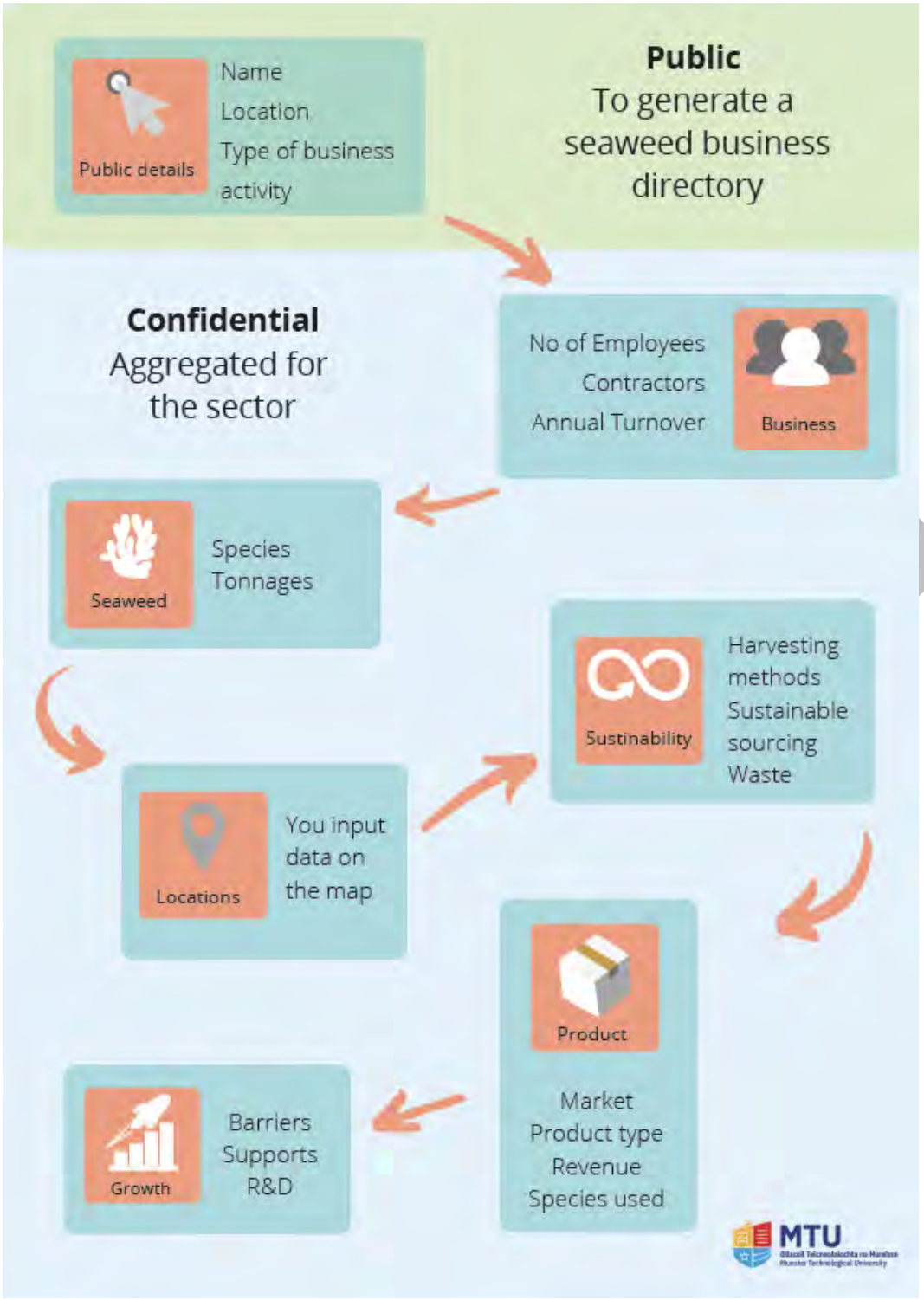


Figure 2.1: *Seaweed survey flow diagram*

2.2.3. Interviews

The interviews were carried out between the start of May and the end of July 2021. Based on the initial round of contact, the initial 83 businesses identified in the database reduced to 58. This was related to businesses closing recently, consolidation of a number of businesses and others that had stopped processing or using seaweed. However, this is a greater number than the 40 companies noted in recent reports (BIM, 2020).

Every effort was made to engage with the remaining 58 businesses with a number of emails sent followed by phone call contact. In some instances, no responses were forthcoming while in a small number of cases the businesses refused to engage. Therefore, the results presented in this report reflect the input from those that participated.

Once the interviews started, it became evident that the full business survey was, for a number of the smaller operations, too extensive. Consequently, in an effort to ensure their participation, and to extract some essential information, a condensed survey, with a number of core quantitative questions, was developed. This was used only where the project team thought it necessary in facilitating engagement with that organisation.

In the end, 36 responses were received with 28 full survey responses completed and 8 of the shorter surveys completed.

While the cut-off date for surveys was the end of July 2021, the project team decided to go back to all the non-respondents during September 2021. Conscious that the surveying period coincided with the busy time of the year for many, as well as the fact that society was re-opening after COVID lock downs, every effort was made to engage with the businesses identified and allow them to participate in the survey and to be included in the business directory. It is important to note that only those businesses that have agreed to be listed on the business directory, and have agreed to the content of their listing, have been included. Unfortunately, no additional responses were received during this period.

2.3. Seaweed Harvesters

While gathering information regarding processors was very important for developing an understanding of the economic impacts of the sector, input from those directly involved in harvesting was equally important. Though the use of mechanical harvesting may grow in the future, most harvesting in Ireland takes place in the intertidal zone and is largely carried out by hand by harvesters based in the communities where they harvest. However, subtidal seaweed such as *Laminaria hyperborea* and *Laminaria digitata* are typically inaccessible to hand harvesters and can only be commercially harvested mechanically by boat, as has been the case in France, Norway and Iceland for over 50 years. In order to understand the broader landscape in which harvesters work, how harvesting contributes to local communities (both socially and economically) and the existing sustainable practices that have evolved over many years, direct input from harvesters was sought.

It is estimated that at least 270 people are currently directly employed in seaweed harvesting in Ireland. While it was not possible to contact all harvesters under the scope of this work,

every effort was made to gather information from as representative a sample as possible. Initially a database of harvesters was prepared from lists of contacts made available by relevant stakeholders (including MI, processors and harvesters).

26 individuals were contacted by phone and/or email and 15 agreed to participate in the structured interviews. A cross section of harvesters in terms of gender, quantities and species harvested, location on the western seaboard (from Waterford to Donegal), and age profiles were interviewed by phone using a prepared survey template. They included:

- Harvesters supplementing their income (or in one case relying on their income) by harvesting *Ascophyllum nodosum*
- Seaweed harvesters harvesting other species (typically edible seaweeds or kelp for use as a fertiliser)
- Licensed seaweed cultivators (aquaculture) harvesting a range of edible seaweeds
- Seaweed foragers (typically foraging edible seaweeds)
- Seaweed harvesting licence applicants and former licence holders
- Seaweed harvester who has also carried out some personal research into the sector.

In addition, two large processors that purchase *Ascophyllum nodosum* from ~150 harvesters provided summary profiles of their seaweed suppliers. Though these were aggregated responses, they provided valuable insights into those involved in the largest formal group of seaweed harvesters in Ireland.

2.3.1. Contacting Harvesters

Due to COVID constraints, face-to-face meetings with individuals or groups of harvesters could not be carried out. Therefore, a survey was developed to facilitate structured interviews with the representative harvesters identified. This survey, developed for growers and harvesters (which included, traditional wrack and kelp harvesters, foragers and growers in cottage industries that grow or harvest and process seaweed into a product or products for sale), was designed to elicit the following information:

- What types of seaweed do you grow, gather or harvest?
- Where do you grow, gather or harvest seaweed?
- How often do you harvest seaweed?
- What time of year do you harvest seaweed?
- How do you harvest or gather seaweed? On shore, in boats, by hand or mechanically?
- How much seaweed do you harvest in a year?
- Do you sell the freshly harvested seaweed or process it in some way?
- If you process it, what do you do? Separate fronds and stipes, dry it, use it to make a product? If so, what product(s) do you make? Who is your market for the processed seaweed? How much do you sell your products for?
- Do you use any harvested seaweed for your own purposes to feed livestock, fertilise fields, etc?

- If you sell it after harvesting, who do you sell it to?
- What price is paid for the fresh seaweed you harvest?
- Do you work full-time or part-time growing and harvesting seaweed?

These interviews were carried out online and by telephone from September to November 2021.

3. Wild Seaweed Harvesting in Ireland

The harvesting of wild seaweed is an integral part of many rural coastal communities in Ireland. With the increasing demand for seaweed as a raw material (primarily in the production of biostimulants and other products such as organic soil amendments, animal feed formulations, human nutritional supplements, beauty products, biochemical applications and pharmaceuticals), it is imperative that good data on this public resource be available to ensure it is managed effectively. The potential economic value of this resource, when sustainably managed, has huge opportunity for growth and can make a substantial contribution to coastal communities. The challenge is to ensure the coexistence of traditional seaweed harvesting while also embracing the opportunities which are now presenting themselves within this sector, including the emergence of a number of Irish companies who are driving innovation and R&D in the areas of plant biostimulants and products for the animal and human health markets.

This section outlines the information gathered during this project on the extent of wild seaweed harvesting in Ireland. Every effort was made to contact as many harvesters and processors as possible, and the findings here reflect the input of those who responded during the surveying process.

3.1. Seaweed Species Harvested

Ascophyllum nodosum is the main seaweed harvested for commercial processing, while kelp (storm blown or harvested) is used personally by harvesters in agriculture and horticulture. Foragers harvest all the wracks, edible kelps, nori, sea lettuce, pepper dulse, carrageen moss, and dillisk. The edible brown seaweed species *Alaria esculenta* and *Saccharina latissima* are cultivated commercially.

Based on the responses received, the following Table outlines the quantities of seaweed (in wet tonnes[2]) harvested in 2020.

Table 3.1: *Reported seaweeds, by quantity (wet tonnes) harvested in Ireland in 2020*

Seaweed species	Quantity used (wet tonnes[1])
Ascophyllum nodosum	33,703
Fucus serratus	220
Fucus vesiculosus	143

[2] *97% of seaweed use data for Irish seaweeds was communicated as wet tonnes, while 3% was communicated as dry tonnes and converted to wet tonne weight, on the basis of seaweed typically losing 85% of mass through the drying process.*

Palmaria palmata	134
Himanthalia elongata	58.5
Laminaria digitata	45.5
Chondrus c./Mastocarpus s.	37.5
Alaria esculenta	14.8
Saccharina latissima	12.3
Undaria pinnatifida	6.7
Pelvetia canaliculata	4
Ulva lactuca	3.4
Fucus spiralis	2.5
Porphyra spp*./Wildemania a.*	1.9
Osmundea pinnatifida	1.6
Asparagopsis armata	1.6

As can be seen from these figures, *Asco* accounts for almost 98% of the total wild seaweed harvested nationally and the quantities of other species used, expressed as wet tonne equivalent, is shown in Figure 3.1.

Asco is a large macroalgae that grows at high densities in highly sheltered areas with suitable substratum, being generally accessible at low tide to hand harvesters on the shore. However, many of the other intertidal seaweeds in Ireland are harvested at much lower quantities as they are generally smaller, yield less biomass, are more difficult to harvest and/or grow at lower densities. In addition, the most valuable bioactive compounds currently used by Ireland's existing seaweed industry are contained in *Ascophyllum nodosum* and species of *Laminaria.* The harvesting of other seaweeds such as *Lamininaria hyperborea* are currently licensed in Ireland and are expected to be harvested in the future for use in the development of alternatives to antibiotics in the pig and poultry sector. Therefore, these species are of most commercial importance to the existing seaweed industry for manufacturing value-added products and developing new and innovative technologies for seaweed processing.

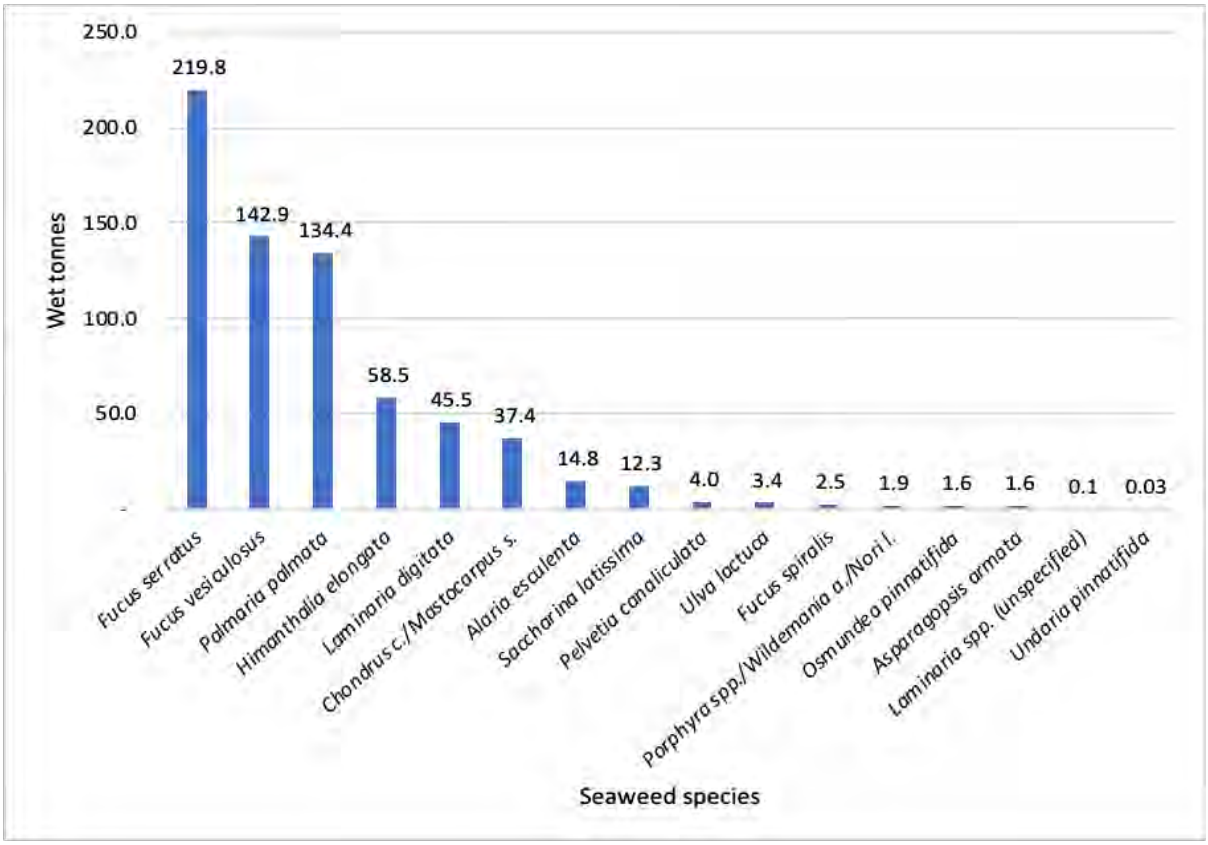


Figure 3.1: *Quantities of main seaweeds harvested in Ireland (excluding Asco) in 2020*

In addition to the above live seaweeds that are harvested in Ireland, over 60,000 tonnes of *Lithothamnion spp.* (calcified or dead seaweed called 'maerl') were imported into Ireland in 2020 for the production of dietary supplements for human and animal use. As this seaweed is imported from Iceland and is fundamentally different from live seaweed harvested in Ireland, it has not been included in Table 3.1 or Figure 3.1.

3.2. Where Seaweed is Harvested in Ireland

Although seaweed is harvested along the whole coastline of Ireland on an informal basis for personal and artisan local use by individuals, foragers and small tourist based businesses, the majority of seaweed tonnage harvested is to supply the processing sector within Ireland for mainly export related businesses. The following maps were generated in conjunction with the data given in the previous section. Figure 3.2 shows the intensity of overall seaweed harvesting in Ireland. As can be seen, the west and north west coast are the areas where the most intensive harvesting, in terms of tonnages, occurs. This is due to the west and northwest having the highest biomass levels of *Ascophyllum nodosum* biomass in Ireland, growing at high density in highly sheltered, intertidal areas (Hession, 1998).

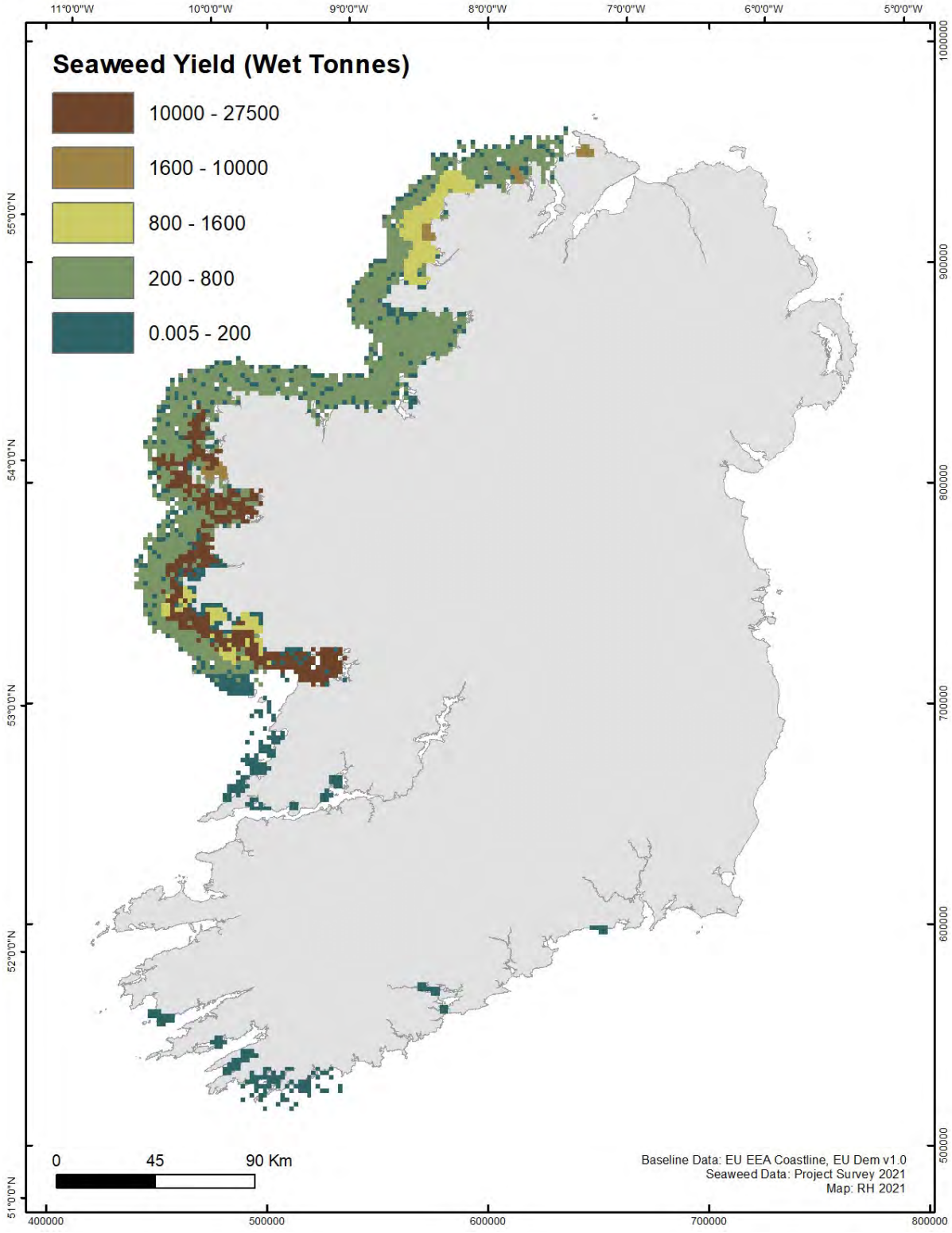


Figure 3.2: *Reported intensity of seaweed harvesting in Ireland*

Similar profiles for the top 5 harvested seaweeds (wet tonnes) as listed in Table 3.1 are given in the following figures. Maps for all seaweeds reported through the processor survey during this work are included in Appendix 2.

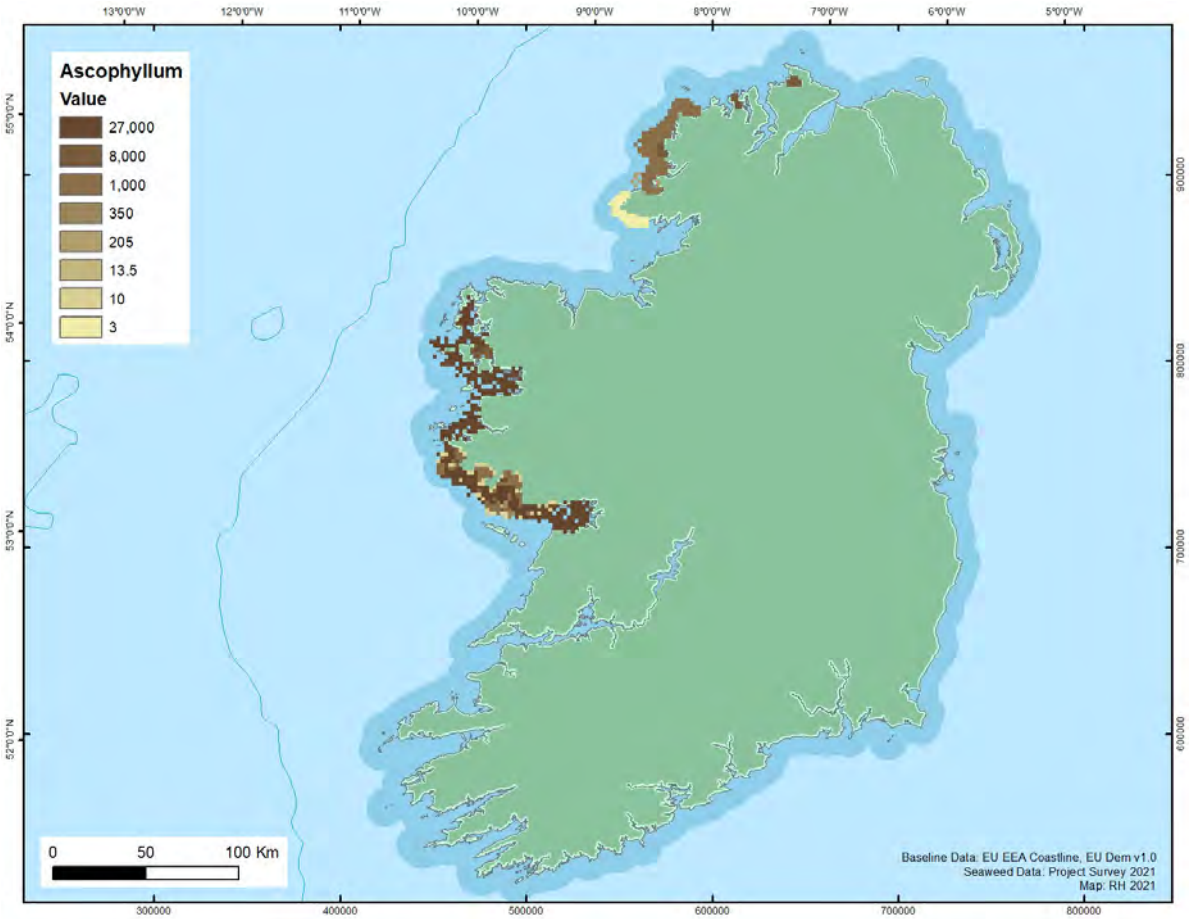


Figure 3.3: *Reported intensity of Ascophyllum nodosum harvesting in Ireland*

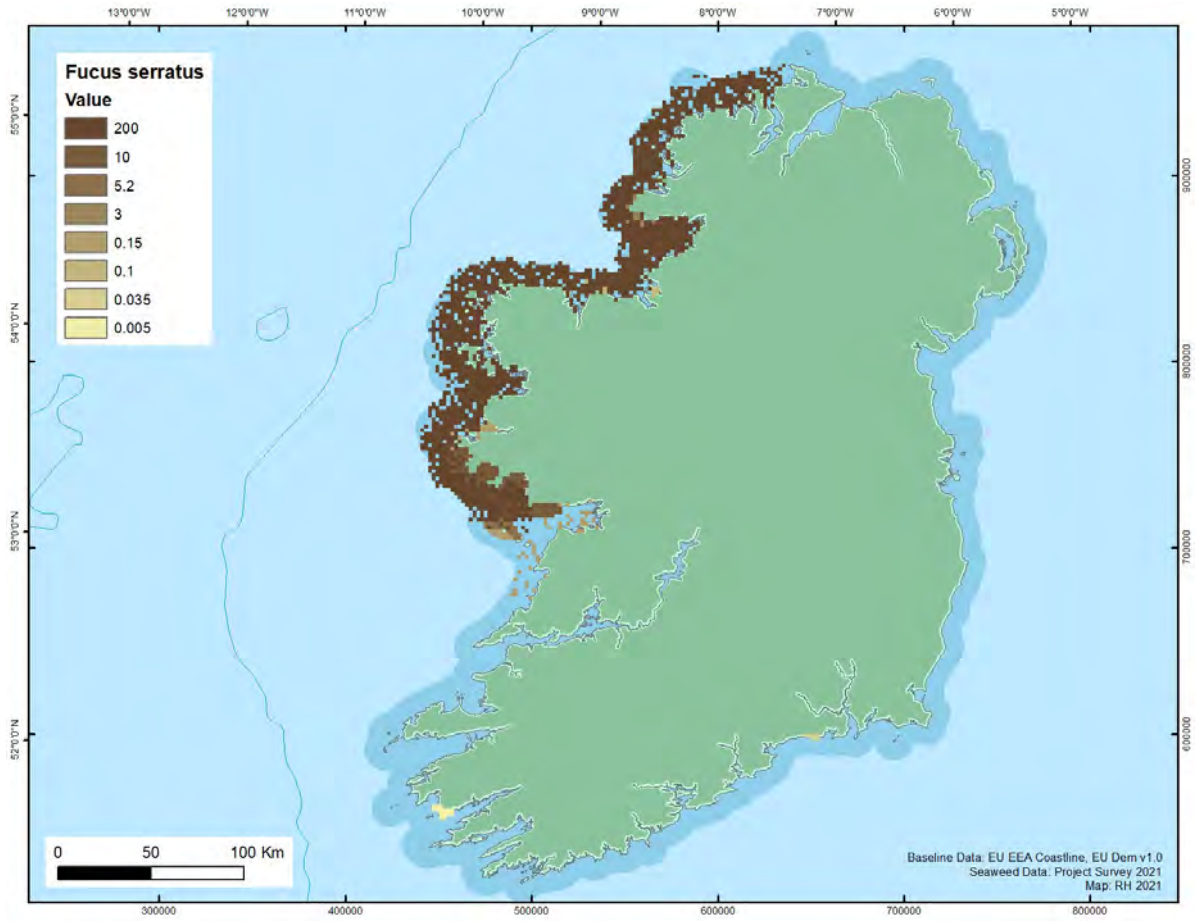


Figure 3.4: *Reported intensity of Fucus serratus harvesting in Ireland*

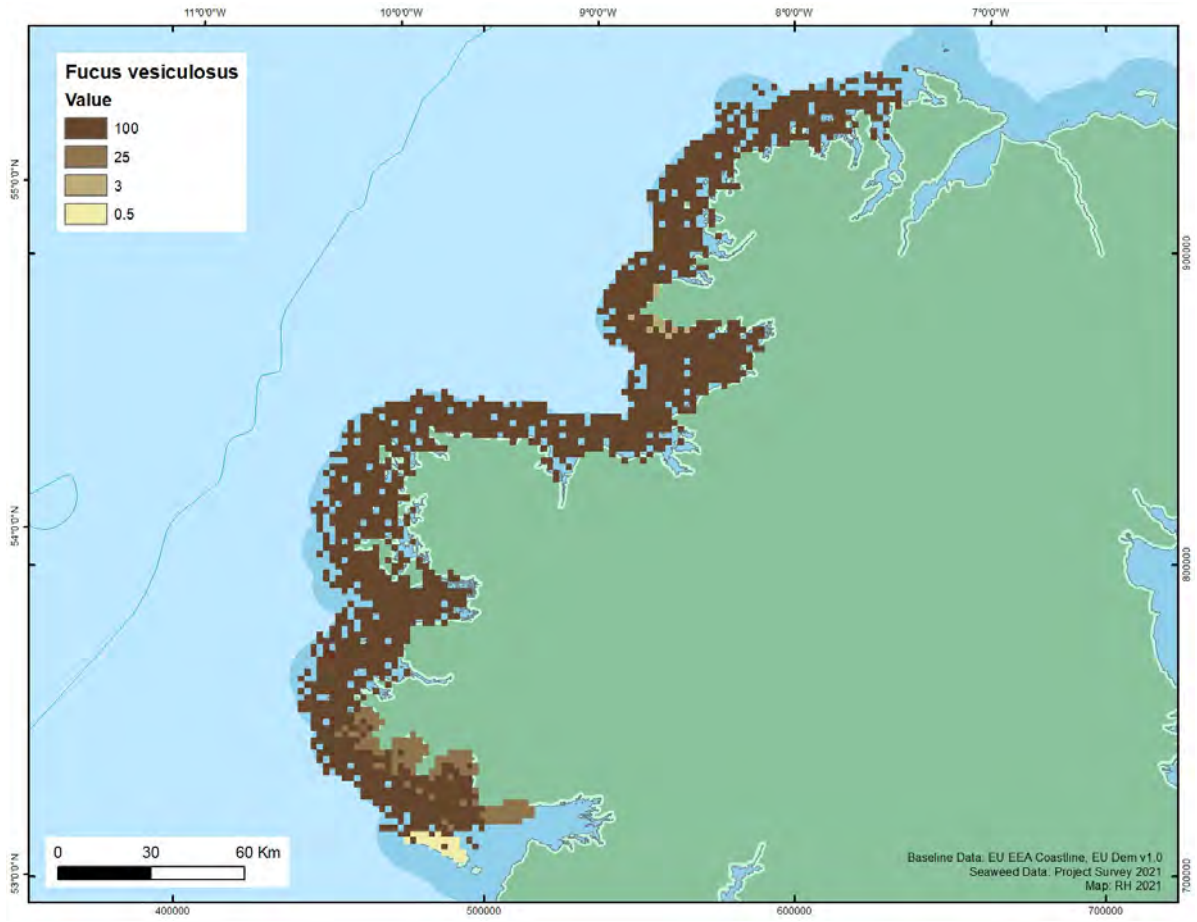


Figure 3.5: *Reported intensity of Fucus vesiculosus harvesting in Ireland (concentrated in the North West)*

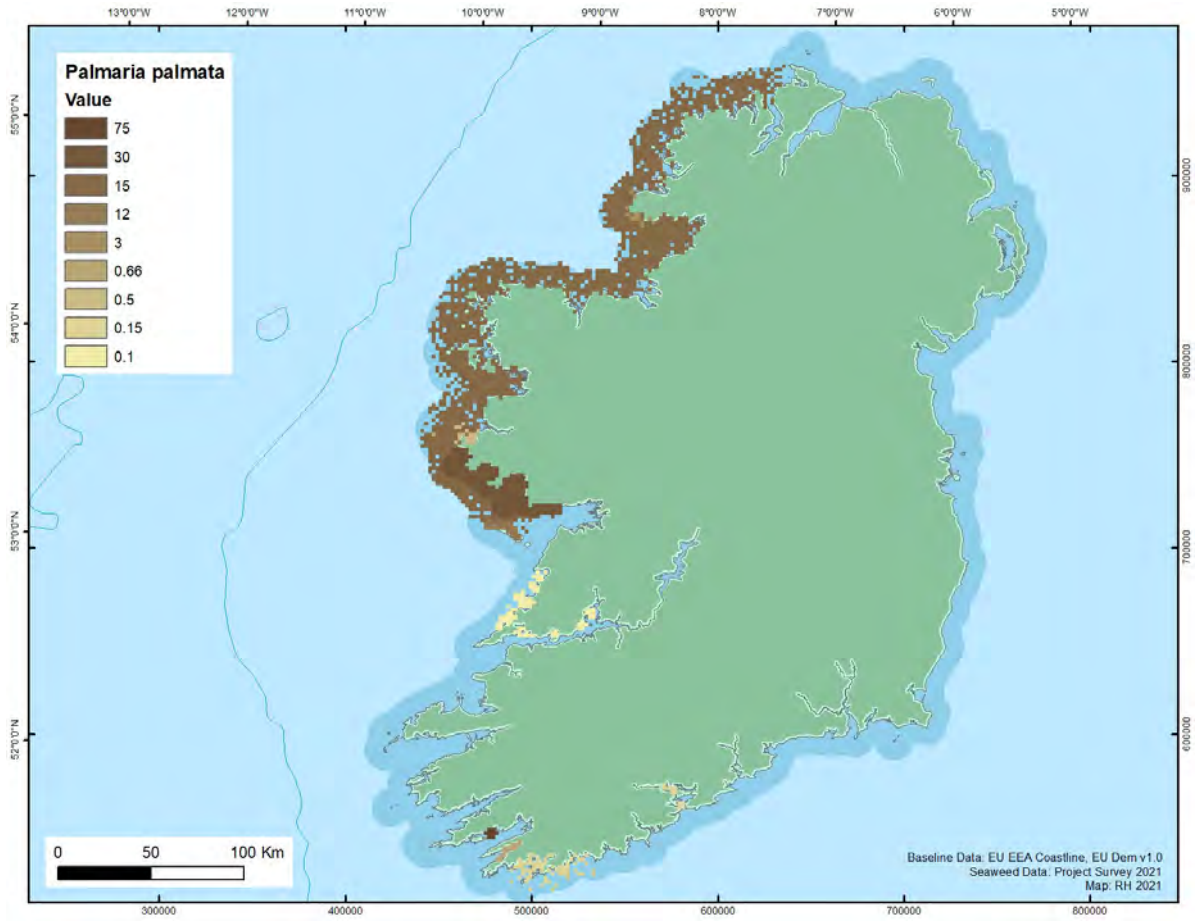


Figure 3.6: *Reported intensity of Palmaria palmata harvesting in Ireland*

3.3. Harvest Times

Ascophyllum nodosum, the main seaweed harvested on a commercial scale, is harvested year round, with harvesters noting that typically 40 of the 52 weeks in the year are suitable/safe to harvest from a weather perspective. In terms of cultivated seaweed, feedstock is added in October and harvested the following May/June with edible seaweeds typically foraged between March and October.

Seasonality was noted as an issue for 28 out of 36 processors within the sector (68%) with the most significant seasonal limiter being the availability of different seaweed types throughout the year (54%). The availability or supply of seaweeds is primarily due to seasonal changes in seaweed and the seaweed life cycle over the course of the year. 29% of businesses indicated that seasonal impact was also driven by sales or demand for seaweed, primarily relating to seaweed use in agricultural and horticulture applications. Demand for fertilisers, biostimulants and animal feed is typically seasonal in Europe, with fertiliser and biostimulant use for agriculture and amenity horticulture occurring during the growing season (mid-Spring

to mid-Autumn) and supplementary animal feed primarily provided to livestock when grass productivity is low and grazing is reduced (mid-Autumn to mid-Spring). Internationally, outside of Europe, there is a demand for these products year-round.

3.4. Harvesting Methods

Most of the seaweeds currently harvested in Ireland are from intertidal areas. Intertidal seaweeds in Ireland are not harvested by mechanical methods, as such methods either do not exist, are unavailable or unlicensed. Mechanical seaweed harvesting is required in order to harvest species that reside in deeper, exposed subtidal water areas that are otherwise less accessible or fully inaccessible to hand harvesters due to health and safety and other reasons (e.g. *L. digitata*, *L. hyperborea*).

Wild seaweed harvesting in Ireland is mostly done by hand - cutting the seaweed with a sickle or knife. Low-tide on-foot methods of hand harvesting take place throughout the country. Boat and rake methods (also considered hand harvesting) have been reported to take place in certain locations in Galway in recent years. *Ascophyllum nodosum* harvesters typically cut 7.5cm to 15cm above the holdfast when cutting. Rotational practices vary from 3 year to 5 year cycles when between one third (33%) or one fifth (20%) respectively of the available seaweed is harvested to ensure sustainability of the resource. Of the harvesters interviewed during this work, over 90% learned about seaweed harvesting methods from a family member or from taking part in harvesting with neighbours when they were young.

Very little pre-treatment of *Ascophyllum nodosum* was required of harvesters that supply to the larger businesses, who subsequently dry and/or process the seaweed for use in the manufacture of high value-added products. For some of the other seaweed types, harvesters often dry the seaweed (air dried naturally outside) prior to being sold to processors.

3.5. Sustainability and Resource Conservation/Protection

All those interviewed were employing some form of sustainable harvesting practices to ensure that the resource is protected for future harvesting. These predominantly involved sustainable harvesting methods for *Asco* (typically 3 to 5 year harvest cycles with knife or sickle cutting leaving c.15cm of the holdfast) and rotating areas where harvesting was carried out. Those involved in foraging said that they take a maximum 1/3 from plants (fronds/leaves) and move around to different areas.

It was noted that while there is species movement to different areas year on year, 80% of respondents said they had not noticed a decline in seaweed resources in their area. That said, the impacts of water quality - related to sewage and agricultural run-off - were noted as having an impact on seaweed quality and re-growth and was seen as one of the main threats to the resource. It was also observed that when economic downturns occur (including Covid), and more people become involved, this can lead to over exploitation of local resources and poor harvesting practices which can result in depletion of the local resources very quickly.

From the processor side, 93% of respondents indicated that they already apply some type of sustainability requirements on those that supply them with seaweed; either independent harvesters or those they employ directly to harvest seaweed. Figure 3.7 outlines some of the responses received in four categories: suppliers, monitoring, harvesting techniques and seaweed types. For those related to suppliers, processors required that seaweed come from licenced harvesters or organically certified entities, reputable harvesters from the local area

or those that have been trained in sustainable harvesting techniques. A small number of companies monitor harvested areas while two currently use independent scientists to assess harvested areas over time to monitor seaweed recovery. And finally, some companies insist that seaweeds are only harvested during their growing season so they can recover more quickly.

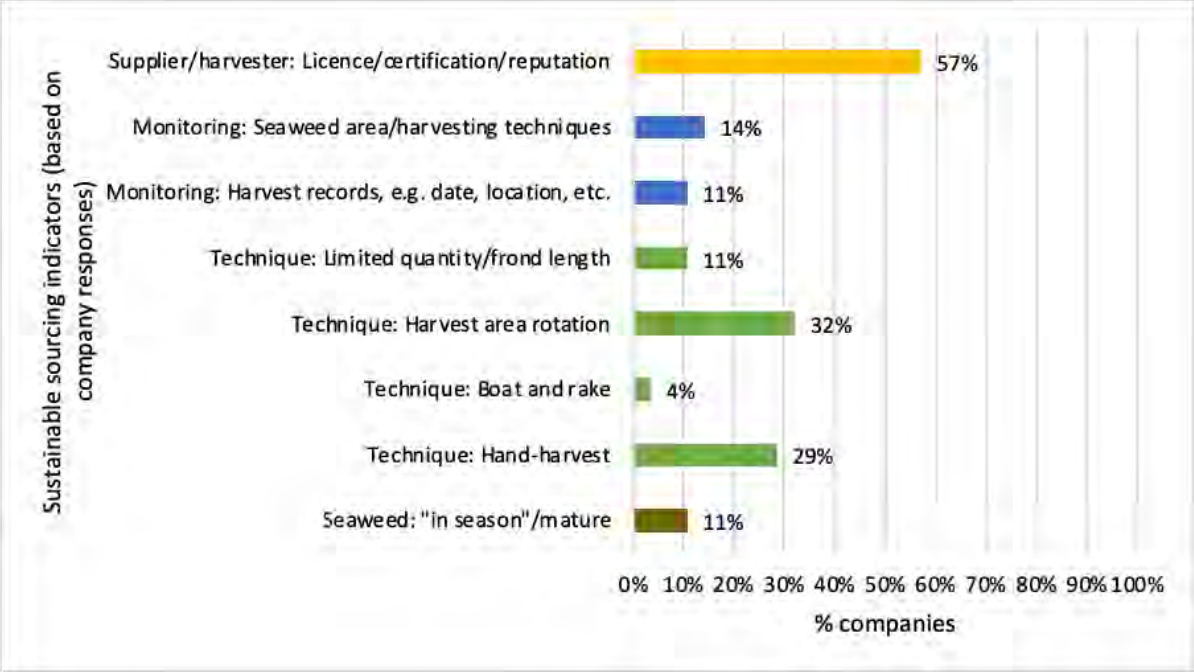


***Figure 3.7**: Existing sustainability measures currently in place*

Key: Yellow = indicators relating to suppliers/harvesters; Blue = indicators relating to seaweed/habitat/harvest monitoring; Green = indicators relating to harvesting techniques; Brown = indicators relating to seaweeds

3.6. Value of Harvested Seaweed

The volume of seaweed collected by individual harvesters varies, depending on the nature of their work (full time, part time or seasonal) and the type of seaweed they harvest. *Ascophyllum nodosum* harvesters can collect anywhere from 20 to 500 wet tonnes per annum with 100 to 200 wet tonnes being typical for those regularly involved.

In terms of the overall prices paid for harvested seaweed, Figure 3.8 summarises the combined findings from both processor and harvester surveys. As can be seen, there is a wide range in the prices paid for different seaweeds with *Asco*, the most significant seaweed harvested in Ireland generating the lowest reported income per tonne at €61 per tonne (typical range noted was €55 - 65/tonne). Based on the typical tonnages harvested by individual harvesters (100 - 200 tonnes), this equates to an annual income somewhere between €6,100 and €12,200.

Edible seaweeds, though they are cultivated or harvested in much smaller quantities than *Ascophyllum nodosum*, command much higher values ranging from €0.5-10/kg, or more, depending on the species. Carrageen and dillisk are reportedly selling to restaurants for prices

ranging from €0.50 to €2/kg (wet weight) though dried dillisk can sell for as much as €20/kg dry weight. This equates to €500-2,000 per wet tonne or up to €20,000 per dry tonne. Interestingly, there was substantial variation around the median values paid for some seaweed species with price differences of over €1,000 per tonne noted. This may be related to the fact that species with higher prices tend to be more difficult to harvest due to their smaller size, lower biomass densities or difficulties in harvesting while *Ascophyllum nodosum* is abundant and comparably easier to harvest.

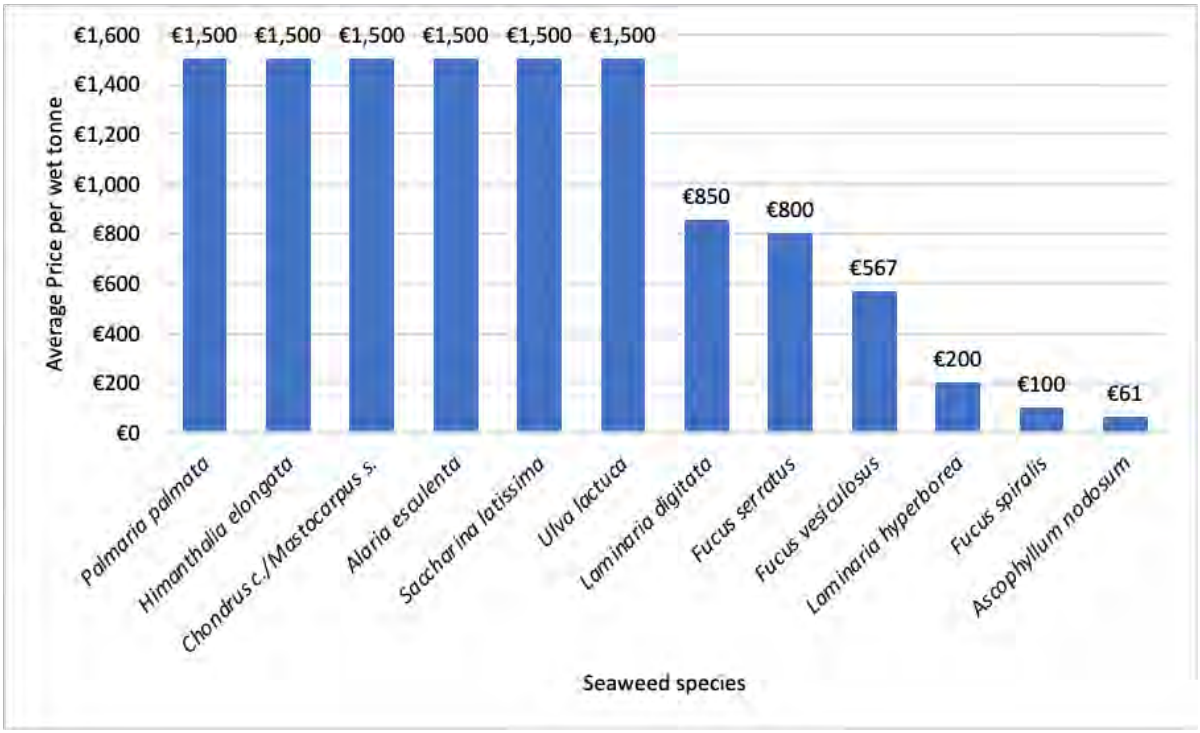


Figure 3.8: *Reported average price paid (per wet tonne) to harvesters for different types of seaweed*

Based on the tonnages harvested, and the values noted here, the following table outlines the estimated total income for harvesters based on seaweed type. Nationally, the value of this resource to seaweed harvesters is at least €2.7 million annually. The 33,700 tonnes of *Ascophyllum nodosum* harvested, which accounts for 98% of the total volume harvested, generates about €2 million for the harvesting community (which is 77% of the total income). Conversely, the revenue earned by harvesters of *Fucus serratus*, where 220 tonnes were harvested, generated a total income of about €176,000 and the 134 tonnes of *Palmaria palmata* generated approximately €200,000 for harvesters. While *Asco* is undoubtedly the most prominent seaweed harvested in Ireland, and will likely remain that way, these values demonstrate the potential earning power other seaweed species could have on the income harvesters in rural coastal communities around Ireland could command.

***Table 3.2**: Value of seaweed by species harvested in Ireland (* - no data provided).*

Seaweed species	*Quantity used (in wet tonne equivalent)*	*Average price per tonne (€)*[3]	*Estimated national harvester income (€)*
Ascophyllum nodosum	33,703	61	2,039,024
Fucus serratus	220	800	175,800
Fucus vesiculosus	143	567	80,997
Palmaria palmata	134	1,500	201,593
Himanthalia elongata	58.5	1,500	87,705
Laminaria digitata	45.5	850	38,671
Chondrus c./Mastocarpus s.	37.5	1,500	56,175
Alaria esculenta	14.8	1,500	22,200
Saccharina latissima	12.3	1,500	18,450
Undaria pinnatifida	6.7	*	N/A
Pelvetia canaliculata	4.0	*	5,100
Ulva lactuca	3.4	1,500	5,050
Fucus spiralis	2.5	100	250
Porphyra spp./Wildemania a.	1.9	*	N/A
Osmundea pinnatifida	1.6	*	N/A
Asparagopsis armata	1.5	*	N/A
Total	**34,390**		**€2,731,018**

Note: the prices quoted are average prices per wet tonne equivalent (with dry tonnes converted to wet tonne equivalents).

[3] *While average and median values were similar, there is substantial variation around the average for some seaweed species, which may lead to this figure being greater than the actual value of seaweed to harvesters.*

3.7. Profile of Harvesters

The demography of harvesters seemed to vary by region with the harvesters in the North and West (where the bulk of *Ascophyllum nodosum* is harvested) predominantly over 50 years old and male, whereas in southern counties, where smaller volumes of different seaweeds are harvested, a broader age range was given. Harvesters involved in bulk *Ascophyllum nodosum* collection are typically part-timers and also involved in fishing or agriculture. While it was noted that historically females were more prominent in *Asco* seaweed harvesting, now it is almost all male. Harvesters foraging for edible species (e.g. carrageen and dillisk) harvest in smaller quantities and are more spread over the age profiles 20-55+. Those involved in seaweed cultivation were typically in the 30-55 age profile.

The majority of those interviewed noted that harvesting contributes no more than 20% of their household income with only one harvester saying that seaweed harvesting was their primary source of income. Interestingly, with the projected increase in the market for seaweed, one cultivator predicted that their seaweed business would increase its contribution to their income to up to 40% of their total income by next year.

Based on the interviews carried out, it was estimated that there are at least 270 harvesters regularly involved in the industry (sources: processors and harvesters interviewed as part of this project). These are predominantly involved in part-time *Ascophyllum nodosum* harvesting in Galway, Mayo and Donegal and primarily supplying members of the ANPG. It was noted through independent research that harvester numbers have reduced by 100 harvesters in the last 5 years in the Connacht/Donegal region with this reduction attributed to ageing and/or concern over potential loss of social welfare payments.

However, a significant area of concern, reiterated by many, is the protection of the tradition associated with seaweed harvesting. Though few younger people are becoming involved, it is still a significant local industry in many parts of the country and there is a fear that through onerous licensing processes there could be a monopolisation of harvesting in certain areas that would reduce the numbers of independent indigenous harvesters.

Young People in Harvesting

Traditionally harvesting was carried out by families with established areas of coastline that they harvested down through the generations. In recent times, with the younger generation less involved in this handed-down tradition due to the difficult nature of the work (hand harvesting on shore or by boat and rake on the inshore), concern over the ongoing availability of harvesters has been identified as a threat to the sector. While a number of harvesters noted that their sons were involved seasonally, in the main, it is now very difficult to recruit younger people. A number of processors suggested that if it was possible to earn a more substantial income to support the lifestyle younger people expect, then more may become involved. However, with the emergence of the high value plant biostimulant market it has been suggested that a higher premium should now be paid for the harvested *Ascophyllum nodosum.*

Additionally, a shift away from the more difficult and traditional hand harvesting, using knives or sickles, towards boat and rake harvesting was suggested as being more attractive to younger people. In addition, some mechanism by which social welfare payments remain

unaffected by part-time harvesting could help in attracting younger people to become involved. Other suggested areas for improvement included: increase payment to harvesters, a career structure, improved skills, scientific knowledge, less bureaucracy in licensing, more investment in harvest infrastructure to improve efficiency and earning potential, more access to perceived "blocked areas" through regulation that would allow new entrants to harvest, assurances to harvesters that their traditional lifestyle will not be compromised, and involving even more young people in processing rather than harvesting.

3.8. Summary

In summary, the following outlines some of the main findings about seaweed harvesting in Ireland from the surveys of national processors and interviews with a subset of harvesters:

- It is estimated that there are currently in excess of 270 harvesters that are consistently involved in harvesting wild seaweed nationally. Though there are many others that forage for personal use, or for local small scale commercial activities, these individuals do not contribute significantly to the tonnages collected.
- The profile of harvesters is mainly male, over 50, with those involved largely doing it to supplement household income (rather than it being a full-time commitment).
- Just under 35,000 tonnes are being collected annually with *Asco* accounting for 98% of this by weight. The majority of the volume harvested is occurring in the north and west with smaller volumes of a wider variety of seaweeds being collected in southern counties. Most of the harvested *Asco* is supplied to members of the ANPG.
- Based on reported average costs per tonne, the value to those harvesting seaweeds is at least €2.7 million annually[4] with the prices paid per wet tonne equivalent varying from €60 - €1,500.
- With the traditional handed down nature of harvesting (with hand harvesting the main method used), it is suggested that seaweed resources are currently reasonably well managed. However, with a dwindling number of experienced harvesters (due to age profile), the lack of tacit knowledge of new entrants (tradition not being passed to the next generation) and an increased demand (leading to using less experienced harvesters from outside the area), there is potential for the resource to become mis- managed quite quickly.

[4] *While average and median values were similar, there is substantial variation around the average for some seaweed species, which may lead to this figure being greater than the actual value of seaweed to harvesters.*

4. Seaweed Processing Sector in Ireland

The seaweed processing sector in Ireland is varied in terms of size, turnover, employee numbers, products produced and seaweeds used. There are businesses all around Ireland using seaweed as a raw material though the majority of processors are situated along the south, west and northern coasts - in proximity to the supply of Irish seaweeds.

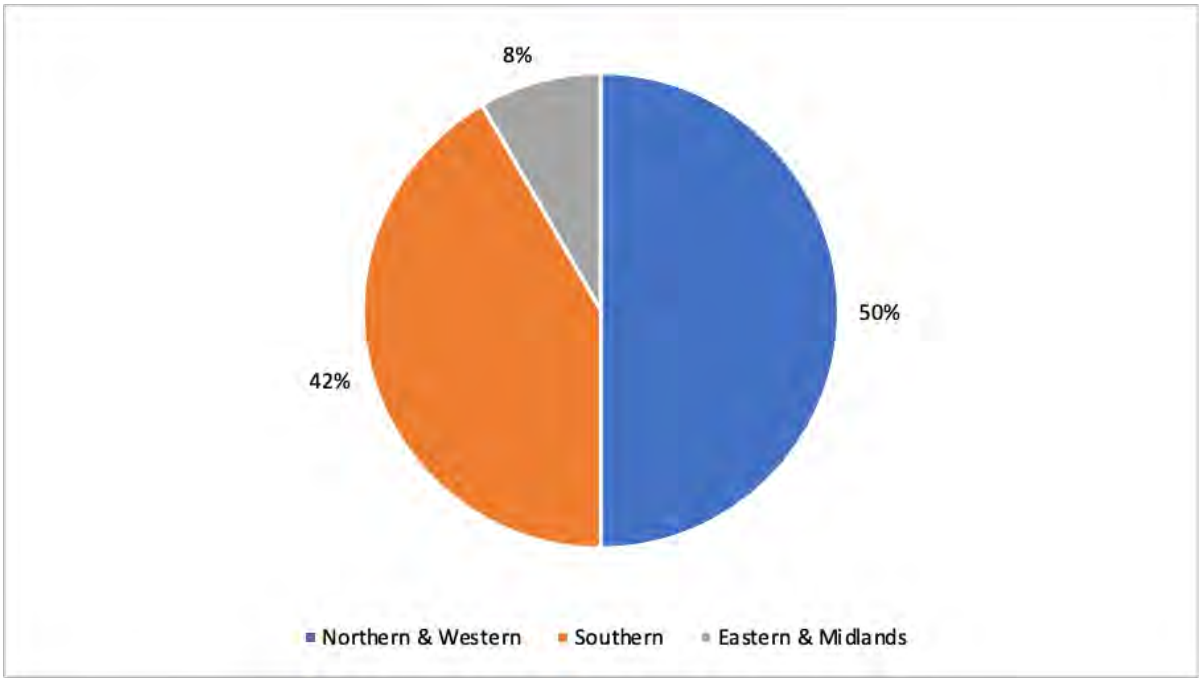


Figure 4.1: *Geographic distribution of processors surveyed throughout Ireland*

With 98% of the wild seaweed harvested in Ireland being *Ascophyllum nodosum*, it is important to note that the *Ascophyllum nodosum* Processors Group (ANPG) represent the main national processors (Arramara Teoranta, BioAtlantis Ltd., Brandon Products Ltd., Oileán Glas Teoranta and Ocean Knowledge) and are responsible for purchasing and processing almost all of the wild *Asco* seaweed harvested in Ireland. The companies within the ANPG have undertaken extensive R&D over the last 15 years and invested in the development of processing technologies that create value-added products from Irish seaweed. They are internationally recognised in the development of biostimulant products and are involved in numerous national and international R&D collaborations.

The following sections outline the information gathered from the processors that participated and provided qualitative and quantitative information for this research work.

4.1. Business Characteristics of Irish Seaweed Processors

The majority of businesses involved in seaweed processing in Ireland identified as SMEs (small or medium enterprises) with 67% employing less than 10 employees. Of those employed by all processors that responded to the survey (359), 84% were employed full-time with a further 11% employed on a part-time basis, 4% sub-contracted with 1% seasonal. These employees

are employed in a variety of tasks with the majority in processing and production, with only small numbers employed directly for seaweed harvesting and cultivation. Companies in the industry also employ people in a wide range of areas, including R&D, the natural sciences, engineering, skilled trades, quality control, processing, accounting, administration, marketing and sales.

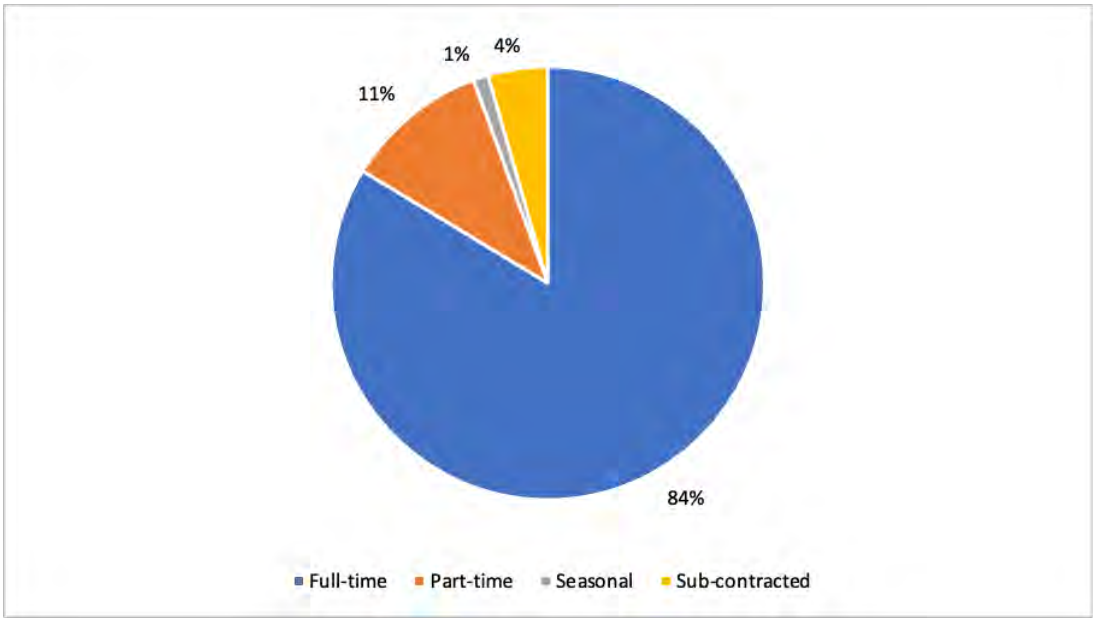


Figure 4.2: *Distribution of employees, by employment status, across the processors surveyed (n=359)*

This appears to be consistent with information gleaned from the harvesters with the majority identifying as independent suppliers. That said, most businesses noted that they source their seaweed from a relatively small number of harvesters with 60% sourcing from 1-2 harvesters and only 14% sourcing from more than 15 - though these relate to the seaweed processing businesses using the largest volumes.

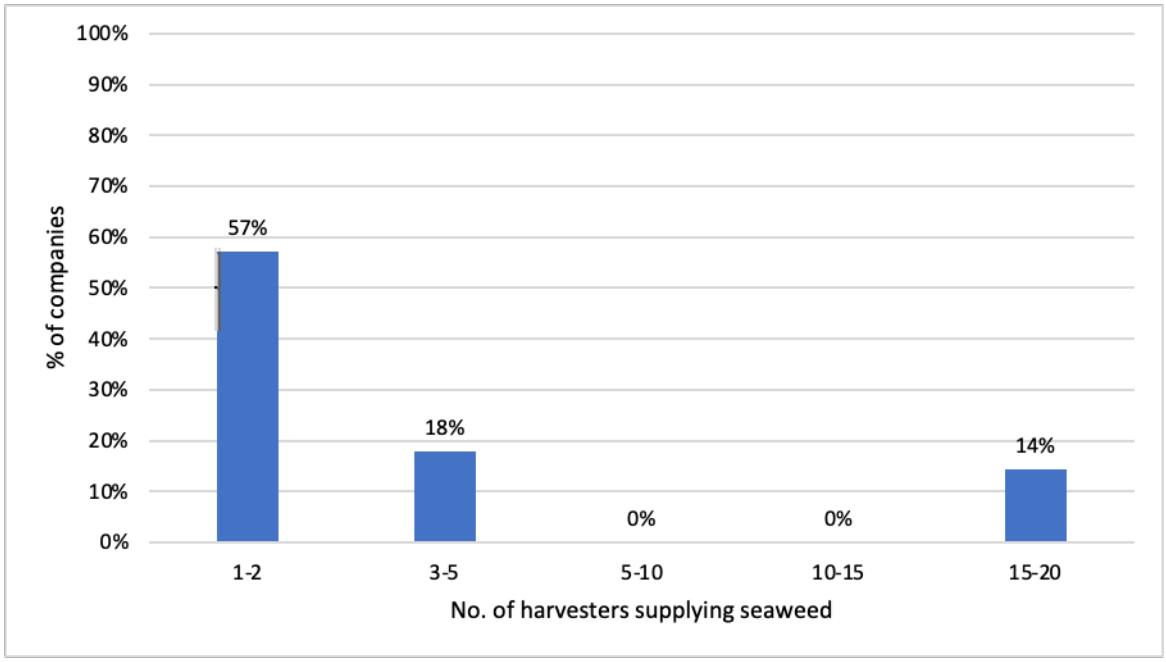


Figure 4.3: *Number of harvesters supplying seaweed to Irish processors*

As shown in Figure 4.4, while 22% of the businesses surveyed were using seaweed for only a small proportion of their business (less than 25% of their revenue), for 64% it accounts for 100% of their business.

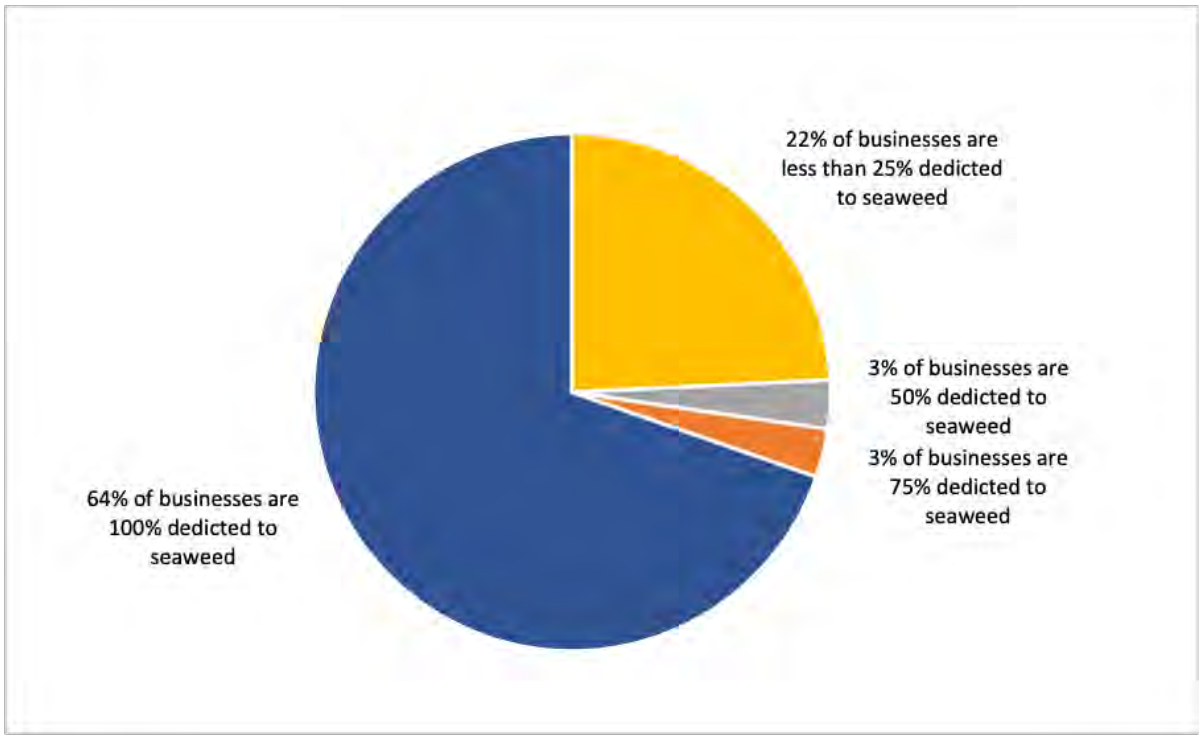


Figure 4.4: *Proportion of business income related to production of seaweed products (non- responses account for 3%)*

In terms of the focus areas that these businesses are involved in, while some are dedicated to one particular aspect of production, most are involved in a number of different stages from harvesting/cultivation through to the selling of final products.

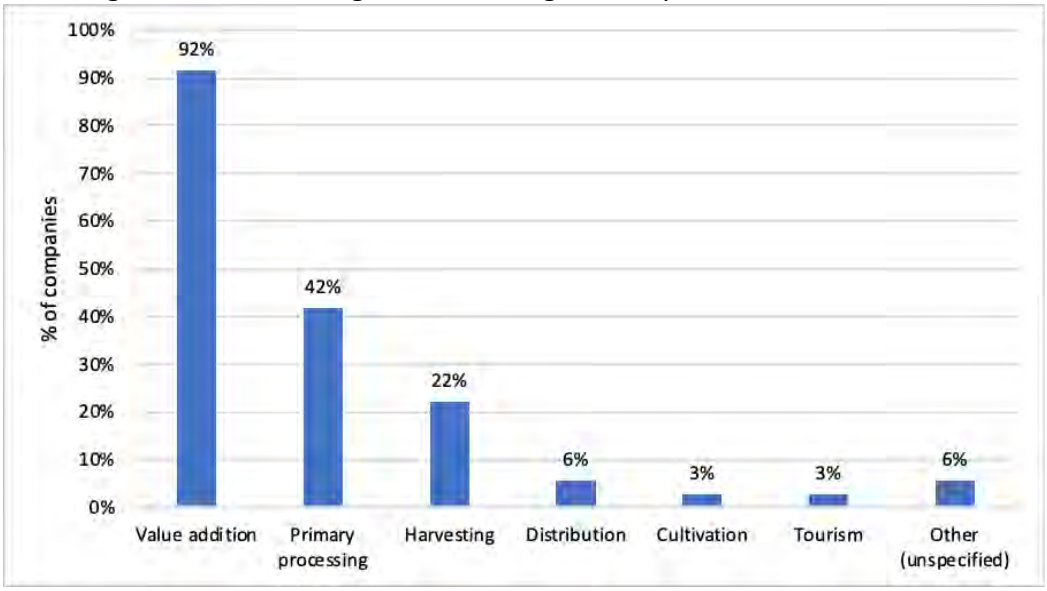


Figure 4.5: *Main internal activities that processors are currently undertaking*

The information noted here points to an indigenous sector that is specialised in the use and conversion of wild harvested seaweed into a variety of value-added products.

4.2. Financial Characteristics of Irish Seaweed Processors

As noted in Section 4.1, the majority of processors are classed as SMEs when considering employee numbers. This is consistent with the financial classifications with most being termed as micro (turnover less than 2 million) for the seaweed portion of their business.

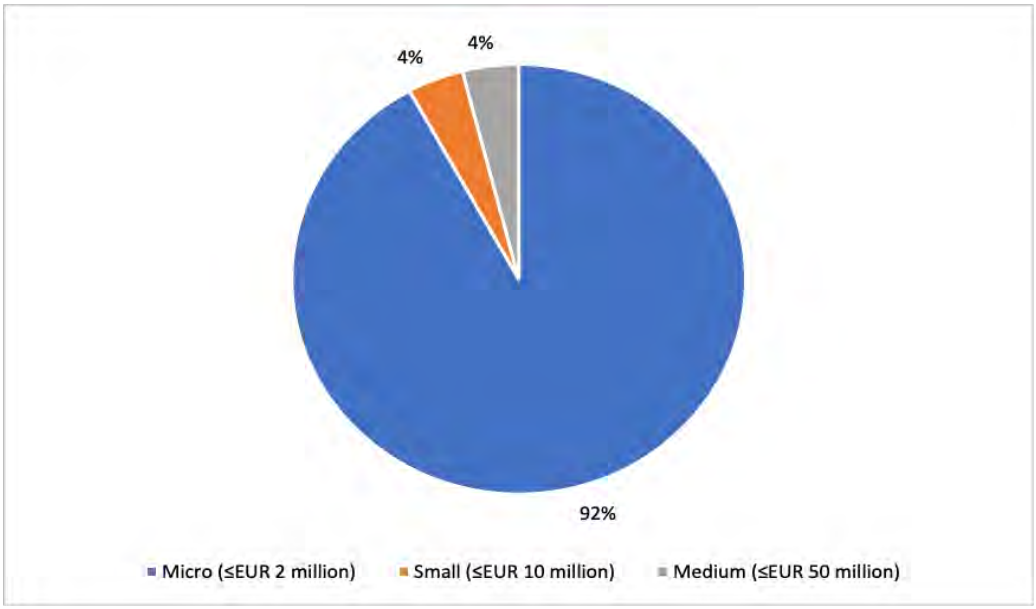


Figure 4.6: *Size of companies based on turnover*

Linking turnover to the quantities of seaweed used shows that there is significant variation in the value that the seaweed products command in the marketplace from a low value of €0.09 per kilo to an upper range in excess of €20 per kilogram - see Figure 4.7. Unfortunately, the data gathered did not provide enough granular data to identify the turnover related to different seaweed species, though this is an area for future research.

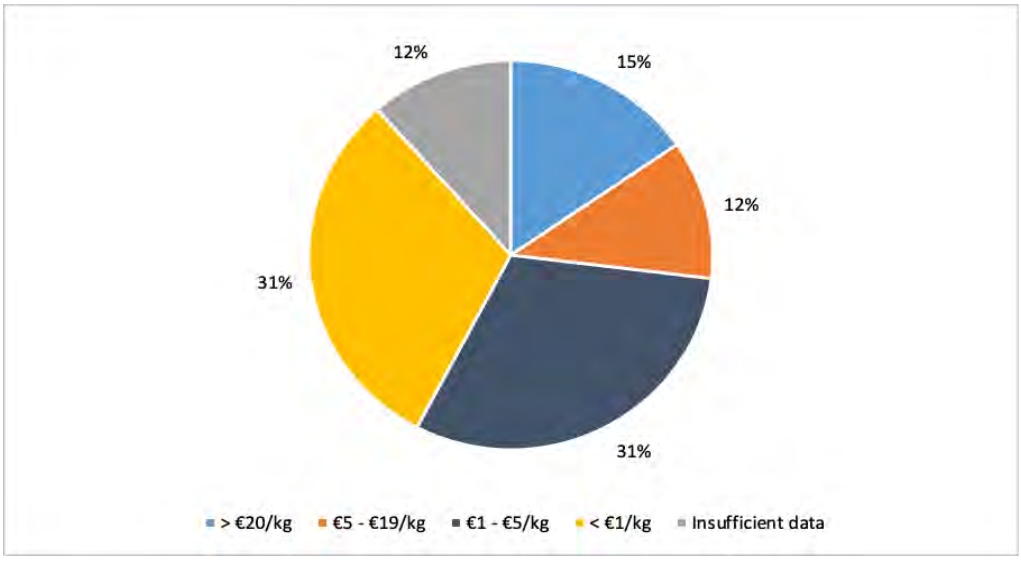


Figure 4.7: *turnover commanded per kg of seaweed processed*

The variation in revenue per kilo correlates with the market breakdown identified by the processors. For example, Figure 4.8 shows that the value of fertiliser and soil amendments account for 34% of the product ranges and this would be consistent with the 31% of turnover of less than €1/kg shown in Figure 4.7. Of the 174 product lines identified, there was a wider range and diversity of products for the human use market whereas, in the agricultural sector, the number of products and product ranges is much more limited. That said, by volume, much more seaweed is used in the latter.

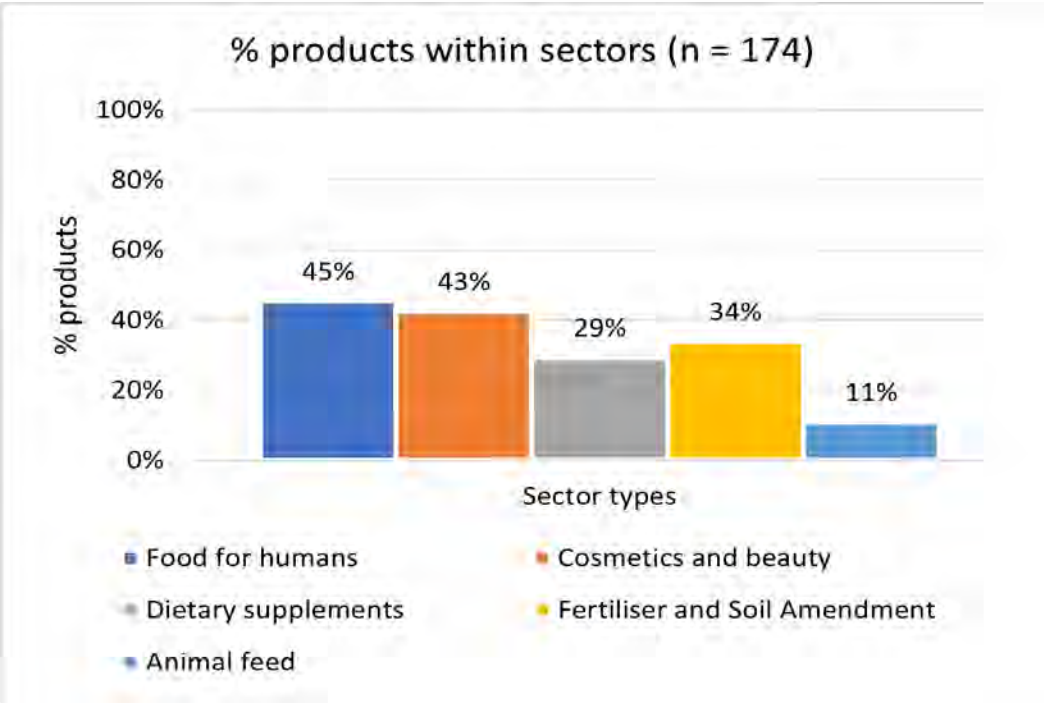


Figure 4.8: *Breakdown of reported product lines by type*

An examination of regional financial trends relating to the processors provided some interesting findings including:

- The average turnover of companies in the northern and west regions, where larger volumes are processed, is substantially greater than in the southern region
- The turnover per kg in the southern region is substantially greater than in the northern and western regions (mean of southern region = €52.50/kg, mean of northern and western regions = €8.90/kg)
- Total seaweed **use** in the northern and western regions is substantially greater than in the southern region (mean of Northern and West region = 2,235 wet tonnes, mean of southern region = 22.5 wet tonnes).

Collectively, these indicated that seaweed enterprises are more profitable in the northern and western regions where larger volumes are used.

4.3. Product Ranges Produced by Irish Seaweed Processors

As outlined in Section 3, a wide variety of seaweeds are harvested in Ireland with the majority of businesses using indigenously sourced seaweed. It is important to note that in addition to the nationally sourced seaweeds, almost 70,000 tonnes of *Lithothamnion* spp. (calcified seaweed or 'mearl') are imported for processing for the export market. This volume is an increase on the figure quoted in 2018 of 58,000 tonnes (BIM, 2020).

Regarding the nationally sourced seaweeds used by the processors surveyed, these tend to be purchased in wet tonnes, though some pre-drying is carried out by harvesters for certain seaweeds. This is typically carried out through a combination of natural drying on lines (as far

as possible) and mechanical drying.

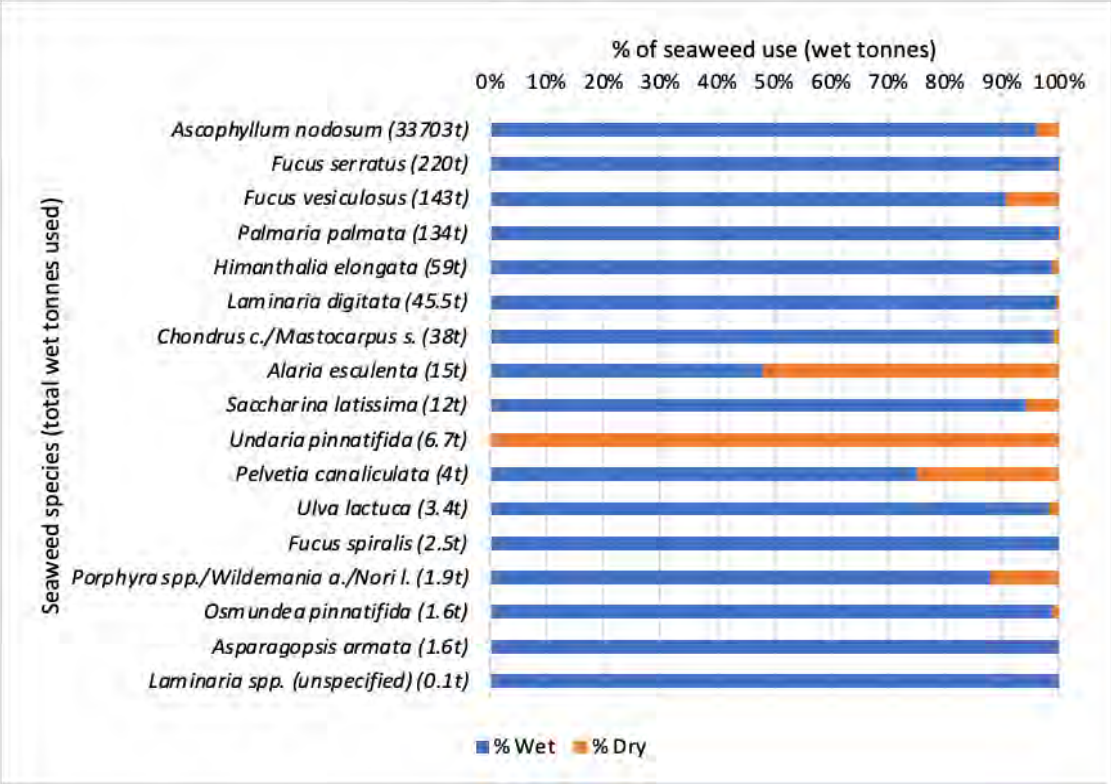


Figure 4.9: *How the Irish harvested seaweeds are used as an input by processors*

Regarding the products (or ranges) produced, processors tend to be quite specialised with 53% focusing on just one product or range and 28% concentrating on just 2 (see Figure 4.10) with 16% producing more than 2 products or ranges.

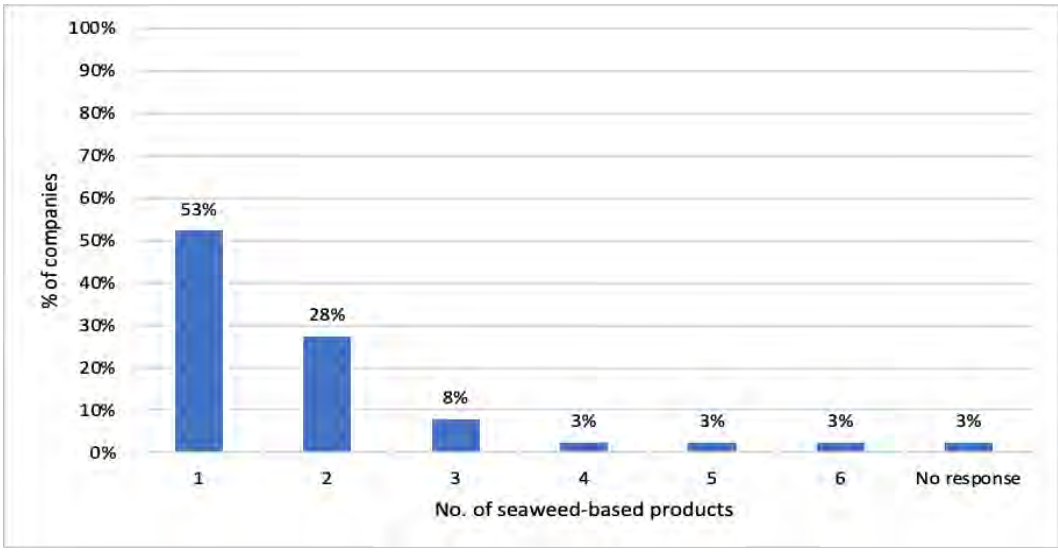


Figure 4.10: *Numbers of product ranges that processors produce*

These product categories vary, with human use (food, cosmetics and supplements) being the predominant target market for most processors. It is important to note that the results shown in Figure 4.11 are based on the absolute numbers of products produced rather than the weight of seaweed used in these products and, due to the high proportion of *Asco* used for agricultural based products, the largest volumes are still concentrated in this market sector.

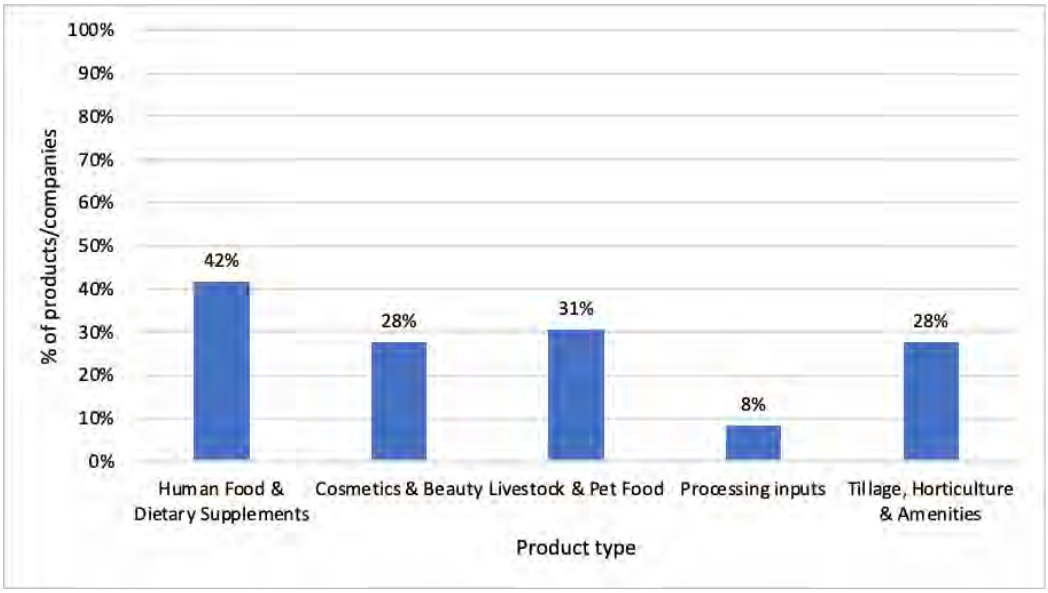


Figure 4.11: *Numbers of product ranges that processors produce*

In terms of the final product being sold, 66% produced intermediary ingredients only with the remainder involved in both intermediary and/or final products.

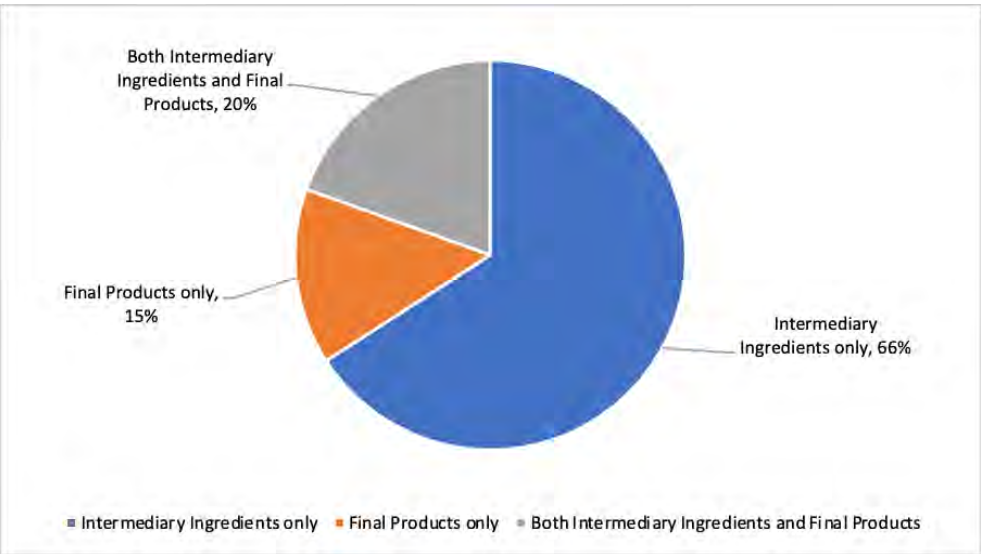


Figure 4.12: *Product ranges sold as intermediary ingredients, final products or both*

4.4. Processing Activities

The processing involved in production of the various product categories of course varies, from very basic drying and milling to liquid extraction and infusion. Interestingly, the most prevalent processes involved in the initial treatment of the wet seaweed materials are drying and milling as shown in Figure 4.13.

The drying and milling of seaweed alone is typically associated with lower value intermediate or final products as this can change the structure of some of the important constituents within the seaweed. That said, with increased volumes of seaweed being used, larger scale mechanical drying has become an important part of processing and, from an energy consumption perspective, an important area to consider. The cost of proper drying was identified as a potential barrier to growth due to the high costs of energy required. However, the option of complimentary processing with seafood processors, who have significant quantities of low grade waste heat available from refrigeration systems (through heat exchange) may be an area worthy of exploration.

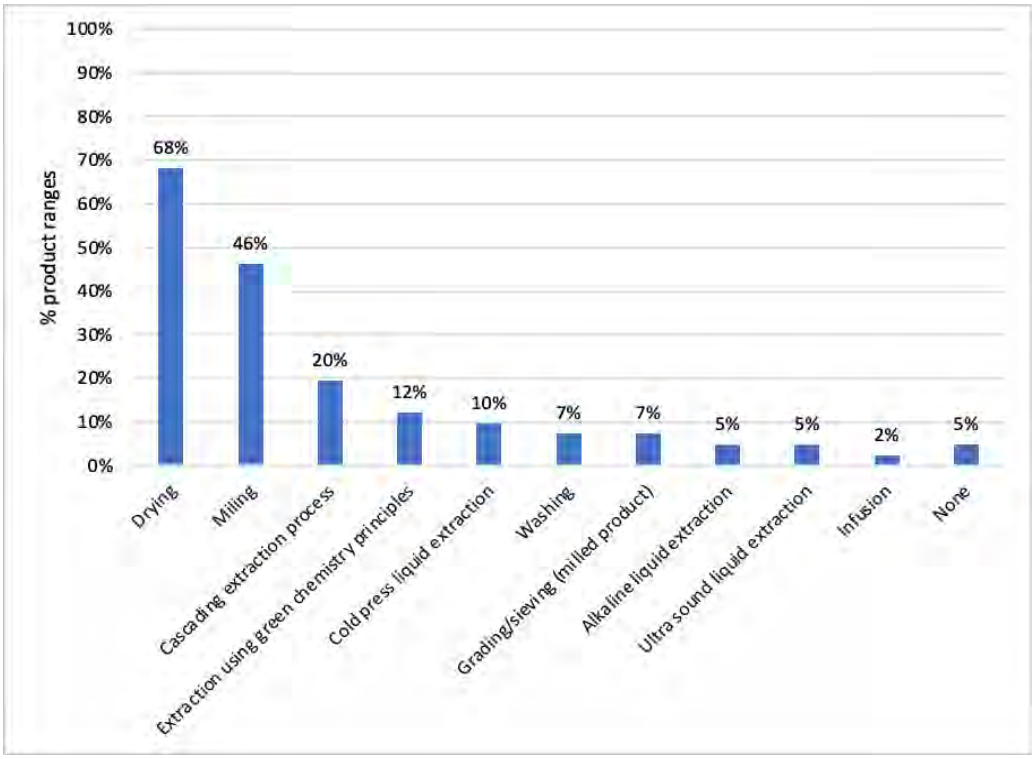


Figure 4.13: *Main steps involved in in production processes*

It was interesting to note that most processors stated that they have little or no wastes from their processing operations and that, where any 'wastes' are generated they are using these by-products for fertiliser, animal feed, and cosmetics, e.g. soap. However, as these processing by-products generate an income they are not recorded as wastes. 18% responded that they produce waste from primary processing (e.g. sand and grit, post-processing liquids and seaweed pulp) with these materials mainly used for fertiliser and animal feed. As these products are not generating income for the companies involved, they classed them as processing by-products.

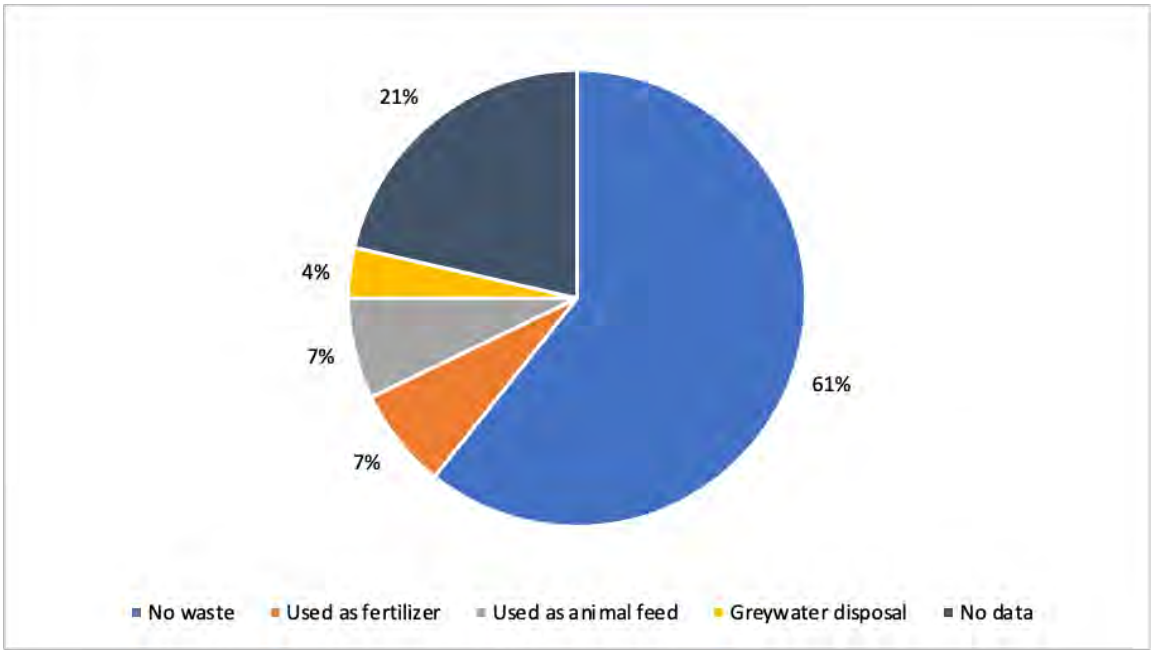


Figure 4.14: *Generation and uses of any wastes produced during processing*

4.5. Markets and Supports

A wide variety of products, including both final products and intermediary ingredients, are produced in Ireland. The nature of these products dictates the final market with sales going to further processors, wholesale suppliers, direct sales to commercial customers (e.g. restaurants) and direct sales to domestic consumers.

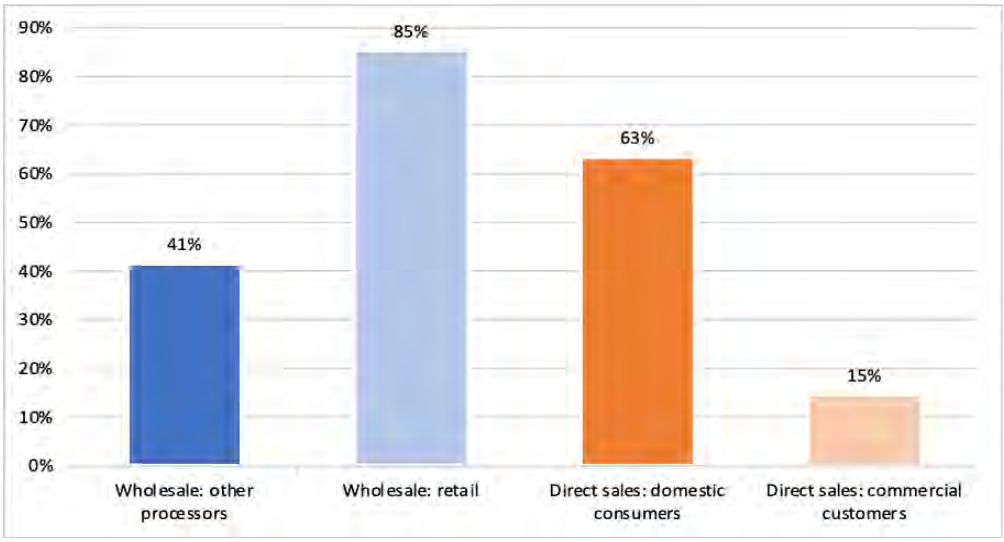


Figure 4.15: *Main markets where seaweed products sold*

Of the original database of processors generated through the research (84 businesses), over 25 had closed or consolidated. While this suggests the potential of a shrinking market, those still involved in the sector noted that their markets have continued to increase. Interestingly, over 60% are now selling via online pathways which helped to mitigate the effects that Covid undoubtedly had on the sector.

This continued growth in the sector is reflected by the fact that 54% are actively involved in R&D with a further 7% proactively engaging with sectoral research. While those that are pursuing R&D tend to focus on a number of different areas, ongoing product development is most prominent as shown in Figure 4.16.

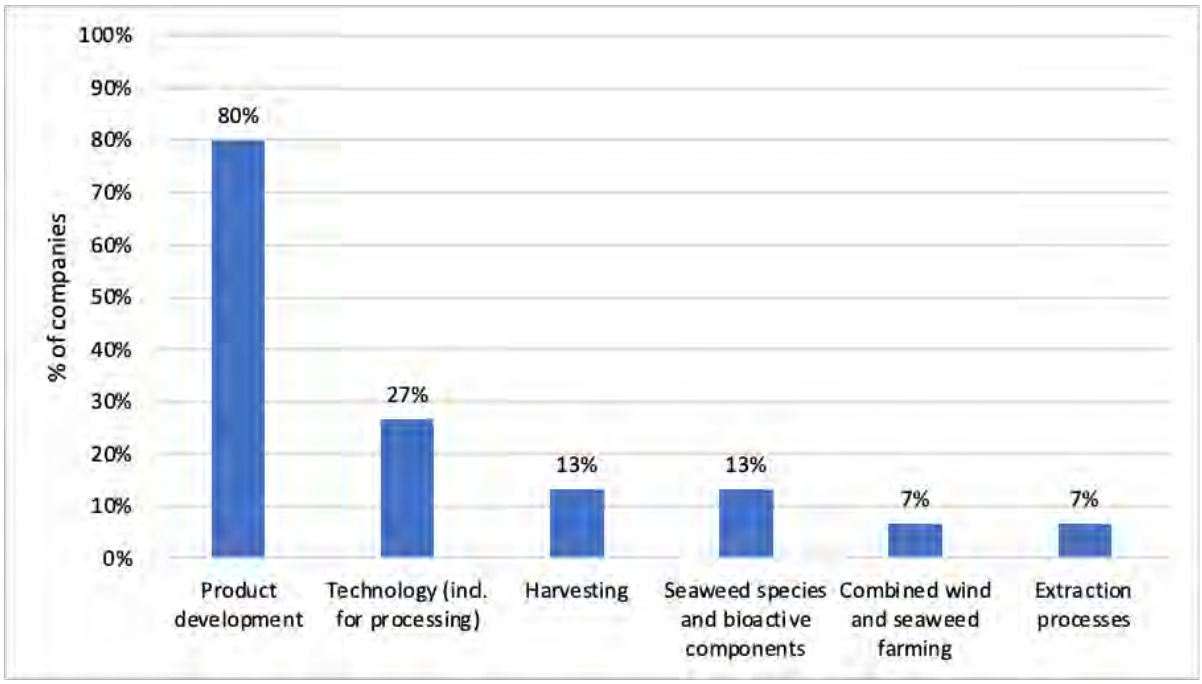


Figure 4.16: *Areas where current research and development focused*

The focus of this product development varies (see Figure 4.17) and, while animal feed is the largest individual focus area (at 25% of respondents), there are high levels of interest in food (18%), cosmetics (18%), fertiliser (14%), biorefining (14%) and dietary supplements. The high interest in animal feed was noted to be related to seaweed use in mitigating methane emissions in cattle, something that has received widespread attention recently.

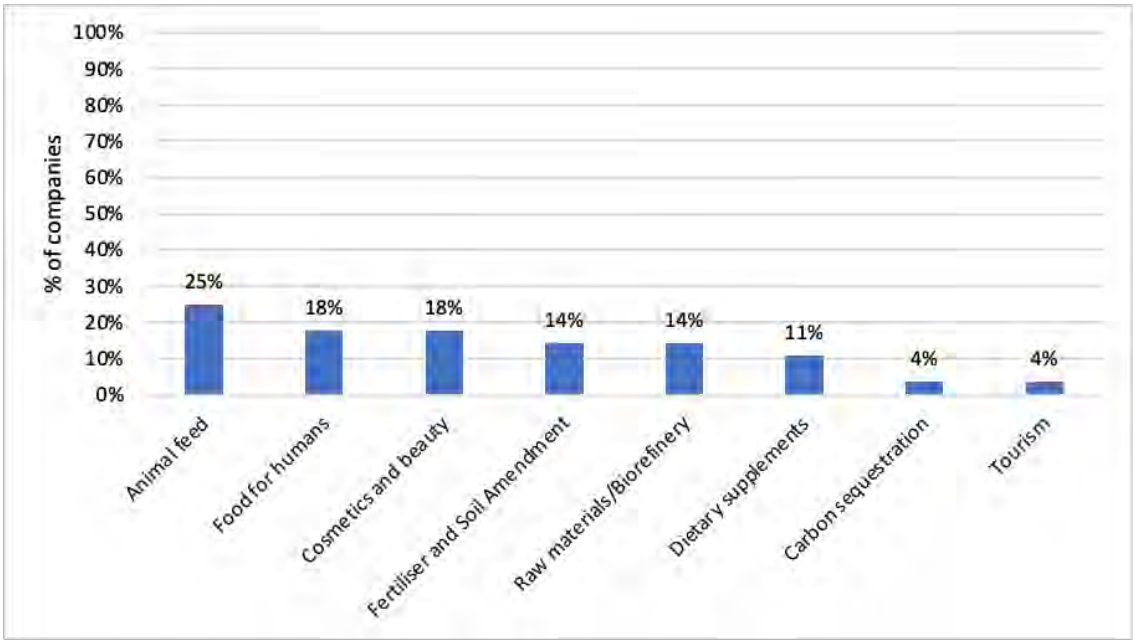


Figure 4.17: *Areas of interest for emerging product development*

The future development and support of the sector was also explored. Though 70% of the respondents had received some form of support in the past 5 years (both financial and non-financial) most agreed that continuing investment was required to grow the industry and increase the return on seaweeds being used. The following profile summarises the main supports that respondents deemed necessary to evolve the sector.

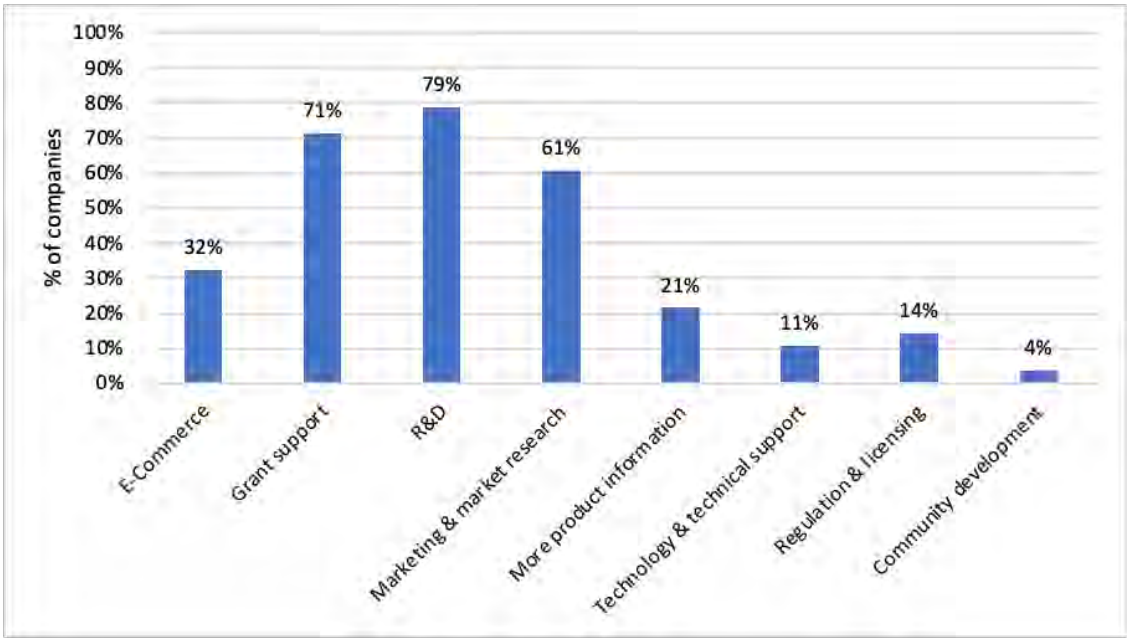


Figure 4.18: *main supports that businesses require to further grow their business offerings*

4.6. Cultivation

The use of cultivation to supplement the supply of wild Irish seaweeds has been identified as an ideal way to create a sustainable year round supply as well as minimising the stresses that over harvesting may place on the wild resource (Walsh and Watson, 2012). However, the anticipated increase in cultivated supply compared with wild harvested seaweed has not been as significant as was suggested in this 2012 study and is discussed in more detail in Section 5. Based on feedback from processors and BIM, 9 growers are currently involved in seaweed cultivation in Cork, Kerry, Clare, Mayo, Sligo and Donegal on 254 hectares of licensed sites harvesting 169 tonnes in 2022 which is an increase from the 40 tonnes reported in 2018 (BIM, 2020). However, this is an area of growing interest with over 40% of the sector having already, or are willing, to invest in this area. However, given the challenges faced by aquaculture in exposed environments and the life-cycle and demographic constraints of some of the main seaweeds currently used in Ireland (e.g. *A. nodosum* and *L. hyperborea*), it is likely that seaweed cultivation will remain, certainly in the short term, a relatively small contributor to the overall tonnages processed in Ireland.

In order to grow this aspect of the Irish seaweed supply chain, investment and support is required. Figure 4.19 summarises the main areas where those interested in progressing cultivation would like assistance, with technical expertise and financial support being the main supports required.

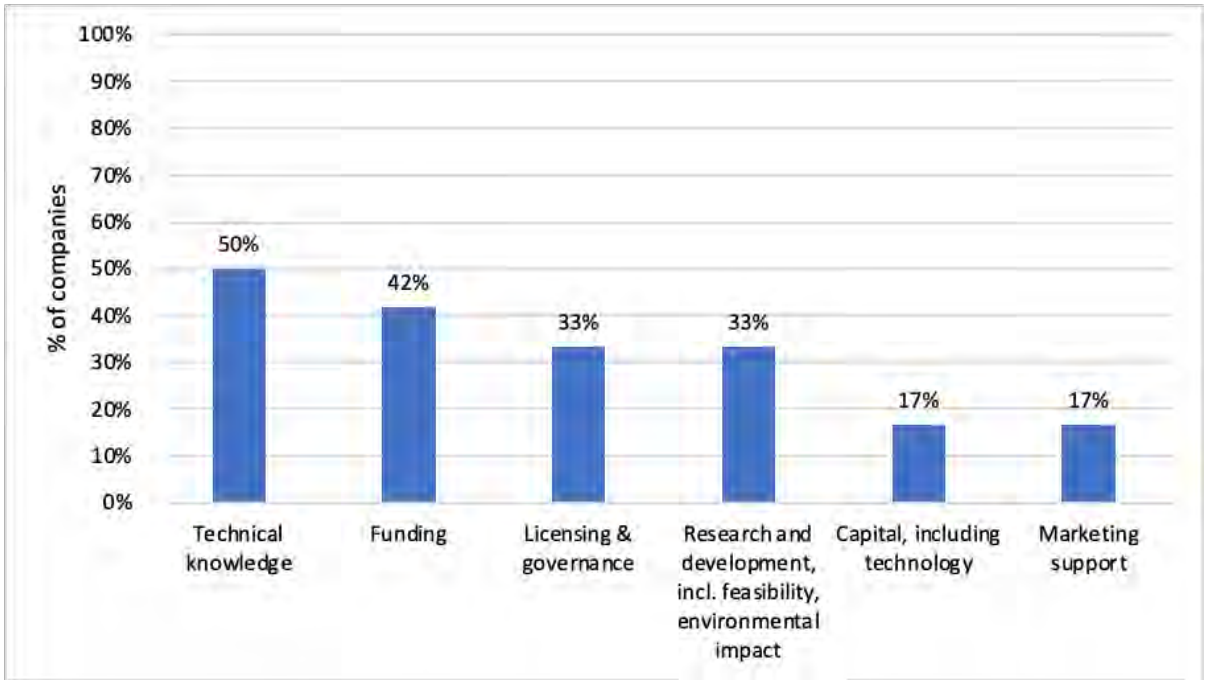


Figure 4.19: *Main areas identified where support for seaweed farming was required*

Feedback from a number of harvesters involved in cultivation was interesting. They noted that, even though they had significant marine experience prior to starting seaweed farming (most had been fishermen), there was still a 3-5 year lead in time in refining the process and optimising cultivation. It was also noted that, with the increased interest in the use of seaweed as a sustainable resource for higher end products, there have been numerous people

interested in getting involved but that the lack of appropriate skills and in-depth knowledge has limited the opportunities to access sufficient start-up funds.

4.7. Regional Trends

An examination of the survey responses indicated that the proportion of export-led trade was significantly greater in the northern and western regions than in the southern region, though the proportion of domestic trade (relative to tonnes harvested) is significantly greater in the southern region than in the northern and western regions. Most *Ascophyllum nodosum* is processed in Ireland for the manufacture of high value products such as biostimulants for subsequent sale on international markets.

Through exploring the responses from processors regarding their markets, a number of points could be deducted:

- Though there is greater export led trade in the northern and western areas of Ireland, an absence of information about final product destination means it is not possible to ascertain if this is primarily cross-border related trade.
- The extent to which companies are dedicated to seaweed is significantly greater in the northern and western regions than in the southern region. This seems to indicate a greater dependence in northern and western region processors on seaweed-based processing in terms of volume (i.e. they tend to produce only seaweed based products) whereas in the southern region there is more diversity.
- The number of harvesters employed by companies in the northern and western regions is statistically greater than the southern region. Most companies involved in primary processing are also based in the northern and western regions.
- Processors in the southern region are generally smaller though more diversified in terms of species used and products produced. Unlike the larger companies in the north and west, who do more primary processing and generate intermediary products, those specialised southern companies tend to produce higher value products that generate more revenue per kilogramme sold.

These indicate that the northern and western regions are the centre of large scale seaweed harvesting and primary processing of intermediary ingredients (*Asco* based) and a critical supply point for companies in other parts of the country for processing to manufacture biostimulants. Conversely, processors appear to be more small-scale and vertically integrated in the southern region of the country producing higher value final products.

4.8. Overall Value to the Irish Economy

The value of the Irish seaweed industry to the Irish economy has been steadily growing over the past decade. In 2011, it was estimated that the industry was worth ~€18 million (Morrissey et al., 2011) and previously the Sea Change Strategy (2006) estimated that the sector would be worth €30 million by 2020. More recently, it was estimated that seaweed worth €37 million (77,000 tonnes) was exported from Ireland in 2018 (BIM, 2020) though much of this may be

related to the large tonnages of *Lithothamnion spp.* (calcified, dead seaweed or 'maerl') imported from Iceland for reprocessing here.

Based on the information gathered from the processors surveyed during this work, it appears that industry has greatly surpassed this estimate. Figure 4.20 represents the turnover bands of the processors surveyed and, based on these, along with specific data relating to a number of individual processors, the current value of the industry is estimated at between €80-90 million. This value is based three groupings:

- The ANPG, which largely deals with *Asco,* generated close to €40 million in revenue during 2021;
- One Irish based company that is harvesting *Lithothaminion spp.* (calcified seaweed or 'maerl') from Iceland for processing in Ireland generated approximately €40 million in revenue for 2020;
- According to our survey work, the remaining seaweed processors generated an estimated €5.7 million in revenue last year.

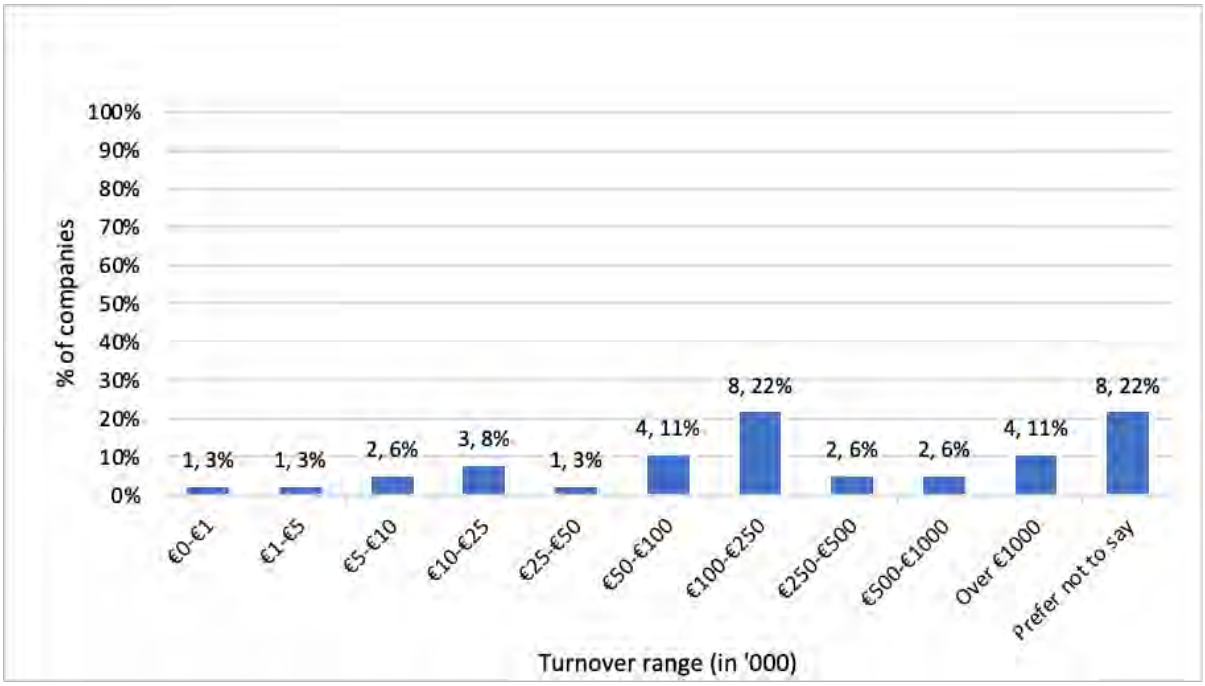


Figure 4.20: *Number of companies with turnover in a range of bands*

4.9. Summary

In summary, the following outlines some of the main quantitative findings from the detailed survey of national processors:

- It is estimated that of 359 people involved in the Irish seaweed processing sector 84% are full time. Many of these are involved in multiple functions including processing, harvesting and other related work (e.g. R&D, the natural sciences, engineering, quality control, processing, accounting, administration, marketing and sales).

- While the sector is dominated by SMEs (based on absolute numbers), with most employing less than 10 people, the ANPG group represents the 5 largest businesses using Irish sourced wild seaweed, primarily in the manufacture of biostimulants. One other company processes almost 70,000 tonnes of imported calcified seaweed ('maerl') from Iceland.
- Processors are involved in the production of a variety of products for agriculture, animal and human use. The largest volumes, relating to *Ascophyllum nodosum*, are harvested in the north and west and are used to produce intermediary ingredients (for valorising) and higher value products for agricultural use such as biostimulants.
- The value of the various seaweeds, which is related to both seaweed type and the final product, varies from less than €1 per kilo to in excess of €10 per kilo. Much of the Irish seaweed currently processed is focused on providing high value-added products for the biostimulants market though there is the potential to expand the use of *Asco* to additional value added areas.
- The current value of the Irish market (based on seaweed harvested in Ireland) is estimated at over €45 million, though when including the one processor using large volumes of imported calcified seaweed (i.e. mearl) the revenue is estimated at between €80-90 million.
- The use of cultivated seaweed is still, relative to the volume of wild harvested seaweed, very small (estimated at ~169 tonnes in 2022). While there is significant interest in exploring this area for growing a variety of seaweed species, including kelp, it is still under-resourced (in terms of research and direct support) and hindered by the lack of responsive licensing. Additionally, there are technical difficulties associated with the cultivation of seaweeds in exposed environments and limitations on species, such as *Ascophyllum nodosum,* that cannot be easily grown in an aquaculture setting due to life-cycle or demographic characteristics.

5. Potential of Seaweed Industry

5.1. Analysing Biomass Valorisation Potential

Seaweed can be classified on the basis of colour, or pigments: red seaweed or *Rhodophyceae* (over 7,200 species); brown macroalgae or *Phaeophyceae* (about 2,000 species); and, green algae or *Chlorophyceae* (>1,800 species) (Tabassum et al., 2017; Ummat et al., 2019), and on the basis of other structural and biochemical composition, including polysaccharides, and other bioactive compounds (Garcia-Vaquero et al., 2017).

Approximately 291 seaweed species are used globally, primarily for human food and hydrocolloid production (White and Wilson, 2015). The seaweed usage data provided by survey participants indicates that Irish seaweed processors use approximately 17 Irish species, and at least 34,390 tonnes of domestically sourced seaweed, on a wet tonnage basis. This figure may be higher as similar species, e.g. *Porphyra* spp./*Wildemania amplissima*, were reported in a grouped format, and excludes imported species, of which there was one: mechanically harvested *Lithothamnion* spp. *(*red calcified coralline algae, or maërl). Calcified seaweed or 'mearl' (*Lithothamnion corallioides* and the similar *Phymatolithon calcareum)* were previously mechanically harvested from Bantry Bay with a harvest of 8-10,000 wet tonnes per annum (Werner and Kraan, 2004). The survey results indicated that extraction of maërl (calcified seaweed) within Ireland is no longer occurring, with maërl being sourced from Iceland by an Irish company instead. The quantity of seaweed used per species is outlined in Table 5.1.

5.1.1. Seaweeds of Commercial Interest in Ireland

5.1.1.1. Brown Seaweed (*Phaeophyceae*)

Brown seaweeds are the most commercially important Irish seaweed biomass (Hession et al., 1998). Of the 161 brown seaweed species which occur in Irish waters (Guiry, 2012), 13 species of commercial interest were considered in this study, the use of which is described in Table 5.1. All but two of these species were in use, the exceptions being *Sacchorhiza polyschides* and *Sargassum muticum*.

5.1.1.2. Red Seaweed (*Rhodophyceae*)

303 red seaweed species occur in Irish waters (Guiry, 2012). Nine of these are of commercial interest, and were considered in this study (see Table 5.1). All of these species were being used by some of the survey participants. It must be noted that the use of carrageen/carageenan was cited by some companies as a common name for both *C. crispus* and *M. stellatus*. It is therefore unclear if *M. stellatus* was used or the more common *C. crispus* was harvested and used. The group of red seaweeds known as maërl also occurs in Irish waters (Kraan et al., 2001), however it is no longer harvested here as it is deemed a non-renewable resource.

5.1.1.3. Green Seaweed (Chlorophyta)

93 green seaweed species occur in Irish waters (Guiry, 2012). One of these species, *Ulva*

lactuca, was of commercial interest, and was considered in this study. This is also listed in Table 5.1 below. Two other variants of this species found in Ireland were also being used by survey participants, *U. lactuca Linnaeus* (commonly known as "sea lettuce") and *U. lactuca spiralis* (commonly known as "Atlantic spirulina"). These species are physiologically similar to other *Ulva spp.* occurring in Irish waters (e.g., *U. rigida* and *U. rotundata)*, with genetic analysis required to accurately discriminate between these species (Wan et al., 2017).

Table 5.1: *Irish seaweeds used, by quantity in wet tonnes (T) (% = % of total use of Irish seaweeds; Use No. = No. of companies using species; * = quantity unknown)*

Seaweed type	Seaweed species	Tonnage	% of Total	Use No.
Phaeophyceae (brown)	*Ascophyllum nodosum* (wrack)	33,703	98%	18
Phaeophyceae (brown)	*Fucus serratus* (wrack)	220	0.6%	12
Phaeophyceae (brown)	*Fucus vesiculosus* (wrack)	143	0.4%	11
Rhodophyceae (red)	*Palmaria palmata* (dulse/dillisk)	134	0.4%	12
Phaeophyceae (brown)	*Himanthalia elongata* (sea spaghetti)	58.5	0.2%	8
Phaeophyceae (brown)	*Laminaria digitata* (kelp)	45.5	0.1%	14
Rhodophyceae (red)	*Chondrus c./Mastocarpus s.* (carrageen/carrageenan)	37.5	0.1%	10
Phaeophyceae (brown)	*Alaria esculenta* (kelp)	14.8	0.04%	9
Phaeophyceae (brown)	*Saccharina latissima* (kelp)	12.3	0.04%	9
Phaeophyceae (brown)	*Undaria pinnatifida* (wakame)	6.7	0.02%	4
Phaeophyceae (brown)	*Pelvetia canaliculata* (wrack)	4.0	0.01%	6
Chlorophyceae (green)	*Ulva lactuca* (sea lettuce, atlantic spirulina)	3.4	0.01%	1
Phaeophyceae (brown)	*Fucus spiralis* (wrack)	2.5	0.01%	5
Rhodophyceae (red)	*Porphyra spp./Wildemania a.* (nori/laver)	1.9	0.006%	2
Rhodophyceae (red)	*Osmundea pinnatifida* (pepper dulse)	1.6	0.005%	1
Rhodophyceae (red)	*Asparagopsis armata* (harpoon weed)	1.6	0.005%	1
Phaeophyceae (brown)	*Laminaria spp.* (unspecified)	0.1	0.0003%	3
Phaeophyceae	*Laminaria hyperborea* (kelp)	*	N/A	1

(brown)				
Phaeophyceae (brown)	Mixed brown seaweeds (alginate extract)	*	N/A	1
Phaeophyceae (brown)	*Sacchorhiza polyschides* (kelp)	N/A	N/A	0
Phaeophyceae (brown)	*Sargassum muticum* (Japanese wireweed)	N/A	N/A	0
Total		34,390		36

5.1.2. Increasing Available Biomass: Seaweed Cultivation

Globally, seaweed cultivation generates 97% of global seaweed use, and accounts for 30% of global aquaculture output, and 5.4% of global aquaculture value (FAO, 2021). Seaweed cultivation offers the potential to produce specific seaweeds without diminishing certain wild seaweed stocks, in a managed environment (at sea) or fully controlled environment (on land), reducing contamination and providing greater security of supply. Most cultivation takes place in Asia, and also provides more than 80% of seaweed used in Africa and Oceania, while in Europe and the Americas, cultivated seaweed accounts for less than 5% of seaweed use (FAO, 2021). Red seaweeds (including *Kappaphycus Alvarezii* and *Eucheuma* spp.) are the main cultured seaweeds (8.3 million tonnes), followed by Japanese kelp (5.7 million tonnes) (Joint Committee on Environment, Culture and the Gaeltacht, 2015). However, there are constraints to increasing seaweed cultivation in an Irish context. For example, certain species, such as *Ascophyllum nodosum*, are difficult to cultivate. In addition, aquaculture in exposed environments faces challenges due to the low survival rate of aquaculture structures and insufficiently durable equipment to withstand rough conditions (Bak et al., 2020). It is likely that higher wave heights may also be problematic for offshore aquaculture in coastal areas of the North Atlantic Ocean which typically experience stronger sea surface winds. It is likely that calmer conditions may be more suitable for seaweed aquaculture, for example, in regions on the East coast of Ireland and in sheltered coves and inlets on the West coast of Ireland where many existing aquaculture operations are situated now to grow fish such as salmon. In fact, research suggests a synergy between fish farming and seaweed growing operations as seaweed can help absorb excess nutrients from fish farming and help to attenuate strong currents and storm waves. These systems are known as integrated multi-trophic aquaculture systems and should be investigated further in an Irish context (as discussed below).

5.1.2.1. Developing Seaweed Cultivation in Ireland

Watson and Dring (2011) describe the need for seaweed cultivation in Ireland as significant, with capacity to enable the development of other sectors, e.g., abalone and urchin aquaculture which require seaweed as feed. Bord Iascaigh Mhara (BIM) has supported development of seaweed aquaculture in Ireland since 2004, focusing on developing and perfecting cultivation methods for *L. digitata, A. esculenta* and *S. latissima* (brown seaweeds) and *P. palmata* and *P. umbilicalis* (red seaweeds) (BIM, 2020). BIM staff reported that 9

licensed growers in Cork, Kerry, Clare, Mayo, Sligo and Donegal harvested about 169 tonnes of farmed seaweed from 254 hectares in 2022. As of November 2021, 13 seaweed aquaculture licence applications are awaiting approval from the Department of Agriculture, Food and the Marine for 522 hectares in Waterford, Kerry, Galway, Mayo, Donegal and Wicklow.

BIM foresees three main directions for seaweed cultivation in Ireland: integrated multi-trophic aquaculture (IMTA), on-shore tank culture of high-value species, and long-line cultivation in bays (Joint Committee on Environment, Culture and the Gaeltacht, 2015). IMTA combines fed aquaculture (i.e. cultivation of high trophic level species requiring feed inputs, such as salmon) and extractive aquaculture (i.e. lower trophic level fish such as scallops, mussels or oysters) with seaweeds that extract nutrients from their environment to grow (Buck et al., 2018). IMTA systems aim to use by-products from some species, such as salmon, as inputs for producing other species. Compared with conventional aquaculture, IMTA reduces waste, improves circularity, and can strengthen business viability through product diversification (Marine Institute, 2020). Marine seaweed cultivation, including IMTA, has also been successfully integrated with offshore wind energy production in places like Germany (Buck et al., 2018). This is a promising venture for seaweed cultivation in Ireland, due to the double dividend of increasing sovereign sources of renewable energy, which could be fed to the national grid to generate revenue, or used to fuel seaweed drying and processing operations to reduce the costs associated with seaweed production.

Currently, IMTA is at an experimental stage in Ireland, e.g. at the Marine Institute's site in Connemara (Marine Institute, 2020). Other organisations such as Bantry Marine Research Station are actively exploring hatchery operations, new cultivation techniques in Ireland and growing methods for additional species found in Irish waters. Elsewhere, innovative cultivation techniques have been developed that can accelerate the capacity for seaweed cultivation e.g. the "seaweed spinner" for seeding of seaweed lines with seaweed, and "SPoKe" robot-assisted seaweed cultivation stations, which automate the seeding of lines and harvesting of seaweed from those lines (GeniAlg, 2020).

5.1.2.2. Regulation of Seaweed Cultivation

Seaweed cultivation is typically a highly regulated activity in European countries with statutory regulations and licensing typical, in addition to voluntary standards, e.g. the Aquaculture Stewardship Council "Seaweed Standard" (ASC International, 2022; Camarena Gómez and Lähteenmäki-Uutela, 2021). Licensing for seaweed farming in Ireland currently requires a foreshore licence from the Department of Housing, Local Government and Heritage and an aquaculture licence from the Department of Agriculture, Food and the Marine. Most of the nine seaweed aquaculture licences that have been issued to date (and the 13 that are pending), focus on edible seaweeds for production of food for humans, while some use of inedible seaweeds for the cosmetics industry is also planned (BIM 2022). The Joint Committee on Environment, Culture and the Gaeltacht (2015) reported that seaweed aquaculture could reach a production level of 2-3,000 tonnes per year by 2020. However, due to licensing constraints, this development in production has not occurred.

5.1.3. Seaweed Composition

Seaweed composition varies based on species and local environmental conditions, and also

varies seasonally, and according to cultivation protocol in the case of farmed seaweeds (Moreira et al., 2021; Tabassum et al., 2016). Seaweeds contain components of interest for industrial, medical and nutritional use as well as other applications, including proteins (7-31% of dry weight), lipids (2-13% of dry weight), carbohydrates (32-60% of dry weight), minerals (e.g. potassium, sodium, magnesium, and iodine), and vitamins (e.g. vitamins A and E) (Biris-Dorhoi et al., 2020). The composition of seaweed varies from species to species and depending on the environmental conditions at the time and location of harvest. These components include bioactive peptides and sugars with demonstrated benefits for human, animal and plant health (Biris-Dorhoi et al., 2020; BIM, 2020).

As described in Section 4 above, a range of seaweed products were created by Irish companies in 2021, for use as human food or dietary supplements, cosmetics and therapeutic use, biostimulants, fertilizer and soil amendments, and food for livestock, horses and pets. These products are created using a range of techniques from simply drying seaweed and selling dried leaves for food, to extractive processes using green chemistry principles and cascading extraction techniques.

5.1.3.1. Seaweed Biorefining

Using the principle of cascading extraction, biorefinery technology enables a range of products to be made from a biomass feedstock, typically the most valuable components are extracted first, followed by maximum utilisation of remaining materials. In seaweed, this includes polysaccharides, phenolic compounds, proteins and other bioactive molecules with a wide range of industrial applications in biostimulants, animal and human health applications, pharmaceuticals, cosmetics and nutraceuticals, e.g., health supplements and functional foods. The biorefinery process can also utilise seaweed residues for renewable energy production. Different extraction processes can be applied to enhance the efficiency of this process. For example, aqueous extraction, green chemistry principles and ultrasound and microwave technology can be used to obtain carbohydrates or phycocolloids (i.e., alginates), while sequentially extracting other target compounds from the remaining biomass and transforming the residual solids into biofuel or organic fertilisers. This cascading use of biomass creates more total value than concentration on extraction of a single compound and is recognised as a high potential development opportunity for the Irish marine sector. This is driven by the significant portfolio of high value bioactive components and the differentiated value chains from seaweed to produce ingredients for biostimulants, functional health foods and nutraceuticals, cosmetics, pharmaceuticals, high value animal feed, bioenergy and potentially carbon capture as technologies progress to create net zero-carbon, zero-waste biorefineries.

5.1.3.2. Seaweed Components

In this study, 23 species were examined for their potential applications as biomass inputs for biorefinery development in Ireland, grouped by seaweed family. These seaweed species differ at a macro level in relative composition of macronutrients (Fig. 5.1) and at a more micro level in terms of the composition of specific molecules, including functional polysaccharides, lipids, proteins, peptides, metabolites and pigments (Table 5.2). This variation in composition is critical to the commercialisation potential of each species, the yields of various high value compounds which they contain and the commercial opportunities associated with each species. Many information gaps exist on the composition of the economically important

wracks, in particular *H. elongata* and *A. armata*. The limited availability of robust information sources that compare the composition of Irish seaweeds in a consistent manner, i.e., with reference to similar components, is an essential issue to address for future development of the Irish seaweed industry.

Table 5.2 *Economically valuable and bioactive components of Irish seaweeds of economic importance, by seaweed family (brown: Phaeophyceae, red: Rhodophyceae, green: Chlorophyta) based on data from Jouanneau et al. (2021), Moreira et al. (2021) and BIM (2020).*

Bio-active components	Brown	Red	Green
Fibres: cellulose	■	■	■
Fibres: phlorotannins	■		
Lipids: omega fatty acids, e.g. omega 3			■
Lipids: polar lipids, e.g. glycolipids, betaine lipids, phospholipids			■
Mannitol	■		
Non-sugar storage carbohydrates: glucan		■	
Non-sugar storage carbohydrates: glycerol glycoside		■	
Pigments: phycobiliproteins (e.g. phycoerythrin, phycocyanin)		■	
Pigments: other (e.g. chlorophyll a and c)	■	■	■
Pigments: xanthophylls (e.g. fucoxanthin, beta-carotene)	■	■	■
Sugars: agar		■	
Sugars: alginate	■		
Sugars: carrageenan		■	
Sugars: fucoidan	■		
Sugars: laminarin	■		
Sugars: ulvans			■

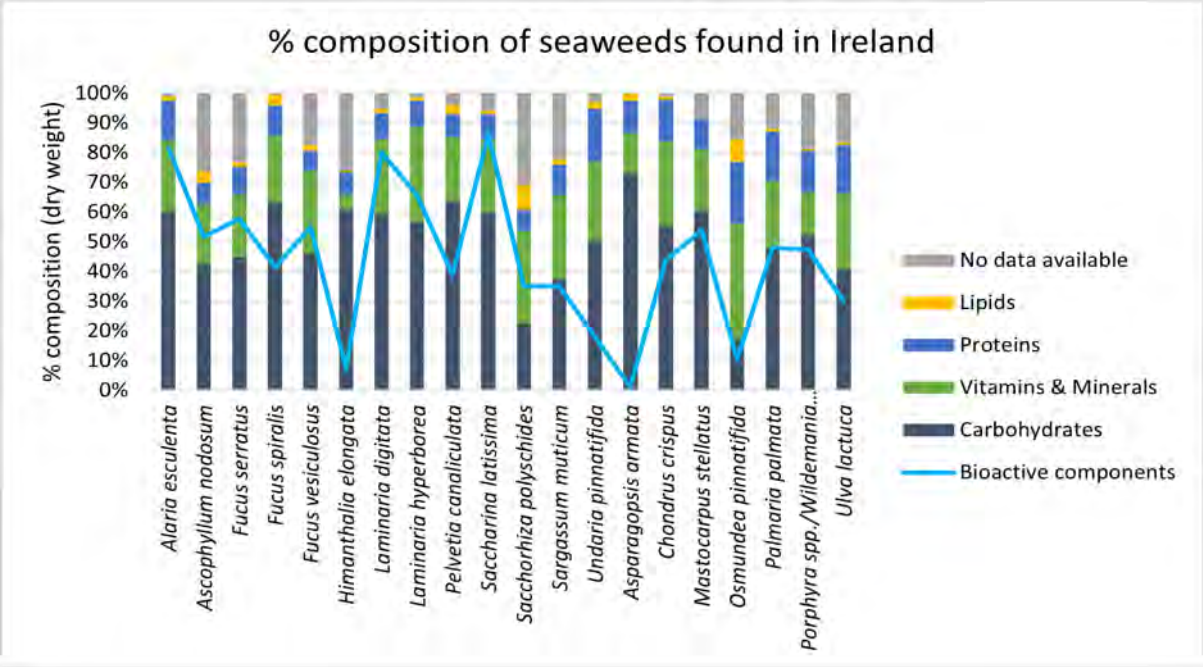


Figure. 5.1 *Composition profiles of Irish seaweeds of commercial interest (see Appendix 4).*

5.1.3.3. Quantity of Seaweed Components, Based on Harvested Material

The quantity of economically valuable components detailed in Figure 5.1 and Table 5.2, including the bioactive components available within the currently harvested mass of the seaweed species in Ireland, are detailed in Table 5.3, based on the composition. *Laminaria hyperborea*, *S. polyschides*, *S. muticum* and *M. stellatus* have been omitted as no usage quantities were reported in the survey of processors.

Table 5.3: *Quantity of economically valuable components (in dry tonnes) from the currently harvested mass of Irish seaweed species of economic interest, based on composition profiles compiled during this study.*

Seaweed Type	Seaweed species	Protein	Lipids	Carbohydrate	Vitamins & minerals	Bioactives	No data
Brown	*Alaria esculenta*	0.3	0.04	1.3	0.5	1.8	0.02
Brown	*Ascophyllum nodosum*	369	190	2,141	1,024	2,608	1,332
Brown	*Fucus spiralis*	0.04	0.01	0.2	0.08	0.2	0.002
Brown	Fucus vesiculosus	1.5	0.4	9.9	5.9	11.8	3.7

Brown	*Himanthalia elongata*	0.7	0.04	5.4	0.4	0.6	2.3
Brown	*Laminaria digitata*	0.6	0.1	4.1	1.7	5.5	0.4
Brown	*Pelvetia canaliculata*	0.05	0.02	0.4	0.1	0.2	0.02
Brown	*Saccharina latissima*	0.2	0.02	1.1	0.5	1.6	0.1
Brown	*Undaria pinnatifida*	0.2	0.02	0.5	0.3	0.2	0.03
Red	*Asparagopsis armata*	0.03	0.01	0.2	0.03	0.003	0.0002
Red	*Chondrus crispus*	0.8	0.06	3.1	1.6	2.5	0.07
Red	*Osmundea pinnatifida*	0.05	0.02	0.04	0.09	0.02	0.04
Red	*Palmaria palmata*	3.3	0.2	9.7	4.5	9.7	2.4
Red	*Porphyra umbilicalis*	0.04	0.002	0.2	0.04	0.1	0.05
Green	*Ulva lactuca L.*	0.08	0.004	0.2	0.1	0.2	0.08

5.1.4. Current Seaweed Uses

Figure 5.2 describes the uses of seaweeds within Irish-made products, as reported by the processors which participated in the survey carried out during this work. Of all Irish seaweeds harvested and used for the creation of products in Ireland, 99.5% are brown seaweeds, with a total of 34,203 wet tonnes of brown seaweeds used per annum. *Ascophyllum nodosum* is the main species of interest for commercial use, accounting for 98% of the total volume of seaweeds harvested in Ireland per annum.

Red seaweeds account for approximately 0.5% of all Irish seaweed use, with ~ 177 wet tonnes of red seaweeds used per annum, based on the survey of seaweed processors. Green seaweeds, namely *Ulva* spp., account for approximately 0.01% of all Irish seaweed use in Ireland, with approximately 3.4 wet tonnes used per annum. Although native to the seas ofIreland and other European waters, *Ulva* spp. are regarded as “nuisance” species, due to their tendency to occur as macroalgal blooms with negative impacts on seagrasses and fish, particularly where anthropogenic nutrient enrichment of waters occurs (Joniver et al., 2021; Wan et al., 2017).

The processors were asked about the main uses of their product ranges, i.e., cosmetics and beauty products, dietary supplements, food for humans, animal feed, and fertiliser, soil amendments and biostimulants. They were also asked to identify the seaweeds that were used to create their product ranges, which provided insight into the applications of different seaweed species by Irish processors. These applications are illustrated in Fig. 5.2 below.

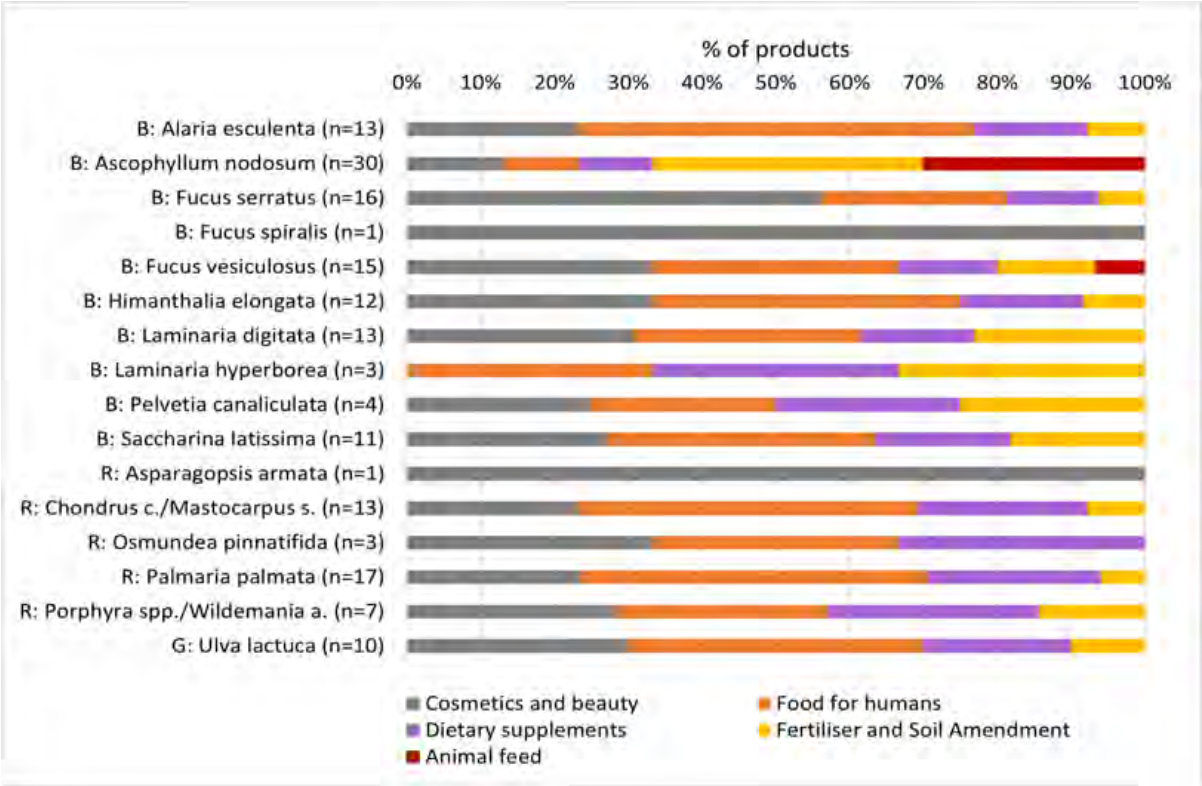


Figure 5.2: *Types of products using specific Irish seaweeds, as a proportion of all products created using those species ("B": Brown seaweeds, "R": red seaweeds, "G": Green seaweeds; "n": number of processors).*

5.1.4.1. Use of invasive Species

Invasive seaweed species in Ireland include *S. muticum*, *U. pinnatifida,* and *A. armata*. Invasive species are prolific and generally undesirable as they potentially pose a risk to habitat quality and native seaweed species that compete for the same habitat (although in some cases, invasive species can also enrich degraded habitats, strengthening the viability of native flora and fauna), e.g., *S. muticum* competes with the native *H. elongata* (Baer and Stengel, 2010).

Industrial utilisation is one option for economically efficient management of invasive species. *Sargassum muticum* has potential use as a dietary supplement for animals, in much the same way as *Ascophyllum nodosum*, but this potential has not yet been exploited, based on the survey results (Table 5.1, Fig. 5.2).

The commercial potential of *U. pinnatifida* is illustrated by the recent arrival of this species in Ireland (2016) (Kraan, 2017), and use so far by three seaweed processing companies (information about specific application was not available). *Asparagopsis armata* is not

recommended for human consumption. It is currently used solely for cosmetics production in Ireland, however experimental research on bovine feed supplementation for methane emissions reduction is being conducted.

However, it should be noted that the harvesting of certain invasive species may facilitate their spread into the wider marine environment. For example, cutting *S. muticum* could lead to the dispersion of its buoyant branches which can continue to shed germlings as they drift, making for a very powerful dispersal mechanism, contributing its further spread within an area (https://www.seaweed.ie/sargassum/). Therefore, harvesting of this species for commercial use may not be permitted due to the potentially negative environmental effects.

5.1.5. Potential Seaweed Uses

The potential application areas of different seaweed species is based upon their relative composition of nutritive and bioactive molecules which varies significantly from species to species. The scope of applications is varied with these broadly grouped into market applications in Table 5.4 below. This shows the potential for increased application of biotechnologies for further refinement and modifications, e.g., supercritical fluid extraction, novel separation technologies and fermentation.

Brown seaweeds are the focus of significant attention for high value human and animal health applications due to the presence of molecules such a fucoidan, fucoxanthin, laminarin, marine polyphenols and mannitor with reported antioxidant, anti-viral, anti-inflammatory, anti-coagulant, anti-thrombotic, immune-regulatory, and anti-tumour effects (Olsthoorn et al., 2021; Ummat et al., 2019). Alginate has hydrocolloidal physical properties used in food, biotechnology, biomedical, paper and textile industries (Ummat et al., 2019). Brown seaweeds also contain an abundance of other high value constituents such as laminarin, marine polyphenols, mannitol and marine fibre which can be extracted via biorefinery technologies and utilised for high value market applications.

Red seaweeds are used in the food industry, as a food and for their biophysical properties, e.g. carrageenan has gelling, thickening and stabilising properties (Ummat et al., 2019). The polar lipids contained within green seaweeds such as *Ulva spp.* have potential use as nutraceuticals, e.g. extraction of glycolipids which have antioxidant, anti-inflammatory, antimicrobial, and antitumor compounds (Moreira et al., 2021). Other seaweed applications are described for each species in Table 5.4, including seaweed applications not yet explored in Ireland (for Irish uses of seaweed see Fig. 5.2)

Table 5.4: *Areas of application of seaweed species of economic interest in Ireland.*

Seaweed type	Seaweed species	Areas of application
Brown	*Alaria esculenta* (kelp)	*Food for humans, food for pets/livestock, health/medical applications, biostimulants and fertilisers*
Brown	*Ascophyllum nodosum* (wrack)	*Food for pets/livestock, food ingredients, health/medical applications, hydrocolloids, biostimulants and fertilisers*
Red	*Asparagopsis armata* (harpoon weed)	*Food for pets/livestock, health medical applications, biotechnology*
Red	*Chondrus crispus/Mastocarpus stellatus* (carrageen/carrageenan)	*Food, food ingredients, health/medical applications, cosmetics/therapeutic*
Brown	*Fucus serratus* (wrack)	*Health/medical applications, cosmetics/therapeutic*
Brown	*Fucus spiralis* (wrack)	*Health/medical applications, cosmetics/therapeutic*
Brown	*Fucus vesiculosus* (wrack)	*Food, health/medical applications, cosmetics/therapeutic, biostimulants and fertilisers*
Brown	*Himanthalia elongata* (sea spaghetti)	*Food, food ingredients, hydrocolloids, cosmetics/therapeutic, biostimulants and fertilisers*
Brown	*Laminaria digitata* (kelp)	*Food for humans, food/feed for pets/livestock, Food, health/medical applications, biotechnology, biomethane*
Brown	*Laminaria hyperborea* (kelp)	*Food for humans, food/feed for pets/livestock, Food, food ingredients, health/medical applications, hydrocolloids, biomethane*
Red	*Osmundea pinnatifida* (pepper dulse)	*Food, health/medical applications, biotechnology*

Red	*Palmaria palmata* (dulse/dillisk)	*Food, health/medical applications*
Brown	*Pelvetia canaliculata* (wrack)	*Food, health/medical applications, biotechnology*
Red	*Porphyra* spp./*Wildemania amplissima* (nori/laver)	*Food, food for pets/livestock, food ingredients, health/medical applications*
Brown	*Saccharina latissima* (kelp)	*Food, health/medical applications, biomethane*
Brown	*Sacchoriza polyschides* (kelp)	*Food ingredients, hydrocolloids, biostimulants and fertilisers*
Brown	*Sargassum muticum* (Japanese wireweed)	*Food for pets/livestock, biostimulants and fertilisers*
Green	*Ulva* spp. (sea lettuce)	*Food, food ingredients, health/medical applications, biotechnology, biostimulants and fertilisers, biomethane*
Brown	*Undaria pinnatifida* (wakame)	*Food, health/medical applications*

5.2. Opportunities for the Diversification of the Irish Seaweed Industry

Irish seaweed processing companies are currently active in the processing of seaweed for food, food ingredients, dietary supplements, cosmetics, animal feed, including livestock, equine and pet feed and dietary supplements, and for plant fertilisers and biostimulants used in agriculture and amenity horticulture, e.g., golf greens. However, from the survey carried out as part of this study, it was apparent that there are value-added opportunities which are not currently being explored or exploited by Irish companies, including medical applications, pharmaceuticals and materials for medical use, material production for packaging, textiles, construction uses, detergent and cosmetics.

While Irish seaweed companies are actively engaged with some of these sectors, both actively and through ongoing R&D (e.g. biostimulants, plant production, animal and human food and feed ingredients, and cosmetics), with the increasing global demand for plant based, sustainable and functional ingredients, there is significant further scope for upscaling of existing companies and the seeding of technological enabled highly innovative start-up companies producing novel and high value marine products.

5.2.1. Opportunities for Under-Utilised Species

The research undertaken with the processors revealed that there are some species which are

"under-utilised", i.e., they have potential to be used for more applications than they are at present, or in some cases are not used at all, such as *S. polyschides* and *S. muticum*, despite having similar utility as other species in high demand, such as *Ascophyllum nodosum.* Invasive seaweed species, such as *A. armata, S. muticum* and *U. pinnatifida*, can pose a risk to native seaweeds and others species that compete for the same habitat, e.g. *H. elongata*, and the seagrass *Zostera marina* (Silva et al., 2021*;* Mac Monagail & Morrison, 2020; Baer and Stengel, 2010). Where habitats are degraded or experience limited seaweed productivity, invasive species can strengthen the viability of native species, and provide an additional food resource to herbivorous species (Kraan, 2017; Baer and Stengel, 2010). However, they can also slow the regeneration of native species in degraded habitats, and disrupt ecological dynamics in healthy habitats, both those not typically colonised by seaweeds, and those associated with the presence of specific native seaweeds, e.g., *F. vesiculosus* beds (Silva et al., 2021; Mac Monagail & Morrison, 2020; Kraan, 2017). Additionally, increasing the commercial use of invasive species can add to the available seaweed supply, though this would need to be done with careful consideration of the potentially negative wider environmental impacts.

Some of the main potential areas for future industry expansion include:

- Increasing the use of some seaweeds as **food and dietary supplements**, e.g. *A.nodosum*, *Porphyra spp*., *S. polyschides, Ulva spp.* and *U. pinnatifida*, especially when the seaweed, particularly *Ulva spp*, is not contaminated with heavy metals.
- Increasing the use of some seaweeds as **health and therapeutic products for animal and human applications**, e.g., *L. digitata* and *L. hyperborea,* and *P. canaliculata*.
- Assess the merits of using *A. armata* as methane-reducing **feed additive for cattle and dairy** cows, and *S. muticum* as **animal feed**.
- Increasing the use of *S. polyschides* and *Ulva spp*. as a **fertilizer and biostimulant** when the seaweed is not contaminated with heavy metals.
- Increasing **research and development** targeting commercial use of bioactive components of Irish brown seaweeds, particularly those with **high levels of bioactive components**, e.g. *A. esculenta, L. digitata* and *L. hyperborea, M. stellatus*, and *S. latissima*.
- Increasing the use of *Ulva* spp. as a **bioremediation** tool where nutrient enrichment or heavy metal contamination of coastal areas has taken place.
- Increasing the use as **biofuel** of suitable biomass from which valuable components can be extracted through biorefineries, e.g. *Laminaria spp.*
- Using *Ulva spp.* as **biofuel** where "nuisance" *Ulva* blooms or bioaccumulation of heavy metals is a problem, e.g. post-bioremediation.

5.2.2. Local Food, Tourism and Leisure Applications of Seaweed in Ireland

Irish companies have an established tradition of utilising seaweeds to leverage Ireland's cultural and place-based assets. These applications indicate that some Irish companies are

using seaweeds in ways which connect with the therapeutic history of seaweed in Ireland associated with joy, relaxation, and beauty to develop new products and services. Others are transforming traditional Irish and international uses of seaweed as food into innovative nutrition products and cosmopolitan dining experiences.

This includes development of food ingredients to create a "twist" on traditional foods linked to a range of food cultures, e.g. Irish black pudding and Middle Eastern flatbreads. Seaweed is also extensively used in coastal tourism and hospitality, such as seaweed foraging tours and workshops in Kerry, Waterford, and Gaeltacht regions. Seaweed is also a key ingredient on many restaurant menus including the Michelin-starred restaurant at the Cliff House Hotel in Ardmore, County Waterford, and Dede at the Custom House in Baltimore, County Cork.

Other hospitality sector uses build on traditional cultural associations including Irish seaweed baths, which have become renowned across the world (MacMonagail & Morrison, 2020). The leveraging of seaweed as an ingredient associated with leisure, wellbeing, and personal consumption is now being explored further by Irish companies with the novel use of seaweed for household goods, such as candles and soaps.

To date, these applications have been considered a form of cottage industry without the capacity to scale or internationalise. With the movement away from mass production, toward higher quality offerings with transparent supply chains and the emergence of sustainable tourism, the market potential and demand for seaweed in the experience economy has significant potential.

5.2.3. Human Health: Functional Foods & Pharmaceuticals

The health and personal care benefits of seaweed and seaweed derived ingredients, extracts, and molecules are well established with research teams and companies globally reporting on existing and new product developments (Moreira et al., 2021; Olsthoorn et al., 2021; Bernard & Tonk, 2019). A number of these are discussed below.

5.2.3.1. Pharmaceutical Applications

Seaweeds have a long association with medical uses and health applications. This is a result of their bio-chemical composition, enriched with bioactive components, such as fucoidan and polyphenols, which are extensively reported to have a wide variety of health benefits, including antioxidant, anti-viral, anti-inflammatory, anti-coagulant, anti-thrombotic, immune-regulatory, and anti-tumour effects. This is in addition to their hydrocolloidal properties which are of interest for medical products. The absence of companies exploiting the medical applications of seaweed is surprising given the strong presence of pharmaceutical and biomedical industries here in Ireland.

Many species found in Ireland contain components of medical interest, e.g. *Ulva spp.* contain glycolipids which have anti-inflammatory properties, and sulfolipids which have antimicrobial properties, which provides an alternative to antibiotics in disease prevention (Moreira *et al*., 2021; Bernard & Tonk, 2019). *Palmaria palmata* also possesses sulfolipids phospholipids, e.g. phosphatidylglycerol and phosphatidylcholine, which are known to have anti-inflammatory properties, and kainic acid which is an anthelmintic of medical and veterinary interest

(Moreira *et al*., 2021; Bernard & Tonk, 2019). *Saccharina spp*., *Alaria spp*., and *Chondrus spp*. have shown potential for treatment of neurological disorders such as Alzheimer's disease (Bernard & Tonk, 2019).

A variety of seaweeds have been linked to cancer prevention, the most promising of which include *U. pinnatifida* and *Porphyra* spp. (Bernard & Tonk, 2019). Meanwhile, extracts from other seaweeds can be used for cancer treatment, e.g. chlorophylls derived from green seaweeds such as *Ulva spp*., and brown seaweeds such as *S. latissima*, have the potential to be used as photosensitisers in photodynamic therapy (Jouanneau et al., 2021).

A key asset and supporting infrastructure in creating this new potential market is the strength of the existing Irish seaweed processors (notably ANPG who have a well established international credentials), Irish pharmaceutical companies, food ingredient firms, and related biotechnology industry in Ireland, including manufacturing centres, technology hubs and a skilled pool of research workers (IDA 2022; Enterprise Ireland, 2021). There is a strong supportive industrial ecosystem for the development of seaweed-derived products in medical, nutraceutical, and cosmeceutical sectors. Ireland is well established as a global leader in all of these areas. For example, Ireland exported over €50 billion in goods to the USA in 2020, 73% of which arose from medical, pharmaceutical, and organic chemical products (CSO, 2021). Exports to the other three main export markets, Belgium, Germany, and the United Kingdom, collectively earned a similar amount of revenue in 2020 (CSO, 2021).

Therefore, there is a strong established market for Irish manufactured medicinal and pharmaceutical products that can be readily accessed. As seaweed bioprocessing technologies are reaching higher Technological Readiness Levels (TRL), Ireland is in an ideal position to take advantage of this opportunity to enable existing and emerging companies to develop capabilities to produce seaweed derived products to create a new and diversified value chain in human health care applications.

Advancements will require significant investment, enterprise innovation support across technologies, talent and market support. The strong established enterprise and innovation ecosystem in Ireland (BIM, EI, DAFM, SFI, KTI, SEAI, and HEA) is ideally suited to deploy a targeted stimulus to accelerate such developments with the support of various Irish agencies.

Case Study: Carragelose

In addition to seaweed components with health-promoting properties related to specific conditions (e.g. inflammation), medical uses of seaweeds utilise similar properties of seaweed to those valued in other industries, e.g. binding and thickening properties of alginate, agar, and carrageenan. Marinomed is a bio-pharmaceutical company based in land-locked Austria, which has developed a targeted medical product from seaweed using an antiviral polymer based on Iota-Carrageenan, or "Carragelose", which acts against respiratory viruses. The carrageenan is derived from red seaweeds, and coats the mucosal surface, creating a physical barrier to which viral particles adhere, trapping them and preventing infection from occurring. Carragelose is active against common cold viruses and influenza, and has been marketed in three formulations, a nasal spray, throat spray, and lozenges. The formulations are marketed as both preventatives and treatments for infections.

For these industries, pristine quality seaweeds free from contaminants, such as shellfish and heavy metals, is essential. In the survey conducted as part of this study, companies reported the need for greater guidance on regulatory matters for products intended for human use; particularly around shellfish allergens.

The very low volumes of seaweed currently available from controlled land-based aquaculture cannot supply the demand and would need substantial investment to increase supply. Even where harvested seaweed will suffice, supply can be unpredictable and seasonal. Sourcing must be managed carefully to ensure harvesting practices, seasonality and volumes do not undermine sustainability claims associated with cosmeceutical products in particular, which could lead to loss of reputation and consumer support.

Also, the location of seaweed drying facilities relative to harvesting sites may result in substantial transportation costs for manufacturers, while existing large-scale drying companies typically focus on a limited range of seaweeds (e.g., Arramara dries large volumes of seaweed, but exclusively Ascophyllum *nodosum*).

Of all the human uses for seaweed, medical applications likely have the greatest potential to overcome the challenges associated with limited seaweed supply and drying capacity due to its high value in this application or market. However, this industry has a particularly high standard for seaweed quality. Aquaculture (e.g. in controlled, land-based systems) is one way to ensure that quality and supply requirements are met. However, profitable margins may be more difficult to achieve considering the high costs associated with such systems. In addition, the delay associated with aquaculture licensing in Ireland is a further disincentive for investment and development of this area.

5.2.3.2. Nutraceutical Applications

Seaweeds possess a wide range of bioactive compounds which have beneficial effects when consumed by humans, e.g. fucoidan, laminarin, polyphenols, fucoxanthin and poly-unsaturated fatty acids. The nutritional composition of seaweeds can also be exploited for production of dietary supplements that satisfy diverse dietary requirements, e.g., gluten-free and plant-based. Bernard and Tonk (2019) note that the calcium content of *A. nodosum*, *Laminaria spp.*, and *Ulva spp.* is double that of milk, for example, while *Ulva* spp. provide a source of plant-based omega oils, such as omega 3, which help prevent cardiovascular heart disease (Moreira et al., 2021).

The market for nutritional supplements and functional foods is continuing to grow in Europe, including ingredients sourced from seaweed (BIM, 2020). Globally, the nutraceuticals market was considered to be worth ~ €310 billion in 2019, with growth increasing rapidly during the first months of the COVID-19 pandemic (Lordan, 2021).

Demand is particularly high for products with antiviral and immune-boosting properties (Lordan, 2021). Many Irish seaweeds contain a variety of components that prevent or fight disease, especially fucoidan from brown seaweeds. The nutraceutical market is where seaweeds could play a strong role, if supported by research and development into profitable applications (e.g., sports nutrition) and targeted dietary supplements that address specific

concerns (e.g., menopause symptoms) and health issues (e.g., diabetes management).

Case Study: InSea for sugar regulation

Seaweed-rich diets are linked to health benefits, including reduced cancer risk, lower obesity rates, and decreased severity of type 2 diabetes (Shannon & Abu-Ghannam, 2019). These benefits can be harnessed through production of dietary supplements with specific health benefits. *InSea*, a "glucose optimizer" created by Canadian nutraceutical and cosmeceutical ingredients company innoVactiv, uses *F. vesiculosus* and *A. nodosum* extracts to inhibit digestive enzymes that convert complex sugars to simple sugars, therefore raising blood glucose (Shannon & Abu-Ghannam, 2019). This product contributes to maintaining insulin homeostasis among those experiencing type 2 diabetes, and reduces post-meal drowsiness among non-diabetics (Shannon & Abu-Ghannam, 2019).

Challenges for nutraceutical applications of seaweed in Ireland

The nutraceuticals industry is particularly vulnerable to fluctuations in consumer trust and demand with risks being undermined by "consumer exploitation" due to a proliferation of products with limited relevance to the issues they claim to address, or unfounded claims (Lordan, 2021). With increasing attention on sourcing and quality in dietary supplements and health food ingredients, these "clean label" factors are important for successful nutraceutical production and adoption.

5.2.4. Cosmeceutical Applications

Cosmeceuticals typically refer to cosmetics with bioactive ingredients that enhance the effectiveness of products. Considering the high proportion of bioactive ingredients in a number of Irish seaweeds that are safe for human use, e.g. *A. esculenta*, *L. digitata*, and *S. latissima*, and the emphasis on specific components of seaweeds that can be efficiently extracted through biorefineries, cosmeceuticals offer an ideal avenue for expansion of the Irish seaweed industry. Table 5.3, previously described species of interest for cosmetics and health applications, and those possessing hydrocolloidal properties of interest for cosmeceutical beauty products.

A number of Irish companies are producing seaweed-based products, including thalassotherapy products, for the cosmetics and personal care sector, a sector worth €1.2 billion in Ireland in 2019 (Power, 2020). There are possibilities to further develop activity in these markets by developing, for example, bespoke extracts and ingredients using target components extracted through biorefinery technology, especially with well-communicated provenance information (BIM, 2020).

Seaweeds and bioactive seaweed extracts which are unsuitable for human consumption, such as *A*. *armata*, can be used for non-ingestible cosmeceuticals, opening up avenues for use of seaweeds for which supply is less competitive. Consumers are also increasingly interested in the environmental and social impact of cosmetics, including the origin of their ingredients and its processing for vegan, cruelty-free, and environmentally non-toxic products (Power, 2020).

Seaweed-based skin products are a good fit for this "low-impact" trend in cosmetics where

consumers are demanding products with environmental and ethical credentials. These products can deliver premium results as a consequence of bioactive ingredients, often with hydrocolloidal properties, that contribute to a texture and quality that is appealing to consumers. Future trends of relevance to seaweed-based companies in or entering this market include products that support the skin microbiome, such as probiotic skincare and nutraceuticals for cosmetic benefit, such as supplements containing ingestible skincare ingredients such as collagen or ingestible deodorants found in such products as Body Mint perfumes and Deo Perfume Candy.

The connection between future trends in the cosmetics industry and the pharmaceutical, food and nutrition, and other biotechnology sectors suggests that the development of the cosmeceutical industry in Ireland will benefit from development in other biotechnology sectors. The utilisation of seaweed and seaweed extracts reflects the potential of the cascading biorefinery development model and provides opportunities for multiple value chain development, industry clustering and symbiosis.

Compared with those other human use applications, which typically require production at scale to achieve profitability, consumers develop strong affiliations with cosmetic products and place high value on product narratives. This factor contributes to the viability of producers of different scales within this sector, which, with respect to seaweed utilisation, could contribute to coastal rural development and capitalise on the historic and contemporary associations of seaweed with health, wellbeing, and coastal tourism.

Examples of such bespoke ingredients that can complement and replace “traditional” cosmetics ingredients include seaweed extracts with anti-aging properties, e.g. innoVactiv’s “VivenSea” extract, derived from *L. saccharina*. In addition to bio-active components with cosmetic benefits, the use of seaweed extracts to replace synthetic ingredients can reduce the environmental impact of cosmetics, those that are considered “washable,” such as shampoo, and non-washables that typically pass into the environment in the course of their use such as sun protection products. In the case of sun protection, mycosporine-like amino acids from *P. umbilicalis* have been used with success for a product called HELIONORI, manufactured by French company GELYMA.

While allergen content must be reviewed and communicated, the stringent quality standards that apply to medical and nutraceutical uses do not apply to cosmetics as they have a different set of regulatory and market specifications which reduce the barrier to market entry. However, these rules are also of a very high quality standard and require significant investment in evidencing efficacy and compliance.

Sustainability claims and credentials are of particular importance for this application of seaweed. The sector is, therefore, particularly vulnerable to sustainability issues which could undermine consumer trust and branding, e.g. habitat degradation due to poor management of seaweed harvesting. Consumers want to be informed about issues of environmental impact and responsibility. This is where a quality standard for Irish seaweed products could add significant value, enabling companies to confidently articulate and demonstrate the sustainability credentials of the seaweed utilised within their products.

5.2.5. Seaweed-Based Materials

Seaweed molecules such as pigments and polysaccharides have potential application for production of many bio-based materials, expanding bio-based composition of materials and for components used in construction projects. Table 5.4, above describes species of interest for biotechnological applications and those possessing hydrocolloidal properties of interest for manufacturing bio-based material products. Opportunities for these include bioplastics, textiles, and pigment-containing products, such as paints and dyes.

Algiknit, an American company, is one example of a textile company using seaweeds (kelp) to produce fabrics for clothing, footwear, and furnishings. French company Algopaint produces a range of paints with colours derived from seaweed pigments. Similarly, Dutch company Zeefier are producing seaweed-based textile dyes from the post-processing of seaweed by-products from cosmetics and food production.

The location of Ireland within the European Union, the largest bioplastics consuming region in the world, indicates opportunity for niche entry into this market to make the most of opportunities to valorise co-products as a part of integrated multi-trophic aquaculture (IMTA) systems, for example, and using post-production seaweed residues in animal feeds (BMRS, 2015). Seaweeds that have limited human use, due to potential toxicity to humans, e.g. ,Asparagopsis *armata*, are well suited for use in the production of bio-based materials.

Bio-based plastics (bioplastics) based on seaweed have demonstrated environmental advantages over plastic-based materials for food packaging (Doh *et al*., 2020), including reduced impact of biodegradable bioplastics on aquatic life compared with traditional plastics, due to their faster decomposition in nature. In addition to packaging, these alternatives to traditional plastics are being used to produce water bottles and drinking straws. There is strong consumer interest in bioplastics, and seaweed-based plastics have an added advantage as they do not compete with use of seaweed as food, which can happen with other bioplastic feedstocks such as corn.

Industrial production of bioplastics is likely to become based on very large volumes of seaweed biomass as a feedstock to be cost efficient. Consequently, increased demand is likely to be met by large-scale seaweed farms developed here or elsewhere in Europe (BIM, 2020). For seaweeds that are used for applications with potentially higher value for medical, nutritional or cosmetic application, the value of bio-based material use may not be sufficient to render these applications competitive without the use of biorefinery techniques that can extract ingredients for a variety of industries.

5.2.6. Animal Feed and Feed Additives

The use of seaweed in this market sector is growing due to a move towards “natural” animal nutrition products, a need to find alternatives to antibiotics and growth promoters, and bespoke nutrition/differentiated products for different animals such as livestock, horses, dogs and cats (BIM, 2020). Table 5.3, above describes species of interest for animal feed applications and those possessing hydrocolloidal properties for animal feed products. Based on survey data, Irish companies are already exploiting this niche, including companies that specialise in animal feed manufacture such as Connolly’s Red Mills and Nutramara. BioAtlantis,

a member of the ANPG, has developed a novel technology based on seaweed bioactives that modulate the immune system and gastrointestinal microbiome in animals. UCD has developed a case study summarising the development of a BioAtlantis' maternal immunity transfer technology that can replace the need for antibiotics and zinc oxide in pig and poultry feed (https://www.ucd.ie/t4cms/CASE_STUDY11_John%20ODoherty.pdf).

Ireland's pet food industry generates exports worth €200 million at present, with consumers paying a premium for foods with clear provenance information and functional properties additional to the provision of macro-nutrients (Enterprise Ireland, 2021). The geographical location of Ireland, the western-most European Union member state, is an attractive factor for international pet-food producers such as Rondo Food.

The use of seaweed to reduce bovine methane emissions when used as a feed additive, e.g., *A. armata*, is a promising growth area for the Irish seaweed industry, given the low volume required to achieve target outcomes (BMRS, 2020). Seaweeds that have limited human use due to potential toxicity, e.g., *A. armata*, may potentially have a role in certain animal feed applications, where is it demonstrated that toxicity to the target species does not exist. In addition, techniques to grow *A. armata* by means of aquaculture are currently being developed by Bantry Marine Research Station for cultivation of this seaweed.

More research is required to identify the value of seaweeds and seaweed extracts for animal feed and feed additives for methane reduction, pet care, and veterinary nutraceuticals. Additional research must take place to ensure that seaweeds used are not toxic to the targeted species. Allergen communication and regulation is necessary for this application including appropriate labelling of products to educate and warn consumers. Again, for seaweeds that are used for animal feed and food additive purposes, the value of these products or ingredients may not be sufficient to render them competitive without the use of biorefinery techniques.

Seaweed has immense potential as a component for fin fish and shellfish feed in aquaculture. These include the use of *S. latissima* as feed for polychaetes that can be fed to Atlantic salmon (SINTEF, 2021), and *P. dioica* as an ingredient in rainbow trout feed (Soler-Vila et al., 2009). The use of seaweed as feed inputs for aquaculture is also linked to the development of other growing areas of Irish aquaculture, such as abalone and urchin cultivation (Watson & Dring, 2011). Seaweed can also be cultivated as part of integrated multi-trophic aquaculture (IMTA) systems with the potential to contribute to the feed inputs of one or more species within the system.

5.2.7. Ecosystem Services

Existing populations of seaweed provide ecosystem services in coastal areas, such as remediation of marine pollution from agriculture and industrial activity, coastal protection from storms and other weather events, and habitat and food sources for a range of flora and fauna, including those of social and economic importance, such as crab, lobster, fish, molluscs and seabirds. These ecosystem services can be strengthened through conservation of existing stocks, by ensuring sustainable harvesting techniques are employed in all areas, and with cultivation of native seaweeds in areas of strategic importance for bioremediation and in certain instances coastal protection.

Similar to other marine areas, seaweed beds provide essential habitat for a range of organisms. Other marine areas that also provide important habitats for marine species such as fish and crustaceans for feeding or during early life stages include: soft bottom areas, shallow open water, salt marshes, seagrass beds, oyster reefs, mussel beds, rocky shores (Seitz et al., 2014) and deep water areas (>30m depth).

In addition to potential value from ensuring regulated and sustainable harvesting practices in protected areas and harvest of cultivated stocks, value can be added to landowners and cultivation enterprises through payments for ecosystem services, as takes place on land for habitat protection, low-impact farming methods and afforestation. In this study, Irish seaweed harvesters identified carbon capture as a future area of opportunity. The potential value of these services has been recognised with respect to both carbon sequestration and bioremediation as described in greater detail below.

The bioremediation potential of seaweed is considered as having a role regarding accumulation of carbon dioxide in the atmosphere. Programmes dedicated to conserving and restoring seaweed "forests," such as SeaForester, and initiatives such as Kelp Blue and The Seaweed Company that cultivate seaweed for certified carbon offsets or "blue carbon credits'' are seen as leading the way in this area to combat climate change and prevent global warming. Preserved seaweed forests or seaweed cultivated for carbon capture need to be conserved as long-term seaweed stocks or stored (e.g. buried on or sunk to the seabed) to avoid the carbon returning to the atmosphere.

A recent report commissioned by the Marine Institute (Cott et al., 2021) considers that the potential role of seaweed species such as kelp in carbon sequestration may be limited. Therefore, the contribution of kelp to carbon sequestration in an Irish context may be low. Uncertainty remains about the long-term storage potential of buried or sunk seaweeds due to the rate of decomposition of specific species and their impact on ocean bio-chemistry and marine life. While some seaweed cultivation companies are selling certificates for sequestered carbon, and others are selling carbon emission offsets, there is substantial uncertainty regarding the true and long term results of these efforts from a carbon accounting perspective. Moreover, most seaweed that is cultivated is sold for use in end products and is not destined for long term storage or sequestration. Therefore, cultivation of seaweed is unlikely to significantly contribute to carbon sequestration. Until more knowledge develops, these questions will restrain the growth of this cultivated seaweed application.

Recent research concerning the bovine methane reduction potential of some seaweed species, e.g., *Asparagopsis spp*., indicates that seaweed cultivation for bioremediation of atmospheric carbon could be integrated with dairy and beef production, in a similar fashion to IMTA systems. There is also potential for seaweed conservation/cultivation to be integrated with watershed management of agricultural wastes to remediate agricultural nutrient accumulation at the coastal exit point of waterways and reduce eutrophication of coastal waters which has negative impacts on coastal habitats and fisheries. If cultivated seaweed is integrated with other marine activities, such as offshore wind energy production and fish production through IMTA, the benefits to seaweed farmers and local communities can be expanded to include diversified products (fish and shellfish) and increased renewable energy production that can strengthen energy sovereignty, reduce domestic and industrial carbon emissions, and provide a lower cost source of energy for associated industrial activities such

as seaweed drying, biorefinery operation, and fish processing and preservation (freezing).

Bioremediation using seaweed to clean up excessive nutrients from livestock production or potential pollutants from industrial facilities must be carefully planned and regulated to ensure that the right species of seaweed is utilised to avoid potential negative environmental impacts associated with invasive species or habitat disruption. This oversight can be achieved through the Environmental Impact Assessment and Strategic Environmental Assessment processes (EIA/SEA) but requires further research. The use of seaweed harvested following the remediation of areas badly contaminated by heavy metals needs to be carefully considered and may be limited due to the bio-accumulation of those same heavy metals in the seaweed used for that purpose. Given market requirements for high quality seaweeds, free of microbial and chemical contamination, such seaweeds used in remediation are unlikely to be suitable in the manufacture of high value products such as plant biostimulants and animal feed. On the other hand, seaweeds used to remediate excessive nutrients can add value beyond their remediation activity when harvested and processed into value-added ingredients or products. For example, seaweeds cultivated as a part of IMTA systems provide several benefits: they can help remediate accumulation of nutrients from farmed fish feces and uneaten fish food, provide physical protection of fish cages from the impact of intense storms, high tides and fast moving currents, and they can be used as a part of the fish feed used to reduce reliance on land grown feed inputs as described in section 5.2.5 above. *Saccharina latissima* and *L. digitata,* both species which are currently cultivated in Ireland, are good candidates for inclusion in IMTA systems (Buck et al. 2018). Companies are currently operating IMTA systems in other European countries with and without off-shore wind turbines, e.g., Seaweed Energy Solutions in Norway, while IMTA has demonstrated success at scale in China, e.g., Zhangzidao Fishery Group Co. Ltd. (Buck et al., 2018).

5.3. Understanding Barriers to Industry Growth

Based on the literature and the survey results, the barriers and constraints of the seaweed industry can be summarised under four broad categories: those related to 1) institutions and policy, 2) material and technology, and 3) economy and growth, and 4) knowledge and networks. These are further discussed below.

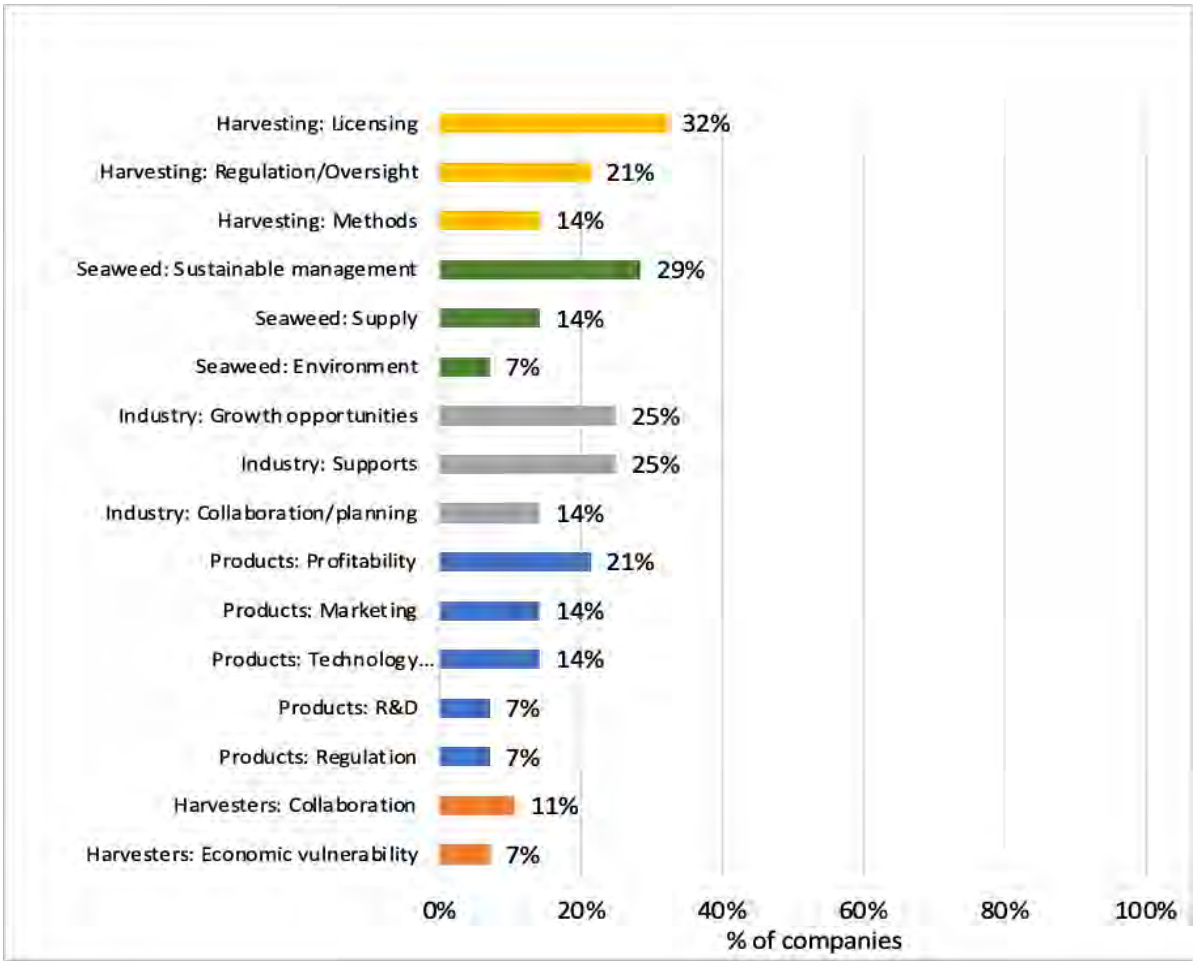


Figure 5.3: *Main barriers identified for developing the Irish seaweed sector by broad categories: Harvesting, Seaweed, Industry, Products and Harvesters*

5.3.1. Institutions and Policy

5.3.1.1. Industry Supports

From our survey of seaweed processors and harvesters, accessing seaweed industry support was considered time consuming and not very straightforward, involving long delays and bureaucratic procedures by those interviewed. Some contributors felt that these procedures were more oriented towards larger producers, while small and start-up companies have had difficulty accessing support, highlighting a need for future policy and support programmes to be accessible for smaller and new entrant companies as well as large and established producers. The input from the seaweed industry clearly points to a lack of support and clarity around seaweed farming, despite the hope that seaweed farming would become a core aspect of Ireland's seaweed industry in the future (BIM, 2020; Mac Monagail and Morrison, 2020).

5.3.1.2. Harvesting Licenses

Seaweed harvesters were concerned about licensing, including traditional harvesters' rights versus companies applying for the licensing of large coastline areas, and the costly and

bureaucratic nature of the licensing process, including Natura 2000 site report preparation. Harvesters felt that this process favoured companies rather than individuals, such as traditional harvesters. However, it was also noted that with the issuing of commercial licences harvesting could become a permanent occupation, though regulation would be needed to limit competitive commercial harvesting and ensure that the resource is managed sustainably in the future. The ANPG has also expressed the need for the Government to develop policy on sustainable seaweed harvesting and to regulate the industry to facilitate the expansion of Ireland's seaweed processing industries, whilst also taking account of Appurtenant and Profit-à-Prendre harvesting rights.

5.3.1.3. Harvesting Regulation & Oversight

Regulation of the industry was also a concern for some harvesters who would like to see it continue as a cash payment business, while others see regulation as necessary, fearing that lack of regulation of the seaweed sector could lead to resource decline, as has been the case with harvesting of periwinkles in Ireland. Harvesters cited access to seaweed as a key issue for the industry and also raised concerns about designation of coastal protection zones such as SACs, SPAs and no harvest areas which could preclude seaweed harvesting.

Seaweed processors cited a lack of a consistent and transparent regulatory framework for the industry, including licensing of harvesting sites and the enforcement of rules that govern harvesting activities, raising concerns that these were limiting the industry. Survey participants indicated that the seaweed industry should have its own dedicated centralised body so that the problems related to licensing, certification, enforcement or general governance issues can be resolved with the help of a single seaweed focussed agency. One harvester felt that more access to perceived "blocked areas" through regulation was required to allow new entrants to harvest seaweed. Regulation that assures rules and regulations are imposed on commercial processors requiring defined Resource Management Plans and continued engagement with traditional harvesters was identified by another harvester as a required support. Companies also felt that clear legislation and rules should be laid out and disseminated to seaweed companies. Both companies and the literature indicate that policy needs to respond to biophysical barriers and constraints to the industry, and projected changes in biophysical conditions such as local ecological conditions and climate change (Mac Monagail and Morrison, 2020).

ANPG, does not favour no-harvest zones, and instead favours a model whereby sustainable harvesting is undertaken within SACs, SPAs and MPAs, subject to complying with conservation objectives and working in line with the relevant Irish and EU regulations (ANPG, 2019). They cite the French model whereby human activities operate in MPAs according to a set of defined criteria and permits the harvesting of seaweeds such as *A.* nodosum, *L. hyperborea* and *L. digitata*, e.g., most French seaweed production comes from the Parc Naturel Marin d'Iroise (PNMI), a MPA in north west France (Mesnildrey, 2012).

5.3.1.4. Product Regulation

In the survey conducted as part of this study, companies reported needing greater guidance regarding regulatory matters for products intended for human use, such as communicating allergen information, particularly around shellfish allergens. Companies were not aware, for

example, about whether product regulations applied to them. Companies require greater engagement and outreach from regulatory bodies concerned with seaweed uses for human consumption and human health, e.g., FSAI, to ensure that they are complying with regulations to avoid consumer dissatisfaction and ill-health.

5.3.2. Material and Technology

5.3.2.1. Harvesting Methods

Seaweed harvesters identified challenges with available technologies for seaweed harvesting due to the labour-intensive nature of harvesting as well as opportunities for mechanical harvesting and seaweed farming. Inherent issues with seaweed harvesting included the remote nature of seaweed resources and bulky nature of harvested materials.

All but one harvester surveyed accepted that multiple methods for seaweed harvesting and cultivation could successfully co-exist. The greatest concerns were voiced against mechanical harvesting. They argued that those using mechanical methods of harvesting and collection of seaweed be educated on the correct operation of the equipment, sustainable methods of mechanical harvesting and the impacts that this equipment could have on the wider environment. Harvesters provided successful examples of large-scale mechanical harvesting working in Scotland, Iceland and USA and outlined various viable approaches to seaweed cultivation co-located with floating solar and wind farms in the North Sea. There are also examples from France and Norway where seaweed has been commercially harvested for over 50 years, both mechanically and by hand. More investment in harvest infrastructure to improve efficiency and earning potential was also identified as needed.

5.3.2.2. Harvesting & Seaweed Supply

Harvesters also observed local declines in seaweed supply and quality. The volume of seaweed harvested through rights-based harvesting and seaweed farming is low, and affected by seasonality, due to the inherent bio-physical characteristics of seaweed and the environment within which it grows.

Seasonality also impacts demand, particularly regarding agricultural products and amenity horticultural applications, which are in greatest demand during crop sowing and growth phases during the spring and summer months. Demand from seaweed tourism, due to the seasonality of the Irish tourism industry, also varies throughout the year. The growth of the seaweed industry has the potential to put pressure on the supply of wild harvested seaweed and sustainability of seaweed management, despite the limited availability of seaweed at present due to bottlenecks at the harvesting stage (licensing and labour).

Additionally, harvesters face challenges accessing seaweed resources due to the physical challenges presented by the marine environment, especially in winter months. As weather conditions become increasingly unpredictable, due to environmental changes related to climate change, these challenges in accessing seaweed stocks are likely to worsen.

5.3.2.3. Sustainable Seaweed Management

Some harvesters commented that the value of seaweed was not optimised and that the resource was not fully exploited but that it must be done sustainably (mechanical harvesting was a concern for many in terms of perceived potential damage to the ecosystem and inadvertent harvesting of other species). However, mechanical harvesting does not take place in the intertidal zone in Ireland (where hand harvesters operate) and is only licensed to take place in deep, subtidal waters that are otherwise inaccessible to hand harvesters. Therefore, though there is no spatial overlap between traditional hand harvesting and mechanical harvesting in Ireland, the use of mechanical harvesting needs to be carefully regulated and monitored. The literature indicates that in addition to seaweed harvesting, other anthropogenic activities threaten seaweed resources, namely invasive species and climate change (Joniver et al., 2021; Mac Monagail and Morrison, 2020).

5.3.2.4. Technology Adaptation / Implementation

Drying of seaweed is very energy intensive and costly, with scope for improvements in efficiency. Both harvesters and processors indicated that there are substantial business challenges related to the spatial distribution of seaweed harvesting areas in relation to processing locations, and the need for specialised equipment required by processors. Smaller companies may utilise equipment housed at other facilities, e.g., Teagasc research centres, which may themselves be far from either harvesting areas or the processor's location. With rising transport costs, the need for local or decentralised processing facilities was highlighted by both harvesters and small processors.

5.3.3. Economy and Growth

5.3.3.1. Industry Growth Opportunities

Greater knowledge is needed within the industry about increasing the volume of seaweed available through seaweed farming, especially at large-scale (BIM, 2020; Mac Monagail and Morrison, 2020). The biggest barriers that limit growth in this area include licensing, nursery capacity, technology and cost.

5.3.3.2. Economic Vulnerability of Harvesting

Coastal communities, where harvesting traditionally takes place, face challenges with maintaining seaweed supply due the limited availability of harvesters. This can be attributed to a decline in the total number of harvesters as older harvesters exit the industry and are not replaced by younger people. At current prices for the main type of seaweed harvested in Ireland (*A. nodosum*), harvesting cannot economically compete with the work opportunities available to younger people, most often in urban areas. It is therefore unsurprising that new entries to the industry are limited and this is likely to persist while harvested *Asco* seaweed is regarded as a low value commodity. Furthermore, the manual nature of work associated with seaweed harvesting is physically demanding for harvesters regardless of age. Improvements in harvesting equipment such as boat and rake methods or mechanical harvesting could improve harvesting efficiencies and lure younger people into the industry. As self-employed suppliers of seaweed, harvesters have high flexibility over how and when they conduct their activities, but are limited in the protection they receive in the case of work-related injury and illness, pension support or loss of income due to the closure of nearby processing facilities.

Many harvesters are on social welfare and expressed a concern that harvesting income could jeopardise the support payments.

5.3.3.3. Product Profitability

Seaweed harvesters faced a range of challenges related to the social context of seaweed harvesting, including lack of markets and restricted market access. Harvesters identified market development, diversification into emerging markets, a network of sectoral contacts, and national/regional support contact as the most needed supports. Meanwhile, companies felt that a greater focus on commercialisation and increased marketing of Irish seaweed products is required. *Ascophyllum nodosum* remains the most commercially viable species in Ireland and its use by Irish companies to date, in developing high value biostimulants products and technologies, is an excellent example of what can be achieved by companies in Ireland who are focused on R&D, investment in large scale processing and export markets. However, licensing and security of supply of seaweeds for industries working in this area is also a key concern. Similarly, investment in product development and marketing is essential to transition the Irish seaweed industry from applications using a limited range of species to high value applications of a wider diversity of seaweeds including the extraction of compounds for industrial use, ingredients for cosmetic, nutritional and pharmaceutical products and the processing of seaweed for animal feed, human food and beauty product consumption.

5.3.4. Knowledge and Networks

5.3.4.1. Industry Collaboration / Planning

Seaweed processors indicated that a lack of information sharing within the industry was a limiting factor. This includes a lack of knowledge about potential markets, a lack of information about processors and suppliers, with trade typically occurring through established relationships, and a lack of information sharing related to more efficient harvesting and processing methods, equipment and technology. Harvester demographics contribute to this issue as harvesters tend to be older, with minimal succession by younger family members, or new entrants that are more plugged into digital sources of information (Mac Monagail and Morrison, 2020; Macken-Walsh, 2009).

Companies felt that they would benefit from greater capability for business-to-business information sharing that could be facilitated by an online directory/atlas to help companies source alternative suppliers. Shared resources among harvesters and smaller processors could also help cut down on the cost of drying.

In an Irish context, it is recognised that policy development in relation to seaweed harvesting should be cognisant of the needs of the industry and other relevant stakeholders, including the National Bioeconomy Forum, which is co-organised by the Department of the Environment, Climate and Communications and Department of Agriculture, Food and the Marine. The National Bioeconomy Forum is tasked with developing the Bioeconomy Action Plan for Ireland and is focused on balancing the research and development, regulatory and market needs to support a thriving seaweed sector. As part of this process, the National Bioeconomy Forum is consulting with circular bioeconomy groups from across Ireland, including emerging bioeconomy clusters (e.g. Circular Bioeconomy Cluster South West -

https://cbcsw.ie/about-us/) to better understand the needs of the sector. Such a forum affords challenges, barriers and recommendations in relation to seaweed harvesting and processing industries to be articulated and such an approach is to be commended.

5.3.4.2. Harvester Collaboration

One harvester felt that they should organise into a co-operative with their own processing facility so they could capture more of the value chain from converting harvested seaweed into an intermediate ingredient or a seaweed product. Several indicated that there is a need for advisers to inform harvesters on how to get maximum benefit from the resource (noting that at the moment there are no advisers) and to help them increase per unit revenue from their harvesting activities. In some areas, purchasing of harvested seaweed is limited to one or two buyers which helps keep harvested seaweed prices on a per tonne basis low.

Other harvesters noted that older people need to upskill to new technology while young harvesters need to be taught to look after the resource. Another harvester identified a training need on other higher value seaweeds, as part of an integrated set of requirements for selling seaweed: training, licensing and sustainable management. Lastly, processing companies showed an interest in training, including for harvesters, related to training in innovative seaweed harvesting and seaweed stock management practices.

5.3.4.3. Product Development

Companies indicated a need for grant support for research and development, for example for ingredient and product testing, and marketing and sales assistance. Many felt that more research was required to assess seaweed content for cosmetics shelf-life, functionality and efficacy. One harvester identified a need to isolate compounds from seaweed and extract them homogeneously as part of the bio-economy. It was noted that the ANPG businesses have already invested considerably in R&D in the past and requires the development of highly skilled R&D teams, spanning life sciences and engineering, often educated to MSc. and PhD levels.

5.4. Policy Options for Addressing Industry Barriers

Europe's Blue Economy provides 4.5 million direct jobs, many in regions where there are few alternatives. It is a broad, fast-moving segment of the economy, which over the past decade has taken significant steps to modernise and diversify in Ireland. Alongside traditional sectors, innovative initiatives are evolving and growing, such as ocean renewable energy, the blue bioeconomy and bio-technology providing new prospects and creating jobs.

As the Blue Economy continues to thrive and scale globally, driven by the recognition of the ocean as a key dimension of the marine bioeconomy, scientists, policy makers and industry representatives have identified seaweed as a high potential marine crop. It is considered a potential means by which to sustainably develop new high value products and services, and mitigate food insecurity and the impacts of climate change.

The seaweed industry is a complex ecosystem with diverse stakeholders and many competing interests and dynamics. The Blue Economy has the potential to create benefits for coastal

communities but risks overexploitation if not sustainably managed. This creates the need for the creation of the conditions for sustainable governance of the sector.

From the discussions with the various stakeholders, key themes have emerged around which a number of positive policy interventions are needed to create the frameworks and investments which will support sustainable Blue Economy development in line with the European Commission's "A New Approach for Transforming the EU's Blue Economy for a Sustainable Future".

The development of the industry must address the existing issues regarding stability of supply and creating the enabling conditions for the development of new high-potential technology-enabled value chains from seaweed into diverse sectors whilst also remaining aware of the threats posed by over-exploitation of seaweed and habitat degradation due to over-harvesting, invasive species and climate change.

Integrating stakeholder feedback within the European context, the following are a series of policy options that would contribute to the development of a resilient, sustainable and progressive seaweed sector and address many of the barriers identified by harvesters and processors surveyed during this project.

1. **Creation of an overarching policy on sustainable seaweed harvesting**

   At present there is no formal national policy on seaweed harvesting, which is considered a barrier for development and growth of the seaweed industry in Ireland. A formal policy on sustainable harvesting would provide a national framework around which the sector could be further expanded. This national policy should be developed with input from industry and relevant national stakeholders within the context of international and European requirements and commitments.

2. **Redevelopment of the seaweed licensing framework**

   Licensing for the sustainable supply of seaweed has been an area of uncertainty and many would say inertia. This may be influenced by the fact that there are licences allocated which are not being used associated with folio rights, with some suggesting that a change in regulation is required to a "use or lose" scenario. There is huge potential and capacity for Ireland to become a world leader in a sustainable Blue Economy, with algae harvesting, farming and processing driving the development of an internationally scaled sector producing high-value, high-tech products and services. This requires careful, agile and active management to ensure that this is done with the utmost attention to the environment, climate and ocean ecosystem health whilst fully considering the opportunities for coastal economic revitalisation.

   There is a need for a clear position from the government on licences for seaweed harvesting and cultivation. This requires a balance between providing sufficient scale of operations in a single licence, which has been suggested should be at least 5 hectares, to over-regulation due to a lack of data and knowledge for decision making and the need for absolute protection of the health and integrity

of the ocean ecosystem.

Transparency on what is foreseen in licence awarding, in volume, timelines, application submission and assessment will provide industry, marine ecosystem and sustainability experts and agencies information to plan, map, assess and respond. One policy option that would help further develop the seaweed industry in Ireland would be to support the granting of licensing to companies that have invested in R&D, processing technologies and are focused on high value export markets.

3. **Investment in a Seaweed Observatory which will support a data driven approach to the sustainable scaling of the industry.**

Legitimate concerns exist on the capacity of the Irish wild seaweed resource to meet increased biomass harvesting demands and the potential damage that it could do to marine habitats, ocean biodiversity and ocean health, unless it is regulated and licensed. Paired with this is a potential to develop capacity and capability to both sustainably harvest and farm multiple species of seaweed which have diverse high value applications. A data driven approach in which ocean ecosystems and seaweed biomass (wild growth, harvested and farmed) are monitored would provide means by which to accurately protect the oceans and support the scaling of the seaweed industry dimension of the Blue Economy.

3. **Creation of a sustainability standard for seaweed harvesting and processing**

The creation of a sustainability standard for the sector will contribute significantly to both the value and potential for scaling of the sector. Supply chain sustainability and raw material traceability are a growing focus for many organisations (both local and global). The ambitious goals of the EU Green Deal, which aims for net zero carbon emissions by 2050, will require a reduction of scope 2 and 3 emissions associated with upstream activities. Through developing a coherent sustainability standard, for all aspects of the Irish seaweed industry (wild harvesting, cultivation, processing and seaweed based products), the sector will give itself a market advantage that in turn can grow all aspects of the sector. The basis for such standards already exists in sustainable practices in the food Industry in Ireland, with Origin Green recognised internationally as an example of best practice that could inform such a development. Putting a formal structure and recognition mechanism in place around this can then be used to promote the Irish seaweed industry as a whole.

4. **Closing the research and innovation gap via investment in transformation of the sector to embrace new technologies and sustainable practices.**

The seaweed sector is a traditional industry, the practices of which are recognised as a key strength, in particular with regard to harvesting approaches and ensuring sustainability of seaweed bioresources. However there are many opportunities for the advancement of the sector via strategic investments in

knowledge and technology deployment along the value chain, such as seaweed cultivation and hatchery capabilities, clean cascading processing technologies (biorefinery approaches), life cycle analysis, blue carbon accounting, new product development and innovation strategies, green procurement and supply chain optimisation - all of which require dedicated investment and prioritisation to position Ireland as a leader in the sustainable Blue Economy.

5. **Professionalisation of the next generation of Sustainable Marine Economy workers.**

   The practices of seaweed harvesting have been passed through generations. With the nature of the work and the relatively low incomes achievable for seaweed biomass it is not attracting newer generations and vital skills where tacit knowledge is being lost. The sustainable transformation of the primary seaweed harvesting and processing into a vibrant and dynamic career pathway requires both a reframing as a profession and the integration of new skills and competencies. Educational programmes and knowledge such as ocean ecosystem health and services, natural capital and biodiversity management, phycology, data monitoring and analysis, biomass bioprocessing and life cycle assessment will support this advancement. This will increase employability in the marine sector, enabling better exploitation of the value of the ocean in a sustainable way. This will require investment in training programmes from level 6 to level 10, encompassing flexible CPD options, and minor and major awards, which could also include apprenticeship models.

6. **Dedicated supports for SMEs and start-ups in the sector**

   It is clear that a range of supports are already available for small and medium enterprises in Ireland to develop their operations though the challenge in accessing existing government support was cited as a significant barrier to the smaller firms in the sector. This is not unique to the seaweed sector as 96% of Irish firms are SMEs. There are a number of larger operators in the sector who are more effectively able to mobilise and access the various supports available. However, given that the support needs of these smaller, frequently more agile and disruptive firms are very different, dedicated support and financial instruments are required for these companies.

7. **Creation of an open and effective marketplace for high value marine products.**

   Technology developments such as biorefining, cascading extraction and fermentation leading to products such as functional ingredients, biochemical building blocks and biogas can face significant challenges in reaching the point of commercialisation and then scaling in national and international markets. In addition to the significant capital and operational expenditure requirements, it includes regulatory hurdles (such as novel foods), and market readiness for new and novel products in a business to business (B2B) and business to consumer (B2C) context. Financial and regulatory acceleration supports are required to support companies to overcome these barriers. In addition, support on

increasing the awareness to and acceptance of new marine products is needed, e.g., consumers may not know what Fucoidan or marine polyphenols are. A dedicated export programme to support the internationalisation of new and novel marine products is required, including, for example, initiatives such as B2B meetings and introductions, engaging with international customers, industry conference attendance and dedicated marketing support to prepare for such engagements.

8. Investment in piloting and biorefinery facilities

In tandem with addressing the supply issue, the processing capabilities in Ireland need to be addressed as well. Currently there is a lack of publicly owned facilities for the piloting and scaling of new extraction and manufacturing processes. While it is acknowledged that a number of Irish based companies have already invested heavily in R&D and state-of-the art processing facilities, development of a national centre of excellence for marine biorefinery development, with the capacity to function as a contract manufacturing facility, would significantly accelerate development of the wider sector. A coastal location for such is essential, while integration of product innovation laboratories, suitable qualified academic staff and innovative start-up companies should also be considered. A pilot biorefining facility would help R&D efforts by academia and innovative start-up companies within the industry.

9. Access to finance

Capitalising on the opportunity landscape of the seaweed based circular bioeconomy requires significant investment. Dedicated funds are required, encompassing the full development-to-market life cycle, research and development, technology transfer, capital investment, product development costs on certifications, regulatory compliance, team and talent development, and market access, entry and internationalisation.

6. Sustainability of Seaweed Industry

6.1. Best Management Practices for Wild Seaweed Harvesting

The existence and growth of the Irish seaweed industry is dependent on the sustainable management of seaweed resources in coastal waters around Ireland. Mismanagement or overexploitation of seaweed resources could adversely impact the wider marine ecosystem affecting the many industries that rely on it such as the seaweed, fish and shellfish industries. There are many factors related to the sustainable harvesting of wild seaweed. First of all, it is important to consider what 'sustainable' refers to, for it can mean the protection of the overall ecosystem from which wild seaweed is harvested or it can refer to the regenerative capacity or potential of the targeted seaweed species itself. This section looks at both, first from the context of an ecosystem and then for seaweed on its own.

6.1.1. Seaweed Ecosystem Services and Benefits

From the overall ecosystem perspective, many seaweed species can be defined as foundational or late successional species that provide critical ecosystem structure, functions and services. Without them, the web of life they support can be adversely affected. Although there is an abundance of scientific literature on individual seaweed species and specific studies about very narrow topics of inquiry, there are very few holistic studies investigating ecosystem impacts from seaweed harvesting, the totality of role that seaweed plays in marine ecosystems or it's impact on or role in, for example, climate change. In fact, there are often very well researched academic papers looking at similar subjects with differing findings or conflicting conclusions. It is important to note that this is an emerging field of study and, like so much of our understanding about individual marine species, ecosystems and climate science, the body of knowledge often lacks scientific consensus. However, with that said, the research element of this work identified two recent comprehensive international reviews on the impact of wild seaweed harvesting on marine ecosystems. These were the "Ecosystem-Based Management of Seaweed Harvesting" by Heike K. Lotze et al. in 2019 and the Scottish Government's (Marine Scotland & Marine Environmental Research, November 2016), "Wild Seaweed Harvesting: Strategic Environmental Assessment Environmental Report." These, supported by other cited research work, outlined the following essential ecosystem functions and services provided by seaweed in the marine environment:

6.1.1.1. Habitat for Biodiversity

Canopy forming seaweeds, including kelps, rock weeds and many red seaweeds provide critical habitats for a wide range of plant and animal marine life. As a source of food, seaweed forests fuel food webs to support high levels of biodiversity. Seaweed biomass feeds grazers and suspension feeders that are then consumed by higher trophic levels of mammals, birds and fish. Seaweed beds also provide habitats for a variety of species, including birds, otters and seals, that use them as foraging grounds, and for fish, shellfish and invertebrates that use them for breeding, spawning and nursery areas, which are essential for supporting Ireland's fishing industry. In addition, seaweeds that wash ashore provide important habitats and act

as a food source for shoreline species of invertebrates and insects which shoreline birds feed on. The seaweed that ends up as detritus within the water feeds an ecosystem of life at the bottom of our oceans. Like terrestrial forests, seaweed beds support extraordinary biodiversity on all levels of the marine food chain.

6.1.1.2. Carbon Storage

Combined with photosynthesis, seaweeds and phytoplankton consume carbon and other nutrients in sea water to convert them into biomass. According to Wernberg et al., kelp forests cover about 25% of worldwide coastlines. Kelp is one of the fastest growing organisms on the planet and rivals tropical rainforests in the amount of carbon they can absorb. On a per hectare basis, seaweed forests absorb more carbon than any other terrestrial habitat. Consequently, seaweeds are a vital part of the carbon cycle within marine ecosystems and are an essential element of thriving oceans that are crucial to the health of our planet. However, as seaweeds share of global photosynthesis is relatively low (Field et al., 1998), their role in carbon sequestration may be limited.

6.1.1.3. Nutrient Cycling

Seaweeds act as natural filters for absorbing excess nutrients (nitrogen, phosphorus and potassium among others) from on-shore wastewater treatment facilities, coastal run-off from agriculture and from in-sea intensive aquaculture operations. Therefore, seaweeds can convert potentially polluting nutrients into biomass that captures carbon and recycles nutrients within the marine environment. This removal of dissolved nutrients reduces eutrophication of coastal waters most associated with potentially toxic algae blooms and ocean dead zones.

6.1.1.4. Coastline Buffering

It has been suggested that seaweed beds buffer coastlines from large waves, storm surges and strong currents that are becoming more common with global warming. It has also been suggested that coastal seaweed stands capture and absorb tidal and wave energy to protect shorelines from excessive erosion and is an important line of defense as sea levels rise in coming years. Beach-cast seaweeds can also provide organic matter and nutrients to dune habitats which in turn stabilise local sediments and contribute to coastal protection. However, other research suggests that seaweeds may be vulnerable to waves and storm surges and may not have much positive affect on hydrodynamics.

6.1.1.5. Summary

The scale of the different ecosystem roles depends on a range of seaweed characteristics, such as the type of species, its frond size and shape, the size of the bed or forest, its three-dimensional canopy structure, and the habitat distribution and connectivity across the marine environment. All of these characteristics can be affected by harvesting and can result in a wide range of ecosystem impacts. Direct harvesting can alter the structure and functions of these vegetated areas and the services they provide, depending on the harvesting methods used, the species harvested, and the scale, duration and frequency of harvesting (Lotze et al., 2019, pp. 396-99).

6.1.2. Ecosystem Impacts of Seaweed Harvesting

The methods used for seaweed harvesting can greatly impact the magnitude and range of consequences from such activities. Typically, these relate to the type of gear used, the harvest intensity and the cutting methods employed. Lotze et al. (pp. 399-401) identify that "while mechanical clear cutting or trawling will remove most of the canopy with years to decades needed for recovery, even lower level hand harvesting changes canopy structure through a truncation of larger, older and more voluminous fronds. Cutting height plays a critical role in frond regrowth, such as for perennial rockweed, and repeated cutting can change the branching, size and density of fronds. Such changes in the amount and structure of the seaweed canopy will affect the quantity and quality of habitat provision and community organisation."

The various potential impacts on marine ecosystems from periodic or over harvesting of seaweed include the following:

6.1.2.1. Reduction of Biodiversity

Seaweed harvesting reduces the area that epiphytes, or plants that live on other plants, can colonise, grow and thrive. This in turn reduces species heterogeneity, refuge areas for a variety of fauna, food for grazers and production of biomass debris that feeds other ecosystems. A reduction in beach cast seaweed, for example, has been shown to cause declines in the richness, abundance and biomass of coastal macrofauna and shorebirds. The research cited by Lotze et. al., (2019, p. 401) found that" the amount of seaweed habitat is more important in determining associated animal abundances, whereas habitat structure and complexity are more important in determining species diversity and composition." Consequently, unharvested seaweed areas with mature and complex frond structure support more species diversity and often times more abundance of aquatic flora and fauna than harvested areas.

6.1.2.2. Slower Speed of Recovery

Intensive harvesting of seaweed by clear-cutting or trawling disrupts and fragments habitats affecting ecosystem composition, organisation and connectivity. When over harvesting of seaweed occurs, dispersal and movement of certain associated fauna may be affected by a variety of factors including the habitat remaining after harvesting, the intensity of harvesting and the area harvested in relation to the size of the overall stand, bed or forest. The Scottish government's Strategic Environmental Assessment (SEA) of Wild Seaweed Harvesting (2016, section 6.4.2) cites research conducted on the regrowth of harvested kelp showing that while the kelp may regrow in as little as 4 years, it took longer for the epiphytes and other dependent species to re-establish themselves.

6.1.2.3. Succession of Species

Over-harvesting can lead to a shift in ecosystem composition with one of the largest ecosystem impacts being the potential replacement of a dominant foundational species, such as kelp or rock weed, with more opportunistic, colonising or invasive species. Lokze et. al (2019, p. 401) reference research that shows "in Atlantic Canada, a shift from Irish moss to coralline algae has been observed multiple times over the past decades due to over-harvesting and did not easily or rapidly reverse. Also, over-harvested rock weed (*Ascophyllum*

nodosum) beds have seen an encroachment of other fucoids, such as *Fucus vesiculosus L.*, with lower harvest value and habitat quality." Another example cited was that harvested kelp beds could potentially be replaced by turf algae. Other research from India has also shown that over-harvesting of seaweed beds in the Gulf of Mannar led to a significant decline in seaweed diversity from 200 species in the 1970s to 80 species in the 1980s.

6.1.2.4. By-Catch

Seaweed harvesting especially using trawling and dredging methods, can capture other flora and fauna as by-catch. Even hand raking and cutting will remove a certain quantity of epiphytes and slow-moving animals attached to harvested seaweed fronds. This has the potential to impact the abundance and biodiversity of seaweed stands, beds or forests. Research cited by Lotze et. al (2019, p. 401) indicate that rock weeds such as *Ascophyllum nodosum,* can harbour more than 100 species of invertebrates and many other algal species. While many of these species are present at the base of the canopy, and therefore may not be harvested as by-catch, there are other species that will be affected.

6.1.2.5. Fisheries

Similar to other marine areas, seaweed beds provide habitats for a wide range of marine organisms, including fish. Seaweed habitats are critical in supporting fisheries by providing breeding, spawning, nursery and foraging grounds for a variety of commercial species including cod, pollock, herring, lobster, crabs, bivalves and gastropods. This highlights the importance of ensuring that seaweed harvesting is carried out in a sustainable manner to protect ecosystems that fisheries depend upon around Ireland.

6.1.2.6. Summary

Although the ecological importance of seaweed canopies are well understood, relatively few studies have directly examined the effects of wild seaweed harvesting on the overall ecosystem. Most have focused on the impacts related to specific seaweed species. From an ecosystem perspective, seaweed harvesting directly affects the biomass quantity and overall structure of seaweed beds, both individual frond structure as well as three-dimensional canopy composition. The reduction in seaweed biomass within a locality can influence not only its ability for regrowth and regeneration after harvesting, but can potentially reduce the types and quantities of other organisms that depend on the seaweed as a host or a refuge. In addition, over-harvesting of some seaweed species can reduce primary and secondary production of algal biomass as harvested fronds have lower average size and age compared to unharvested areas. The influence of intensive harvesting on carbon storage is unclear and the contribution of Irish kelp species to carbon sequestration may be limited (Cott et al., 2021). Similarly, the potential influence of Irish seaweeds on nutrient retention within the seaweed forest, detritus accumulation on beaches and in deeper waters and shoreline buffering and protection warrants further investigation.

6.1.3. Factors Influencing Seaweed Regeneration

While it is clear that seaweed plays an essential role in maintaining the health of marine

ecosystems, there are numerous factors that influence seaweed regeneration after harvesting, including:

6.1.3.1. Type of Seaweed Species

There are thousands of seaweed species in our natural world with only a small fraction used by humans in a variety of ways (food, animal feed, fuel, fertiliser and industrial compounds among others). Microalgae or seaweeds grow in a variety of conditions: freshwater and saltwater, tidal and subtidal areas, warm and cold waters among others. Therefore, the rate of regeneration- how it grows and how fast it regrows in its natural habitat- varies depending on the species and local conditions. Consequently, the creation of best management practice guidelines for wild seaweed harvesting is challenging because what applies to one type of species may not apply to others.

6.1.3.2. Harvest Location

The rate of regrowth of a specific species of seaweed can vary greatly depending on the environmental conditions of the ecosystem from which it is harvested, including:

- water temperature,
- availability of nutrients,
- depth of water affecting sunlight penetration,
- wave exposure,
- other flora and fauna growing in the area,
- presence of grazers (eg., sea urchins, limpets),
- the salinity and pH of water,
- the level of potential pollutants,
- substrate composition of the seafloor or shoreline (muddy, sandy, gravelly or rocky)

and for tidal species:

- shading by other species that can reduce desiccation and irradiation,
- exposure to fresh rainwater, and
- shoreline characteristics (sheltered or exposed).

Again, this highlights the variability and local unique conditions that need to be taken into account when considering best management practice recommendations for seaweed harvesting. Therefore, scientific monitoring to measure regeneration rates and potential ecological effects should be incorporated into the licensing regime, as is currently the case for a number of foreshore licenses that have been recently granted in Ireland.

6.1.3.3. Proportion or Percentage of Resource Harvested

The size or proportion of the harvested area in relation to the whole seaweed community can also affect regeneration of harvested seaweed, especially when other factors including the method of harvesting and how much of the seaweed plant is removed are considered. If holdfasts are removed and all of the seaweed bed is harvested at once, the regeneration of that bed may take a much longer time to return to its initial state. Consequently, leaving sufficient standing stock around harvested areas, which allows seaweeds to reproduce and

"reseed" harvested areas, is essential.

6.1.3.4. Harvesting Method

The method of harvesting has probably the most significant impact on the regeneration rate of harvested seaweed. Hand cutting, picking or gathering are considered as having less impact than mechanical methods of harvesting including sledging, trawling, dredging, or "hedge cutting" and suction of cut fronds. Dredging that disturbs the bottom substrate or methods using a "scoubidou" which pulls up holdfasts damage the harvested area and slows down the regenerative process. However, scientific studies have shown that seaweed harvesting can also be undertaken sustainably by mechanical means given careful management within the others factors mentioned in this section. It should be noted that excessive removal of holdfasts or trampling of the harvested area by heavy machinery in tidal areas (e.g., tractors) can also damage seaweed beds and impact the regrowth of seaweed. Another important consideration is the pattern of harvesting in grids or strips and how large those areas are in relation to unharvested areas. Wider strips or bigger squares will take longer to regrow and have a higher potential for facilitating the establishment of colonising or invasive species.

6.1.3.5. Quantity of Fronds Harvested

How much of the individual seaweed plants is harvested influences its rate of regrowth- the less that is taken from the seaweed plant, the faster it will regrow. The boat and rake method of seaweed harvesting uses a serrated cutting rake head to remove a part of the floating seaweed canopy to harvest large clumps at the distal end of seaweed plants. This is akin to pruning trees or bushes and can stimulate regrowth within a shorter period of time when compared to hand cutting a short distance (10-20cm) above the holdfast (1-2 years versus 5+ years for *Ascophyllum nodosum* or 6 months versus 18 months for some types of red seaweed).

6.1.3.6. Frequency or Intensity of Harvesting

The time allowed between harvesting and re-harvesting a seaweed area also affects the regeneration of seaweed beds. Combined with the factors outlined above, the frequency of harvesting can determine whether the area is being sustainably managed or overexploited.

6.1.3.7. Time of Year

Lastly, the time of year or season when harvesting takes place also affects the regenerative capacity of the different seaweeds. Seaweed harvesting should be avoided during peak reproduction periods so that a species can recolonise in harvested areas. Harvesting seaweed during the active growth season allows for quicker recovery of the harvested plants or area, depending on the species involved.

6.1.3.8. Summary

The Scottish Strategic Environmental Assessment concludes in their extensive study that regeneration of harvested seaweed will be "site specific" and "will depend on a range of factors, including the species to be harvested, the harvesting method, the amount taken, the timing (season) of harvest, the harvesting location and its environmental context, and the time

allowed for regeneration prior to harvesting again. Harvesting practices, most notably the extent and scale of harvesting (i.e., frequency of harvesting, the proportion of a seaweed community harvested, the proportion of an individual plant harvested) and the species harvested have been identified as key factors in ensuring plant regeneration and recovery of harvest areas, and ensuring the sustainability of the resource and the biodiversity it supports" (2016, section 12.2.6).

6.1.4. The Need for a Sustainable Seaweed Harvesting Framework in Ireland

Currently there is little oversight or regulation related to the harvesting of wild seaweed resources along the coasts of Ireland by local or national government. Any efforts to date to sustainably manage wild seaweed resources comes from a tradition of seaweed harvesting by inhabitants of coastal communities and by some commercial operations that purchase seaweed from independent small-scale, part-time harvesters. In contrast, the mechanical harvesting of *L. digitata* and *L. hyperborea* in subtidal waters is regulated and is a licensed activity in Bantry Bay, County Cork, Ireland, which involves the cutting of kelp a minimum of 25 cm above the holdfast, without making contact with the seabed, along with scientific monitoring of kelp regeneration rates and flora and fauna 3 and 5 years post-harvesting (BioAtlantis Aquamarine Ltd, 2014).

In research conducted by MacMonagail et al. (2017, p. 381), they note that: "Although seaweeds have been harvested since ancient times, in the face of growing commercial interests and pressures it is important that specific management tools are developed and implemented to help maintain the health and integrity of not only seaweeds, but of all resources. There should be a concomitant vigilance with respect to global resource science, management, and accountability. There is definite potential for mismanagement of these important resources. A clear distinction must be made between the harvesting of wild stocks for personal and artisanal use and exploitation of seaweed biomass on an industrial commercial scale."

As the age profile of independent harvesters increases, especially those with the traditional values of protecting the resource retire and stop harvesting activities, they will be replaced by a new generation of harvesters that may not carry on the methods of hand harvesting or the unwritten traditions to protect the long-term sustainability of the resource. In fact, through our research, anecdotal evidence suggests that this is already happening. Consequently, there is a need to create a regulatory framework and the necessary training/education to ensure that our seaweed resources are not overexploited and can be managed sustainably for future generations.

While there is extensive information available from different countries, the research, findings and lessons learned from the better established French and Norwegian industries may be most applicable to Ireland as both countries share similar seaweed species of commercial relevance (e.g. *A. nodosum*, *Laminaria spp.*). In the Scottish Strategic Environmental Assessment of Wild Seaweed Harvesting referenced above, there is an acknowledgement that there is little evidence that small-scale artisanal hand cutting or gathering of living and beach-cast seaweeds at discrete locations have any significant environmental impacts. However, the

report does acknowledge that there may be a potential for significant cumulative impacts as a result of multiple harvesting activities within the same geographical area, but those impacts in terms of type and severity would need to be studied further. Also, the impacts of small scale harvesting, in conjunction with large scale industrial processing of seaweed, would require further research. The report concludes that these cumulative assessments should be identified and quantified as a part of the review phase of individual licence applications.

Considering these well founded conclusions, from an Irish context, and taking into account the obvious need for careful protection of the broader marine ecosystem, it is imperative that a systematic approach be put into place to manage the harvesting of wild seaweed resources along the coasts of Ireland. So the issue at hand becomes what to do and how to do it, within the Irish context. In other words, what are the various ways of mitigating against overexploitation of seaweed resources or managing the resource in a sustainable manner, and what sort of system needs to be put in place to manage the harvesting of wild seaweed resources along the coasts of Ireland.

6.1.5. Mitigation Measures Toward Sustainable Management of Wild Seaweed Resources

Both the Scottish Strategic Environmental Assessment report (Section 9.2) and the summary research compiled by Lotze et al. provide a range of options for mitigation against the overexploitation of wild seaweed resources. These potential policy and regulatory options are discussed below:

6.1.5.1. Monitoring Programmes

Monitoring programmes allow harvesters, processors and regulators the opportunity to assess the status of the proposed harvesting areas by documenting the types of species present, both flora as well as fauna, and evaluate the level of biodiversity present. It also allows for the quantification of biomass in the area by species type. Pre and post harvesting survey work can record damage done by harvesting (both by method and quantity) as well as the regenerative rate of seaweed plants in harvested areas. Surveys can also be used to record volumes of seaweed by species harvested by date and location. If specific “no harvest” areas are set aside, these can be used as reference sites and serve as a baseline to help determine the scale of various impacts from harvesting activities. As part of the licensing process for *Laminaria spp.* in Ireland, “no harvest” areas are required in licensed areas (BioAtlantis Aquamarine Ltd., 2014).

6.1.5.2. Quotas & Harvest Limits

Another way to control the impacts of wild seaweed harvesting is to impose quotas or harvest limits on the amount of seaweed harvested. This can be done on an annual volume or weight basis per harvester or within a specific area, especially when multiple harvesters are working in the same area. Harvest limits as a percentage of standing stock can also be applied to specific species or areas. For example, the Scottish SEA notes that “The total amount harvested should be set in accordance to the status and availability of the wild resource and the recovery rates of individual species. Only a small percentage of standing stock should be harvested where possible. For example, Comhairle Nan Eilean Siar (2013) advises that the

annual harvest of *Ascophyllum nodosum* should be no more than 25% of the total accessible biomass." (2016, Table 14, p. 126)

6.1.5.3. Harvesting Methods

Since the method of harvesting can influence the rate of seaweed regeneration, efforts to promote sustainability can limit, restrict or prohibit certain types of harvesting methods or equipment. These, of course, would be specific to the type of seaweed harvested and the technique that is best employed for the crop and its location. Options for the main types of controls that can be used include:

- Prohibiting holdfast removal in most cases to support frond regrowth and to maintain holdfast communities within the seabed floor.
- Prohibiting mechanical clear cutting of an entire seaweed bed or area.
- Creating distinct species specifications on the amount of material harvested from individual plants or cutting height to maintain canopy structure and/or rates of regrowth for both foundational canopy species as well as smaller colonising or opportunistic species.
- Requiring spatial management in terms of area limits, pattern and size of harvested patches or strips and exclusion areas to ensure both quicker rates of regrowth and connectivity among habitat patches and along migration routes.
- Prohibiting certain types of harvesting equipment that uproot holdfasts, damage the seabed floor, or cut mature as well as juvenile seaweed plants.
- Instituting provisions that require a substantial portion of a harvested area to contain sufficient levels of mature plants to sustain reproductive capacity or reseeding ability within an area.
- Employ methods that allow or ensure the regeneration of the seaweed bed post harvest.

6.1.5.4. Rotational Fallowing

Another way to encourage the regrowth of harvested areas is to rotate harvesting areas to allow ample time for recovery. The length of time or frequency of harvesting will depend on the rate of recovery for the associated species as well as the habitat and can be site specific. This control method can also apply to beach cast seaweed by not harvesting from the entire length of the shoreline area.

6.1.5.5. Seasonal Restrictions

Restricting harvesting and cutting to the growth season of certain species where it is scientifically justified may be another important control measure as this can promote faster regrowth of harvested seaweed. However, it may also be advisable to cut certain species outside of their growth season to avoid other ecological effects. It may also be more sustainable to cut certain species all year round, as is currently the case with *Asco.* Similarly

prohibiting harvesting of seaweed during peak reproductive times of the year could be considered for certain species. In addition, limiting harvesting when canopy seaweeds provide refuge for vulnerable species or commercially valuable fish and shellfish can be another option. For beach cast seaweed, limits on harvesting may be imposed during the migratory bird season between October and April but would need to be species and location specific. Limits on removal of beach cast seaweed may be imposed in certain locations and during certain times of year, however, such restrictions may not apply if beach cast seaweeds cause a nuisance or a pollution problem and must be removed.

6.1.5.6. By-Catch Measures

Where possible, requiring the in-situ rinsing of harvested materials to remove some of the by-catch, especially epifauna, can help reduce the impact of seaweed harvesting on species that live on, feed on or depend on seaweed for survival. This can help protect and preserve biodiversity within the marine environment.

6.1.5.7. Harvesting in Vulnerable Areas

Regulating harvesting activities in vulnerable areas is hugely important for both seaweed and fisheries. Such vulnerable areas include:

- Special Areas of Conservation (SACs)
- Special Protection Areas (SPAs)
- Marine Protected Areas (MPAs)
- No take zones that prohibit extraction of any marine resources
- Shoreline areas that are especially exposed to waves and strong currents
- Erosion prone coastal areas

No take zones can provide year-round refuge areas for vulnerable species of flora and fauna and for commercial fisheries in general. They provide reference sites for ecosystem assessments, especially in the era of climate change, and ensure better connectivity between multiple marine habitats.

6.1.5.8. Cross Contamination

An important way to enhance biodiversity and protect seaweed areas from degradation is to put in place a system to check, clean and dry equipment used for the harvesting of seaweed to avoid the movement of invasive species, pests and diseases between harvested seaweed areas. The Scottish SEA report suggests that a biosecurity plan should be developed as part of the programme for monitoring harvested seaweed areas.

6.1.5.9. Summary

The following table, compiled by Lotze et al. (2016, p. 400), provides a summary of the main elements to be considered for the sustainable management of Ireland's wild seaweed resources. It outlines the ecosystem functions and services of canopy forming seaweeds, the associated ecosystem characteristics that can be measured, the possible effects of harvesting on marine ecosystems and the potential ecosystem-based management strategies and control options that can be considered for sustainable management of wild seaweed harvesting.

Ultimately, ensuring the sustainability of individual seaweed species cannot be taken out of the context of overall ecosystem management within our marine environment.

Table 6.1: *Ecosystem functions and services of canopy-forming seaweeds, the associated ecosystem characteristic that can be measured, generalised possible effects of harvesting, and potential ecosystem-based management (EBM) strategies (Lotze et al., 2016)*

Ecosystem roles	Ecosystem characteristic		Effects of harvesting	EBM strategies
Energy capture and transfer	Canopy biomass/standing stock	=>	Reduced	Harvest limits (quota)
– Primary production	Plant mass/growth	=>	Altered (decrease/increase)	Cutting methods (height/spacing/plant size)
– Secondary production	Canopy/plant regeneration	=>	Altered (decrease/increase)	Gear restrictions (mechanical/clear-cut)
– Detrital production	Detritus accumulation	=>	Reduced	Seasonal closures (peak growth/reproduction)
– Carbon storage				Spatial management (area limits/rotation/ exclusion)
Nutrient cycling/retention	Canopy biomass/standing stock	=>	Reduced	Harvest limits
	Tissue nutrient content	=>	None	Spatial management
	Detritus decomposition/release	=>	Reduced	
Habitat provision (quantity/quality)	Seaweed species	=>	Shift in dominance/diversity	Harvest limits
– Settlement (epiphytes, holdfast)	Plant morphology:	=>	Altered	Cutting methods
– Spawning/breeding	– Plant height	=>	Reduced	Gear restrictions
– Nursery	– Plant mass/size	=>	Reduced	By-catch limits (holdfasts/epiphytes)
– Feeding/foraging	– Plant circumference	=>	Reduced	Seasonal closures (breeding/nursery periods)
– Connectivity	– Holdfast size/age	=>	Reduced	No-take protected areas (refuge/reference)
	Canopy structure:	=>	Altered	Spatial management
	– Density	=>	Altered (decrease/increase)	Community co-management (governance)
	– Branching	=>	Altered (decrease/increase)	
	Habitat patchiness/fragmentation	=>	Increased	
	Habitat diversity/linkages	=>	Reduced	
Community organization	Species abundance/diversity	=>	Altered (decrease/increase)	Harvest limits, Cutting methods
– Biodiversity	Functional abundance/diversity	=>	Altered (decrease/increase)	Gear restrictions
– Community structure	Habitat diversity/linkages	=>	Altered (decrease/increase)	By-catch limits (vulnerable species)
– Species interactions	Habitat patchiness/fragmentation	=>	Altered (decrease/increase)	Seasonal closures
– Food webs	Genetic diversity/fragmentation	=>	Altered (decrease/increase)	No-take protected areas
– Connectivity	Vulnerable species	=>	Reduced	Spatial management, Community co-management
Fisheries support	Species abundance	=>	Reduced	Harvest limit, Cutting methods
	Species richness	=>	Reduced	Gear restrictions, By-catch limits
				Seasonal closures, No-take protected areas
				Spatial management, Community co-management
Shoreline protection	Canopy biomass/structure	=>	Reduced	Spatial management
Buffer/filter zone				Community co-management

6.2. A Strategic Approach to Ensure Sustainable Levels of Wild Seaweed Harvesting

It is clear that use of Irish wild seaweed has significant potential but how that potential is realised needs careful consideration. Previous work has suggested that the current levels of harvesting could be sustainably doubled to ~75,000 tonnes per annum (Hession et al., 1998). However, since this report many changes have occurred in the sector (both harvesting and processing) and within the broader environment, where the importance of seaweed beds' contribution to the wider marine ecology has become more apparent. In a recent review, *Regulatory Regime for Seaweed Harvesting and Cultivation*, the Scottish Sustainable Inshore Fisheries Trust (SIFT) outlines a series of relevant factors that need to be considered for the future of harvesting and cultivation. The following section of that report (SIFT, 2019, pp. 19-20) provides a comprehensive summary of what is critical for managing, monitoring and regulating the seaweed industry with these findings being equally pertinent for Ireland as we consider a sustainable approach to the future of the industry.

"The mechanism by which the sustainable threshold for harvest is determined should be further refined. Default values for the percentage of biomass that can be removed or the frequency of harvesting areas and fallow periods cannot be relied upon. These values will differ according to area, species and other environmental factors, such as temperature or nutrient levels. Reliance on such static default figures fails to recognise the natural variation within the ecosystem, or how the act of harvesting may affect the local productivity. It is an approach that risks over-exploitation."

"Instead, harvest strategies must be more adaptive. An effective strategy should clearly state target and limit biomass levels, informed by empirical evidence for the species involved. An effective strategy should also detail how harvest rates will be adjusted in response to changes identified in on-going monitoring. The setting of harvest strategy parameters should be informed by science, but also shaped in an integrated and participatory manner and with a long-term perspective. Ecosystem-based management plans are key to this, which recognise not only the inherent ability of the species to reproduce for maximum yield, but also the ecosystem function played by that species. Given the critical role that seaweeds play in marine ecosystems, it may be that the target harvest level should be set at a more precautionary level than Maximum Sustainable Yield."

"Harvest strategies should also be subject to review, to ensure that they are achieving the stated objectives and if necessary, adjusted. This form of adaptive and strategic management should help to ensure that the level of harvest is not only initially sustainable, but continues to be sustainable as the environment changes and the industry develops."

"As the popularity of seaweed grows, demand may grow for previously unharvested species, with novel applications, therefore the management framework must be robust to changes in the character of the industry. A regulatory regime which relies upon a static percentage for biomass removal and harvesting frequency will lack the strategic considerations to ensure on-going sustainability as the industry develops."

"The science of empirical stock assessment of seaweeds is relatively young. Much of this focuses on making a static assessment of existing biomass. Modelling of future biomass levels under differing harvesting scenarios has not been developed to the extent it has in fisheries. Therefore, the consequences of seaweed harvesting, both the target stock and the wider ecosystem are, to some extent, unknown. For this reason, an appropriate level of precaution is required."

"When considering a new and emerging industry, it is important that government policy helps to intentionally shape the composition of the future industry. It is entirely possible to have an ecologically sustainable and well managed seaweed harvesting industry made up of many, many small scale, local harvesters. Just as it is entirely possible to have an ecologically sustainable and well managed seaweed harvesting industry made up of a single large, perhaps even multi-national company. Government policy should seek to shape which of these outcomes is preferable or more likely, what balance should exist between these two outcomes. This will influence the long-term social and economic sustainability of the seaweed industry and will also influence the degree of support from a wide spectrum of stakeholders for the emerging industry."

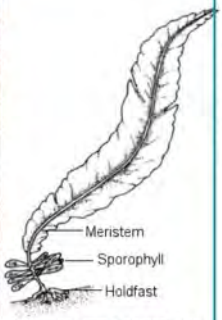
It is possible to achieve a seaweed harvesting industry in Ireland which is ecologically sustainable. "However, this will only be achieved if the regulatory framework is sufficiently robust to ensure the controlled development of the industry as it matures. The regulatory framework should therefore not only have a clear requirement for empirical evidence but also a strategic approach, informed by appropriate monitoring which can adjust patterns of exploitation according to industry developments and changes in the environment (e.g., climate change). The setting of harvest levels should focus not solely on the ability of the targeted resource to recover and re-grow, but should also recognise the ecological function of the resource and demonstrate that this functionality is not adversely impacted by the proposed harvest level. This approach to informed and adaptive strategic management of harvest is equally applicable to large or small scale harvesting, regardless of the species or location. Whilst it is reasonable for smaller scale applications to be supported by a lower level of empirical evidence, the overall requirements for strategic management and feedback mechanisms should be the same." (SIFT, 2019, p.22)

6.2.1. Wild Seaweed Harvesting Guidelines

The following Guidance Note, *Detailed Guidance for Seaweed Harvesting - Hand Gathering* (Natural Resources Wales, 2019), provides an excellent summary of sustainable methods for **hand harvesting** specific types of seaweed found in the British Isles, including Ireland (pp. 20-25). Although this guide has been created for individuals harvesting seaweed for personal use or for artisanal purposes, it does provide best management advice for the sustainable harvesting of wild seaweed resources. A similar guide could be produced for commercial harvesting activities.

Table 6.2: *Species specific considerations for harvesting* ***brown seaweeds*** *(reproduced from Natural Resources Wales, 2019)*

Seaweed Species	Species ecology	Sustainable harvesting advice
Himanthalia elongata Common name: Thongweed/ sea spaghetti 	Usually reproduces at 2 years. Reproduces once before dying. Has a unique life cycle and growth strategy. Unusual morphology, reproductive fronds make up 98% of the seaweed's biomass.[40] Reproductive fronds grow throughout the winter and spring, before summer reproduction. Fronds then disintegrate.[41, 42]	Harvest in summer after the reproductive season if possible. Reproductive structures are visible as dark circles on fronds. If harvesting occurs during the reproductive season, then harvest only one of the two main fronds. Do not remove the buttons which remain attached to the rock.
Laminaria digitata Common name: Kelp/ oarweed 	Perennial Growth is from the meristem at the base of the fronds, rather than the tips. Growth is fastest throughout spring and summer.[32] Two reproductive peaks; in early summer and late summer /autumn.[32]	Cut by hand, avoiding the meristem (growing point) at the base of the fronds. Cut approximately 5cm below the top of the stipe (as in picture) and collect only the upper parts of the frond. Harvest areas sparsely, as kelp forests have a function in wave dissipation, shoreline protection and habitat provision. Harvest during early spring, before the summer reproductive peak.

Seaweed Species	Species ecology	Sustainable harvesting
Laminaria hyperborea Common name: Kelp/ oarweed 	Can live up to 20 years Growth is from the meristem at the base of the fronds, rather than the tip of the fronds. The new blade grows below the older one and the old blade is shed in spring and early summer. Growth occurs November to June and completely ceases at the end of summer until the next year.[32] Habitat for at least 238 species of macrofauna.[1] It is also important for large mobile mammals, such as grey and common seals.	Cut by hand, avoiding the meristem (growing point) at the base of the fronds. Cut approximately 5cm above the top of the stipe (as in picture) and collect only the upper parts of the fronds. Harvest areas sparsely. Growth is most rapid in the first half of the year. [43] Spores are produced over much of the blade surface from September to April [44] so harvesting of fronds advised from May to August. If the stipe is to be harvested, this will be considered on a case-by-case basis.
Alaria esculenta Common name: Dabberlocks   Amended from Fish and Fish (1996)	Perennial Growth is from the meristem at the base of the fronds, rather than the tips. Reproduction occurs during the autumn and winter. Reproductive sporophylls are located in clusters at the top of the stipe, just below the fronds.[47]	Cut by hand, avoiding the meristem (growing point) and sporophylls at the base of the fronds. Avoid harvesting during autumn and winter, when the seaweed is reproductively active.

Seaweed Species	Species ecology	Sustainable harvesting advice
Ascophyllum nodosum Common name: Knotted wrack 	Long lived (several decades) perennial species. Reproduction peaks during spring.[49] Lots of other seaweeds and animals live on knotted wrack, particularly when older individual plants link up to form a complex habitat.[50]	Collect only the upper parts, leaving lengths of 10-20cm of the older, more complex habitat. Avoid harvesting during the spring reproductive peak. Slow growing and a poor recruiter so harvesting should be substantially limited. Harvest only from small areas, and leave unharvested areas in between. This may help avoid detrimental effects on associated fauna.[17] Leave at least two years before re-harvesting, preferably longer.[51] Easily damaged by trampling: sites should be carefully selected in discussion with NRW.
Fucus vesiculosus Common name: Bladder wrack 	Short-lived (4 to 5 years) perennial species. Appearance varies markedly in different environments. Most common form has many distinct air bladders in the frond.[47] Reproduction peaks in the spring and summer.[48]	Cut fronds at 30cm or more from the holdfast.[48] Avoid harvesting during the spring/summer reproductive period. Number of reproductive receptacles on the seaweed increases greatly as it ages and regrowth potential decreases. Harvesting only the large mature individuals from an area is not advised.[48]
Fucus serratus Common name: Serrated wrack 	Short lived perennial species, with one distinct form.[47] Reproduction peaks in the autumn/winter, although can vary greatly with locality.[48]	Cut fronds at 30cm or more from the holdfast [48]. Avoid harvesting during the autumn/winter reproductive season. Number of reproductive receptacles on the seaweed increases greatly as it ages. Harvesting only the large mature individuals from an area is not advised.[48]

Table 6.3: *Species specific considerations for harvesting* ***green seaweeds*** *(reproduced from Natural Resources Wales, 2019)*

Seaweed Species	Species ecology	Sustainable harvesting advice
Ulva spp. Common name: Sea lettuce 	Pseudo perennial with the base, but not the fronds, surviving from year to year. [50] Rapid growth in spring and summer, when reproduction also peaks.[52] *Ulva* species can rapidly form algal blooms in favourable conditions, sometimes known as 'green tides'. These can be damaging to both other marine organisms and the wider ecosystem.[53]	Harvest during the rapid growth phase in spring and summer.

Table 6.4: *Species specific considerations for harvesting* ***red seaweeds*** *(reproduced from Natural Resources Wales, 2019)*

Seaweed Species	Species ecology	Sustainable harvesting advice
Porphyra species Common name: Laver 	Ephemeral, often on sand-scoured rocks. There are several species of Laver in Wales. Separating the different species can be difficult. They have a microscopic shell boring stage in their life cycles.[55]	There is some evidence that regeneration is quicker if the base of the seaweed remains intact.[56] Leave small plants attached where possible.
Corallina species Common name: Coral weed 	Calcareous seaweed which grows to only 12cm. Unusual appearance, more like that of coral. Distinctive pink colour, due to the white lime in the base and the seaweed's reddish pigment.[47] Perennial base, with new fronds growing each year. Fronds can regrow from the base.[57]	Ensure the crustose base is left intact for regrowth. NRW would not support large scale collection of this seaweed.
Osmundea species Common name: Pepper Dulse 	Perennial.[58] There are various species in this group, but the most frequently encountered (*O. pinnatifida*) reproduces mainly from March to June. Can show considerable variation in form and colour due to its position on the shore.	Ensure the holdfast and some of the blade is left intact for re-growth. Turfs of Pepper Dulse may expand through lateral growth of the perennial holdfast, so the reproductive season is not so critical for the species most frequently encountered on the shore.

Seaweed Species	Species ecology	Sustainable harvesting advice
Palmaria palmata Common name: Dulse 	Perennial Growth occurs each year from the holdfast. Rapid growth during February and March, with reproductive fronds from November to April. If is often found growing on other algae, especially kelps	Ensure the holdfast and some of the blade is left intact for re-growth. Harvest from May to October, when not reproductive.
Chondrus crispus Common name: Carrageen/ Irish moss 	Normally perennial Rapid growth during spring and summer.[54] Reproduction occurs during the autumn and winter.[54]	Re-grows from the holdfasts and the edge of severed fronds so make sure to leave these intact. Harvest only a small proportion of the largest blades[54], during spring/ summer rapid growth period. Avoid harvesting during autumn and winter when reproduction is ongoing and recovery is much slower.[54]

Mastocarpus stellatus Common name: False Irish moss / Grape Pip Weed 	Perennial Long reproductive season.	Ensure the holdfast and some of the blade is left intact for re-growth. Harvest only a small proportion of the largest blades. Harvest during the spring/summer rapid growth period. Avoid harvesting during the autumn and winter when reproduction is ongoing and recovery is much slower.

6.3. Best Management Practices in Reporting of Wild Seaweed Harvesting

6.3.1. International Context

This section begins with a summary of how other countries outside of Ireland are regulating the wild harvesting of seaweed to provide a context in which Ireland can be compared to. The 10 areas reviewed are Norway, France, Scotland, Iceland, Maine (US), California (US), Washington (US), Alaska (US), Nova Scotia (Canada) and British Columbia (Canada). The European countries included represent the countries currently harvesting the most wild seaweed in Europe with Norway as the largest producer (130-180,000 tonnes/year) followed by Iceland (around 90,000 tonnes per year), France (60,000 tonnes/year) and then Ireland and Scotland and in terms of volume. The state of Maine leads wild seaweed harvesting in the US with a majority of seaweed harvested consisting of *Ascophyllum nodosum*. One jurisdiction prohibits commercial harvesting of seaweed altogether (Washington State). All but one requires reporting, Alaska, where there is very little seaweed that is harvested for commercial purposes anyway. There is more seaweed cultivated there, 400 tons per year, than harvested from wild stocks, 38-78 tons per year. This is small compared to the almost 35,000 tonnes per year of wild seaweed harvested around the coasts of Ireland. What follows is a summary table listing the permitting or licensing requirements, exemptions from licensing or permitting requirements, and reporting requirements, followed by more detailed commentary on each country, state or province.

Within an EU context, harvesting of seaweed in the wild should be undertaken in a manner that is sustainable in both the short and long term, allowing for regeneration of the resource and preventing negative impacts on the marine and coastal ecosystems, habitats and species (Werner & Kraan, 2004, Kelly et al., 2001 and 2005). In EU countries, harvesting must be carried out in line with the habitats and birds directives (Habitats Directive 92/43/EEC, Birds Directive 2009/147/EC), particularly when working in protected areas such as Natura 2000

sites, Special areas of Conservation (SACs), Special Protection Areas (SPAs) and Marine Protected Areas (MPAs). In particular, measures are required to ensure that activities associated with seaweed harvesting do no impact on the conservation objectives and targets set for qualifying interests (habitats, species, etc.) within protected sites (NPWS, 2012). Conservation objectives and targets are typically assigned to protect a wide array of marine and coastal species and habitats listed on Annex I/II of the E.U. Habitats Directive, including harbour/common seal (*Phoca vitulina*), otter (*Lutra lutra*), specific bird species, reefs, shingle, tidal mudflats and sandflats, estuaries, inlets and bays, salt meadows and sand dunes and a range of harbour seal haul out sites and bird wintering or breeding sites (Nelson, 2019, NPWS, 2019). Adherence to conservation objectives and targets form a key part of legal frameworks aimed at ensuring that activities such as seaweed harvesting are undertaken in a sustainable manner, thus ensuring no significant impacts on protected habitats and species in the marine zone.

Table 6.5: *Seaweed Licencing & Reporting Requirements in Selected Countries in Europe, United States and Canada*

Country, Canadian Province or US State	Permitting & Licencing Requirements	Exceptions	Reporting Requirements
Norway	-Two companies are permitted by the national government to harvest Asco and mechanically harvest *Laminaria hyperborea* (dredge method) and are regulated by Regional Fisheries Directorates		Logbooks showing catch composition, quantity and origin are inspected by the Fisheries Directorate and a yearly report is submitted to the national regulatory agency.
France	-On-shore and at sea seaweed harvesting is regulated by national and regional entities. -Beach or low tide harvesting activities require authorisation or permission by local authorities. -Licenses are required for all mechanical kelp harvesting boats (dredge and scoubidou methods). -Specific regulations vary according to seaweed type and region. -The French Research Institute for the Exploitation of the Sea monitors the kelp harvest and advises government agencies involved.		Log books are required to be filled in by harvesters for documenting and reporting of location, species and quantities harvested.
Scotland	-Licences are required for commercial harvesting of wild seaweed. -Crown Estate licence fees based on flat rate plus additional fees based on tonnage.	-No licence required for manual harvesting of seaweed for personal use. - No licences are required on privately owned foreshores	Reporting of location and quantities is required for Crown Estate/Marine Scotland licences. No reporting is required from wild seaweed harvested from privately owned foreshores.

Iceland	-Permitting is required for all commercial harvesting of seaweed by the Directorate of Fisheries		Monthly reporting of seaweed quantities by species and area is required with the data published on line for transparency purposes.
Maine, USA	-Permit required to harvest, posses, ship, transport or sell seaweed (permit fee paid to state) -Buyer's licence required to buy, posses, ship, transport or sell seaweed (licence fee and per ton surcharge paid to state) -*Asco* must be harvested 16" above holdfast so that the lowest branches remain undisturbed and attached to the main stalk and holdfast.	-No permit required for persons harvesting 50 pounds (23kg) or less for non-commercial purposes; for Charitable or municipal use; and for naturally detached or dead seaweed	Daily logging of location, method, species and weight submitted monthly to Maine Department of Marine Resources
California, USA	-All commercial harvesters are required to be licensed and pay the state a royalty on the amount harvested. -Harvesting of seaweed in state marine reserves prohibited	-No licenses or permits are required for harvesting up to 10 pounds per day for personal use	Monthly reports due by the 10th of the following month. Reports include daily logging of location, type of seaweed, the amount harvested in wet tonnes and who the seaweed was sold to (unless utilised by the harvester). Royalty rates of $17-24/ton are calculated and paid depending on the type of seaweed harvested.
Washington, USA	-Licence is required for harvesting of seaweed for personal use. Daily limit is 10 pounds per day. -Harvesting is not allowed in state parks. -No commercial harvesting of wild seaweed is permitted in WA		No reporting of seaweed harvesting for personal use is required.
Alaska, USA	-Commercial harvesting of kelp for sale requires a permit from the Alaska Department of Fish & Game. -Harvesting of seaweed in non-subsistence areas is prohibited (near urban areas) for both personal and commercial use.	-No permits are needed to harvest seaweed in"sub sistence" coastline areas for personal use and there are no seasonal limitations or quantity restrictions.	None currently

Nova Scotia, Canada	-Regulation of seaweed harvesting for commercial purposes is controlled through a system of foreshore or coastal area leasing. -Leases contain specific conditions related to open or closed areas, harvesting methods and fees collected (flat annual fees and royalty payments). -Lease applications must include management and commercialisation plans.	-A person who harvests less than 4 tonnes per year of *Asco* for agricultural or personal use -A person or organisation that harvests less than one tonne of *Asco* per year for scientific or research purposes	Harvesting records must be kept by leasees with reports submitted monthly to include dates of harvest, areas harvested, and type and quantities taken. Based on monthly reports, fees and royalties are collected annually.
British Columbia, Canada	-A licence for commercial harvesting of seaweed over 100kg is required.	-No licence is required for harvesting of 100kg or less of seaweed for personal use	Annual reports require specifying types, quantities (wet weight), location and payment received from buyers.

6.3.1.1. Norway

"Norway leads the harvest of seaweed from wild stocks in Europe, annually harvesting 130,000 - 180,000 tonnes of brown seaweed including kelp species. The right to harvest seaweed belongs to the state and is prohibited unless permission is granted. Regulations for harvesting of seaweed in Norway were commenced in 1995 under its Marine Resources Act. The purpose of the regulations is to ensure sustainable use, defined as use that will produce economic growth and better living conditions for people without destroying natural resources, the environment or preventing future generations from fulfilling their needs. The regulations include the following requirements and definitions: Management plans designate areas for harvest under an explicit cycle, and locked areas where it is prohibited to harvest in all or part of the year; Areas are considered to be suitable for harvesting where the resource and ecosystem can withstand the strain of harvesting; Regional Fisheries Directorates may establish regional regulations on where and when it is permitted to harvest seaweed in each region; Regional Directorates may open areas for harvesting seaweed for up to 5 years at a time if it is likely that the resource and ecosystem can withstand the strain; Regional Directorates may make regulations regarding the tools that can be used for harvesting seaweed and regulate the use of machinery; Mechanical vehicles including trawlers used for seaweed harvesting must be registered in the Fisheries register of vessels for seaweed harvesting. An appointed committee, comprised of industry representatives, fishermen's associations and marine research institutes, oversee the industry." (Kelp Harvesting, The Scottish Parliament Information Centre, November 12, 2018, p.12)

"Norway has a well-established management regime for the sustainable exploitation of seaweed based on sound knowledge and cross-sectorial spatial plans. Seaweed harvesting and management is the responsibility of the seaweed processing industry, with one company for *Ascophyllum nodosum* and one company for *Laminaria hyperborea*, each with exclusive harvesting rights. *Asco* is harvested by vessels owned by the company and the annual permitted tonnage is set by the processing company. Access to the intertidal zones require negotiation and payment to private landowners but even within these privately-owned areas, national regulations apply. *L. hyperborea* is also harvested by vessel, some of which are

company owned and some of which are privately owned. All are registered fishing boats. Although the total catch level is set by the company, there is a requirement to submit a harvest plan to the Fisheries Directorate (FD) prior to harvesting. Logbooks showing catch composition, quantity and origin are inspected by the FD and a yearly report is submitted to the FD. Harvesting is undertaken in zones, which are rotated. Again, this rotation is managed by the company. Initially this was a 4-year rotation, but this has since increased to 5 years. Fishers harvest 10 to 15% of the available biomass each year. The Norwegian State research institute is directly involved in the scientific aspects of the Norwegian seaweed harvest. The evaluation of kelp stock is assessed by Institute of Marine Research (IMR), as is the monitoring of impacts of trawl activity (financed by the FD). Although the Norwegian seaweed harvesting model is often referred to in a positive light in much of the academic literature, it is not immune from regional conflicts between seaweed trawling industry and other coastal resource users such as fishermen and marine conservation groups." (taken from A Review of the Regulatory Regime for Seaweed Harvesting and Cultivation, Sustainable Inshore Fisheries Trust, September 2019, p. 17).

Mechanical harvesting of L. hyperborea occurs along 40% of the Norwegian coastline and is managed on a 3 to 5 year rotational basis, regenerating within 4 years post-harvesting (Steen, 2016, Gómez, 2021). Kelp is mechanically harvested commercially by boat at depths between 5- 20m depth, using a 3-meter-wide dredge with pointed prongs that when towed across the seabed, removes kelp plants from the substratum (Gómez, 2021, Steen, 2016). Following canopy removal, understory kelp plants flourish with the improved light conditions, ensuring a short regeneration time of the canopy which grows back at higher densities compared to control sites (Steen, 2016). Mechanical harvesting is sustainable as evidenced by the recovery of biomass between 2 and 6 years post-harvesting, depending on the location (Christie, 1998, Sjøtun, 2006, Steen, 2016).

6.3.1.3. France

"Approximately 60,000 tonnes of seaweed is harvested annually in France, the majority from wild stocks. The beach, foreshore and sea are controlled by the state and seaweed gathering is regulated at a regional and national scale. In Brittany, where most harvesting takes place, there is a special working commission on seaweed harvesting. Part of France's fishing legislation (Order n°2009-0329) covers the sustainable exploitation of seaweed at sea. Kelp harvested by boats requires a harvesting licence. The French Research Institute for the Exploitation of the Sea monitors the kelp harvest and advises administrations involved. *Laminaria digitata* is one of the most harvested species. Total landings are dictated by the processing industry in relation to their capacity to process fresh algae. The total amount of seaweed required by the industry is agreed and divided among boats. For *Laminaria hyperborea*, the total annual catch is fixed at a maximum level. There are fixed harvest areas, and each area is closed for 5 years following harvest." (Kelp Harvesting, The Scottish Parliament Information Centre, November 12, 2018, pp21-2).

"Since the mid-1980s, licensing and logbooks have been mandatory. Further restrictions on seasonality and quota were introduced shortly thereafter. Since then, management of seaweed resources has fallen to fishermen's organisations alongside other fisheries resources. The quota system has evolved further into individual quotas and with scientific input and

monitoring from the state marine research institute (IFREMER)." (A Review of the Regulatory Regime for Seaweed Harvesting and Cultivation, Sustainable Inshore Fisheries Trust, September 2019, p. 18).

Most French seaweed production comes from the Parc Naturel Marin d'Iroise (PNMI) which is a Marine Protected Area near Brittany. Here, human activities, including seaweed harvesting operate according to a set of defined criteria and permits the harvesting of seaweeds such as *A. nodosum*, *L. hyperborea* and *L. digitata*. *L. digitata* is mechanically harvested by boat with a gear called a "scoubidou". *L. hyperborea* is also mechanically harvested by boat using a large rake-like dredge device. *A. nodosum* is typically harvested by hand. From a biomass recovery perspective, mechanical harvesting seems to be sustainable as evidenced by the recovery of *Laminaria spp*. biomass post-harvesting to levels comparable to unharvested zones (Davoult, 2011; Leclerc, 2015).

6.3.1.4. Scotland

Hand removal of seaweed for any form of monetary or other reward from the Crown foreshore or seabed in Scotland requires a licence from Crown Estate Scotland. Removals from the seabed by hand, i.e., where no vehicle or vessel is used, for personal use do not require a marine licence. Larger scale proposals (> 90tonnes wet weight/year) for foreshore and near-shore harvesting of seaweed that is not subject to statutory licensing will be subject to the Crown Estates Harvest Licence Options process. This is a fuller application and requires detailed geographical coordinates, details of the species and proposed harvest volumes, provisional harvesting and monitoring strategies and a viable business plan. This secures the area for the grantee for a period of 3 years to enable stock assessments and associated sustainable harvesting and monitoring strategies to be developed. There are restrictions for the harvesting of wild kelp. The manager of a Scottish Crown Estate asset must not grant a right to remove wild kelp from the seabed if the removal of the kelp would inhibit the regrowth of individual plants and the kelp removed is intended for commercial use. Any commercial harvesting of wild seaweed from a vessel would require a licence from Marine Scotland. If using a mechanical harvesting method, an environmental assessment and report must be submitted alongside the application. Lastly, wild seaweed harvesting from privately owned foreshores is not subject to licensing.

6.3.1.5. Iceland

Wild seaweed has been harvested for the past 900 years in Iceland but harvesting for commercial purposes started in 1975. Thorverk is the largest wild seaweed harvesting company in Iceland. The company lands approximately 15-20,000 tonnes of rockweed (*Ascophyllum nodosum*) and 2-3,000 tonnes of kelp (*Laminaria digitata*) per year. In 2018, the regulation on Seaweed Harvesting for Commercial Purposes was adopted to improve the management of seaweed stocks and promote sustainable utilisation to ensure long-term maximum yields. The regulation stipulates that no party can harvest seaweed without a permit and harvesting companies must have permission from landowners to harvest seaweed that grows on their properties. The holdfast of seaweed must not be harmed while harvesting and harvesting areas should be rotated every four years. The Ministry of Fisheries is given responsibility to monitor harvested seaweed beds to control harvesting methods or limit harvesting activities. Under the Fisheries Management Act, the minister of fisheries can set,

in line with recommendations from the Marine & Freshwater Research Institute, allowable rates of exploitation (quotas) for individual species of seaweed to be harvested. Harvesting companies are required to log harvested quantities and submit reports to the Directorate of Fisheries. Based on reported volumes, a fee or resource tax is assessed and paid to the Icelandic government. The Directorate is responsible for uploading and publishing the data online which must be made available to the public. The national coastguard is tasked with monitoring harvesting activities and seaweed utilisation. The Directorate of Fisheries has been given the right to appoint fishing inspectors to carry out random inspections of equipment and facilities operated by the harvesting companies. Lastly, violation of the regulations can lead to a revoking of the harvester's permit and may lead to, in extreme cases, criminal prosecution.

6.3.1.6. United States of America

In America, states are given the responsibility to manage, regulate, licence or permit wild seaweed harvesting activities. There are three states that permit or licence commercial harvesting of wild seaweed resources. These are Maine, Alaska and California. Maine harvests the majority of wild seaweed in the US with *Ascophyllum nodosum* representing 95% of wild seaweeds harvested in the state (16,000-23,000 tons per year). Maine is also where a large portion of farmed seaweed is grown in America with up to 800 tons projected for 2021. California follows with the wild harvesting of kelp beds generating volumes of between 2,000-4,000 tons per year. Finally Alaska, despite its large uninhabited coastlines, comes in third with 38-78 tons of wild seaweed harvested, consisting mostly of bull kelp. The state however, hosts a number of seaweed farming operations which produce up to 400 tons per year.

6.3.1.7. State of Maine, USA

Over 95% of seaweed landings in the state consist of *Ascophyllum nodosum* valued at over $1.1 million. The coast of Maine is divided into 14 harvest management zones. A regulatory system is in place to permit and license the harvesting and selling of all wild seaweed along the coast of Maine. Specific laws protect sensitive areas with the commissioner of the Marine Resources allowed to identify areas that are closed to harvesting. In sensitive areas, harvesting can take place after a biomass assessment and harvesting plan are submitted for approval. Plans to include proposed biomass removal, harvesting methods used, description of how marine organisms harvested with the rockweed will be managed and a description of harvester training. The Fisheries Management Plan for Rockweed (*Ascophyllum nodosum*) compiled by the Maine Department of Marine Resources in January 2014 makes five recommendations for the sector: maintain 16" minimum cutting height, implement coast wide sector management principles, designate no harvest areas, implement harvester training, and conduct 5 year reviews of the resource, management practices and the regulatory structure. A seaweed-specific law, allows the Commissioner to adopt rules that limit the number of licences, designate seasons, limit the quantity that may be harvested in a season, establish areas that are open or closed to harvest, designate sectors, establish limitations on harvest by sector, allocate sectors, and regulate gear and techniques that may be used in harvesting.

6.3.1.8. State of California, USA

The Fish & Game Commission has designated 87 kelp areas along the coastline that may or may not be harvested according to one of four status indications: open, closed, lease only and leasable. Commercial harvesters must obtain a licence to harvest kelp or other seaweeds. Licence applications must specify the type of seaweed to be harvested: kelp, edible seaweed or agar algae. Kelp harvesting is limited to four feet below the surface of the water. A Commission-approved kelp harvest plan is required for kelp bed leaseholders and for the mechanical harvesting of kelp in all locations where harvesting is allowed. Harvesting of some edible seaweeds (bull kelp) is limited to 2 tons per year. Sustainable harvesting techniques are encouraged including the cutting of blades (fronds) only and rotating harvest areas to allow time for regrowth. The Commission has the right to close any area not being managed sustainably so it can be given time to regenerate. Monthly reports are due by the 10th of the following month even if nothing was harvested within the permitted area.

6.3.1.9. State of Washington, USA

All harvesting of wild seaweed for personal use requires a licence from the Department of Fish & Wildlife. For personal use, the following rules apply: only a knife, scissors or similar instrument may be used; bull kelp must be cut a minimum of 24" above the bulb and short stemmed kelps must be cut a minimum of 12" above the anchor point and the anchor point must be left in place at all times; 10 pounds wet weight per day per person is allowed; using rakes or forks to tear plants is prohibited; harvesters must use their own scale; and drying or partial drying prior to weighing is prohibited. It's illegal to harvest any seaweed if herring eggs are attached. This licence does not require a catch record card (required for fish species such as salmon) thus tracking seaweed harvests is left to on-the-ground enforcement and management staff from the Department of Fish & Wildlife. Currently, no commercial harvesting of naturally growing seaweed is permitted in Washington State.

6.3.1.10. State of Alaska, USA

Harvesting of wild seaweed in Alaska depends on location: whether in subsistence or non-subsistence areas. There are no seasonal restrictions or quantity limitations in subsistence areas which cover the majority of coastline areas in Alaska. In closed areas (special areas of conservation, marine reserves or near urban areas), a person may not harvest kelp that is alive and growing, even if the live kelp or seaweed is attached, free-floating, or washed up on the beach. Harvesting of wild seaweed for commercial sale is authorised under a Commissioner's permit. This type of permit is issued by each regional office and is evaluated on a case-by-case basis. Harvesting requirements for kelp include: (a) kelp shall be harvested in a manner that prevents dislodging of the entire plant from the bottom, and prevents straining or breaking the plant; (b) kelp may not be cut at a depth greater than one foot below the surface of the water, and only the upper portion of the plant may be retained; (c) The use of diving gear to harvest kelp is prohibited; and (d) The department shall close the harvest of kelp areas in which herring are spawning.

6.3.1.11. Canada

Canada has limited regulations surrounding the harvesting of various types of seaweed. Under

the Fisheries Act, the federal Department of Fisheries and Oceans Canada (DFO) is ultimately responsible for the regulation of seaweed harvesting. The DFO has jurisdiction below the low water mark and where regulations exist concerning the harvesting of seaweed populations in the intertidal zone. These existing regulations are listed under the Fisheries Act and referenced as the Atlantic Fishery Regulations. Under these regulations, four types of seaweed (dulse, Irish moss, horsetail or wire weed, and rockweed) are defined as marine plants. The regulations identify appropriate harvesting methods and gear but also prohibits, for example, the use of a basket drag rake to harvest marine plants. The regulations also identify districts where seaweed harvesting is restricted or prohibited. Although the federal government has the jurisdiction to regulate the harvesting of seaweed along the country's coastlines, the current regulations are limited in scope and are sometimes supplemented by provincial regulations in places such as British Columbia on the West coast and Nova Scotia on the maritime east coast.

As is the case in the rest of Canada, the seaweed harvesting industry in Nova Scotia is small in scale compared to other regions of the world. However, there has been a particular interest in regulating this industry because Nova Scotia is home to one of the world's leading seaweed harvesting companies, Acadian Seaplants Limited. It is a multinational company that employs over 350 people in 12 countries including Ireland, Scotland and the United States (in the state of Maine). In Canada, the company has been granted long term leases along the coasts of New Brunswick and Nova Scotia and operates four large seaweed processing plants in those two maritime provinces.

6.3.1.12. Province of Nova Scotia, Canada

Seaweed harvesting is controlled by the leasing of the foreshore and coastal areas by the provincial government. Individuals or companies may apply for a lease which can be granted for a period of up to 15 years. No person shall be allowed to harvest seaweed in leased areas unless they get a permit from the minister. Lease applications must include detailed management and commercialisation plans. The minister has the right to specify terms of the lease including areas to be harvested or periodically closed to harvesting, methods of harvesting, and fees or royalties due under the lease. General conditions for harvesting *Asco* include doing so in a manner that will not interfere with the regrowth of the seaweed or impact the sustainable yield of the area harvested; harvesting in a manner that pulls up no more than 15% of holdfasts by weight; cutting at least five inches above the holdfast to leave an upright shoot; and only using cutting methods approved by the minister. Individuals that harvest seaweed from leased areas must carry an identification card issued by the minister.

Any person may harvest seaweed in areas that are not closed and not leased. Leasees must keep records of seaweed harvested including date of harvest, type and quantities of seaweed harvested, and area harvested from with reports submitted monthly. A lessee shall pay an annual fee of $663.45 and a per tonne royalty fee of $2.45. If the amount of the royalty fee is greater than the annual lease fee, the annual fee is deducted from the total due.

6.3.1.13. Province of British Columbia, Canada

The Ministry of Forests, Lands and Natural Resource Operation, and Rural Development is responsible for the regulation and licensing of wild seaweed harvesting and growing of aquatic

plants in British Columbia. A commercial licence is required for the harvesting of quantities of over 100 kilogrammes. All harvesting must be done manually. Raking, dredging and diving methods of harvesting as well as methods that impairs regrowth or destroys the integrity of the bed are prohibited. If harvesting occurs on the foreshore, the substrate must not be disturbed or exposed. Care must be given to protect the holdfast. Licenses may be given for up to ten years in duration. Licence applications must include a fee of $110 Canadian Dollars and a harvest plan that includes a description of the distribution and quantity of plants harvested in a proposed area by species type, proposed methods and duration of harvesting, and an assessment of the potential impacts of harvesting on the overall ecosystem and the ability of the targeted seaweed to regrow. Records must be kept to document date and location of harvested seaweed, species harvested and wet weight of material. If the seaweed is distributed or sold, records must be kept on the amount, by species, who it is distributed or sold to, contact information about the receiver(s) and the amount of money received for the goods. Annual reports are to be submitted along with royalty payments based on the type of seaweed and quantity harvested. Seaweed processors are also licensed. Applications for processing must include food safety and sanitation plans. Records and monthly reports must include quantities of seaweed received and distributed by species and date as well as the amount of funds paid to harvesters and received from buyers. Processor licence fees are based on a flat fee of $210 Canadian Dollars for the processing of seaweed.

6.4. Future Reporting of Wild Seaweed Harvested in Ireland

Reporting of wild seaweed harvesting by independent harvesters and companies is an essential part of sustainably managing and regulating the seaweed industry. This is evidenced through the best practice examples internationally, yet, to date, there has been no formal process for monitoring seaweed harvesting activities or quantifying volumes harvested around the coast of Ireland. There have been many attempts to undertake this task in the past but these have been based on voluntary declarations by those involved in the processing industry, namely from the Ascophyllum Nodosum Processors Group (ANPG) which represents the five largest seaweed processing companies in Ireland. Although data from this project shows that *Asco* represents 98% by weight of all seaweeds harvested in Ireland, past estimates have not included other species.

Therefore, in terms of future reporting, which is crucial to the sustainable development of the sector, there are three reporting options for consideration by policy makers:

1. Status quo
2. Voluntary reporting
3. Mandatory reporting

6.4.1. Status Quo

Under this option, there would be no change in how quantities of seaweed would be measured, estimated and reported. The government would continue to rely on the industry to provide an overall estimate of volumes harvested with no delineation of what is coming or from where. There also would be no way of verifying amounts reported.

6.4.2. Voluntary Reporting

Voluntary reporting could take place at two levels: from harvesters and/or by processors.

One way of getting **harvesters** to report types and quantities of seaweed harvested is to encourage them to sign up to a charter of sustainability which would include voluntarily reporting of seaweed harvesting levels on an annual basis, i.e., what and how much is being harvested from where. One problem identified by this project is that there is no list of active harvesters in Ireland and it is therefore difficult to know for certain how many people are engaged in harvesting activities, let alone who they are, where they are located and who is harvesting what from where. Also, due to the fact that many of the part-time harvesters are relying on social welfare to make ends meet, many would be reluctant to report seaweed volumes due to a fear that their support payments would be reduced or curtailed. In addition, some harvesters may not want to specify harvesting locations due to the fact that so much of the rights to harvesting are murky and steeped in history, so that any declarations may result in the loss of their perceived rights to harvest in a particular location. And then there may be some that are simply harvesting in locations where they do not have any rights at all. All of these factors would limit the participation in voluntary reporting activities by harvesters.

Voluntary reporting could also take place at the **processor** level. For this study, the project team contacted all of the known processors to ascertain how much of their seaweed came from locations they could identify. This approach had limited success. Only 62% of the companies surveyed cooperated in providing the information sought. Although the information gathered by this project is in many ways better than what has been gathered in the past, it is still incomplete. To get more processors to voluntarily report harvesting quantities and locations, there needs to be an advantage to such cooperation. Some such benefits could include a bonus payment, free technical assistance, access to grants and/or promotional opportunities. It could also be one of the rules or conditions for signing up to the voluntary sustainable charter that could ease the industry into increased oversight and eventual regulation.

6.4.3. Mandatory Reporting

Considering what is happening internationally, and the importance of a data-based approach to managing wild Irish seaweeds, the best way to get verifiable and complete data is to make reporting a mandatory part of a registration, licensing or permitting process. Again this could take place on both the harvester level as well as for processors and in order to develop how this would work, best practice examples from the 10 other jurisdictions outlined in the previous section should be considered. Typically, this will require information on seaweed species, volumes collected and locations with the frequency of reporting varying from weekly

to annually. In many of the jurisdictions, processors are also licensed. In Canada, for example, processors must report, on a monthly basis, the quantities of seaweed purchased and seaweed products sold, not only in terms of quantities for specific species but also in value as well. By requiring reporting of seaweed quantities from both harvesters and processors, aggregated quantity figures can be compiled, compared and verified.

6.4.4. Remote Sensing

As a supplement to reporting, and a way to monitor harvesting activities, verify reporting figures and/or estimate standing stocks of various seaweed species, remote sensing technologies could be used to spatially map and quantify seaweed resources around the coast of Ireland. Remote sensing involves the observation of a target area by a device from a distance and covers a wide variety of technologies, platforms and sensors. Information can be obtained from satellites via multispectral sensors, from aircraft or drones via aerial imagery/LiDAR, and from ships using SONAR and underwater imagery via autonomous underwater vehicles, or drop down/towed cameras (Bennion et al., 2019, p.130). There are advantages and disadvantages or limitations with each technique used and results can be affected by weather, water turbidity, water depth and changing tides. For example, satellite imagery can provide snapshots of larger areas, but lack the granularity of aerial imagery. Luckily there is a lot of remote sensing already taking place with many of the recordings and maps made publicly available from organisations such as the US National Oceanic & Atmospheric Administration, the UK's National Network of Regional Coastal Monitoring Programmes, and AlgaeBase.

Bennion et al. contend that "baseline information of standing stocks is vital to the successful creation and implementation of any 'standard' or 'best practice' guide for wild harvesting, but kelp resources remain without baseline data at a time when threats to their global distribution are increasing. Moreover, the estimation of seaweed standing stocks via traditional methods is difficult, and often inaccurate with large margins of error (reportedly up to ±40% in some cases)" (Bennion, et al., 2019, p. 129). "Remote sensing technologies are rapidly evolving and these advances are routinely being applied to marine habitat monitoring, especially by unmanned aerial vehicles or drones. Furthermore, the availability of open-access (free) data from governmental and non-governmental agencies significantly reduces costs associated with data collection. Compared to traditional field surveys, remote sensing allows for the monitoring of a much greater geographic coverage. Methods can be standardised, and therefore, replicated, offering a more robust assessment which is significantly more reliable than comparatively patchy ground surveys" (Bennion et al., 2019, p. 130).

"Climate change, overfishing, invasive species and increased wild harvesting form a complex synergistic relationship which adversely impacts kelp habitats in the Northeast Atlantic. A rapid assessment technique is therefore required, to adequately and responsibly monitor, and inform the management of standing stocks. When choosing any given mapping technique, there is a trade-off between spatial coverage, resolution and labour intensity (either field or desk based). The answer to a standardized remote sensing technique to quantify kelp resources may therefore lie in a combination of multiple sensors. Until standardized monitoring procedures are available to industry regulators, kelps will remain without a baseline from which to accurately inform management and harvesting 'best practice'. The

rapid evolution of remote sensing technologies provides new and increasingly accurate ways to monitor kelp and other macroalgae" (Bennion et al., 2019, p.136).

The Marine Institute's INFOMAR team recently completed an Irish project that supported SME development of innovative commercial solutions to map intertidal seaweed distribution. It took advantage of modern technologies such as satellite earth observation, drone surveys, high resolution multi and hyperspectral cameras in combination with advanced machine learning and data analysis powered by cloud computing. The research was co-funded by Enterprise Ireland and Marine Institute (European Maritime Fisheries Fund).

Therefore, when considering any future framework for seaweed management in Ireland, the use of remote sensors and publicly available information should underpin the approach as this data can be used to create a consistent baseline for ongoing monitoring. The following remote sensing decision tree (Bennion et. al., 2019, p 134) provides a useful guide to aid in the selection of appropriate remote sensing techniques for mapping submerged and intertidal macroalgae knowing that the best results may involve using a combination of both acoustic and optical methods because acoustic sensors are ineffective in waters less than 2m in depth.

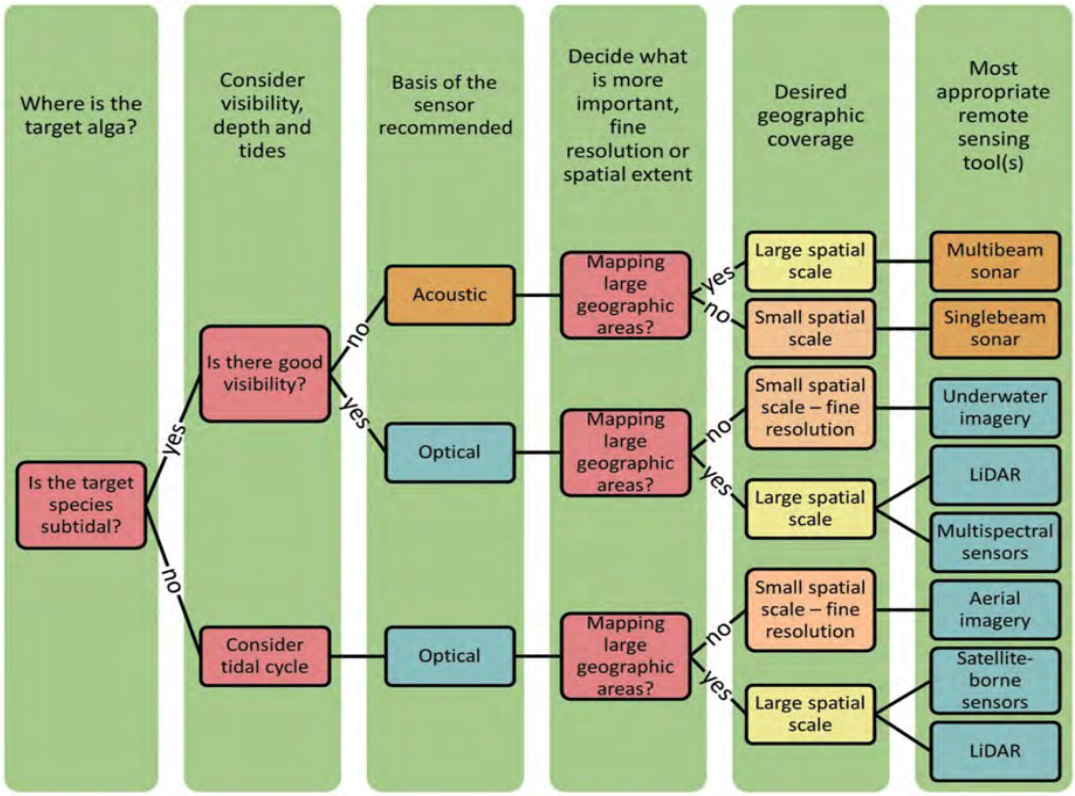


Figure 6.1: *'Remote sensing of macroalgae decision tree' provided to aid the selection of appropriate remote sensing tools for mapping submerged and intertidal macroalgae. The detection of submerged algae will likely be best achieved using a combination of acoustic and optical techniques as acoustic sensors are ineffective in water <2 m (Bennion et. al., 2019).*

6.5. Revised Methodology for Measuring Wild Seaweed Biomass Quantities

The data collection methodology developed for this project was based on surveying of seaweed processors to collect both quantitative data as well as qualitative information about seaweed harvesting and the socio-economic characteristics of the seaweed industry. Most surveys were conducted over Zoom to allow for interaction between project team members and representatives from the participating businesses. This allowed survey respondents to identify harvesting areas from which seaweed was gathered and helped inform the spatial mapping of seaweed harvesting outlined in Section 3.

The surveys collected the following quantitative data:

- quantities, by seaweed type and broad location of where it was harvested from
- number of employees dedicated to seaweed activities
- business turnover

In addition, the following qualitative data were gathered:

- business contact details for the directory of seaweed businesses
- nature and description of the businesses
- methods of seaweed harvesting (where applicable)
- specifications regarding harvested seaweed used/accepted
- sustainable harvesting practices
- use of cultivated or farmed seaweed as opposed to harvested wild seaweed
- pre-treatment steps by harvesters prior to sale to processors
- seasonal impacts to the business
- processing steps employed to create seaweed based products
- waste generation and management from seaweed processing
- types of products made from seaweed
- markets for seaweed products: wholesale/retail and export/national
- marketing & sales of seaweed based products
- barriers to business and seaweed industry growth
- research & development related to seaweed processing and product & business development
- types of business supports desired by seaweed processors

Through combining the collated process or responses with the select group of harvesters that participated, a comprehensive snapshot of the Irish seaweed industry was extrapolated along with sectoral input on both the challenges and opportunities for the industry.

In order to build on this, so that consistent and comparable information is gathered regularly, repeating this approach with the businesses included in the processor directory should be considered. Interactive surveying through online meetings is now commonplace and is much more effective than written surveys which are not as effective in encouraging participation or in gathering nuanced or more detailed information. Should this approach be considered, the survey questions applied here should be reviewed and fine-tuned to elicit the exact information desired.

Regarding the accuracy of the quantitative information, due to the voluntary nature of the process applied, a more complete picture of harvesting activities would be to require reporting by all harvesters and processors. As discussed in the international context section previously, almost all other jurisdictions require reporting of seaweed harvesting with some mandating reports from processors as well. Based on best practices from other countries, harvesters would be required to keep daily logs of harvesting activities specifying the location and method of harvesting, species harvested and quantities taken in wet tonnes or kilogrammes per species. These daily logs can then be compiled into weekly or monthly reports and submitted to the regulatory authority. In addition, monthly reports can be

submitted from processors that specify the location, types and quantities of seaweed accepted from harvesters including contact information. Through such an approach, harvesting reports can be cross-checked with reports from processors and quantities can then be verified. These data in turn will help inform the development and protection of the sector based on the associated research that also needs to take place.

7. Discussion and Conclusions

7.1. Irish Seaweed Harvesting Sector

It is estimated that there are currently in excess of 270 harvesters that are consistently involved in harvesting wild seaweed nationally. Though there are many others that forage for personal use, or for local small scale commercial activities, these individuals do not contribute significantly to the tonnages collected.

The profile of harvesters is mainly male, over 50, with those involved largely doing it to supplement household income (rather than it being a full-time commitment). Just under 35,000 tonnes are being collected annually with *Ascophyllum nodosum* accounting for 98% of this by weight. The majority of the volume harvested is occurring in the north and west with smaller volumes of a wider variety of seaweeds being collected in southern counties. Based on reported average costs per tonne, the value to those harvesting seaweeds is at least €2.7 million annually with the prices paid per wet tonne equivalent varying from €60 - €1,500. On an aggregate basis, the value of *Asco* to harvesters is about €2 million annually (or about 77% of the value for 98% of wild seaweed harvested by volume) while €700,000 was generated, 23% of harvester revenue, for all of the other wild seaweed species harvested within Ireland (2% of the volume of seaweed annually harvested).

With the traditional handed-down nature of seaweed harvesting (with hand harvesting the main method used), it has been noted that the Irish harvesting industry already has in place many of the internationally recognised sustainable management practices that ensure the conservation of seaweed resources. However, with a dwindling number of experienced harvesters (due to age profile), the lack of tacit knowledge of new entrants (traditional techniques and information not being passed to the next generation) and an increased demand (leading to using less experienced harvesters from outside areas), there is a legitimate concern that the resource could become mis-managed quite quickly. Sustainability needs to be achieved through appropriate licensing regimes and associated licensing conditions by regulatory authorities under the Foreshore Act 1933, the Maritime Area Planning Act 2021 and by new Maritime Area Regulatory Authority.

Currently, no standards or register of seaweed harvesters exists in Ireland. This is complicated by the unresolved issue of managing different rights, and the nature of harvesting in rural Ireland, though it is an area that needs to be addressed urgently for the sustainability of the resource, as well as the sustainability of the indigenous Irish harvester industry. While some degree of regulation is essential, it must respect the legal rights of hand harvesters and ensure that no one company monopolise the resource in Ireland. Ultimately, the mechanism by which any regulation is applied must protect seaweed resources and be equitable to those with existing appurtenant or profit a prendre seaweed harvesting rights while at the same time recognising the importance of the seaweed processing industry in Ireland without which harvesters would not be able to sell harvested seaweed. Finally, a licensing system for seaweed harvesting needs to include processing companies to ensure that the industry has access to a guaranteed, sustainable supply of seaweed.

7.2. Irish Seaweed Processing Sector

Based on the available information, the number of businesses involved with processing seaweed into commercial products is between 40 (BIM, 2020) and 58 (this research). The 58 companies identified here were included in a sectoral directory, though only 36 responded to requests for information. Though the sector is primarily made up of SMEs (based on absolute employee numbers), with most employing less than 10 people, there are also a number of larger businesses. The 5 members of the Ascoplyllum Nodosum Processors Group (ANPG) represent the largest businesses sourcing and processing the majority of brown seaweeds harvested in Ireland and employ over 200 staff. There is also one company, which processes almost 70,000 tonnes of imported, calcified seaweed called "maerl" (which is a form of dead seaweed), from Iceland, employing 70. Based on the input from those respondents that participated during this study, it is estimated that there are 359 people, from young professionals to older adults, involved in the Irish seaweed processing sector, with many of these involved in multiple roles which include harvesting, processing and other related work such as R&D, the natural sciences, engineering, skilled trades, quality control, accounting, administration, marketing and sales.

A wide range of products are produced here in Ireland for agriculture, animal and human markets. The largest volumes, relating to *Ascophyllum nodosum*, are harvested in the north and west and are used primarily to produce intermediary ingredients for valorising within the state. Most are used to produce high value plant biostimulants for agricultural use with the by-products from this process being sold as low value animal feed or organic fertiliser. The southern region businesses tend to use smaller volumes of a wider variety of seaweeds for the production of higher value products for the human health food, cosmetics and beauty product markets.

The value of wet seaweed, which is related to both seaweed type and the final product, varies from less than €1 per kilo to in excess of €10 per kilo. While most of the Irish seaweed is already destined for higher value markets such as biostimulants, there is certainly potential in the further expansion and use of the current volumes for more value-added production.

The current value of the Irish seaweed industry (based on seaweed harvested in Ireland) is estimated at over €45 million, though, when including the one processor using large volumes of imported maerl (calcified seaweed) from Iceland, the annual revenue is estimated at between €80-90 million.

The use of cultivated seaweed is still, relative to the volume of wild harvested seaweed, very small (estimated at ~169 tonnes for 2022). While there is significant interest in exploring this area for growing a variety of seaweed species, including kelp, it is still under-resourced (in terms of research and direct support). It is also hindered by the lack of responsive licensing as well as with technical difficulties associated with the cultivation of seaweeds in exposed environments and limitations on species of interest to the current processing sector, such as *Ascophyllum nodosum,* which cannot be easily grown in an aquaculture setting due to life-cycle or demographic characteristics.

The seaweed processing industry appears to be a growing sector in Ireland and, with the benefits and different uses of various seaweed species being continually explored, it is

anticipated that the sector will continue to evolve in the coming years. It is likely that this change will see a shift away from predominantly agricultural based products towards ingredients for human use and, with this shify, it is likely that the provenance of seaweed supplies will come into greater focus. Seaweed has traditionally been sourced in Ireland from wild sources and with the growing importance of sustainable supply chains, transparency in this regard will become an important aspect of premium seaweed-based products.

Similar to the case of harvesters, processors of Irish sourced seaweed (other than those cultivating) are availing of a wild and public resource. Up to now, there has been no requirement for processors to apply an Irish quality standard to the seaweeds they accept or the seaweed based products they sell. However, most companies that produce extracts for animal feed or plant biostimulants already have quality and sustainability standards in place to comply with strict EU regulatory standards and requirements related to product quality. Therefore, to ensure that our local supplies are protected, that the true value of sustainably sourced Irish seaweeds are achieved, and that businesses and local Irish communities can benefit from this emerging market, it is imperative that consistent standards are introduced.

7.3. Barriers to the Expansion of the Seaweed Industry in Ireland

From information received from surveying of both individual harvesters and processing businesses in combination with research conducted by the project team, the following barriers to growth have been identified and categorised within four broad areas. These a detailed in Chapter 5, but are summarised below:

Institutions & Policy

By far the most frequently mentioned barriers were those related to the difficulties with the current regulatory system associated with licences for harvesting, reporting of harvested seaweed and the lack of Irish product quality standards and regulation (though companies producing seaweed extracts for animal feed or plant biostimulants are already adhering to EU regulatory standards and requirements in relation to product quality and organic certification). The lack of a formal national policy on sustainable seaweed harvesting is also frequently mentioned as an impediment to the development of the industry and causes significant delays in the prioritisation and assessment of license applications. These barriers have hindered investment in the sector due to the uncertainty that they create in terms of supply security and consequently the ability to expand markets. Additionally, the current disjointed nature of institutional support and regulation hampers development and oversight of the sector.

Materials & Technology

This group of barriers consists of concerns about the lack of reliable and consistent supply of seaweed due to the declining number of harvesters, seasonality, climate change and sustainable management of existing wild seaweed areas, including the lack of oversight and regulation of existing harvesting. It also includes barriers related to harvesting methods and

mechanical harvesting equipment as well as processing technology, from energy efficient drying to the extraction of various compounds or ingredients from cascading biorefinery systems. For the members of the ANPG, who have invested substantially in R&D, extraction technologies and facilities, the primary concern is having a guaranteed sustainable supply of seaweed to ensure further expansion, business development and job creation.

Economy & Growth

Barriers in this category include the economic viability of hand-harvesting of seaweed by individuals given the low prices paid for seaweed biomass; the ability to generate a profit, (especially for small or start-up businesses where processing or manufacturing costs are increasing lately due to higher energy costs); the difficulty in increasing seaweed supply from farmed sources, mainly related to the slow and onerous permitting process and finally, a lack of guaranteed supply of seaweed for companies due to the on-going licensing issues.

Knowledge & Networks

Barriers within this category included the lack of cooperative processing facilities or marketing organisations (for both individual harvesters and small processors) to reduce overhead and capital investment; the lack of a national seaweed forum for sharing information and R&D within the industry; a lack of knowledge regarding potential markets, other processors and prospective suppliers; and the lack of an industry or trade association for sharing expertise and providing training opportunities for continued professional development.

7.4. Potential Growth of the Irish Seaweed Industry

Ireland's marine industry had an estimated turnover of €5.8 billion in 2018, providing employment of c.32,000. Within this, seaweed harvesting and processing contributed about €37 million Euro (BIM, 2020), though this current research suggests that, with seaweed imports included, this figure could be closer to €90 million. Regardless, the technologies and business models of the circular bioeconomy have the potential to unlock transformation of Ireland's seaweed based economy into a highly innovative and diversified sector underpinned by new bio-based value chains. Key opportunities identified include nutrition, cosmetics, pharmaceutical, biomaterials, agri-biotech and high value feed applications and commercial application of seaweed based bioremediation as outlined in Section 5.2 above.

Exploiting these options has the potential to further increase the value of seaweed use by processors in Ireland. This will require a diversification in the use of current supplies (mainly *Asco*) but also by increasing the diversity of wild species harvested or targeted species grown (e.g., kelp). As shown by some of the main Irish processors, changing from the traditional markets (e.g. selling dried seaweed meal for animal feed or organic fertiliser) to the higher value emerging markets (e.g. biostimulants, dietary supplements, animal and human health products, medicine and cosmetics) can increase the revenue per kilo processed significantly. This in turn would positively impact the income received by our indigenous harvesters from a low base of €60-200/wet tonne to, potentially, €500-1,500/wet tonne. However, prices for harvested seaweed are inevitably linked to the markets that companies sell in. Therefore, in order to convert this potential into reality, a greater emphasis on high value uses and processing, and the markets targeted, would have a whole sector impact. This would positively

impact the revenue generated for processors but also, and more importantly, generate more income for those involved in the harvesting sector.

The introduction of a sustainability charter or standard would further increase the value of Irish seaweed biomass, whether harvested or cultivated, and further support the scaling of the sector into the new value chains identified in this report. In addition to these options, this study identified a need for more research on the composition of all Irish seaweeds, enabling comparison of seaweeds in a consistent manner. This is particularly relevant for those components which have high value for the areas of potential industry application outlined above, such as bioactive components. This is an essential issue to address to realise the potential of the Irish seaweed industry. However, it is also acknowledged that R&D has been undertaken on the composition of Irish seaweeds for a number of years, by universities in Ireland and abroad and also through internal R&D programmes of companies and processors located within Ireland for mostly *Ascophyllum nodosum* and *Laminaria* spp. The Irish companies working in this area, including those of ANPG, are world-leaders in biostimulant technologies and are involved in major national and international R&D collaborations with some of the world's leading seaweed scientists.

A key area that the industry must address in order to develop the industry is the stability of supply that companies who add value to the resource require. This challenge needs to be met while also addressing the concurrent threats posed by over-exploitation of seaweed and habitat degradation due to harvesting activities, invasive species and climate change. In terms of supply, there are three main options, each of which will require consideration and investment. These are:

- Diversify the use of current supply – this builds on our existing supply but targets a shift from lower value products towards a greater emphasis on existing and emerging high value opportunities.
- Increase the supply of wild harvested seaweeds (both *Asco* and other species) – this is an area of undoubted opportunity. However, given the potential negative impacts for the broader ecosystem, this needs a considered and well researched approach. Additionally, this needs to be carefully regulated and managed to ensure sustainability of seaweed harvesting, in line with Irish policy, EU regulations and our international commitments.
- Significant expansion of seaweed cultivation – given the low relative volumes currently produced here, and the positive impacts that cultivation provides both as a stand-alone venture, and in conjunction with aquaculture or renewable energies, this should be an area of extensive investment. However, as with the other options, expansion needs to be done in a considered manner that allows targeted growth and development of a more resilient and diversified sector, notwithstanding the technical challenges that may exist for seaweed aquaculture in Ireland.

In reality, a combination of these three will most likely be required. Supporting the scaling and diversification of the industry requires development in the key areas outlined in the policy recommendations in Section 5.4 and the following framework provides a proposed holistic approach to the sustainable development of the sector.

7.5. A Proposed Framework to Support the Development of a Sustainable Seaweed Industry in Ireland

Considering national and international research on the sustainability of wild seaweed (both in terms of the wider ecosystem and the viability of individual seaweed species as a source of useful materials), it is clear that the creation of best management practice guidelines for wild seaweed harvesting is complex and specific to both the locality and the individual seaweed species. In Ireland, any such locality based approach is further complicated given the issues surrounding shoreline ownership and rights related to wild seaweed harvesting and the fact that a "one size fits all" approach does not apply in relation to the different types of seaweeds harvested and utilised in Ireland.

Therefore, based on international best practice, and input from interviews with the sector, establishing an iterative framework for the oversight and regulation of wild seaweed harvesting appears to be the most appropriate way to ensure sustainability of the resource now and in future years.

Such a framework should include, as a minimum, the following five essential elements:

1. A formal national sustainable seaweed harvesting policy

2. Establishment of geographically defined no-harvest seaweed zones around Ireland for scientific monitoring (both within and outside MPAs)

3. Creation of a transparent and responsive registration, licensing, reporting and regulation system

4. Development of an independent dedicated seaweed research centre

5. Fast tracking the development of a seaweed farming industry

6. Coordination of business supports

It is important to note that this framework approach is predicated on it being developed by an overarching agency with a sole focus on the whole seaweed industry and its continued and sustainable growth. A key issue noted through stakeholder engagement is the fact that there are multiple public agencies partially involved with different aspects of the seaweed industry with no single entity responsible for managing, monitoring, regulating and facilitating the growth of this sector, or associated industry. Some of those involved in this currently fragmented approach include: BIM (seaweed farming), the Department of Housing and Local Government (shoreline licences, OSPAR), the Department of Agriculture, Food and Marine (food regulation and aquaculture licences), the Marine Institute (research, policy) and National Parks and Wildlife Service (mapping, biodiversity). Additionally, there are a slew of

other organisations supporting research and business development activities in this area. Yet no one entity is overseeing, regulating and coordinating the different aspects of work that is being and has been done. If the wider sector is to be developed and reach its full potential, while importantly protecting the resource it is founded on, then one agency needs to be put in charge of seaweed nationally and given the authority to facilitate both the regulation and development of the industry. Appropriately skilled and sector-experienced staff are needed to lead in the areas of policy development, science-based regulation, complementary and targeted research and business growth and expansion. Considering the current estimated value of the indigenous sector (almost €50 million) and its projected expansion, then it is vital that such an agency be adequately resourced so it can be responsive to the challenges, and opportunities, facing the seaweed industry.

The following sections discuss in more detail the main elements of the proposed framework approach. It is important to note that these are not listed chronologically as they are all interlinked and dependent on each other.

7.5.1. Establish geographically defined no-harvest seaweed zones

The establishment of geographically defined no-harvest seaweed zones or reserves around the coast of Ireland, either stand-alone or within defined targeted areas (e.g. SACs, SPAs or MPAs), are essential to protect whole ecosystems and provide a baseline for what healthy ecosystems encompass. These should be in both tidal and subtidal areas and would serve various functions. Firstly, these would preserve a variety of different healthy marine ecosystems and the biodiversity they contain. Fishing, shellfish gathering and wild seaweed harvesting would be prohibited in these areas to allow fully functioning ecosystems to thrive. In terms of seaweed, these areas should be viewed as essential seed banks that preserve the genetic diversity unique to Ireland. These areas would help the preservation of seed stock that may be needed to regenerate other areas or to provide seed stock for aquaculture and seaweed farming operations. Secondly, these areas would provide a baseline for what healthy ecosystems look like and would be used to scientifically assess or evaluate various types and levels of resource use (seaweed harvesting) and help in determining what sustainability looks like in the context of a healthy marine environment.

Additionally, these no-harvest zones should be considered in the wider context of Ireland's need to develop more Marine Protected Areas (MPAs). Currently only 2.1% of Ireland's maritime area is protected and this is well short of the international targets that Ireland has signed up to. As part of the UN SDGs, Ireland has committed to protecting 10% of its total marine area. A similar target arises in the OSPAR Convention where 30% of each marine habitat will be protected by 2030. This is reflected in the EU Biodiversity Strategy 2030, which also argues for strict protection for 10% of the EU seas, focused on areas of 'very high biodiversity value or potential'. In 2020, the Marine Protected Area Advisory Group completed a report for DHLGH which included a series of recommendations supporting the creation of MPAs Irish coastal waters and seas. It noted that "Ireland's MPA coverage should not be increased solely to reach a specified target of 10 or 30% (via large, blanket designations) but expansion should be strategically targeted to meet requirements for Good Environmental

Status (GES) under the EU Marine Strategy Framework Directive (MSFD) and protect those species and habitats that are not currently sufficiently protected and are at risk. Designations should be based on scientific knowledge, with appropriate and proportionate coverage and appropriate objectives and management such that the network is coherent, connected, representative and resilient." Following public consultation on the recommendation, the Government is currently preparing new legislation for MPAs in Irish waters. This will present an opportunity to consider the related needs of seaweed management.

As part of this process, the designation of 'harvest management zones' should also be considered. As noted in Section 6, many jurisdictions use these to regulate the management of different seaweeds in different areas. This reflects the fact that different species, and even different genetic strains of the same species, can be found in different areas. Additionally, as the re-growth cycle of seaweed is so dependent on a variety of factors, these zones allow changes in seaweed harvesting practices to be initiated based on local needs rather than broad sweeping changes. In Ireland, when it comes to coastal areas, there have been no clear demarcations (other than local authority areas) that adequately reflect the marine seaweed landscape in this regard. Consequently, as part of the ongoing mapping of the national seaweed resource, and supported by detailed research, such zones should be designated. Ideally these would be linked to the no-harvest zones as these can be used as a reference point for the harvested areas.

An ideal mechanism for this may be through the use of "Designated Maritime Area Plans" (DMAPs), which were legislated for in the recently published Maritime Area Planning Act (2021). DMAPs are geographically defined maritime areas that are designated for particular maritime usages. All applications for Maritime Area Consents (MACs - the equivalent of current foreshore leases) will be linked to these DMAPs. Seaweed harvesting management zones could be developed using the DMAP process and this could then be used as reference for the regulation of seaweed harvesting (MACs). It is noted that under the current licensing process for seaweed harvesting, "no harvest" sites are typically included in foreshore licenses to allow for scientific evaluation and comparison between harvested areas and non-harvested areas. For example, no harvest sites are included in BioAtlantis Aquamarine Ltd.'s license to mechanically harvest kelp *(L. digitata* and *L. hyperborea)* in Bantry Bay to allow for scientific monitoring of kelp regeneration rates and flora and fauna 3 and 5 years post-harvesting (BioAtlantis Aquamarine Ltd, 2014). The practice of including harvest and non-harvest sites should continue in future licensing regimes.

It should be noted that there may be challenges when designating no harvest zones around the coast of Ireland. In particular, existing legal rights to harvest seaweed (e.g. appurtenant rights, profit à prendre rights) may preclude establishing no harvest zones in such areas. However, under the current licensing process for seaweed harvesting, "no harvest" sites are typically included in new foreshore licenses to allow for scientific evaluation and comparison between harvested areas and non-harvested areas. This practice of including harvest and non-harvest sites should continue in future licensing regimes.

7.5.2. Create a Registration, Licensing and Reporting System

As commercial interest in seaweed harvesting grows in Ireland, it will be essential that the industry is regulated to ensure its ongoing viability which is linked to the sustainability of the seaweed resource. This cannot be left as an altruistic responsibility of either individuals or companies operating within the industry as none of these, regardless of intentions, can or will look at it from a macro perspective, in a geographical sense or from an ecosystem perspective. Based on previous experiences, for example the overharvesting of periwinkles, there is a potential for a "tragedy of the commons" outcome that no one wants and could, in the end, destroy or undermine the industry that supports so many jobs, businesses and communities. Therefore, it is essential that one national entity or agency is given the responsibility to oversee the totality of the 'seaweed sector' to ensure it is sustainably managed for future generations.

Currently there are many public stakeholders involved in this area and a dedicated seaweed agency, which would need to be given the authority and support, needs to assess, through targeted, species specific research, the cumulative effects of activities in relation to the use of this public resource which is ultimately owned by the Irish State. It is important to note that this does not relate to the small-scale local harvesting of wild seaweed resources for personal or artisanal use - a crucial part of our national heritage. Rather, this refers to the large-scale, systematic gathering of wild seaweed resources for commercial purposes, whether this is done by individual harvesters, employees of commercial enterprises or by a network of independent harvesters that supply medium and large-scale seaweed processors.

In Ireland, seaweed harvesting is currently regulated by government departments and licensed under the Foreshore Act 1933 (as amended) though with the introduction of the Maritime Area Planning Act 2021, seaweed harvesting will be regulated and administered in future by the Maritime Area Regulatory Authority (MARA). However, it has been suggested that, as MARA may initially be heavily focused on renewable energy projects (e.g., off shore wind), the regulation and coordinated approach that is required for the seaweed industry may be of secondary importance. If this is to be the case, then a dedicated and resourced section within MARA should be established and given the authority to regulate the harvesting industry, enforce regulations and coordinate with other national stakeholders on areas such as R&D, seaweed monitoring, establishing no-harvest zones and sectoral development supports. Regardless of which agency is given responsibility for the management and oversight of seaweed harvesting, a formal government policy on sustainable seaweed harvesting should be prioritised and is critical for the further development of the industry.

While the importance of a dedicated seaweed focused agency cannot be overstated, based on considerations of international best practice and input from the sector, the following should be considered as part of an integrated regulatory framework for Ireland:

a. Start by phasing in a **voluntary** integrated system of registering wild seaweed harvesting and processing activities. Through this system, a harvester would include the type of seaweed harvested, dates of harvesting, general location and quantities. Processors would be required to report on types and volumes processed and would agree to use harvesters registered to the scheme. While

this research has provided a first pass at mapping the current harvesting and use of seaweeds in Ireland, a formalised and regular data collection process would lead to more detailed spatial mapping of wild seaweed harvesting activities - crucial information for our understanding and ongoing monitoring of the resource. It is envisaged that such a scheme could lead to a beneficial branding of Irish seaweeds (e.g. Sustainable Irish Seaweed) which in turn would lead to market advantage when promoting products in an age where supply chain requirements are continually shifting towards sustainable supply.

b. Establish thresholds for registration and licensing based on type of seaweed harvested/processed and the quantity of seaweed taken on an annual basis from specific areas, for example:
    - Small quantities for personal or artisanal use could be **exempt,** below a certain threshold.
    - A maximum threshold could be established for individual independent harvesters for registration and reporting of seaweed harvesting activities. For example, individuals that harvest up to a certain quantity of seaweed would be required to **register** and report their seaweed harvesting activities.
    - A minimum threshold could then be established for licensing harvesters, a network of harvesters or employees of commercial enterprises. This **licence** would be required when harvesting over a defined amount of seaweed per year. As part of this, those involved would be required to report on the quantities, types and location of seaweed harvested.
    - A minimum threshold would also apply to processors using over a specified amount. As part of this same integrated system, processors would be required to report periodically on quantities processed, species used and sources. This would be important information to support the development of the industry and ensure a consistent and guaranteed supply is available - a crucial barrier noted during this work.

c. Phase in a mandatory **registration** system over a 3-5 year period. As one of the only regions in this part of the world where no registration or reporting of seaweed harvesting/use is in operation, it is clear that some form of registration/licensing system is required. Such a system, and the process underpinning it, would allow regulators an opportunity to map seaweed harvesting activities and to assess cumulative impacts in specific areas. Eventually no wild seaweed harvesting activities by individual independent harvesters would be allowed unless they register their rights or permission to harvest in a specific location - this would specify the type of seaweed to be harvested and declare proposed quantities of wild seaweed to be harvested on an annual basis. Renewal of registration rights would be based on harvesters submitting monthly and/or annual reports detailing actual seaweed

harvesting activities during a calendar year including dates of harvesting, types of wild seaweed harvested, location of harvesting and quantities harvested. Similarly, processors would be required to register and, as part of this, agree that they would only use seaweed provided by registered harvesters and that species specific standards are met. This registration process needs to be simple, quick and accessible.

d. Phase in a **licensing** system for small, medium and large scale commercial wild seaweed harvesting activities within the next 3-5 years. In Scotland, the licensing process begins with initial scoping and an assessment of the proposed areas to be harvested. This includes an inventory of biomass by type of seaweed and the biodiversity it supports. After that, harvesting plans should be submitted for approval that identify the area to be harvested, the type(s) of seaweed to be harvested, the method and frequency of harvesting, the proportion of seaweed to be harvested within the targeted area, the height of cutting (how much of the plant is harvested), mitigation measures to ensure regrowth of the seaweed harvested, and a monitoring programme to assess the ecological regeneration of the harvested areas. While registration of individuals would be renewed on an annual basis, licenses could initially be granted for an initial period of 3-5 years and then, subject to certain conditions, renewed for periods of 10 years or more. The renewal of these licences would be predicated on licensees demonstrating sustainable management of the areas under licence. However, for such a system to be effective, regulators must inspect areas and verify compliance using competent marine biologists and a rigorous, well-defined and transparent science-based methodology (linked to evidence from no-harvest zones). It will be crucial for the regulatory agency responsible for licensing to build trust and credibility within the industry by first introducing voluntary measures and then by phasing in regulatory requirements around registration and licensing that are supported by current scientific research.

e. Develop a qualified and **responsive regulatory system**. The agency in charge of this needs to be properly resourced with the appropriately skilled and sector-experienced staff. The registration and licensing system that is put in place needs to be transparent, equitable with easy to follow and well-defined requirements. Agency staff need to help facilitate compliance and assist applicants with both the registration and licensing processes. Licences will need to be approved or rejected within months, not years. Close collaboration between public and private interests can help the industry develop to its full potential resulting in increased job opportunities and local economic development, especially in rural coastal communities.

The creation of a registration, licensing and reporting system should be considered in the context of the wider reform of the marine management system in Ireland, the establishment of MARA and implementation of the MAP Act.

7.5.3. Develop & Support a Dedicated Independent Seaweed Research Centre

In many countries, such as France, Norway and Iceland, where the seaweed industry has evolved into a robust and sustainable industry, there have been three interconnected stakeholders involved: industry, regulators and academia. Industry does the work of harvesting and creating value-added products that are sold in the marketplace. Regulators oversee the industry and regulate both harvesting and processing activities in order to protect the publicly owned seaweed resources and the environment, ensure that the resource and industry are managed in a sustainable fashion, and allow room for industry growth and expansion to create jobs and stimulate rural economic development. Academia is also an essential element as it brings a scientific, data-based approach into both the regulatory framework and business development efforts and activities. Academia in this context can be defined as a university department or a stand-alone non-profit institute. Both are staffed with professional scientists with expertise in biology, marine ecosystems and engineering (chemical, mechanical, electrical, civil, genetics, etc.) and are funded to support research in a variety of areas needed to sustainably manage our seaweed resources.

In an Irish context, some of these research supported topics should include:

- Inventorying and mapping seaweed resources around Ireland, including the use of remote sensing technologies
- Defining what level of harvesting is sustainable within the context of the seaweed industry, specific species of seaweed and for ocean ecosystems
- Creating models for life cycle analyses and blue carbon accounting
- Developing and testing various seaweed harvesting methods and equipment
- Conducting seaweed regrowth and ecosystem regeneration trials
- Developing and/or trialling best practice methods for growing various types of seaweed from creating seed stock and hatcheries to growing methods and harvesting techniques
- Researching and developing new processing technologies especially clean cascading methods and biorefinery extractive technologies
- Researching and developing innovation strategies and new value-added products for seaweed in the nutraceutical, pharmaceutical, renewable energy and biochemical industries
- Initiating other research needed by regulators and the industry as it evolves

An essential element for consideration in this regard is the choice or development of an entity with this purpose in mind. For example, with its existing status and experience in this field, establishing a dedicated departments within third level institutes could be an excellent option. However, regardless of the research entity, the important thing is to create an ongoing funding mechanism to support the senior staff and research assistants required on a long-term basis. Given that the industry generates €80-€90 million in revenue annually (including Irish sourced and imported seaweed), it would not be unreasonable to establish an annual budget of €1-2 million per year and increase it as the industry grows. A side benefit of integrating this into an

existing research institute would be the opportunity to provide graduate and post-graduate students with targeted research topics and the experiential training needed to enter this growing industry. Models for conducting applied scientific research may involve collaboration between academia and industry, which is the norm in many Irish Government-funded and EU Horizon 2020 research programs.

In terms of funding, many of the international examples require a royalty to be paid when harvesting or processing seaweed. Due to the fact that seaweed is a public resource that is harvested in Irish waters, it does not seem like an unreasonable proposition to require a royalty be paid, especially if these funds are then reinvested for the betterment of the whole seaweed industry. As has been noted many times in the past, and outlined in this report (in particular in Section 5), there is significant potential to grow this industry in emerging high value markets. Should this occur, it is essential that it is done for the betterment of the whole sector including businesses that have invested in the development of new products and markets, the indigenous harvesters that are crucial for a sustainable harvesting industry and the local communities from which these resources are sourced.

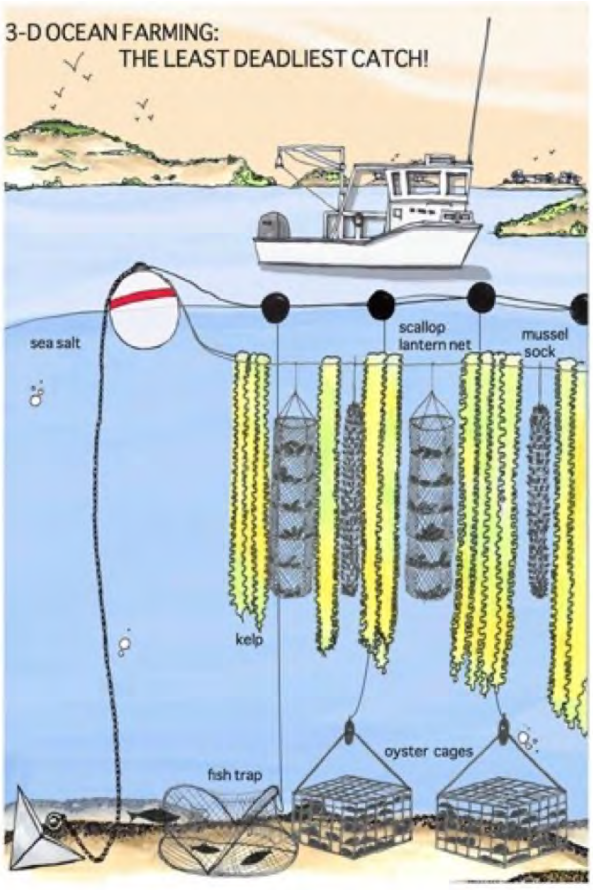
7.5.4. Encourage the Development of Seaweed Farming

An essential element in the future of sustainably managing wild seaweed harvesting activities, and to protect our wild seaweed resources and the ecosystems they support, is to encourage the diversification and development of a robust seaweed farming industry. Recognising the importance of the current *Asco* focused industry in Ireland (98% of the volume harvested yet 77% of the reported value to the industry), and the challenges associated with farming it, there are still significant opportunities for growing other species of seaweed. A direct benefit of this strategy is that it takes some pressure off certain wild resources and potentially over-exploited areas while still accommodating the growth of the industry by producing a guaranteed supply of a variety of targeted seaweed species to fuel industry expansion.

Some of the potential indirect benefits that have been linked with seaweed cultivation include the provision of habitats for fish, and the biodiversity they support around the Irish coastline, increasing the capacity to photosynthesise and fix carbon, establish a buffer system to protect shorelines from storm surges and rising sea levels, and expand the capability to transform potentially polluting nutrients from wastewater treatment, agricultural run-off and intensive aquaculture operations into useful food, feed, fuel, fertiliser and other value-added products.

It is in such integrated scenarios that seaweed aquaculture appears to provide significant opportunities. For example, GreenWave, an open source non-profit based in the US, is successfully growing kelp, on seeded lines, along with shellfish (oysters, clams, scallops and mussels) in an integrated multi-trophic aquaculture system in many areas of the East and West coasts of North America, and in other parts of the world (see https://www.greenwave.org).

Pictures of line grown kelp and oysters in the GreenWave IMTA system



A schematic of GreenWave's IMTA system which has been installed in dozens of locations along the east coast of America from the Long Island Sound off the coast of Connecticut to the coves and inlets off the coast of Maine.

This is certainly an area that merits further exploration as a complementary activity to the growing global aquaculture industry, which would lead to benefits for local coastal communities while developing Ireland's growing Blue Economy. Additionally growing seaweed in an aquaculture setting could prove an attractive alternative to traditional seaweed harvesting of *Asco* or the fishing industry, as fishermen already have the skills, marine experience and vessels required. This in turn would enhance the resilience of our local coastal communities as the seasonal nature of seaweed production could be used to complement existing fishing activities.

7.5.5. Establish & Coordinate Dedicated Business Supports

The last element of this framework involves the delivery of supports for Irish seaweed businesses in order to remove barriers to growth and encourage development of the industry. This in turn will stimulate job creation and create economic growth in coastal communities. Areas for consideration include:

- Development of third-level and postgraduate educational programmes and higher level degrees in the biosciences and the Blue Economy. This can support both research efforts in universities but also create a corps of well trained professionals for entry into this growing industry.
- Creation of a targeted grant fund and technical assistance programme to encourage private sector research and development of harvesting equipment, growing methods, processing technologies and new value-added products. Funding could also be used to pilot new equipment, methods, processing technologies and scaled-up biorefinery facilities.
- Development of sustainability standards for seaweed harvesting, cultivation and processing as well as for supply chain management and raw material traceability.
- Development and coordination of an effective branding and marketing campaign to help sell “Sustainable Irish Seaweed” products within export markets around the world to educate potential buyers and stimulate product demand.
- Creation of a targeted investment fund to help commercialise growing techniques, harvesting equipment and seaweed biorefinery processing technology.

8. Recommendations for Sustainably Managing Seaweed Industry Growth in Ireland

The Irish seaweed sector is one that is steeped in heritage and tradition. It currently encompasses many well established harvesters that apply handed-down sustainable practices, and processors that have been availing of this resource for decades. It also comprises an emerging new industry that aims to expand the range of products produced and invest in seaweed farming to target these markets.

Over the years, numerous reports and submissions have been made on developing and evolving different aspects of the sector, with well researched and considered recommendations. Thanks to the input of those currently involved in this sector, this report provides an update on the current status of Irish seaweed harvesting and processing, outlines best practice sustainability guidelines from international examples and explores the opportunities arising in emerging markets. The recommendations outlined here provide a series of actions that can, and need to, be taken to ensure the ongoing development of the sector while taking due care of the important seaweed resource it is based upon. However, it is important to note that many of these reiterate previous recommendations and, as such, will only be of use if put into action.

1. Develop a formal national **sustainable seaweed harvesting policy.** At present there is no formal national policy on seaweed harvesting, which is considered a barrier for development and growth of the seaweed industry in Ireland. A formal policy on sustainable harvesting would provide a national framework around which the sector could be further expanded. This national policy should be developed with input from industry and relevant national stakeholders within the context of international and European requirements and commitments.

2. Establish a **voluntary charter**. This would essentially be an agreed code of good management conduct for the sector (harvesters and processors) that would cover best practices for harvesting various species. It could also include a voluntary reporting aspect. This should be seen as a starting point for a more formal system to be developed in the coming years (see #5 below). It is important to note that many Irish harvesters are already harvesting sustainably so this should be viewed as a way of acknowledging the established traditions currently applied.

3. Appoint one **overarching body** to coordinate all national seaweed work (research, support, regulation, etc.). Currently, multiple different agencies and departments (e.g., DAFM, BIM, MI, DHLGH, Údarás na Gaeltachta) have oversight on different parts of this complex area. An empowered, resourced and dedicated national seaweed body, that has sight on all aspects of the industry, is needed to realise the potential of the industry. Importantly, this body would be charged with coordinating the protection of the resource,

which will ensure a sustainable supply to national processors while also caring for the wider marine ecosystem that so many rely upon.

4. Develop an ongoing and consistent **mapping and monitoring** method - this project and other work underway provides a starting point in this regard, but this needs to be built upon so that the level of accurate information is increased and improved. This mapping should consider developing 'harvest management zones' (through DMAPs) which would facilitate the cumulative assessment of the seaweed resource in different geographic areas, or areas where different seaweed varieties (species and/or genetic strains) exist. These could also be used to monitor and direct the sustainable extraction (permitting/licensing) of the resource around the coast.

5. Create geographically defined **no-harvest zones.** These could be stand alone areas or within MPAs, SACs or SPAs and are needed for a number of broader marine reasons and goals - to protect biodiversity and ensure resilient fish stocks as well as fulfil our SDG targets for MPAs. For seaweed, they will serve as a seed bank for the rich diversity of seaweed species in Irish coastal waters and can be used for replenishing over-exploited areas or as a seedstock for cultivation operations. These would also provide a baseline from which to monitor proximal harvested areas and need to be linked to the zones outlined in recommendation #3 above.

6. Introduce an **integrated regulatory system** for the registration, permitting and/or licensing of harvesters and processors. The purpose of such an integrated system would be to ensure that many of the high standards that already exist in Ireland are maintained and enshrined for new entrants. The regulatory system, managed through a dedicated national agency (e.g., MARA), would include reporting requirements for all and specific harvesting/use related requirements depending on species and sourcing. This would facilitate the ongoing monitoring of the sector.

7. Develop a series of **standards** to support the sector. These standards would form the basis for the harvesting, cultivation, processing, use and management of seaweed resources and could include: training for all those registered (e.g. FETAC Sustainable Seaweed Harvesting or Seaweed Cultivation training courses), best practice guidance for the harvesting, farming and management of different species (developed in conjunction with existing harvesters so that traditional expertise is maximised), product and production standards for processors so that Irish sourced and produced seaweed products can benefit from the ever growing green economy. These standards should be developed through the national agency, supported by international best practice, the experienced Irish processing and harvesting sector and continually updated as targeted research is conducted. These standards could also be linked with other existing standards for example, Origin Green (though food focused it could be explored as an option), Organic Trust, Marine Stewardship Council, etc.

8. Support a coordinated programme of **targeted research**. It is imperative that the development of the sector is evidence based - in terms of protecting the seaweed resources and marine ecosystems, the development of emerging and high value products and the expansion of our seaweed farming capacity. A dedicated research centre, that works in partnership with industry, regulators and other institutes and agencies, is essential to guide the trajectory of the sector while also ensuring its development is sustainable. Tied into academic institutions of higher learning, targeted research initiatives can help develop new skills and competencies for graduate students and create a career path into this growing industry.

9. Expand the **seaweed farming** industry. Seaweed farming, both on land and marine based, provides significant opportunities for individuals, communities and the wider marine sector (e.g., through availing of capacity within the fishing industry). This expanding industry needs to be stimulated through targeted research on different species so that emerging markets can be targeted. This approach would reduce pressure on wild resources, increase security and consistency of supply and also has potential as a complementary industry to aquaculture and renewable energy production that needs to be explored, e.g., integrated multi-trophic aquaculture on the site of off-shore wind energy production

10. Introduce a formal **funding mechanism** that supports the research and business support needs of the industry. The recommendations listed here need to be supported, both financially and with appropriately skilled professionals. Considering that this industry is currently worth €80-€90 million annually, with a future possibly focused on higher-value products, then a consistent annual funding of €1-2 million should be considered. Part of this funding could take the form of a royalty charge on the use (commercial harvesting or subsequent processing) of this public resource. The funds raised through this (linked to the regulatory system) would be reinvested into growing the industry. This in turn will create jobs, develop resilient Irish businesses and sustain local communities while providing a scientific, data-driven approach to the sustainable management of the resource.

11. Facilitate the development of a **seaweed trade association**. Such an association (as an example see the Irish BioEnergy Association) would facilitate networking, access to research and funding, training, branding, international product promotion (e.g., similar to Origin Green for Irish food) and professional development. The association would represent the different interest groups involved in the industry. While different sub-groups could be included (e.g., for harvesters, processors, seaweed cultivation) the function of the association would be to represent all the industry with a common voice. This would allow a collective interaction with regulators, policy makers, research organisations and funders.

References

ANPG, Submission on the draft Marine Planning Policy Statement by the *Ascophyllum nodosum* Processors Group (ANPG), 2019

ASC International. 2022. ASC-MSC Seaweed Standard. 2022. https://www.asc-aqua.org/what-we-do/our-standards/seaweed-standard/.

Baer, Julia, and Dagmar B. Stengel. 2010. Variability in Growth, Development and Reproduction of the Non-Native Seaweed *Sargassum Muticum (Phaeophyceae*) on the Irish West Coast. Estuarine, Coastal and Shelf Science 90 (4): 185–94. https://doi.org/10.1016/J.ECSS.2010.08.011.

Bak et al. Technical Challenges for Offshore Cultivation of Kelp Species: Lessons Learned and Future Directions. Bot. Mar. 2020, 63, 341–353.

BC Laws, November 7, 2016. Fish & Seafood Licencing Regulation, British Columbia Reg. 261/2016

Bennion, M., Fisher, J., Yesson, C., Brodie, J., 2019. Remote Sensing of Kelp (Laminariales, Ochrophyta): Monitoring Tools and Implications for Wild Harvesting, Matthew Bennion, Reviews in Fisheries Science & Aquaculture, Vol. 27, No. 2, pp. 127–141

Bernard, M., Tonk, L., 2019. Medicinal uses of seaweeds. Wageningen.

Bikker P., Stokvis L., van Krimpen M.M., van Wikselaar P.G, Cone J.W., 2020. Evaluation of seaweeds from marine waters in Northwestern Europe for application in animal nutrition. Animal Feed and Technology, 263, 114460

BIM, 2020. Scoping a seaweed biorefinery concept for Ireland, Carrigaline.

BioAtlantis Aquamarine Ltd, 2014. Foreshore Licence Application for Mechanical Harvesting of Seaweed in Bantry Bay, County Cork, Ireland. Reference Number: FS006061. 2014. Available online: https://www.gov.ie/en/foreshore-notice/e62b9-bioatlantis-ltd-bantry-bay/

Biris-Dorhoi, Elena Suzana, Delia Michiu, Carmen R. Pop, Ancuta M. Rotar, Maria Tofana, Oana L. Pop, Sonia A. Socaci, and Anca C. Farcas. 2020. Macroalgae—A Sustainable Source of Chemical Compounds with Biological Activities. *Nutrients* 12 (10): 1–23. https://doi.org/10.3390/nu12103085.

BMRS, 2015. SeaBioPlas – Seaweeds from sustainable aquaculture as feedstock for biodegradable bioplastics [WWW Document]. URL https://www.bmrs.ie/bmrs-projects/past/seabioplas (accessed 2.2.22).

BMRS, 2020. Methane Project [WWW Document]. URL https://www.bmrs.ie/bmrs-

projects/current/methane-project (accessed 2.2.22).

Breanna M.Roque, Joan K.Salwen, RobKinley, ErmiasKebreab, 2019. Inclusion of *Asparagopsis armata* in lactating dairy cows' diet reduces enteric methane emission by over 50 percent. Journal of Cleaner Production, 234, 132- 138

Buck, Bela H, Max F Troell, Gesche Krause, Dror L Angel, Britta Grote, and Thierry Chopin. 2018. State of the Art and Challenges for Offshore Integrated Multi-Trophic Aquaculture (IMTA). *Frontiers in Marine Science* 5: 165. https://doi.org/10.3389/fmars.2018.00165.

California Department of Fish & Wildlife, April 1, 2014. Informational Digest to the Regulations Governing the Harvest of Kelp and other Marine Algae in California.

Camarena Gómez, TM, and A Lähteenmäki-Uutela. 2021. European and National Regulations on Seaweed Cultivation and Harvesting. Helsinki.

Chopin, T., Ugarte, R., 2006. The Seaweed Resources of Eastern Canada

Christie, H., Fredriksen, E., Rinde, E. 1998. Regrowth of Kelp and Colonization of Epiphyte and Fauna Commuinty after Kelp Trawling at the Coast of Norway. Developments in Hydrobiology Book Series, DIHY, Volume 132

Cott, G., Beca-Carretero, P., Stengal, D. 2021. Blue Carbon and Marine Carbon Sequestration in Irish Waters and Coastal Habitats, Marine Institute

CSO. 2021. Ireland's Trade in Goods 2020. Cork.

Department of Housing, Planning and Local Government (DHLG), 2019, National Marine Planning Framework Consultation (Draft).

Department of Housing, Planning and Local Government (DHLG), 2020, Expanding Ireland's Marine Protected Area Network.

Department of the Taoiseach, 2018, National Policy Statement on the Bioeconomy, Project Ireland 2040

Davoult et al. (2011). Cahiers de Biologie Marine, 52(4), 429–434.

Doh, H., Dunno, K.D., Whiteside, W.S., 2020. Preparation of novel seaweed nanocomposite film from brown seaweeds *Laminaria japonica* and *Sargassum natans*. Food Hydrocoll. 105, 105744. https://doi.org/10.1016/J.FOODHYD.2020.105744

Elwany, et al. J. Waterw. Port Coast. Ocean Eng. 1996, 122, 34–37.

Elwany, et al. J. Waterw. Port Coast. Ocean Eng. 1995, 121, 143–150.

Enterprise Ireland. 2021. Petfood & Animal Nutrition. 2021. https://www.enterprise-ireland.com/en/Start-a-Business-in-Ireland/Food-Investment-from-Outside-Ireland/Key-Sectors/Petfood-and-Animal-Nutrition/ .

FAO. 2021. Seaweeds and Microalgae: An Overview for Unlocking Their Potential in Global Aquaculture Development. Rome.

Field et al., 1998. Primary Production of the Biosphere: Integrating Terrestrial and Oceanic Components. Science 1998, 281, 237–240

FSAI, 2020. Safety Considerations of Seaweed and Seaweed-derived Foods Available on the Irish Market. FSAI, Dublin.

Garcia-Vaquero, M., Rajauria, G., O'Doherty, J. and Sweeney, T. (2017). Polysaccharides from macroalgae: Recent advances, innovative technologies and challenges in extraction and purification. Food Research International, 99 (3): 1011-1020.

GENIALG. 2020. A Future for Seaweed Farming in Europe. 2020. https://genialgproject.eu/2020/08/28/a-future-of-seaweed-farming-in-europe/ .

Gómez et al., 2021. European & National Regulations on Seaweed Cultivation and Harvesting. (SUSCULT) Project Report.

Guiry, MD. 2012. A Catalogue of Irish Seaweeds. Ruggell: Gantner Verlag.

Guiry, MD. 2021. The Seaweed Site: Information on Marine Macroalgae. 2021. https://seaweed.ie/.

Hay 1979. Experimental Ecology with Particular Reference to Proposed Commercial Harvesting of Durvillaea (Phaeophyta, Durvilleales) in New Zealand. Bot. Mar. 1979, 22, 431–436

Hession, C., M.D. Guiry, S. McGarvey, and D. Joyce. 1998. Mapping and Assessment of the Seaweed Resources (*Ascophyllum nodosum*, *Laminaria spp.*) off the West Coast of Ireland. *Marine Resource Series*. Dublin. https://oar.marine.ie/handle/10793/202

IDA Ireland, 2022. Bio-Pharmaceuticals & Biotechnology Ireland, 2022. https://www.idaireland.com/doing-business-here/industry-sectors/bio-pharmaceuticals

Inmara Ltd., September 2019. A Review of the Regulatory Regime for Seaweed Harvesting and Cultivation: Contributing to SIFT's engagement with the Scottish Government Review of Seaweed Harvesting and Cultivation, Sustainable Inshore Fisheries Trust

Joint Committee on Environment, Culture, and the Gaeltacht. 2015. Developing the Seaweed Industry in Ireland. Dublin.

Joniver, C.F.H., Photiades, A., Moore, P.J., Winters, A.L., Woolmer, A., Adams, J.M.M., 2021. The global problem of nuisance macroalgal blooms and pathways to its use in the circular economy. Algal Res. 58, 102407. https://doi.org/10.1016/J.ALGAL.2021.102407

Jouanneau, D., Hanbidge, A., Cascella, K., Potin, P., 2021. Biorefinery Manual: Benefits and Sustainability of Seaweed Biorefinery. Roscoff. https://doi.org/10.5281/ZENODO.5046385

Kapetsky et al., J. A Global Assessment of Offshore Mariculture Potential from a Spatial Perspective; FAO Fisheries and Aquaculture Technical Paper No. 549; FAO: Rome, Italy, 2013; 181p.

Kelly, E. (ed.) 2005. The role of kelp in the marine environment. Irish Wildlife Manuals, No. 17. National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, Dublin, Ireland.

Kelly, L., Collier, L., Costello, M. J., Diver, M., McGarvey, S., Kraan, S., Morrissey, J. & Guiry, M. D. Impact Assessment of Hand and Mechanical Harvesting of Ascophyllum nodosum on Regeneration and Biodiversity", Marine Resource Series, Marine Institute 2001.

Kraan, Stefan, Jim Morrissey, Michael D Guiry, and Martin Ryan. 2001. A Guide to Commercially Important Seaweeds on the Irish Coast. Dublin.

Kraan, Stefan. 2017. *Undaria* Marching on; Late Arrival in the Republic of Ireland. *Journal of Applied Phycology* 29: 1107–14. https://doi.org/10.1007/s10811-016-0985-2.

Leclerc et al., (2015). Community, trophic structure and functioning in two contrasting Laminaria hyperborea forests. Estuarine, Coastal and Shelf Science, 152, 11-22.

Lordan, Ronan. 2021. Dietary Supplements and Nutraceuticals Market Growth during the Coronavirus Pandemic – Implications for Consumers and Regulatory Oversight. *Pharmanutrition* 18 (December): 100282. https://doi.org/10.1016/J.PHANU.2021.100282.

Lotze, Heike K, Inka Milewski, Julia Fast, Lauren Kay & Boris Worm, 2019. Ecosystem-Based Management of Seaweed Harvesting, Botanica Marina Journal 2019: 62nd edition, issue 5.

Maack, Á., The International Institute for Industrial Environmental Economics, September 2019. Wild Seaweed Harvesting: Ways to encourage sustainable exploitation and improve the regulatory framework on wild seaweed in Iceland.

Mac Monagail, Micheal, Lynn Cornish, Liam Morrison, Rita Araujo & Alan T. Critchley, 2017. Sustainable Harvesting of Wild Seaweed Resources, European Journal of

Phycology, 54th edition, issue 4.

Mac Monagail, M., Morrison, L., 2020. The seaweed resources of Ireland: a twenty-first century perspective. J. Appl. Phycol. 32, 1287–1300. https://doi.org/10.1007/s10811- 020-02067-7

Macken-Walsh, A., 2009. Barriers to Change: A sociological study of rural development in Ireland.

Maine Department of Marine Resources., January 2014. Fishery Management Plan for Rockweed (*Ascophyllum nodosum*).

Marine Institute, 2020. Lehanagh Pool Marine Research Site. 2020. https://www.marine.ie/Home/site-area/infrastructure-facilities/lehanagh-pool-marine-research-site?language=en .

Marine Protected Area Advisory Group (2020). Expanding Ireland's Marine Protected Area Network: A report by the Marine Protected Area Advisory Group. Report for the Department of Housing, Local Government and Heritage, Ireland.

https://www.gov.ie/en/publication/135a8-expanding-irelands-marine-protected-area-network/

Mesnildrey, et al., 2012. Seaweed industry in France. Report Interreg program NETALGAE.

Moreira, A.S.P., da Costa, E., Melo, T., Lopes, D., Pais, A.C.S., Santos, S.A.O., Pitarma, B., Mendes, M., Abreu, M.H., Collén, P.N., Domingues, P., Domingues, M.R., 2021. Polar lipids of commercial *Ulva* spp. Of different origins: Profiling and relevance for seaweed valorization. Foods 10, 914. https://doi.org/10.3390/FOODS10050914

Morris, et al.,. Kelp Beds as Coastal Protection: Wave Attenuation of Ecklonia Radiata in a Shallow Coastal Bay. Ann. Bot. 2020, 125, 235–246.

Morrissey K., O 'Donoghue C. and Hynes S., Quantifying the value of multi-sectoral marine commercial activity in Ireland, Marine Policy 35 (2011) 721-727.

Natural Resources Wales, 2019. Detailed Guidance for Seaweed Harvesting - Hand Gathering Natural Resources Wales, September 2019. Detailed Guidance for Seaweed Harvesting – Hand Gathering

Nelson, B., Cummins, S., Fay, L., Jeffrey, R., Kelly, S., Kingston, N., Lockhart, N., Marnell, F., Tierney, D. and Wyse Jackson, M. (2019) Checklists of protected and threatened species in Ireland. Irish Wildlife Manuals, No. 116. National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Ireland

Northwest Straits Commission, NOAA's National Marine Fisheries Service, Puget Sound Restoration Fund, Washington State Department of Natural Resources, and Marine Agronomics, May 2020. Puget Sound Kelp Conservation and Recovery Plan

NPWS (2019). The Status of EU Protected Habitats and Species in Ireland. Volume 1: Summary Overview. Unpublished National Parks and Wildlife Service (NPWS) report.

Olsthoorn, Simone E.M., Xi Wang, Berend Tillema, Tim Vanmierlo, Stefan Kraan, Pieter J.M. Leenen, and Monique T. Mulder. 2021. Brown Seaweed Food Supplementation: Effects on Allergy and Inflammation and Its Consequences. Nutrients 13 (8). https://doi.org/10.3390/NU13082613.

Power, Jim. 2020. Economic Value of Hair & Beauty Market in Ireland. Dublin

Rak, P., March 1, 2019. The Regulation of Seaweed Harvesting in Multiple Jurisdictions.

Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 Laying Down Rules on the Making Available on the Market of EU Fertilising Products and Amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and Repealing Regulation (EC) No 2003/2003.

Report of the Joint Oireachtas Committee on Environment, Culture and the Gaeltacht, 2015. Developing the Seaweed Industry in Ireland

Rock Weed Harvesting Regulations under Section 71 of the Fisheries and Coastal Resources Act, S.N.S. 1996, c. 25, O.I.C. 2001-240 (May 25, 2001, effective May 15, 2001), N.S. Reg. 55/2001 as amended to O.I.C. 2016-274 (November 1, 2016), N.S. Reg. 239/2016

Scottish Government (Marine Scotland & Marine Environmental Research), November 2016. Wild Seaweed Harvesting: Strategic Environmental Assessment Environmental Report.

Seitz, et al. Ecological Value of Coastal Habitats for Commercially and Ecologically Important Species. ICES J. Mar. Sci. 2014, 71, 648–665.

Shannon, E., Abu-Ghannam, N., 2019. Seaweeds as nutraceuticals for health and nutrition, Phycologia 58, 563–577. https://doi.org/10.1080/00318884.2019.1640533

Silva, C.O., Lemos, M.F.L., Gaspar, R., Gonçalves, C., Neto, J.M., 2021. The effects of the invasive seaweed *Asparagopsis armata* on native rock pool communities: Evidences from experimental exclusion. Ecol. Indic. 125, 107463. https://doi.org/https://doi.org/10.1016/j.ecolind.2021.107463

SINTEF, 2021. POLYKELP [WWW Document]. URL

https://www.sintef.no/en/projects/2021/polykelp-seaweed-as-feed-source-for- protein-rich-polychaetes-aimed-for-salmon-feed/ (accessed 2.2.22).

Sjøtun, K., Christie, H. and Fosså, J.H, 2006. The combined effect of canopy shading and sea urchin grazing on recruitment in kelp forest (Laminaria hyperborea). Marine Biology Research, 2(01): 24-32.

Soler-Vila, A., Coughlan, S., Guiry, M.D., Kraan, S., 2009. The red alga Porphyra dioica as a fish-feed ingredient for rainbow trout (Oncorhynchus mykiss): effects on growth, feed efficiency, and carcass composition. J. Appl. Phycol. 21, 617–624. https://doi.org/10.1007/S10811-009-9423-Z

Steen, 2016. Regrowth after Kelp Harvesting in Nord-Trøndelag, Norway. ICES J. Mar. Sci. J. Du Cons. 2016, 73, 2708–2720.

Tabassum, M.R., Xia, A., Murphy, J.D., 2016. Seasonal variation of chemical composition and biomethane production from the brown seaweed *Ascophyllum nodosum*. Bioresour. Technol. 216, 219–226. https://doi.org/10.1016/J.BIORTECH.2016.05.071

Tabassum, M.R., Xia, A., Murphy, J.D., 2017. Potential of seaweed as a feedstock for renewable gaseous fuel production in Ireland. Renew. Sustain. Energy Rev. 68, 136–146. https://doi.org/10.1016/J.RSER.2016.09.111

The Scottish Parliament Information Centre, November 12, 2018. Kelp Harvesting

Ummat, V., Garcia Vaquero, M., Tiwari, B., O'Donnell, C., 2019. The value of seaweed. TResearch 14, 28–29.

Walsh, M., Watson, L., 2012, A Market Analysis towards the Further Development of Seaweed Aquaculture in Ireland, BIM

Wan, Alex H.L., Robert J. Wilkes, Svenja Heesch, Ricardo Bermejo, Mark P. Johnson, and Liam Morrison. 2017. Assessment and Characterisation of Ireland's Green Tides (*Ulva* Species). *PLOS ONE* 12 (1): e0169049. https://doi.org/10.1371/JOURNAL.PONE.0169049

Watson, Lucy, and Matthew Dring. 2011. Business Plan for the Establishment of a Seaweed Hatchery and Grow-out Farm. Dublin; Belfast.

Wernberg, T., Krumhansl, K., Filbee-Dexter, K. and Pedersen, M.F., 2019. Status and trends for the world's kelp forests. In World seas: An environmental evaluation (pp. 57-78). Academic Press.

Werner, A., Kraan, S., 2004. Review of the Potential Mechanisation of Kelp Harvesting in Ireland, Marine Environment and Health. Galway.

White, W.L., Wilson, P., 2015. World seaweed utilization, in: Tiwari, B., Troy, D.J. (Eds.),

Seaweed Sustainability: Food and Non-Food Applications. Academic Press, San Diego/Waltham/Oxford, pp. 7–25. https://doi.org/10.1016/C2013-0-12836-X

Attachments

Appendix 1: Survey Forms

Appendix 2: Spatial Maps

Appendix 3: All Survey Results

Appendix 4: Seaweed composition references (Figure 5.1)

Seaweed species	References
Alaria esculenta	(Guiry 2021; Kraan *et al*. 2001; BIM 2020; Schiener *et al*. 2015)
Ascophyllum nodosum	(Guiry 2021; Kraan *et al*. 2001; Olsson, Toth, and Albers 2020)
Fucus serratus	(Catarino, Silva, and Cardoso 2018; Kraan *et al*. 2001; Olsson, Toth, and Albers 2020)
Fucus spiralis	(Catarino, Silva, and Cardoso 2018; Francisco *et al*. 2020)
Fucus vesiculosus	(Catarino, Silva, and Cardoso 2018; Kraan *et al*. 2001; Olsson, Toth, and Albers 2020)
Himanthalia elongata	(Kraan *et al*. 2001; Amorim-Carrilho, Lage-Yusty, and López-Hernández 2014; Martínez–Hernández *et al*. 2018; Fernández-Segovia *et al*. 2018)
Laminaria digitata	(Guiry 2021; Kraan *et al*. 2001; BIM 2020; Schiener *et al*. 2015; Olsson, Toth, and Albers 2020)
Laminaria hyperborea	(Kraan *et al*. 2001; Schiener *et al*. 2015)
Pelvetia canaliculata	(Kraan *et al*. 2001; Sousa *et al*. 2021)

Saccharina latissima	(Kraan *et al*. 2001; BIM 2020; Schiener *et al*. 2015; Olsson, Toth, and Albers 2020)
Saccorhiza polyschides	(Garcia, Palacios, and Roldán 2016; Belattmania *et al*. 2018; Zubia *et al*. 2009)
Sargassum muticum	(Balboa *et al*. 2016; Milledge, Nielsen, and Bailey 2015)
Undaria pinnatifida	(Chronakis and Madsen 2011; Fernández-Segovia *et al*. 2018; Arijón *et al*. 2021; Vallorani *et al*. 2004; Smith, Summers, and Wong 2010)
Asparagopsis armata	(Félix *et al*. 2021; Pereira *et al*. 2021)
Chondrus crispus	(Kraan *et al*. 2001; Olsson, Toth, and Albers 2020; Carpena *et al*. 2021; Tasende, Cid, and Fraga 2013)
Mastocarpus stellatus	(Carpena *et al*. 2021; Tasende, Cid, and Fraga 2013; Gómez-Ordóñez, Jiménez-Escrig, and Rupérez 2014)
Osmundea pinnatifida	(Silva and Pereira 2020; Campos *et al*. 2019)

Palmaria palmata	(Guiry 2021; Kraan *et al*. 2001)
Porphyra spp./*Wildemania amplissima*	(Kraan *et al*. 2001; Fernández-Segovia *et al*. 2018; Venkatraman and Mehta 2019; Schmid, Guihéneuf, and Stengel 2014; Stack *et al*. 2017; Varela-Álvarez *et al*. 2019; da Costa *et al*. 2018)
Ulva lactuca L.	(Guiry 2021; Kraan *et al*. 2001; Olsson, Toth, and Albers 2020; Dominguez and Loret 2019)

Amorim-Carrilho, K, MA Lage-Yusty, and J López-Hernández. 2014. Variation of Bioactive Compounds in Dried Seaweed *Himanthalia Elongata* Subjected to Different Culinary Processes. *CyTA - Journal of Food* 12 (4): 336–39. https://doi.org/10.1080/19476337.2013.877082.

Arijón, Marianela, Nora M.A. Ponce, Valeria Solana, Fernando G. Dellatorre, Ezequiel A. Latour, and Carlos A. Stortz. 2021. Monthly Fluctuations in the Content and Monosaccharide Composition of Fucoidan from *Undaria Pinnatifida* Sporophylls from Northern Patagonia. *Journal of Applied Phycology* 33 (4): 2433–41. https://doi.org/10.1007/s10811-021-02465-5.

Balboa, Elena M., Cristina Gallego-Fábrega, Andrés Moure, and Herminia Domínguez. 2016. Study of the Seasonal Variation on Proximate Composition of Oven-Dried *Sargassum Muticum* Biomass Collected in Vigo Ria, Spain. *Journal of Applied Phycology* 28 (3): 1943–53. https://doi.org/10.1007/s10811-015-0727-x.

Belattmania, Z, AH Engelen, H Pereira, EA Serrao, and L Custodio. 2018. Fatty Acid Composition and Nutraceutical Perspectives of Brown Seaweeds from the Atlantic Coast of Morocco. *International Food Research Journal* 25 (4): 1520–27.

BIM 2020. Scoping a Seaweed Biorefinery Project for Ireland. Carrigaline.

Campos, Ana M., Joana Matos, Cláudia Afonso, Romina Gomes, Narcisa M. Bandarra, and Carlos Cardoso. 2019. Azorean Macroalgae (*Petalonia Binghamiae*, *Halopteris Scoparia* and *Osmundea Pinnatifida*) Bioprospection: A Study of Fatty Acid Profiles

and Bioactivity. *International Journal of Food Science and Technology* 54 (3): 880–
90. https://doi.org/10.1111/IJFS.14010.

Carpena, Maria, Cristina Caleja, Eliana Pereira, Carla Pereira, Ana Ćirić, Marina Soković, Anton Soria-Lopez, 2021. Red Seaweeds as a Source of Nutrients and Bioactive Compounds: Optimization of the Extraction. *Chemosensors* 9 (132): 1–20. https://doi.org/10.3390/chemosensors9060132.

Catarino, Marcelo D., Artur M.S. Silva, and Susana M. Cardoso. 2018. Phycochemical Constituents and Biological Activities of *Fucus* Spp. *Marine Drugs* 16 (8): 249. https://doi.org/10.3390/MD16080249.

Chronakis, IS, and M Madsen. 2011. Algal Proteins. In *Handbook of Food Proteins*, edited by GO Philips and PA Williams, 353–94. Sawston: Woodhead Publishing. https://doi.org/10.1533/9780857093639.353.

Costa, Elisabete da, Vitor Azevedo, Tânia Melo, Andreia M. Rego, Dmitry V. Evtuguin, Pedro Domingues, Ricardo Calado, Rui Pereira, Maria H. Abreu, and Maria R. Domingues. 2018. High-Resolution Lipidomics of the Early Life Stages of the Red Seaweed *Porphyra Dioica*. *Molecules* 23 (1): 187. https://doi.org/10.3390/MOLECULES23010187.

Dominguez, Herminia, and Erwann P. Loret. 2019. *Ulva Lactuca*, A Source of Troubles and Potential Riches. *Marine Drugs* 17 (6): 357.
https://doi.org/10.3390/MD17060357.

Félix, Rafael, Pedro Dias, Carina Félix, Teresa Cerqueira, Paula B. Andrade, Patrícia Valentão, and Marco F.L. Lemos. 2021. The Biotechnological Potential of *Asparagopsis Armata*: What Is Known of Its Chemical Composition, Bioactivities and Current Market? *Algal Research* 60 (December): 102534. https://doi.org/10.1016/J.ALGAL.2021.102534.

Fernández-Segovia, Isabel, María Jesús Lerma-García, Ana Fuentes, and Jose M. Barat. 2018. Characterization of Spanish Powdered Seaweeds: Composition, Antioxidant Capacity and Technological Properties. *Food Research International* 111 (September): 212–19. https://doi.org/10.1016/J.FOODRES.2018.05.037.

Francisco, João, André Horta, Rui Pedrosa, Cláudia Afonso, Carlos Cardoso, Narcisa M. Bandarra, and Maria M. Gil. 2020. Bioaccessibility of Antioxidants and Fatty Acids from *Fucus Spiralis*. *Foods 2020, Vol. 9, Page 440* 9 (4): 440.

https://doi.org/10.3390/FOODS9040440.

Garcia, JS, V Palacios, and A Roldán. 2016. Nutritional Potential of Four Seaweed Species Collected in the Barbate Estuary (Gulf of Cadiz, Spain). *Journal of Nutrition & Food Sciences* 6 (3): 7. https://doi.org/10.4172/2155-9600.1000505.

Gómez-Ordóñez, Eva, Antonio Jiménez-Escrig, and Pilar Rupérez. 2014. Bioactivity of Sulfated Polysaccharides from the Edible Red Seaweed *Mastocarpus Stellatus*. *Bioactive Carbohydrates and Dietary Fibre* 3 (1): 29–40. https://doi.org/10.1016/J.BCDF.2014.01.002.

Guiry, Michael D. 2021. The Seaweed Site : Information on Marine Algae. 2021. https://www.seaweed.ie/

Kraan, Stefan, Jim Morrissey, Michael D Guiry, and Martin Ryan. 2001. A Guide to Commercially Important Seaweeds on the Irish Coast. Dublin.

Martínez–Hernández, Ginés B., Noelia Castillejo, María del M. Carrión–Monteagudo, Francisco Artés, and Francisco Artés-Hernández. 2018. Nutritional and Bioactive Compounds of Commercialized Algae Powders Used as Food Supplements. *Food Science and Technology International* 24 (2): 172–82. https://doi.org/10.1177/1082013217740000.

Milledge, John J., Birthe V. Nielsen, and David Bailey. 2015. High-Value Products from Macroalgae: The Potential Uses of the Invasive Brown Seaweed, Sargassum Muticum. *Reviews in Environmental Science and Bio/Technology* 15 (1): 67–88. https://doi.org/10.1007/S11157-015-9381-7.

Olsson, Joakim, Gunilla B. Toth, and Eva Albers. 2020. Biochemical Composition of Red, Green and Brown Seaweeds on the Swedish West Coast. *Journal of Applied Phycology* 32: 3305–17. https://doi.org/10.1007/s10811-020-02145-w.

Pereira, Antia G., Maria Fraga-Corral, Paula Garcia-Oliveira, Catarina Lourenço-Lopes, Maria Carpena, Miguel A. Prieto, and Jesus Simal-Gandara. 2021. The Use of Invasive Algae Species as a Source of Secondary Metabolites and Biological Activities: Spain as Case-Study. *Marine Drugs* 19 (4). https://doi.org/10.3390/MD19040178.

Schiener, Peter, Kenneth D. Black, Michele S. Stanley, and David H. Green. 2015. The Seasonal Variation in the Chemical Composition of the Kelp Species *Laminaria digitata*, *Laminaria hyperborea*, *Saccharina Latissima* and *Alaria Esculenta*. *Journal of Applied Phycology* 27 (1): 363–73. https://doi.org/10.1007/S10811-014-0327-1.

Schmid, Matthias, Freddy Guihéneuf, and Dagmar B. Stengel. 2014. Fatty Acid Contents and Profiles of 16 Macroalgae Collected from the Irish Coast at Two Seasons. *Journal of Applied Phycology* 26 (1): 451–63. https://doi.org/10.1007/S10811-013-0132-2.

Silva, Paulo, and Leonel Pereira. 2020. Concise Review of *Osmundea Pinnatifida (Hudson) Stackhouse*. *Journal of Applied Phycology* 32 (5): 2761–71. https://doi.org/10.1007/S10811-020-02183-4.

Smith, JL, G Summers, and R Wong. 2010. Nutrient and Heavy Metal Content of Edible Seaweeds in New Zealand. *New Zealand Journal of Crop and Horticultural Science* 38 (1): 19–28. https://doi.org/10.1080/01140671003619290.

Sousa, Gabriela, Marija Trifunovska, Madalena Antunes, Isabel Miranda, Margarida Moldão, Vítor Alves, Rajko Vidrih, 2021. Optimization of Ultrasound-Assisted Extraction of Bioactive Compounds from *Pelvetia Canaliculata* to Sunflower Oil. *Foods* 10 (8): 1732. https://doi.org/10.3390/FOODS10081732.

Southern Region Assembly (SRA), 2020, Regional Spatial & Economic Strategy (RSES), http://www.southernassembly.ie/regional-planning/rses

Stack, Julianne, Paul R Tobin, Anna Gietl, Pádraigín A Harnedy, Dagmar B Stengel, and Richard J FitzGerald. 2017. Seasonal Variation in Nitrogenous Components and Bioactivity of Protein Hydrolysates from *Porphyra Dioica*. *Journal of Applied Phycology* 29: 2439–50. https://doi.org/10.1007/s10811-017-1063-0.

Tasende, Manuel Garcia, Miguel Cid, and M. Isabel Fraga. 2013. Qualitative and Quantitative Analysis of Carrageenan Content in Gametophytes of *Mastocarpus Stellatus (Stackhouse) Guiry* along Galician Coast (NW Spain). *Journal of Applied Phycology* 25 (2): 587–96. https://doi.org/10.1007/S10811-012-9893-2.

Vallorani, Luciana, Nada Milanović, Vilberto Stocchi, and Nada Kolb. 2004. Evaluation of Marine Algae Wakame (*Undaria Pinnatifida*) and Kombu (*Laminaria digitata Japonica*) as Food Supplements. *Food Technology and Biotechnology* 42 (1): 57–61.

Varela-Álvarez, Elena, Paul R. Tobin, Freddy Guihéneuf, Richard J. FitzGerald, and Dagmar B. Stengel. 2019. Phycobiliproteins, Nitrogenous Compounds and Fatty Acid Contents in Field-Collected and Cultured Gametophytes of *Porphyra Dioica*, a Red Sea Vegetable. *Journal of Applied Phycology* 31 (6): 3849–60. https://doi.org/10.1007/s10811-019-01841-6.

Venkatraman, Kalkooru L., and Alka Mehta. 2019. Health Benefits and Pharmacological Effects of *Porphyra* Species. *Plant Foods for Human Nutrition* 74 (1): 10–17. https://doi.org/10.1007/S11130-018-0707-9.

Zubia, Mayalen, Marie Sophie Fabre, Véronique Kerjean, Klervi Le Lann, Valérie Stiger-Pouvreau, Marilyne Fauchon, and Eric Deslandes. 2009. Antioxidant and Antitumoural Activities of Some Phaeophyta from Brittany Coasts. *Food Chemistry* 116 (3): 693–701. https://doi.org/10.1016/J.FOODCHEM.2009.03.025.