The Socio-Economic Marine Research Unit (SEMRU)
National University of Ireland, Galway

Working Paper Series

Working Paper 14-WP-SEMRU-09

An economic analysis of the seaweed industry in Ireland

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Abstract

This paper examines the seaweed industry in Ireland from an economic perspective and as such categorises the strengths and weakness of the industry as well as the opportunities available and any threats to successful growth that may exist. The Irish industry is analysed within its global and European context and the value chain of the industry within Ireland is presented. The findings from this research emphasise the continued need for forward thinking by government in relation to the development of a sustainable and profitable industry, where it appears that in reality little has changed over the past decade. The potential economic contribution offered by the industry could be significant given the quality and abundance of the resource along Irish coastlines but the industry to date remains an underdeveloped sector with an essentially non-existent share of the global market.

Keywords: Economic analysis, seaweed, Ireland, Marine economy

This work was funded through the Beaufort Marine Research Award, which is carried out under the *Sea Change* Strategy and the Strategy for Science Technology and Innovation (2006-2013), with the support of the Marine Institute, funded under the Marine Research Sub-Programme of the National Development Plan 2007–2013.

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1. Introduction

Until recently, little research has been done on analysing the seaweed sector's contribution to the Irish marine or ocean economy, with little research having been conducted on the true economic value of the seaweed industry in Ireland. In order for the government to efficiently, effectively and sustainably utilise the marine resources available, as well as to create economic gains from the sector as a whole it is necessary to have a thorough understanding of the individual components that compose the industry. This paper attempts to map the supply or value chain of the seaweed industry as a whole in Ireland in an effort to fill this research gap.

This research is carried out within the value stream management framework, whereby the processes involved in delivering end products are examined so as to determine specific value-adding activities and in turn identify such changes as can be implemented in order to maximise industry yield. This framework builds upon the traditional supply or value chain framework and has been adjusted accordingly so as to provide economic insights that can in turn be used to form the basis of policy recommendations.

A value chain is a chain of activities that a firm operating in a specific industry performs in order to deliver a product or service for the market that provides the consumer with some form of value and as such links the activities that a firm performs to their competitive position. The concept comes from business management and was first described and popularised by Michael Porter in "*Competitive Advantage: Creating and Sustaining Superior Performance"* (1985). The idea of the value chain is based on the process view of organisations, that is to say that an organisation as a system is made up of sub-systems, each with inputs, transformation processes and outputs. Products pass through the activities of a chain in a certain order, and at each stage the product increases in value. The way in which value chain activities are carried out determines costs and therefore affects overall profits.

At the industry level, an industry value-chain is a physical representation of the various processes involved in producing goods and services, from harvesting (in the case of seaweed) or extracting the raw materials to delivering the end product. The industry value chain is also known as the supply chain and is based on the notion of value-added at the 'link' i.e. at each stage of production. The theoretical framework utilises a simple business concept, namely that maximising the potential of the individual business units creates a profitable whole.

In order to fully understand the different value streams in which the industry participants operate, it is first necessary to map inter-company and intra-company value adding processes. Such value adding processes make the final product more valuable to the end consumer than otherwise would have been the case. Value stream management as further developed by Hines and Rich (1997) is a "strategic and operational approach to the data capture, analysis, planning and implementation of effective change within the core cross-functional or cross company processes required to achieve a truly lean enterprise". The difference between the traditional supply chain and the value stream is that "the former includes the complete activities of all the companies involved, whereas the latter refers only to the specific parts of the firms that actually add value to the specific product or service under consideration" (Hines and Rich, 1997).

With these concepts in mind, this paper aims to, (1) discuss how to utilise the seaweed resource of Ireland efficiently and effectively, so as to provide economic gains in a manner that is sustainable and environmentally friendly and that preserves naturally occurring ecosystems. (2) Give an in-depth analysis of the seaweed industry in Ireland, its strengths and weaknesses, the opportunities available and the challenges facing the industry that must be overcome in order to ensure that economic gains occur in a sustainable manner and that the contribution of such an industry to coastal economies can aid in reducing regional differences within Ireland and that GDP is equally distributed among various regions and (3) Provide a mapping of the supply chain of the seaweed industry in Ireland, allowing for ease of understanding of the processes and activities that add value to the end product and as such identification of areas where improvements may be possible.

In the subsequent sections, we first review the seaweed sector at a global, European and national scale. A discussion of the methodology utilised in the research is then presented. This is followed by a discussion of the findings of the research in addition to concluding remarks and recommendations for further research and policy.

2. The Seaweed Industry

Seaweeds, also called macroalgae, are plant-like marine organisms that generally live attached to rock or other hard materials in coastal and maritime areas. They can be categorised into three distinct groups, on the basis of colour: brown algae (Phaeophyceae), red algae (Rhodophyta) and green algae (Chlorophyta) (Seaweed.ie, 2014). Naturally growing seaweeds are also referred to as wild seaweeds, in contrast to those seaweeds that are cultivated or farmed.

In a global context, it is estimated that the value of the global seaweed industry is between US$5.5 and US$6 billion, with up to US$5 billion of this figure, coming from food grade products for human consumption (McHugh, 2003). A large proportion of the remainder is accounted for by the hydrocolloids industry, with other products such as fertiliser and animal feeds making up the remainder. According to McHugh (2003), the main uses of seaweed are as sources of the following

- Agar
- Alginates
- Carrageenan
- Food
- Fertilisers and soil conditioners
- Animal and fish feeds
- Biomass for fuel
- Cosmetics
- Integrated aquaculture
- Wastewater treatment

The first three represent the hydrocolloid industry and are the principal commercial seaweed extracts, with an annual sales value in 2009 of just over US$ 1 billion (Bixler & Porse, 2011). A hydrocolloid is an industrial gum and can be defined as "a non-crystalline substance with very large molecules and which dissolves in water to give a thickened (viscous) solution" (McHugh, 2003). The processed food industry continues to be the primary market for hydrocolloids.

Harvesting takes place on a commercial scale in approximately 35 countries globally (McHugh, 2003), with cultivated seaweed from Asian producers, in particular China and Japan, accounting for the some 90% of global production of seaweed (Douglas-Westwood, 2005). According to one report, forecasted annual growth in the global market was estimated at 3% for the period from 2006 to 2009 (Douglas-Westwood Report, 2005). However, elsewhere worldwide seaweed production has been estimated to have increased by 5.7% every year during that same period. (Netalgae.eu, 2012), with capture production accounting for only a very small proportion of the total. It is estimated that the global seaweed industry uses 7.5-8 million wet tonnes of seaweed annually (McHugh, 2003).

Whilst increasing production has been reported worldwide, year on year, the situation in Europe proves to be somewhat different with the industry remaining relatively stagnant until the turn of the century and subsequently demonstrating a decline in production. The production had remained stable above 350,000 tonnes until 2000, and has since decreased by almost one third (Netalgae.eu, 2012). The major players in the European industry include France and Norway, with a smaller proportion of the market belonging to Ireland. Other producers include Spain, Portugal and the UK. However production in the UK has almost disappeared with the recent closure of the last processing plant in Scotland (Netalgae.eu, 2012). France remains the only country that has developed seaweed aquaculture to any commercial extent, with the production of *Wakame*, a Japanese delicacy (Douglas-Westwood, 2005).

The commercial value and the landings for each species of seaweed vary widely and are directly related to harvesting techniques. The most important species in Europe, in terms of landings and value, are *Laminaria digitata*, *Laminaria hyperborea* and *Ascophyllum nodosum*, with the first two being harvested mechanically in both France and Norway and the latter being harvested by boat in Norway, whilst being manually harvested in Ireland and France. The other species of commercial interest, in all three countries, are harvested manually either on foot or by diving (Netalgae.eu, 2012).

The European seaweed processing industry is divided into two main sectors

- Alginic acid
- Crude extracts

Alginic acids are mainly used in the production of processed foods, with certain additional applications in the biotechnology sector, whilst crude extracts are used in the production of end products for agriculture, such as fertilisers, soil conditioners, animal feeds etc. These applications require large amounts of raw material, but provide low returns (Netalgae.eu, 2012). The European industry, similar to the Irish industry is therefore characterised by high volumes of landings but low industry profit margins. Another key issue for the European industry is that of preserving kelp forests and the ecosystems that they support. As a result a number of countries have decided to protect these habitats by restricting the use of mechanical harvesting or by creating protected areas around them. This in turn limits the potential for large landings, as are required for the low-value added applications.

As with the global industry local seaweed production in Europe is not sufficient to satisfy the level of demand of the processing industries (especially those extracting alginates). As such many processing industries, which are generally located close to the wild source material, have in recent years increased their imports of dried seaweed in order to meet the shortfall. This coupled with the recent interest in bio-fuel production from seaweed biomass should serve as added impetus for the further development of seaweed cultivation in Europe.

According to a recent report on the state of the European seaweed industry (BIM, 2014) the demand for European farmed seaweed has increased by approximately 7-10% per annum in recent years and the European market is suffering from “under-supply”, with imports comprising 75 per cent of total sales volumes last year. This, according to the authors, could lead to 100 new jobs being created on seaweed farms predominantly along Ireland's west/ south-west coastline while downstream processing of the new seaweed crops could also lead to a further 80 to 100 jobs in the region. The report also estimated that approximately 472 tonnes of sea vegetables were sold in 2013 in the EU and indicates that it would have taken almost 5,000 tonnes of harvest weight seaweed to generate this finished product.

Ireland currently has a very low share of the global seaweed industry, close in fact to zero per cent (Douglas-Westwood, 2005). As such, the industry is, as of yet, still underdeveloped and characterised by high volume, low value added processing activities (Walsh & Watson, 2011). The industry is mostly concentrated on the western seaboard with collection taking place in many areas that may be considered economically disadvantaged, in relation to other regions in Ireland. As such the seaweed industry provides a valuable economic resource for the populations of coastal regions, acting as a source of primary and supplementary income.

History and utilisation of Seaweed in Ireland

Seaweed harvesting has played a major role in the history and tradition of rural and coastal communities in Ireland. It is thought that the practice, of harvesting *Palmaria Palmata (dulse, dillisk)* may even date back as far as the 12^{th} century (Guiry, 2008). *Palmaria Palmata* has since been used in Ireland as food, in traditional medicine and even as chewing tobacco (Guiry, 2010). Other edible species of seaweed that have been traditionally harvested in Ireland include *Chondrus crispus (Irish moss, carrageen)* and *Porphyra umbilicalis (laver).* Irish moss is still popular as a cold remedy and as a thickener for desserts, soups and sauces (Morrisey et al., 2011)

Seaweeds have also been traditionally used as fertilisers, in particular in coastal areas where soil conditions were poor. In addition Ireland also has a history of kelp harvesting dating back to the 17^{th} century. Storm cast kelp was gathered and burned in kelp kilns. The resulting ash contained soda and potash, which were used in pottery glazing and for glass- and soap-making (Guiry, 2008 and Clow & Clow, 1947). Nowadays, seaweed has many different applications, perhaps the most exciting of which is its potential for biotechnological uses.

Seaweed is one of Ireland's most under-utilised natural resources. As an island nation on the periphery of Europe and at the edge of the Atlantic Ocean, Ireland has access to a vast marine resource, which remains under-developed. In addition, a unique location, where the northern limit for warm-water species meets the southern limit for a variety of cold-water species, lends itself to a level of biodiversity that is in stark contrast to the landmass of the nation (Kraan, 2008) and over 500 different species have to date been discovered and identified in Irish waters (Seweed.ie, 2014 and Guiry, 2007).

Most of the seaweed biomass in the North Atlantic is provided by a relatively small number of species, namely kelps, wracks and maërl. *Ascophyllum nodosum* is the most important species in Ireland, commercially speaking, with the main sources occurring in the southwest, mid-west and northwest (Guiry, 2007 and Seaweed.ie, 2014).

Table 1. Ireland's Seaweed Resources

	Red	Brown	Green	Total
Ireland	274	147	80	501
Scotland	208	137	70	415
England and Wales	311	181	85	577
France	268	193	128	689
North Atlantic	620	329	256	1205

Source: Research and Development of a Sustainable Irish Seaweed Industry (Guiry, 1997)

The Irish seaweed industry can be broadly categorised into six different sub-sectors as follows (National Seaweed Forum, 2000)

- Sea vegetables
- Maërl
- Biotechnology
- Biopolymers
- Cosmetics and Thalassotherapy
- Agriculture and Horticulture

Of the main commercial species harvested in Ireland, many uses have already been identified. However there exists additional potential in the form of niche markets and alternative uses as identified by companies in other countries such as
Jaan and Canada

Table 2. Seaweed resources in Ireland: Uses and Potential

Genus	Colour/Type	Species	Common names	Usage	Potential
Fucus	Brown/Wrack	*Fucus vesiculosus*	Bladderwrack	Cosmetics, thalassotherapy, body-care products, seaweed baths, land fertiliser, packing material for transporting shellfish.	
	Brown/Wrack	*Fucus serratus*	Serrated Wrack, Saw Wrack, Toothed Wrack, Míoránach, Dulamán, Múrach Dhubh	Seaweed extracts for cosmetics, and for seaweed baths.	
Pelevitia	Brown/Wrack	*Pelevita canaliculata*	Cow Tang, Channel(led) Wrack, Dubhlamán, Múirín na Muc, Caisíneach	Purified chemicals called fucoidans from Pelevetia have been described as having anticoagulant properties. Natural production of chloroform from this species has been reported, likewise from kelps and other wracks.	
Ascophyllum	Brown/Wrack	*Ascophyllum nodosum*	Yellow Tang, Knotted Wrack, Sea Whistle, Egg Wrack, Feamainn bhuí	Harvested for use in alginates, fertilisers and for the manufacture of seaweed meal for animal and human consumption. It can also be used as packing material for shellfish transport.	
Laminaria	Brown/Kelp	*Laminaria digitata*	Kombu, Oarweed, Tangle, Leathrach, Coirleach	Used as an organic fertiliser and for the extraction of alginic acid, the manufacture of toothpastes and cosmetics, and in the food industry for binding, thickening and moulding. It is also harvested in small quantities for sea-vegetable production.	Used in Japan for culinary purposes, in particular in a soup called *Dashi*. L. digitata is one of the species currently cultivated on long-lines in Ireland, providing potential for increased aquaculture.
	Brown/Kelp	*Laminaria hyperborea*	Kombu, Sea Rods, Forest Kelp, Cuvie	Aginate production, used in wound dressings to prevent adhesions, human consumption.	Potential as biomass for fuel. This species is cultivated on long lines in Ireland, offering further potential for seaweed farming
Saccharina	Brown/Kelp	*Saccharina latissima*	Laminaria saccharina, Sweet kombu, Sugar kelp, Lásaá, Rufa, Rufaím Fruill, Ribíní, Láin, Cupóg	Not currently widely harvested but small amounts are collected for kombu (popular in Japan), also used in Irish cuisine.	Has been used to make vegetarian/vegan imitation caviar. This species is one of those, currently cultivated on long lines in Ireland.

Saccorhiza	Brown/Kelp	*Saccorhiza polyschides*	Furbellows,Sea Hedgehog, Claíomh, Madra, Clabhtaí		Cultivated at experimental scale for its biomass. Cultivated on long lines in Ireland.
Chondrus crispus	Red	*Chondrus crispus*	Carrageen moss, Carrageen, Carragheen, Jelly moss, Irish moss, Mousse d'Irlande (French), Irisch Moos (German) Carraigín, Carraigín Fiadhám	Small amounts are collected in Ireland for cooking and food purposes (desserts, jellies, blancmanges, aspics and puddings, food thickener, beer production) and as a health drink. It is also used as a folk remedy for respiratory disorders, for leather curing, soap making, shampoos, lubricants and paper and linen production. In the food industry carrageenan (produced by chondrus crispus) is classified as a food additive, E407	One company in Canada is growing colour and morphological variants of this species, which are then sold dried as a novelty salad.
Numerous but collectively termed Maërl/ Rhodoliths	Red	*Lithothamnion corallioides* *Lithothamnion glaciale* *Phymatolithon calcareum*	Maërl, Rhodolith Beds, Gruán, Gruánach, Feamainn Choirleach	Organic fertiliser/soil conditioner, calcium supplement, water filtration, food (as a dried snack or pan-fried into chips, baked in the oven, or incorporated in dough)	Maërl should be considered as a non-renewable resource, and readily available alternative products such as garden lime make modern day exploitation questionable. However it has been successfully cultivated on long-lines and tanks in Europe.
Palmaria	Red	*Palmaria palmata (or Rhodymenia palmata)*	Dulse, Dillisk, Duilleasc, Chreathnach	Food (dried and uncooked)	Cultivation has been successfully achieved on ropes and in tanks in Ireland and Germany, respectively.

Sources: Macroalgae Fact-Sheets (Edwards et al., 2012), A guide to the Seaweed Industry (Mc. Hugh, 2003), Seaweed Resources in Europe: Uses and Potential (Guiry & Blunden Eds, 2003)

It is estimated that Ireland's marine biotechnology and bio-products sector, including seaweed harvesting, whole or unprocessed foods and processed foods for consumption, industrial texturants, plant fertilisers, animal and fish feeds, bio-actives and energy and biofuels, is currently worth €29.8 million per annum and employs approximately 304 people (FTE) (Vega et al., 2013). The majority of raw material originates from manual harvesting of the wild resource with harvesting activity mostly taking place in the coastal areas of Donegal, Sligo, Mayo, Galway, Kerry and Cork. Approximately 36,000 tonnes of wild seaweed is processed in Ireland annually (Morrisey et al., 2011) with *Ascophyllum nodosum* representing the most commercially important species at 25,000 tonnes or approximately 95% of overall domestic production (Walsh & Watson, 2011).

The industry currently has a major impact on the socio-economic status of coastal communities and contributes to their maintenance by providing employment for many people who depend on the industry to supplement their income from mainly farming enterprises. Despite this potentially valuable resource, to date only 16 different species of seaweed are exploited on a commercial scale in Ireland (National Seaweed Forum, 2000).

Table 3. Key figures for Ireland's marine biotechnology and bio-products sector

Year	Turnover (€'000)	Gross value added (€'000)	Exports (€'000)	Employment (FTE)
2010	29,867	12,990	11,645	304

Source: Ireland's Ocean Economy (Vega et al., 2013)

In the Irish market, agricultural products account for nearly 100% of the raw seaweed material used and 70% of the value generated, with cosmetics and therapies accounting for approximately 1.0% of the raw material used and 30% of the value generated (Walsh & Watson, 2011). However according to other estimates agricultural products typically generate revenue of €1.50/2.00 euro per litre (5-7% seaweed solids), which is subsequently offset by the high volume of sales that are being achieved in the sector and the relatively low marketing costs when compared to food and cosmetic products (Sea Change, 2007-2013)

2020 Scenario

Current production of seaweed is mainly limited to harvesting of Ireland's wild resource, with very little production occurring as a result of cultivation. In addition the majority of seaweed products are high volume, low value products intended for the agricultural-horticultural sector. A very small proportion of the seaweed resource is utilised for the production of high value-added goods e.g. cosmetics, nutraceuticals and pharmaceuticals (Walsh & Watson, 2011).

According to the Sea Change Strategy (Marine Institute, 2007-2013), the Irish seaweed production and processing sector will be worth €30 million annually by 2020 and both wild and cultivated stocks are included in this goal.

The sector turnover of approximately €30 million for Ireland's marine biotechnology and bio-products sector indicates that this target has already been reached. However, as proposed by Harnessing Our Ocean Wealth: An Integrated Marine Plan for Ireland, there are more ambitious targets yet to be reached in the coming years. Two such targets of €1 billion and €61 billion have been set for the seafood and Marine ICT and Biotechnology sectors respectively, both to be achieved by 2020 (HOOW, 2012). The seaweed industry will be an important contributor to the success or otherwise of efforts to achieve these goals. BIM (2014) indicate that seaweed farming offers Ireland the opportunity to become a producer of one of the EU's fastest growing food categories that by 2020 and forecast that expansion of the seaweed industry could boost seafood sales by an additional EUR 10 million per year.

As such it will be necessary to capitalise on the resource available as well as investing in seaweed aquaculture, with *Laminaria digitata* and *Palmaria palmata* having been two species identified as offering potential for cultivation (Walsh & Watson, 2011). Ensuring a sustainable supply in conjunction with the movement of industry participants along the value chain will aid in forming the basis of an industry that produces high value end products, whilst dealing with environmental concerns and security of supply.

Important issues

The majority of seaweed in Ireland is harvested manually. Seaweed harvesters either gather the seaweed after storms or use specific equipment such as knives sickles etc. to cut the seaweed at low tide. For certain seaweeds e.g. *Ascophyllum nodosum*, the cut seaweed is tied in bundles and left to float to the surface and then pulled ashore by small boats (Netalgae.eu, 2012). The Irish industry currently enjoys a high level of sustainability due in large to the methods of harvesting employed as well as the knowledge developed by generations of harvesters regarding regeneration and regrowth periods.

Efforts have been made to assess the potential impacts of mechanical harvesting in Ireland, however more research is yet to be done on how such will affect local ecosystems. Environmental NGOs claims have for the moment essentially halted the expansion and widespread adoption of mechanical harvesting (Netalgae.eu, 2012). In particular the National Parks and Wildlife Service (NPWS) has expressed its opposition to the introduction of mechanical harvesting of seaweed in Ireland, with specific concerns in relation to kelp and are of the opinion "that such activities are not compatible with the conservation objectives of, and should not be permitted in Natura 2000 sites" (Netalgae.eu, 2012).

Access regulations

Harvesting rights predate the formation of the State and can be traced back to British rule in Ireland (Guiry, 2010). In the 19th century, certain landowners were given "seaweed rights", allowing them to harvest seaweed along the foreshore adjacent to the boundaries of their land. These traditional rights are still considered valid if the landowner can produce the title; however such rights are also considered one of the major obstacles to the development of the seaweed industry in Ireland (Netalgae.eu, 2012).

Following the "Foreshore Act (1933)[1]" all persons or companies, seeking to harvest wild seaweed, must possess a seaweed harvesting licence. However there is still some doubt in the public mind about the spatial extent of the foreshore. The term foreshore has different meanings for different statutory purposes. The principal definition can be found in the 1933 Act, which states that the foreshore "is the bed and shore, below the line of high water of ordinary or medium tides, of the sea and of every tidal river and estuary and of every channel, creek and bay of the sea or of any such river or estuary" (Foreshore Act, 1933). In 2005 a new definition was inserted in the 1933 Act, which formally confirms that the outer limit of the foreshore is synonymous with the outer limit of the territorial seas (Long, 2007).

The requirement to obtain a Foreshore licence for the harvesting of seaweed from State owned Foreshore is set out in Section 3(1) of the Foreshore Acts, 1933 – 2009. Section 3 (1) states

> 3 - (1) If, in the opinion of the appropriate Minister it is in the public interest that a licence should be granted to any person in respect of any foreshore belonging to the State authorising such person to place any material or to place or erect any articles, things, structures, or works in or on such foreshore, to remove any beach material from, or disturb any beach material in, such foreshore, to get and take any minerals in such foreshore and not more than thirty feet below the surface thereof, or to use or occupy such foreshore for any purpose, that Minister may, subject to the provisions of this Act, grant by deed under his official seal such

[1] Available at: http://www.lawreform.ie/_fileupload/RevisedActs/WithAnnotations/EN_ACT_1933_0012.PDF

licence to such person for such term not exceeding ninety-nine years commencing at or before the date of such licence, shall think proper.

The Act defines "beach material" as sand, clay, gravel, shingle, stones, rocks, and mineral substances on the surface of the seashore and includes outcrops of rock or any mineral substance above the surface of the seashore and also includes bent grass growing on the seashore and provides for special mention of seaweed "... and also seaweeds whether growing or rooted on the seashore or deposited or washed up there on by the actions of tides, winds; and waves or any of them" (Foreshore Acts, 1933 – 2009).

The process to acquire a license however is quite complicated. Mechanical harvesting also requires special authorisation from the State. Under the Foreshore Acts the Minister for Agriculture, Food and the Marine is responsible for

(a) any function in relation to a fishery harbour centre
(b) any function in respect of

(i) an activity which is wholly or primarily for the use, development or support of aquaculture, or
(ii) an activity which is wholly or primarily for the use, development or support of sea-fishing including the processing and sale of sea-fish and manufacture of products derived from sea-fish

While a Foreshore Licence is needed to harvest seaweed anywhere along the coast those responsible for issuing the licence vary based on different circumstances. For example a Foreshore Licence would be required from the Minister for Agriculture, Food and the Marine if seaweed harvesting was proposed in any of the six Fishery Harbour Centres, that is to say Howth, Dunmore East, Castletownbere, Dingle, Rossaveal and Killybegs. A Foreshore Licence would also be required from the Minister for Agriculture, Food and the Marine if seaweed harvesting were proposed primarily for the use, development or support of aquaculture e.g. collection of seaweed for use as food source for the aquaculture production of shellfish such as abalone or sea urchins. In all other cases a Foreshore Licence would be required from the Minister for the Environment Community and Local Government (DECLG) (Foreshore Acts, 1933 – 2009).

In Ireland, the majority of harvesters operate without a proper license. As a result, the true number of harvesters is unknown. It would appear that in recent years the number may have increased due to the economic downturn and the increase in migrants returning to coastal and maritime areas (Netalgae.eu, 2012).

3. Methodology

This work is based on the methodological foundation known as value stream management or value chain analysis, from which the practical tools and techniques employed in the research are derived. Following on from work by Hines and Rich (1997), Jones and Womack (2002) and Taylor (2005) the methodology is employed to provide an overview of the seaweed industry and subsequently recommendations for policy. The process follows the following steps:

- Identify publicly available economic data
- Collect non-public data from alternative data sources
- Analyse the global industry from an economic perspective
- Analyse the industry at country specific level both within and outside of the global context
- Create understanding of the industrial processes
- Develop the 'Current State' map of the whole chain
- Develop recommendations for improvements.

The first step in analysing the seaweed industry in Ireland involved identifying publicly available economic data. This included the statistical collections of the Fisheries and Aquaculture Department of the Food and Agriculture Organisation of the United Nations (FAO). Outside of these statistical collections, there appears to be no comparable resource, at least with regards the extent of the countries covered. The second step involved collecting non-public data from alternative sources. This was aided by access to the resources of the Irish Marine Institute. A previously conducted SEMRU company survey was also used to identify indicators relating to those companies operating in the seaweed industry.

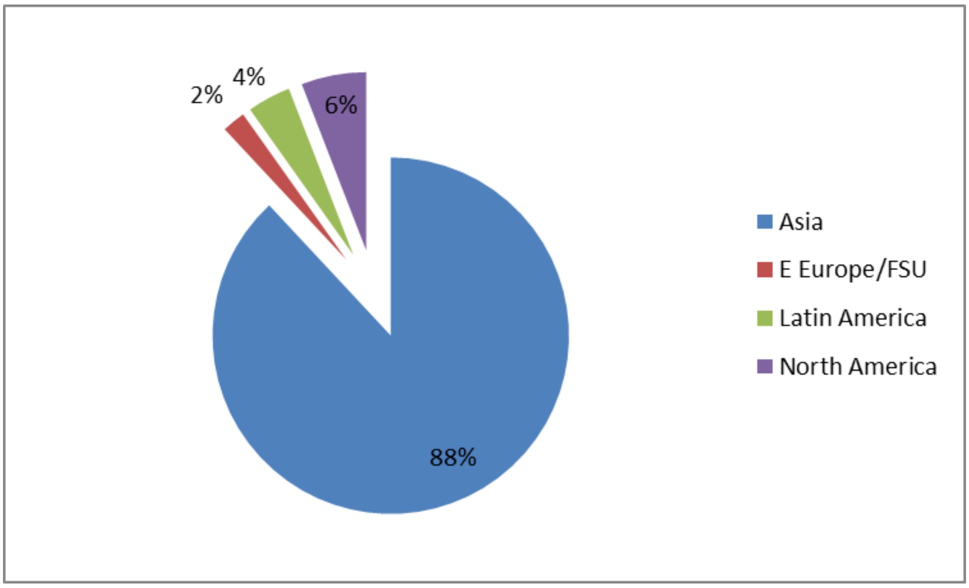
As identified in previous international studies on the sector there exist particular difficulties with regards conducting an analysis of the seaweed industry. Internationally comparable statistics are often out of date, with data available in 2014 often relating to 2012. This presents a particular problem due to the considerable increase in activity in many marine sectors during the intervening years. In addition the statistics available on the seaweed industry from the FAO often contain only estimates. When national offices fail to report their annual aquaculture statistics, FAO, in the absence of other verifiable information, repeats or estimates the data previously reported by the country. Such data are flagged by "F" (which stands for FAO estimate) within the FAO database and are indicated here underneath the relevant tables.

Data about seaweed production are also subject to caution as it is rarely made clear if the data refer to raw material or to dried material. FAO statistics are the only source of data covering all countries in the world. With particular regard to the seaweed industry in Ireland, there are also issues relating to the level of secrecy present among industry participants and harvesters, with many companies unwilling to reveal profit levels as well as many harvesters remaining undeclared. In general this paper is considering markets as opposed to the economic benefit to the country, which is often a multiple of the stated market, as the national economic databases do not explicitly contain values or data for the sector.

4. Results

The data analysed was available for the ten-year period from 2003 to 2012. The year 2012 represents the most recent year for which global data on seaweed capture production and aquaculture exists. An analysis of the segmentation of the market reveals that Asia retains approximately an 88 percent share of the market (Figure 1). Following the market leader, North America has a 6 percent share and Latin America has a 4 percent share of the market. The European players follow behind with only a 2 percent share of the global market.

Figure 1. Regional Segmentation of the Global Market



Source: Douglas Westwood

Regarding actual global production figures, these can be broken down into the three distinct categories of seaweed i.e. brown algae (Phaeophyceae), red algae (Rhodophyta) and green algae (Chlorophyta) and subsequently further broken down into quantity produced and market value of such. The figures for the past ten years have been included here (Table 4).

The production of aquatic plants, mostly seaweeds, reached 24.9 million tonnes in 2012, of which aquaculture produced 23.8 million tonnes (96 percent). Carrageenan seaweeds (including Kappaphycus alvarezii and Eucheuma spp.) are the main cultured seaweeds (8.3 million tonnes), followed by Japanese kelp (5.7 million tonnes) (Fishery and Aquaculture Statistics, FAO 2012)

Table 4. World aquaculture production by species groups

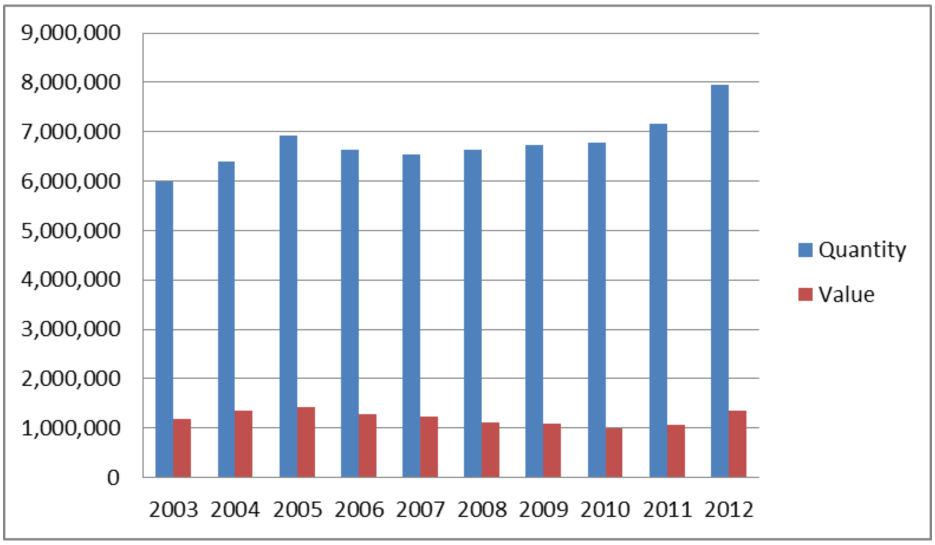
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Brown Seaweeds Quantity	5,983,337	6,402,367	6,926,355	6,644,891	6,536,197	6,628,214	6,726,316	6,787,493	7,153,019	7,955,093
Brown Seaweeds Value	1,177,589	1,352,748	1,428,757	1,292,315	1,223,576	1,121,102	1,087,150	983,675	1,065,807	1,353,161
Red Seaweeds Quantity	3,125,513	3,963,305	4,682,490	5,292,961	6,071,748	6,700,174	8,043,083	8,977,849	10,841,808	12,906,177
Red Seaweeds Value	1,226,162	1,548,185	1,699,933	1,782,844	2,002,990	2,023,435	2,654,615	3,186,312	3,205,885	3,797,775
Green Seaweeds Quantity	7,952	18,636	12,266	18,329	16,676	26,133	22,368	21,546	21,540	19,900
Green Seaweeds Value	3,608	12,567	6,655	11,451	8,137	17,226	12,966	12,835	14,879	13,979

* Quantity is expressed in tonnes
** Value is expressed in US$ 1000

Source: FAO Statistics

It is important to note here that production includes both cultivated seaweeds and wild harvest (which represents a significantly smaller proportion of the global figure). Brown seaweeds have remained fairly stable in terms of production growth and value. The species included within this category prove to offer the least in term of value to quantity ratios (Fig 2).

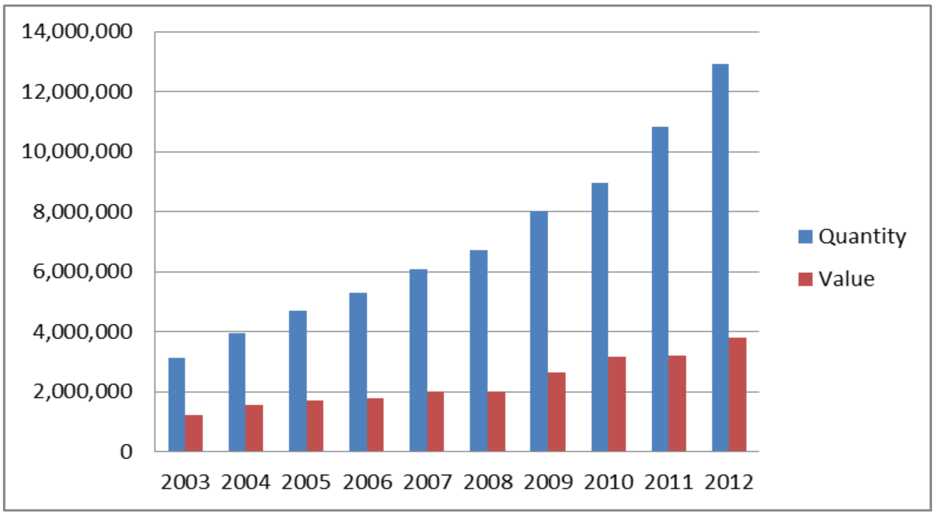
Figure 2. Global quantity and value of brown seaweed



Source: FAO Statistics

Red seaweeds have steadily been increasing in terms of quantity produced, with capture production peaking in 2012 (as per the data available from the FAO) accompanied by stable but relatively low growth in value (Fig 3). BIM (2014) also puts forth the view that Ireland should target higher value red seaweed, which is used as nori in sushi (Porphyra umbilicalis).

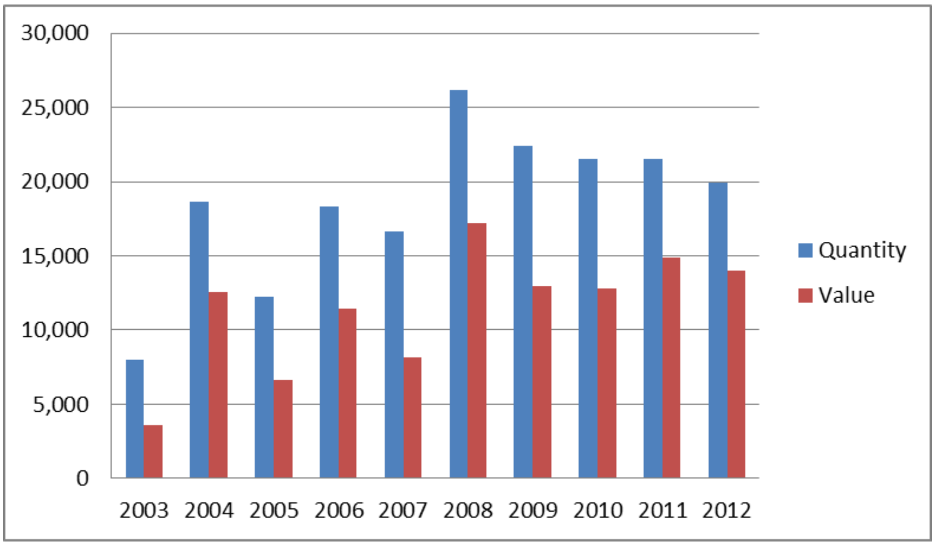
Figure 3. Global quantity and value of red seaweed



Source: FAO Statistics

Green seaweeds on the other hand exhibit a high level of change in capture production in the years prior to 2008. Following this there has been a period of stability in production. Green seaweeds provide the highest returns for quantity produced (Fig 4).

Figure 4. Global quantity and value of green seaweed



Source: FAO Statistics

The results indicated in the previous graphs with regards returns per tonne of seaweed are summarised in the following table indicating the yearly values of each of the three categories per tonne of capture production. This has been calculated on the basis of quantities and values provided by the FAO statistical database by simply dividing the value yielded by each species group by the tonnage for that group (Table 5).

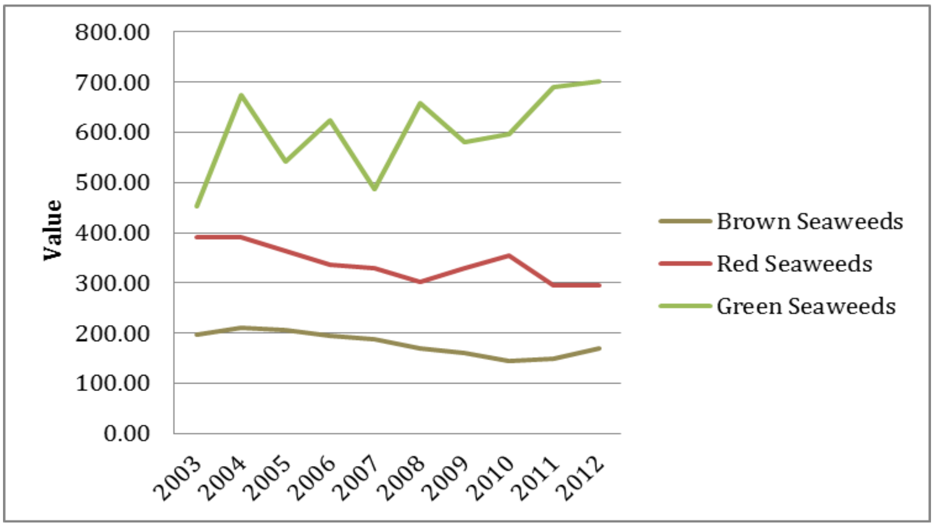
Table 5. Value per tonne by species group (US$)

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Brown Seaweeds	196.81	211.29	206.28	194.48	187.20	169.14	161.623	144.92	149.00	170.10
Red Seaweeds	392.31	390.63	363.04	336.83	329.89	301.00	330.05	354.91	295.70	294.26
Green Seaweeds	453.7	674.34	542.56	624.75	487.95	659.17	579.67	595.70	690.76	702.46

Source: Based on quantities and values from FAO statistics

As can clearly be seen in the graph below (Figure 5), emphasising the results from the previous graphs and tables, the value per tonne for green seaweeds is much higher than that of both red and brown seaweeds. Brown seaweeds yield the lowest returns although they comprise the second largest quantity in terms of raw material. Red seaweeds, which make up the largest proportion of total global production, yield the second highest level of returns per tonne. Finally, green seaweeds with by far the lowest production volumes, in the thousands as opposed to the millions of tonnes produced of the other two categories, has the highest value per tonne of production with a record high of US$702.46 per tonne in 2012.

Figure 5. Value per tonne by species group



Source: Based on quantities and values from FAO statistics

Seaweed Industry in Ireland

As mentioned previously, Ireland currently has essentially a non-existent share of the global market for seaweeds. According to FAO estimates the annual capture production of Ireland in 2012 was 29,500 wet tonnes. For comparison purposes both the Canadian and Norwegian seaweed industries were chosen, due in large part to the fact that both countries acquire the majority of their raw material from harvesting of the wild resource, as opposed to cultivation. In 2012 Canada, although larger than both Ireland and Norway, had a production figure of just 13,800 tonnes. This is a trend that was also present in 2011, as well as 2008. This can be attributed to the fact that Canada is turning its focus towards lower volume higher value added products and as such creating a more sustainable industry.

Table 6. Seaweeds and other aquatic plants, capture production by country

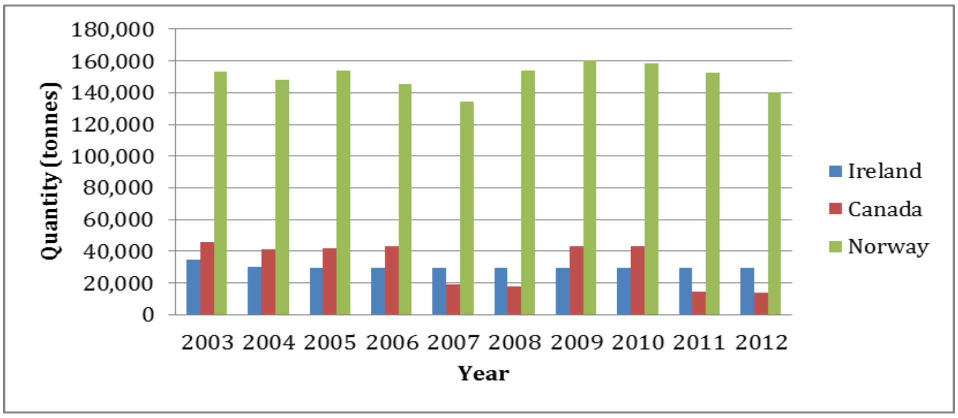
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Ireland	35	30	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5
Canada	45.7	41.1	41.8	43.2	19.4	17.7	43.3	43.4	14.8	13.8
Norway	153.2	148.3	153.9	145.4	134.8	154.2	160.4	158.5	152.4	140.3

* Quantity is expressed in thousand tonnes (wet weight)
** The values included here for Ireland from 2006 onwards are FAO estimates as national offices have failed to report their annual aquaculture statistics

Source: FAO Statistics

Norway was the largest producer of the three with a capture production that has remained relatively stable over the ten-year period and was just over 140,000 tonnes in 2012. As can be seen below (Fig 6), based on FAO estimates, the capture production in Ireland has also remained relatively stable over the period 2005 to 2012.

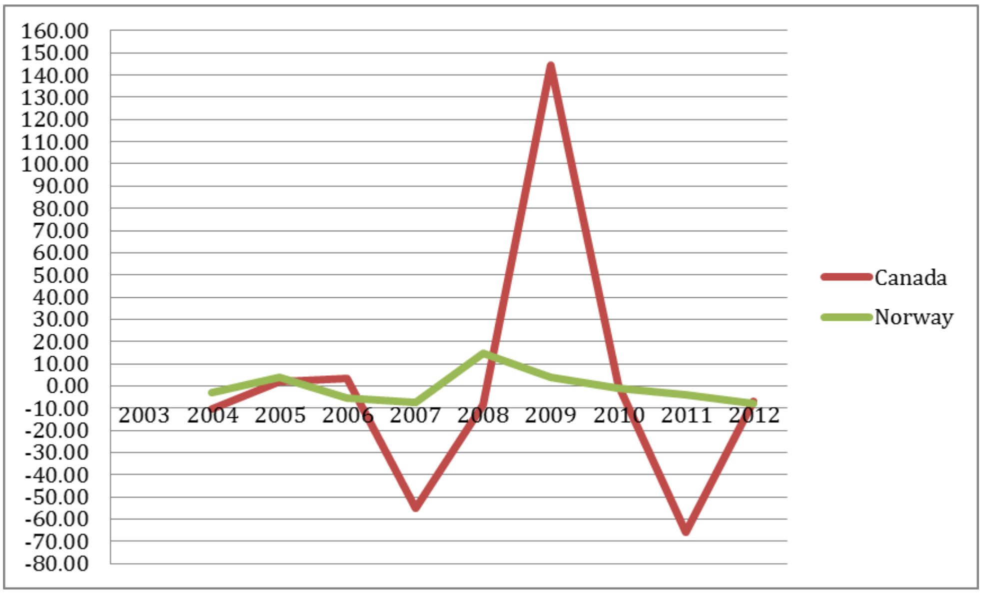
Figure 6. Capture Production by Country



Source: FAO Statistics

The growth rates (percentage) in capture production for Norway and Canada are illustrated below (Fig 7). The corresponding values for Ireland have not been calculated due to the nature of the data contained within the FAO statistical database for capture production in Ireland i.e. the figure for the period 2006 to 2012 is simply repeated from the base figure of 29,500 tonnes in 2005. As previously mentioned this is as a result of a failure on the behalf of national offices to supply the FAO with their annual statistics. However it has been estimated elsewhere that the current production figure for Ireland is approximately 36,000 tonnes, so we can assume that the growth rate in capture production has remained relatively stable over the ten year period.

Figure 7. Growth rates in capture production



Source: FAO Statistics

The main commercial species harvested in Ireland are *Ascophyllum nodosum, Laminaria hyperborea* and miscellaneous red seaweeds (Table 7).

Table 7. Irish Capture production by common species

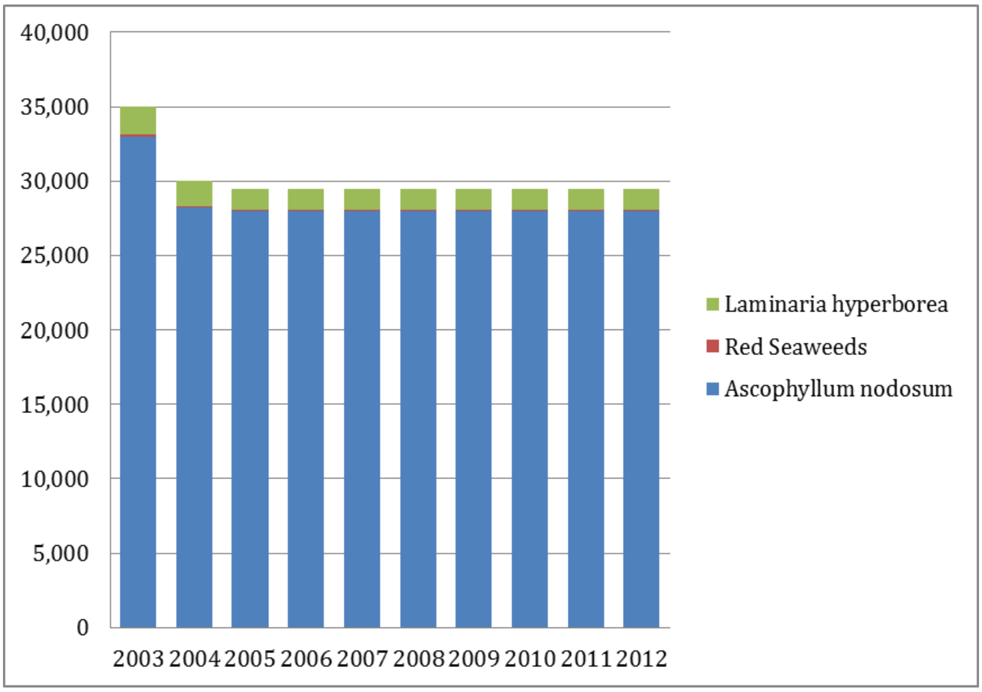
Species	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Ascophyllum nodosum	33,000	28,200	28,000	28,000	28,000	28,000	28,000	28,000	28,000	28,000
Red seaweeds	100	100	100	100	100	100	100	100	100	100
Laminaria hyperborea	1,900	1,700	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400

* Quantity is expressed in thousand tonnes (wet weight)
** The values included here for 2006 onwards are FAO estimates as national offices have failed to report their annual aquaculture statistics, FAO

Source: FAO Statistics

Ascophyllum nodosum is currently the most important species commercially speaking and accounts for the largest proportion of the raw material harvested. According to FAO estimates the harvest of *Ascophyllum* peaked in 2003 at 33,000 tonnes and has since remained relatively stable at approximately 28,000 tonnes (Fig 8). *Laminaria hyperborea* accounts for the second largest proportion of capture production with miscellaneous red seaweeds accounting for the majority of the remainder.

Figure 8. Irish capture production by species



Source: FAO statistics

Based on the global values per tonne calculated for the three categories of seaweed (brown, red and green), which are presented in Table 5, the annual capture value for the common species in Ireland has been calculated using these as a proxy measure; i.e. the value for *Ascophyllum* and *Laminaria* have been calculated on the basis of the global annual value for brown seaweeds, whilst the value for red seaweeds in Ireland has been calculated on the basis of the global annual value for red seaweeds.

The values in Table 8 are calculated in US$ as per the original values calculated in Table 5. The subsequent values in Table 10 are shown in Euro and have been calculated using historic annual exchange rates (midpoint) between the US dollar and Euro for the ten-year period, shown in Table 9.

As previously discussed *Ascophyllum* comprises the majority of the raw material harvested but also the majority of the value of the Irish seaweed industry. However with the value of brown seaweeds falling in recent years, the value of this sector has also fallen. Red seaweeds contribute a relatively small amount to the value of the Irish industry over the ten-year period; however their value has remained quite stable. The steady decline in the value of brown seaweeds has also led to a corresponding fall in the value of *Laminaria digitata* to the Irish industry until 2010, with a subsequent increase, albeit a modest one, in 2011 and 2012.

Table 8. Irish capture value by common species (US$)

Species	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Ascophyllum nodosum	6,494,777	5,958,342	5,775,793	5,445,510	5,241,600	4,735,945	4,525,538	4,057,890	4,172,028	4,762,799
Red seaweeds	39,231	39,063	36,304	33,683	32,989	30,200	33,005	35,491	29,570	29,426
Laminaria hyperborea	373,942	359,191	288,790	272,275	262,080	236,797	226,277	202,895	208,601	238,140

* Quantity is expressed in US$
Source: Based on quantities and values from FAO statistics and calculated from the values per tonne in Table 5.

The following table contains the historic annual exchange rates for the period, which have been used to adjust the values listed above to the corresponding Euro values.

Table 9. Historic exchange rates (USD/EUR)

Period Average	0.7676
Period High	0.8852
Period Low	0.6833

Year	Exchange rate (Midpoint)
2003	0.8852
2004	0.8050
2005	0.8044
2006	0.7969
2007	0.7307
2008	0.6833
2009	0.7191
2010	0.7548
2011	0.7189
2012	0.7782

Source: http://www.oanda.com/currency/historical-rates/

Using the corresponding Euro values there appears to be an even sharper decline in the value of *Ascophyllum nodosum,* with a low of €2.9 million in 2011, followed by a slight recovery in 2012 with a value of €3.7 million in 2012. The value of red seaweeds to the Irish industry has also fallen, with a slight increase in 2010, followed by a subsequent decline in 2011 and very small recovery in 2012. The situation with regards *Laminaria digitata* is similar to that of *Ascophyllum* with a steady decline over the period 2003 to 2011, followed by a modest increase in 2012.

Table 10. Irish capture value by common species (Euro)

Species	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Ascophyllum nodosum	5,749,176	4,796,465	4,646,048	4,339,527	3,830,037	3,236,071	3,254,315	3,062,895	2,999,271	3,706,410
Red seaweeds	34,727	31,446	29,203	26,842	24,105	20,635	23,734	26,788	21,258	22,899
Laminaria hyperborea	331,013	289,149	232,302	216,976	191,502	161,804	162,716	153,145	149,964	185,321

* Quantity is expressed in Euro
Source: Based on quantities and values from FAO statistics and calculated from the values per tonne in Table 5 and historic exchange rates

As expected, the figures for Irish aquaculture are relatively low (Table 11). Seaweed cultivation has not been developed to any extent in Ireland and at present is mostly being carried out on an experimental basis only. The main species involved include *Palmaria palmata (Dulse)* and *Laminaria digitata (Tangle)*. *Palmaria* yields a relatively high return with 9 tonnes contributing a value of $11,000 (Table 12).

Table 11. Irish aquaculture production (Quantity)

Species	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Alaria esculenta	…	…	…	…	3	…	…	1	…	…
Palmaria Palmata	…	…	…	…	…	…	…	1	…	9
Laminaria Digitata	…	…	…	…	…	…	…	1	3	…
Total	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**3**	**3**	**9**

* Quantity is expressed in tonnes (wet weight)

Source: FAO statistics

Table 12. Irish Seaweed Aquaculture Production (Value)

Species	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Alaria esculenta	...	...	...	...	2	...	...	1	...	...
Palmaria Palmata	...	...	...	...	...	...	...	1	...	11
Laminaria Digitata	...	...	...	...	...	...	...	1	2	...
Total	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**2**	**2**	**11**

* Value is expressed in US$ '000
Source: FAO statistics

Table 13 contains information on the trade flows of Ireland for agar as well as seaweed and seaweed products. As can be clearly seen from the table the import of seaweed and seaweed products has risen sharply over the ten year period, reaching a peak in 2012 of 43,601 tonnes, whilst exports of same after initially falling to 5,541 tonnes in 2005, have subsequently been steadily rising and reached a peak of 28,821 tonnes in 2012.

Table 13. Commodities production and trade

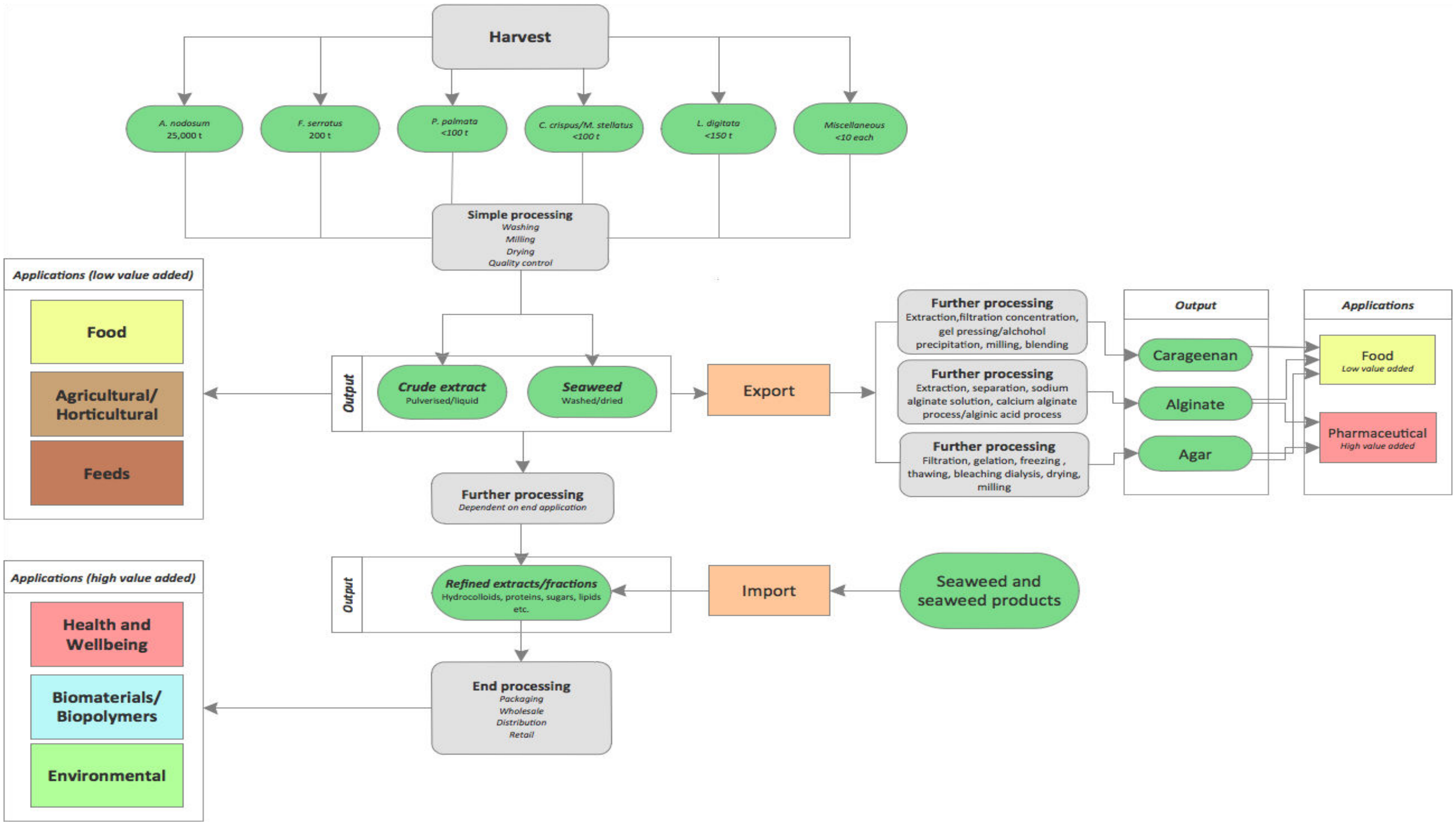
Commodity	Trade Flow	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Agar agar nei	Export	-	3	-	-	-	-	-	-	-	-
Agar agar nei	Import	7	6	7	10	3	11	25	4	3	5
Seaweed and seaweed products	Export	3518	2750	5541	9529	12566	12520	16188	23103	24409	28821
Seaweed and seaweed products	Import	167	194	169	161	454	643	3731	7316	14558	43601

* Quantity is expressed in tonnes
Source: FAO Statistics

Supply Chain analysis

The final stage in analysing the seaweed industry in Ireland involved undertaking a complete mapping of the industry within the value chain context. The majority of raw material harvested is utilised in the production of agricultural products i.e. low value added end products for the consumer. Cosmetics and therapies account for the majority of the remainder of the raw material used in Ireland (approximately 1%). Such applications are included within the higher value added applications alongside applications such as biomaterials and biopolymers as well as bioremediation (Fig 9).

Figure 9. Value Stream and Supply Chain of the Irish Seaweed Industry



5. Discussion and Conclusions

It has been estimated that the value of global seaweed industry is between US$5.5 and US$6 billion (McHugh, 2003). According to the most recent FAO statistics (2012) the combined value of the seaweed industry is US$ 5.16 billion. Based on a literature review cultivated seaweed from Asian producers, in particular China and Japan, was found to account for some 90% of global production of seaweed. The results here as per Figure 1 are approximately the same (88%).

In addition it was estimated that the global seaweed industry uses 7.5-8 million wet tonnes of seaweed annually pre 2003 (McHugh, 2003). According to our analysis the actual capture production in 2012 was 20.8 million wet tonnes of seaweed, which represents a significant increase. The main applications of seaweed in the global market remain as hydrocolloids, food, fertilisers and soil conditioners, animal and fish feeds, biomass for biofuel, cosmetics and bioremediation.

The major players in Europe are still Norway and France with Ireland following behind. France remains the only country in Europe that has developed aquaculture to any extent.

Ireland’s marine biotechnology and bio-products sector, including seaweed harvesting is currently worth €29.8 million per annum (Vega et al., 2013) and approximately 36,000 tonnes of wild seaweed is processed in Ireland annually with *Ascophyllum nodosum* representing the most commercially important species at 25,000 tonnes (Walsh & Watson, 2011) or approximately 95% of overall domestic production.

Our analysis revealed that the estimated value of the three main categories of seaweed in Ireland, namely *Ascophyllum nodosum, Laminaria* digitata and miscellaneous red seaweeds is approximately €3,914,630 based on values for the average global values for brown and red seaweeds. Such a low figure is however to be expected taking into consideration the final applications for these three categories i.e. agricultural and horticultural and only serves to emphasise the need for increased focus on higher value added applications. The analysis also revealed that the estimated capture production of *Ascophyllum* in 2012 was 28,000 tonnes.

It has previously been estimated that the national production of *Palmaria* is between 16 and 30 tonnes per annum with national production of *Laminaria* likely to be similar or lower (Walsh & Watson, 2011). However according to FAO statistics the aquaculture production figure in Ireland was 9 tonnes in 2012, representing production on an experimental basis only. However, with an associated value of US$11,000, it seems that this sector will continue to offer significant potential for development in the coming years.

It was found in the literature that agricultural products typically generate revenue of €1.50/2.00 euro per litre (5-7% seaweed solids), but that this low value is offset by the high volume of sales present in the sector coupled with the relatively low marketing costs in comparison to some of the higher value added products. However our analysis revealed that figure is much lower than expected at approximately €3,914,630 (based on values for the average global values for brown and red seaweeds), which can largely be associated with agricultural applications. Such figures are indicative of the weaknesses plaguing the Irish industry, that is to say the lack of investment in high-value end products that use a fraction of the wild resource, allowing for sustainability of the industry.

Other studies had emphasised the need for increased concentration within the Irish industry on higher value added applications such as biomaterials, biopolymers and the health and well being sector and such findings as those present here are concurrent with this view (Douglas-Westwood, 2005; Walsh and Watson, 2011). The majority of the raw material is still utilised in agricultural applications and as previously mentioned yield low returns, whilst requiring large amounts of the wild resource.

In conclusion, maintenance and expansion of the Irish seaweed industry depends on stable and continued, economically viable as well as environmentally sustainable access to the raw material as well as the development of high value end products. Raw material supply will be a key driver for the sector in the coming years. It is becoming increasingly difficult to maintain the supply of *Ascophyllum nodosum* from manual harvesting techniques. However, it may prove more beneficial for the industry to stay with this form of harvesting if the sector moves towards lower volume applications that provide higher value-added for the end consumer. Cosmetics, nutraceuticals, pharmaceuticals and functional foods require a smaller amount of the raw material, whilst offering much larger potential for generating value in the industry than that of traditional agricultural applications. Furthermore there is considerable interest in the potential of seaweed for bioremediation purposes such as reducing excess nutrients in waters from sewage treatment plants as well as from aquaculture production units, and treatment of tannery wastes.

It will be also be necessary for policy-makers to ensure that the many benefits and opportunities of seaweed industry are effectively communicated to the scientific and academic communities, to industry and to the public in general, so as to ensure that the level of awareness is expanded.

The processing industries have raised doubts concerning the usefulness of remaining based in Europe and are already partly compensating for the lack of Irish and European product by using outsourcing supply. This trend could be counteracted through moves towards applications that utilise much lower volumes of the wild resource.

Ireland stands to gain significantly from developing its overall marine industry, in particular by ensuring that the sub-sectors contained therein realise their full potential. It is therefore imperative that Ireland take a proactive stance with regards development and growth in the industry. A timely implementation of the relevant supportive actions is therefore necessary, in order for Ireland to take full advantage of its natural resources. These relevant supportive actions include

(i) Increasing awareness levels of the seaweed industry and its potential,
(ii) Insuring access to adequate funding
(iii) Ensuring sufficient linkages between industry and academia
(iv) Identifying research requirements
(v) Overcoming legal and policy barriers.

Regulators will need to ensure that the wild resource is managed sustainably through thorough analyses of harvesting regimes for key species such as kelp. Investment in research and development as well as a collaborative and coordinated interdisciplinary and industry-academia approach will therefore be critical for the success of the seaweed sector in Ireland. There is a critical need to improve communication and information pathways between relevant stakeholders and connect research activity and findings with the business oriented goals of industrial participants engaged in the commercialisation of such findings in the form of new and novel goods and services. The resulting environment will offer a more attractive opportunity for entrepreneurial investment and significant sector development and would facilitate Ireland becoming a key player in one of the EU's fastest growing industries.

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