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Seaweed in the UK and abroad – status, products, limitations, gaps and Cefas role

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Executive Summary

Global seaweed production has more than doubled between 2000 and 2014, from 10.5 to 28.4 million tonnes. The 2012 world production of seaweeds was estimated to be about US$6 billion (FAO, Food and Agriculture Organization, 2014); 95% of this production was from Asian aquaculture.

In the UK, harvesting of wild seaweeds for food, feed and fertilizers has been carried out for centuries, however seaweed farming does not have a long history. Nevertheless, in recent years, there has been increasing interest in seaweed aquaculture, mainly driven by research into algal biofuel technologies. Seaweeds could become an important source for third generation biofuels production as its aquaculture does not compete for land and freshwater with either food or non-food crops. Furthermore, seaweeds have high productivity, fast growth rates and high polysaccharide content; all important qualities for biomass for biofuels. Macroalgae could also represent a significant sink for anthropogenic CO_2 ("Blue Carbon"), and cultivation and the harvesting of seaweeds could play an important role in carbon sequestration and reduction of greenhouse gas emissions.

Due to our extensive coastline, seaweed production in the UK could be increased beyond the current level through farming. However, various limitations to the development of the seaweed sector are perceived by industry and there is a need to establish how macroalgae cultivation can be carried out at a large scale in an environmentally and economically sustainable manner.

The aim of this report is to give Defra an overview of the national and international seaweed sector and its products, as well as an overview of constraints to further development of the sector, particularly in the UK. The report also aims to identify potential gaps in the regulatory and licensing system for seaweed aquaculture, and to identify the services that Cefas could provide to ensure the development of this area occurs respecting the relevant regulations and the health of the marine environment.

Estimates from the FAO indicate that China alone accounts for 50.8% of the world production of aquatic plants (in 2014). In the period 2009-2013, Indonesia, Peru, and France saw the biggest growth in production of seaweeds from wild harvest, while Solomon Island and Indonesia made the biggest advance in seaweed production from aquaculture. The FAO database has no records of production for the UK although seaweed production from wild harvest in the UK, in 2013, has been estimated at around 2,000-3,000 dry tonnes (AB-SIG 2013). In addition, unknown quantities of subtidal kelp and storm-cast seaweeds are also collected in the UK. To our knowledge, there are no comprehensive estimates of seaweed production in the UK. Furthermore, there are no recent estimates of the wild seaweed standing stock of the UK, nor of the potential algal stock that could be sustainably harvested (with exception of *Ascophyllum nodosum* stocks in the Outer Hebrides which were investigated in 2010). Seaweed aquaculture is currently limited in the UK and existing pilot seaweed farms remain in research and development status.

Multiple products can be obtained from seaweeds, ranging from food to chemicals and bioenergy. For the UK, a total of 27 seaweed-related businesses were identified, based on web searches; 16 of them use seaweeds harvested in the UK. The majority of UK seaweed-related businesses produce seaweeds for food (or "sea vegetables") or condiments, and for cosmetics. Other products, based on seaweeds and produced in the UK, include animal feed and supplements, chemicals (e.g. hydrocolloids), fertilizers and nutraceuticals (e.g. nutrients and dietary supplements). Production of seaweeds for other uses such as bioremediation, or biofuel production (via anaerobic digestion), is at the development stage.

There are various issues and barriers limiting or affecting the development of seaweed production and markets. In Europe and the UK, there is a perceived bottleneck in the seaweed supply chain in terms of production capacity (result of high costs for seaweed biomass production and/or shortage of seaweed biomass due to seasonality).

Seaweeds aquaculture could contribute to meet the demand for algal biomass; however, factors such as lack of information on operational costs, potential biomass yields and ecological effects of seaweeds farms, as well as unclear regulatory context (particularly for marine licensing), are perceived to limit the development of the seaweed aquaculture industry.

It appears, however, that there is no specific regulation for seaweed farming in the UK and the established licensing procedure for finfish and shellfish would not always be applicable to seaweed farms. The lack of information on potential environmental impacts of seaweed farms and their management (e.g. control of nuisance species) results in uncertainties for the regulator on how to interpret requirements under national and international regulations (for example, under which circumstances an Environmental Impact Assessment would be required).

Cefas expertise can contribute to clarify the potential for sustainable harvest, and the potential environmental effects of large-scale seaweed farms. In addition, we can help develop the marine licensing procedure for offshore cultivation and, more generally, Cefas can contribute towards creating roadmaps to identify and prioritise activities and policies to accelerate blue growth.

To enable further development of the seaweed industry in the UK, further work and investments should be directed at:

- determination of the seaweed standing stock in the UK and of the amount of seaweed that could be sustainably harvested;
- development/update of regulations/licensing procedure, to account for seaweed aquaculture;
- development/maintenance of pilot farms for investigating seaweed species/strains and growth rates; yield; costs (setting up and running a farm); potential environmental effects; farm locations; storage of surplus algal biomass;
- Life Cycle Analysis of products (e.g. is economically viable to produce seaweed as biomass for biofuels production?), and development of supply chains for seaweed-related products;
- knowledge transfer between research and industry, with development of algal-business clusters.

It would also be important to obtain and record comprehensive figures of annual seaweed production for the UK (which could then be submitted regularly to the FAO).

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1 Introduction

Seaweeds, or macroalgae, are aquatic plants that, based on their pigmentation, can be divided into 3 groups, red (Rhodophyta; e.g. *Gracilaria*), brown (Phaeophyta; e.g. kelp such as *Saccharina latissima*) and green (Chlorophyta; e.g. *Ulva*; Figure 1).

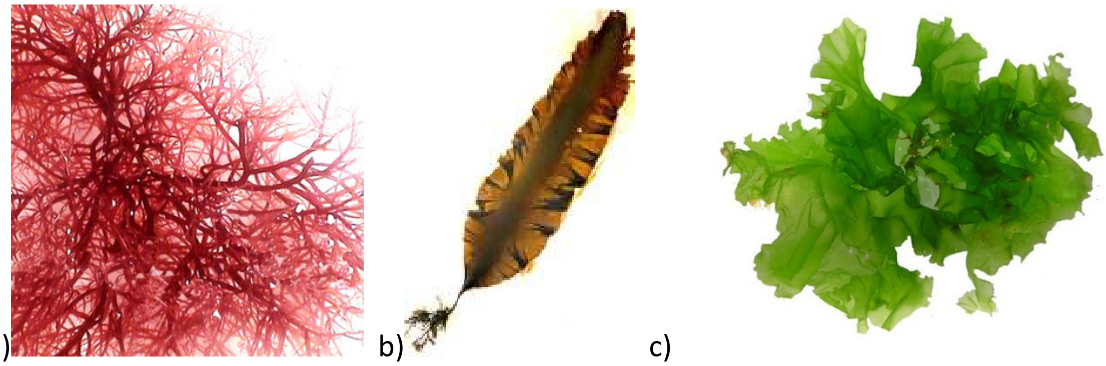
a) b) c)

Figure 1. Examples of red (a - *Gracilaria*), brown (b - *Saccharina latissima*) and green (c - *Ulva*) seaweeds[1].

Currently, more than 500 species of seaweeds, belonging to 100 genera, are collected and utilised (Mourisen 2013), although only 33 genera of seaweeds (mainly red and brown) are harvested and/or farmed commercially worldwide (McHugh 2003; West et al. 2016).

Seaweeds have been used by humans for millennia, with earliest records of seaweeds used as food source and medicine dating back to 14,000 years ago (Dillehay et al. 2008). Initially seaweeds were harvested from the wild but, in the last 50 years, the increased demand for seaweeds has moved the production mainly to aquaculture sources (Buchholz et al. 2012). Most recent figures from the Food and Agriculture Organization, FAO (FAO 2014; West et al. 2016), estimate world seaweed production at ~ 25 million tons in 2012, with a value of around US$6 billion. The majority of this production (96%) was from aquaculture, with China and few other Asian countries as top producers.

About 80% of macroalgae produced is used for human consumption (particularly in Asian countries such as China, Japan and the Republic of Korea) or for flavouring (West et al. 2016).

[1]a) http://www.nps.gov/acad/learn/nature/brownalgae.htm
b) http://cfb.unh.edu/phycokey/Choices/Rhodophyceae/Macroreds/GRACILARIA/Gracilaria_image_page.htm
c) http://protistaproject.weebly.com/ulva.html

The remaining 20% is used for extraction of phycocolloids, as well as for animal feed, fertilizers, water remediation and probiotics in aquaculture (West et al. 2016).

In the UK, harvesting of wild seaweeds for food, feed and fertilizers has been carried out for centuries, however seaweed farming does not have a long-standing history[2]. Nevertheless, in recent years, there has been an increased interest in seaweed aquaculture, as suggested by the development of different projects (e.g. EnAlgae[3], At~Sea[4], BioMara[5], SeaGas[6], MacroFuel[7], MacroBioCrude[8]), mainly driven by research on algal biofuel technologies. In fact, seaweeds could become an important source for third generation biofuels production as they do not compete for land and freshwater with food crops and non-food crops. Furthermore, seaweeds have high productivity, fast growth rate and high polysaccharide content (Hughes et al. 2012; Kerrison et al. 2015), important qualities for biomass for biofuels. Marine macroalgae could also represent a significant beneficial use as they can act as a sink for anthropogenic CO_2 ("Blue Carbon", Nellemann et al. 2009), and cultivation and harvesting of seaweeds could play an important role in carbon sequestration and reduction of greenhouse gas emissions (Chung et al. 2011).

Pilot seaweeds farms are currently developing in the UK with pilot facilities established in Northern Ireland (Queen's University, Belfast), Scotland (SAMS), Shetlands (University of Highlands and Islands) and, from this year, Wales (Swansea University). Due to its extensive coastline, seaweed production in the UK could be increased beyond the current level. This is likely to occur through farming as wild harvest is close to maximum capacity at locations with current activity[2]. However different limitations are perceived to the development of the seaweed sector, such as the need of a clearer marine licensing procedure for macro-algae, based on various criteria than the ones used for shellfish and finfish farms[2]. Furthermore, there is the need to establish how macroalgae cultivation can be done at a large scale in an environmentally and economically sustainable manner[2].

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[2] https://connect.innovateuk.org/documents/3312976/3726818/AB_SIG+Roadmap.pdf
[3] http://www.enalgae.eu/
[4] http://www.atsea-project.eu/
[5] http://www.biomara.org/
[6] http://www.seagas.co.uk/
[7] http://www.macrofuels.eu/
[8] http://community.dur.ac.uk/p.w.dyer/page2/styled-2/index.html

Following from the above considerations, the objectives of this report are to:

- review the current national and international seaweed sector (Section 2);
- investigate the status of the UK seaweed industry, summarising projects, applications and products (Section 3);
- investigate limitations (barriers) and issues associated with the development of the seaweed sector (Section 4);
- highlight the presence of potential gaps in regulation, licensing, for seaweed aquaculture (Section 5);
- identify Cefas current and potential new capabilities relevant to the seaweed industry (Section 6).

The final aim of this report is therefore to give Defra an overview of the national and international seaweed sector and products, as well as an overview of constrains to further development of the sector, particularly in the UK. Seaweed production has the potential of rapidly expanding, and therefore we sought to identify potential gaps in regulations for seaweed aquaculture in order to ensure that the development of this area is carried out in a sustainable manner. Further, the analysis of potential limitations in the seaweed sector, in relation to Cefas capabilities, will allow the identification of services that Cefas could provide to ensure the development of this area occurs respecting the relevant regulations and the health of the marine environment.

2 Where in the world is there a growing market for seaweed farming (or the potential for one)?

The FAO provides estimates of annual production of various types of aquatic plants for different countries in the world[9]. FAO estimates of aquatic plant production are divided between wild harvest (or capture), aquaculture and global (wild harvest + aquaculture), and can be queried from the FAO website based on continents, country, water type (inland water or marine areas), species and time. It is important to specify that the classification by continent is based on 'geographical' continents rather than 'political' continents. Therefore, in the FAO statistics, Norway is included under Europe, while America refers to both North and South America.

For the preparation of figures and tables presented in this Section of the report and Annexes 1 to 4, estimates of aquatic plant production (global, wild harvest and aquaculture) were extracted by country, for 'marine areas'-only, in the period 2000-2014. The 'aquatic plant' category included: brown seaweeds; green seaweeds; red seaweeds; and miscellaneous aquatic plants (combining unidentified seaweeds, eel-grass, and phytoplankton, such as *Spirulina*). All estimates of production are expressed as tonnes wet weight.

The FAO records are the only source of data on aquatic plant production covering the whole world. However, while records from some countries exist, these may not be reliable (e.g. unclear units, estimated production). For example, in the latest FAO report on aquaculture (FAO 2014), tonnage figures for North Korea and Vietnam were considered unreliable, whilst recognizing that these two countries are major producers of aquatic plants. For similar reason, monetary value of aquatic plant production has also been difficult to assess.

2.1 Global production of marine aquatic plants

On a global scale, production of aquatic plants has consistently grown (Figure 2). In 2000 aquatic plant production was on the order of 10.5 million tonnes, while in 2014 it was more than double, reaching 28.4 million tonnes (Figure 2).

[9] http://www.fao.org/fishery/statistics/en - latest download in March 2016

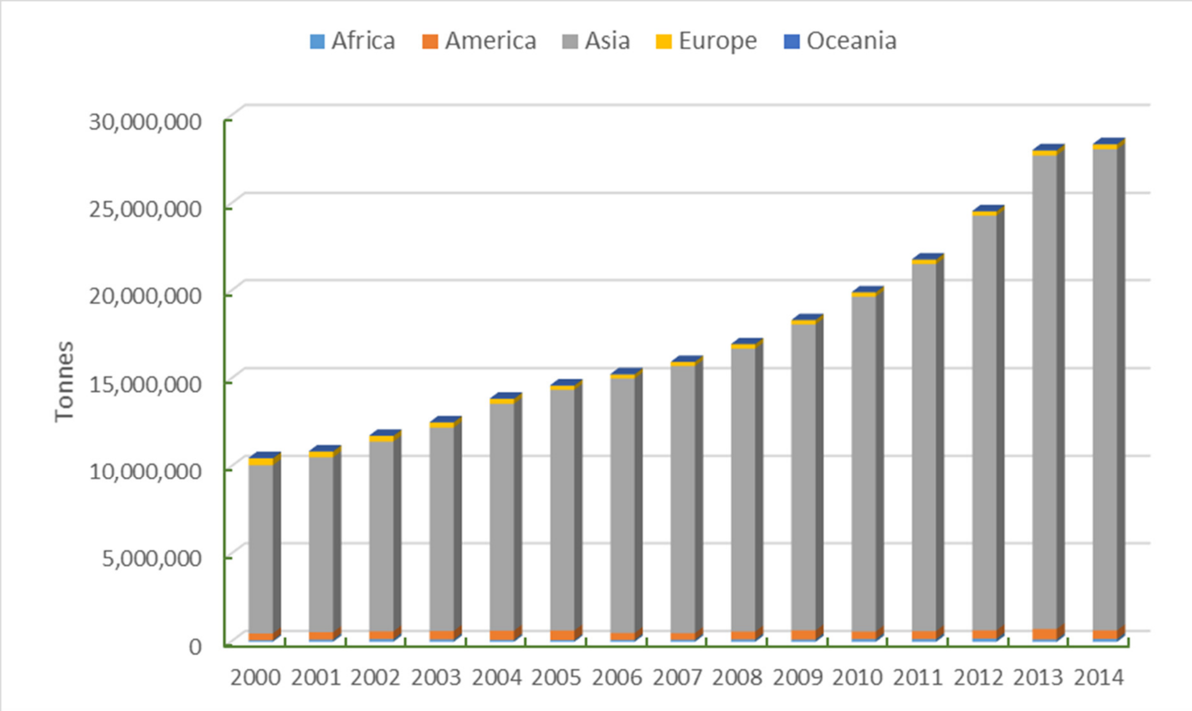
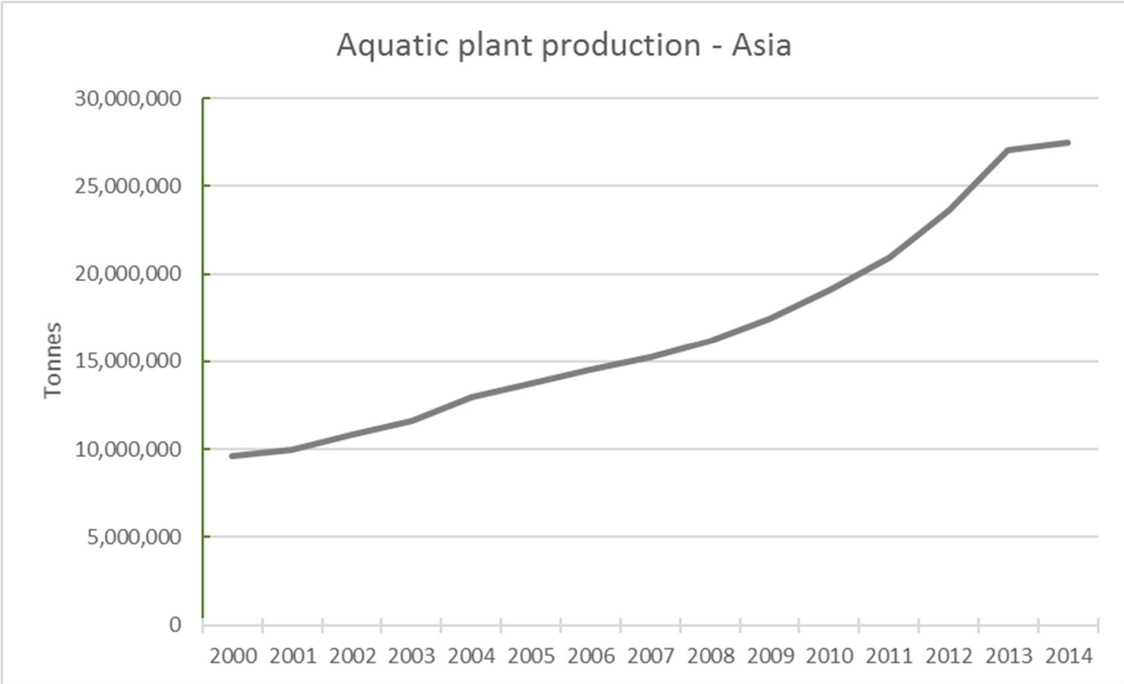


Figure 2. Cumulative annual world aquatic plant production (tonnes).

Asia dominates the global production of aquatic plants (96.6%, in 2014; Figure 2). Of the remaining continents, America accounts for 1.7%, Europe 1%, Africa 0.6% and Oceania 0.1%. All continents have seen an increase in aquatic plant production (Figure 3); for example, considering the period 2010-2014, production increased 44% in Asia, and 6, 11 and 14% in Africa, America and Europe, respectively. Although Oceania accounts for the smallest proportion of global production, in the period 2010-2014, it has seen a 73% increase in production.

A total of 51 countries produce marine aquatic plants; of this 6 Asian countries (China, Indonesia, Philippines, South Korea, Japan and Malaysia) accounted for 94.4% of the world production of marine aquatic plants in 2013 (Table 1). China alone accounted for 50.8% of production, while Indonesia for 30.8%. The only non-Asian countries ranked in the top 10 aquatic plant producers are Chile (2% of world production in 2013), Norway (0.6%) and Zanzibar (0.4%; Table 1). Countries, such as Indonesia, Malaysia, France, Peru, Solomon Island and Mexico, have shown a marked increase in production in the period 2009-2013, contrarily to Philippines, Japan, Norway, Iceland, Canada, Morocco, Russia and India which showed a decline (Table 1). Temporal trends of marine aquatic plant production for the different countries listed in Table 1, for the period 2000-2013, are shown in Annex 1.

a)


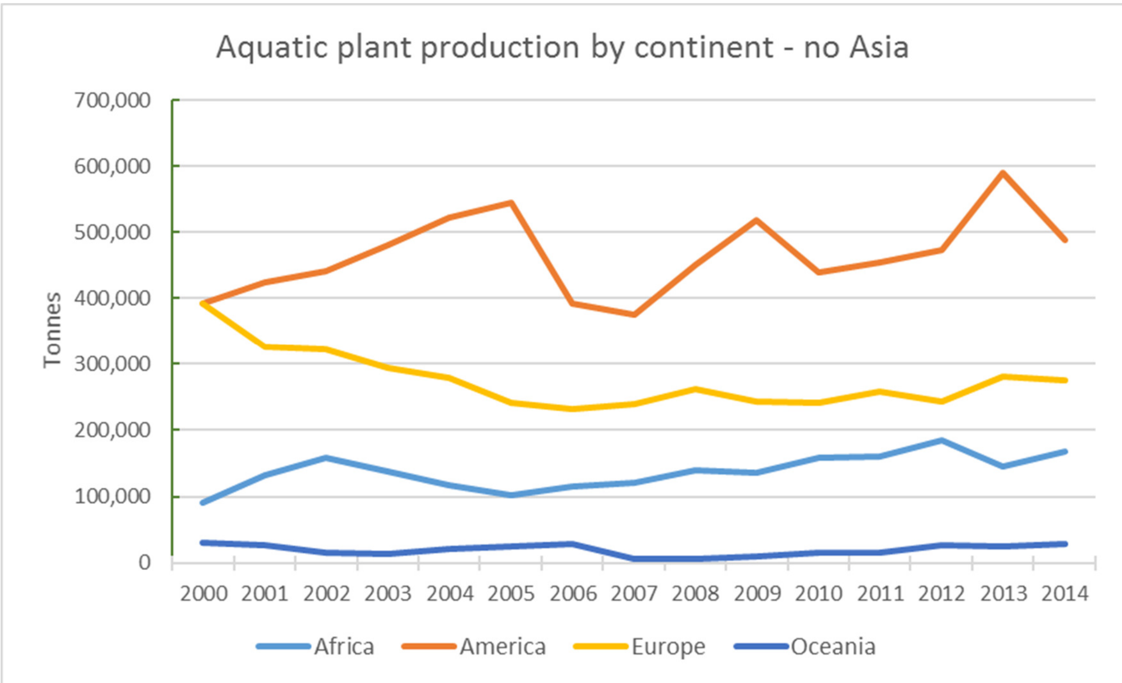
b)


Figure 3. Global production of aquatic plants (tonnes) from 2000 to 2014 for a) Asia, and b) Africa, America, Europe and Oceania.

Table 1. **Global** production of marine aquatic plants (tonnes) by country in the period 2009-2013 and summary statistics: per-cent 5-year change in production (green – increase; red – decrease); share of country production in 2013; cumulative country share production for 2013. Figures for North Korea and Vietnam are in grey-italic as considered unreliable by the FAO.

Country - tonnes	2009	2010	2011	2012	2013	5yr change	2013 % world prod	2013 % world prod - cumul
1 China	10700845	11241570	11750155	13009090	13759715	29%	50.81%	50.81%
2 Indonesia	2794718	3402133	4544892	5746329	8340399	198%	30.80%	81.61%
3 Philippines	1740429	1801745	1841291	1751476	1558778	-10%	5.76%	87.37%
4 South Korea	869502	914715	1007070	1032449	1139871	31%	4.21%	91.58%
5 Chile	456184	380742	417965	440146	530389	16%	1.96%	93.54%
6 Japan	560529	530027	437516	539268	502863	-10%	1.86%	95.40%
7 *North Korea*	*444300*	*444300*	*444300*	*444300*	*444300*	*0%*	*1.64%*	*97.04%*
8 Malaysia	138857	207892	239450	331490	269431.2	94%	0.99%	98.03%
9 Norway	160361	158516	152382	140998	154150	-4%	0.57%	98.60%
10 Zanzibar	102682	125157	130400	150876	110438	8%	0.41%	99.01%
11 France	19031.8	22717	47687	41579	69430	265%	0.26%	99.27%
12 Ireland	29500	29503	29503	29508.5	29541.5	0%	0.11%	99.37%
13 Peru	5677	4368	5801	3731.05	22133	290%	0.08%	99.46%
14 Iceland	22563	21014	15737	18079	17168	-24%	0.06%	99.52%
15 Solomon Islands	5100	8000	8000	12850	16700	227%	0.06%	99.58%
16 Canada	43300	43431	14824	13833	14842	-66%	0.05%	99.64%
17 South Africa	12648	13836	13786	18234	14583	15%	0.05%	99.69%
18 *Vietnam*	*15000*	*18221*	*14019*	*18544*	*13561*	*-10%*	*0.05%*	*99.74%*
19 USA	8207	9027	9614	9382	11388	39%	0.04%	99.78%
20 Mexico	5152	1128	5072	5725	10122	96%	0.04%	99.82%
21 Tanzania	5800	7172	7251.8	6966	7129	23%	0.03%	99.85%
22 Morocco	10368	7405	5797	5150	6138	-41%	0.02%	99.87%
23 Russian Federation	6567	6531	7460	8181	5983	-9%	0.02%	99.89%
24 India	6920	4242	4500	4500	4500	-35%	0.02%	99.91%
25 Madagascar	4400	4800	2514	2200	4375	-1%	0.02%	99.92%
Rest of the world	14463.6	15868.75	17775.64	25080.78	20645.8	NA	0.08%	100.00%
Total	**18183104**	**19424061**	**21174762**	**23809965**	**27078574**			

Total production of marine plants is the result of production via aquaculture and harvest of wild marine plants. Figure 4 highlights how the different continent's plant production is distributed between aquaculture and wild harvest. Aquaculture is the main source of production of marine plants for Africa and Asia, contrarily to America and Europe where production is almost entirely from harvest of wild plants (Figure 4). Oceania shows an intermediate pattern with wild harvest dominating production up to 2006, but switching to aquaculture as main source of marine plant production from 2007 (Figure 4). As Asia accounts for the majority of world marine plant production, it follows that almost all of the world production (95%) is from aquaculture.

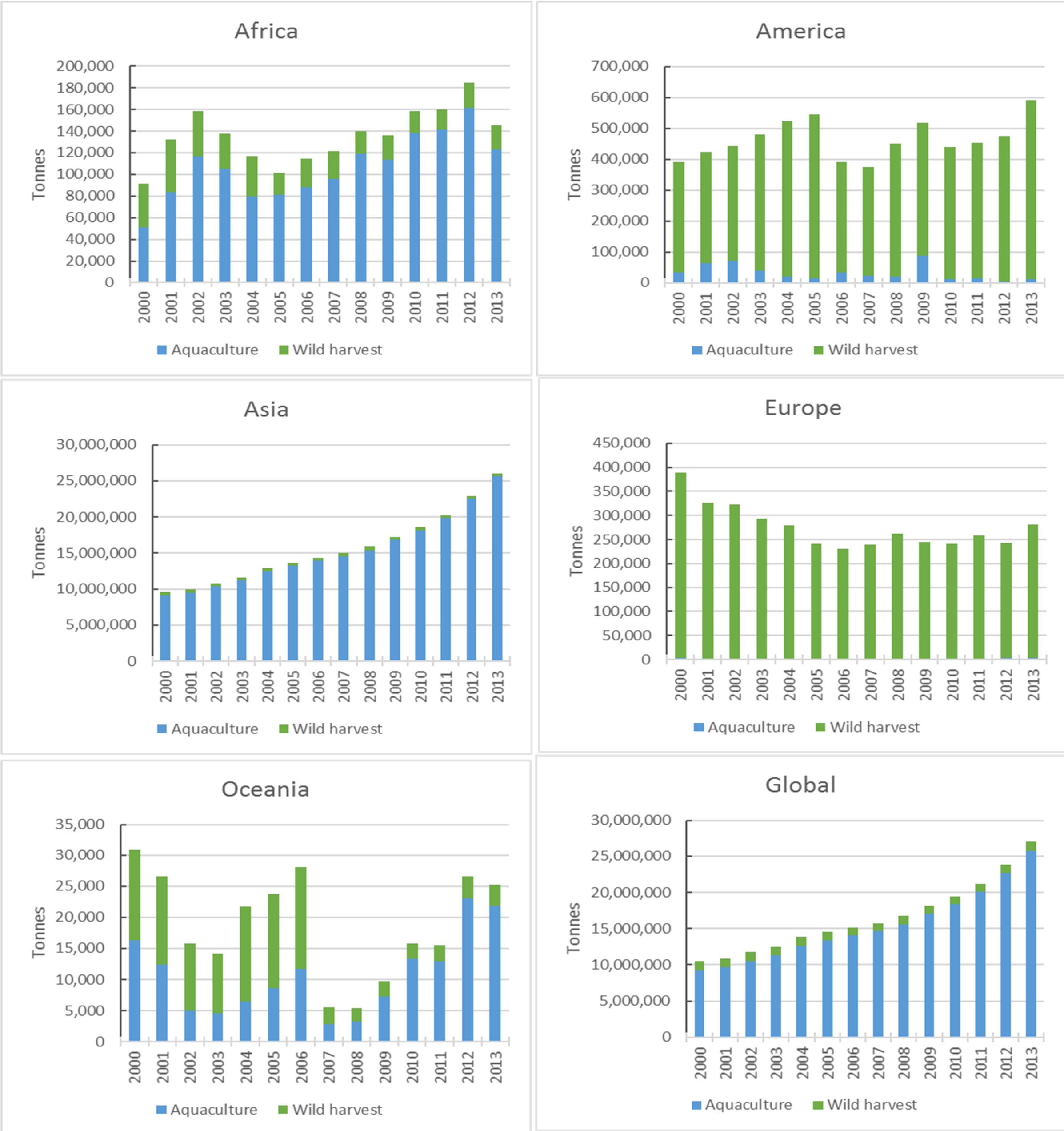


Figure 4. Annual aquatic plant production (tonnes) for the different continents and globally, highlighting the type of production source (aquaculture or wild harvest).

Annex 2 shows the relative contribution of the main producing countries in each continent in 2013. For America, Chile was the main producer both from wild harvest and aquaculture; in Europe, Norway and France were main producers of wild harvested aquatic plants while Denmark dominated production from aquaculture. In Africa, South Africa and Morocco were the main producers of wild plants while Zanzibar was leading producer from aquaculture. Asian production was dominated by China for both wild harvest and aquaculture, however Japan contributed significantly to the wild harvest production while Indonesia to production from aquaculture. Australia and New Zealand were responsible for the majority of marine plant production from wild harvest for Oceania while Solomon Island dominated the aquaculture production (Annex 2).

A final aspect to consider in relation to the world production of marine plants is how the production is distributed between typology of marine plant (i.e. brown seaweeds, red seaweeds, green seaweeds and miscellaneous). The majority of marine plants produced globally are red and brown seaweeds (97.4%; Figure 5). In particular, red seaweeds production has globally increased by 84% in the period 2010-2014, while brown seaweeds production increased by 47% in the same period. Contrarily global green seaweeds and miscellaneous aquatic plants productions decreased 30% and 79% respectively between 2010-2014. Figure 5 also highlights that almost all of Africa's production is red seaweeds, while Europe produces mainly brown seaweeds. Asia and America produce both red and brown seaweeds although the former has seen an increase in red seaweeds production in recent years. Similarly, production in Oceania changed from a dominance by brown seaweeds up to 2006 and then by red seaweeds from 2007. It would be reasonable to conclude that Oceania production was based on wild harvest of brown seaweeds up to 2006 and changed to aquaculture of red seaweeds from 2007.

Figure 5. Cumulative annual production (tonnes) of the different types of aquatic plants (brown, green and red seaweeds, miscellaneous aquatic plants), by continent and globally.

2.2 Production of marine aquatic plants from wild harvest

A total of 35 countries produce marine aquatic plants from harvest of wild resources. The top 15 producers for 2013 are listed in Table 2. Asian countries (China, Japan, Indonesia and South Korea) only account for 30.6% of world production of wild aquatic plants, which is dominated instead by American and European production (Table 2). In particular, Chile was responsible for 40.7% of global production, followed by China (22%), Norway (12%), Japan (6.6%), and France (5.4%). Considering the change in production for the period 2009-2013, countries such as Chile, France, Peru, Indonesia, South Africa, USA and Mexico showed a significant positive increase in production, while China showed only a small increase (2%). Norway, Japan, Iceland, Canada, South Korea and Morocco reduced their production between 2009-2013 (Table 2).

Table 2. Production of marine aquatic plants (tonnes) from **wild harvest**, by country in the period 2009-2013 and summary statistics: per-cent 5-year change in production (green – increase; red – decrease); share of country production in 2013; cumulative country share production for 2013. Figures for Ireland are in grey-italic as they appear estimates rather than actual production.

Country - tonnes	2009	2010	2011	2012	2013	5yr change	2013 % world prod	2013 % world prod - cumul
1 Chile	368032	368580	403496	436035	517929	41%	40.72%	40.72%
2 China	275980	246360	273620	257280	280360	2%	22.04%	62.77%
3 Norway	160361	158516	152382	140998	154150	-4%	12.12%	74.89%
4 Japan	104103	97231	87779	98514	84498	-19%	6.64%	81.53%
5 France	18907	22597	47307	41229	69126	266%	5.44%	86.97%
6 Ireland	*29500*	*29500*	*29500*	*29500*	*29500*	*0%*	*2.32%*	*89.29%*
7 Peru	5677	4368	5801	3585	22089	289%	1.74%	91.03%
8 Iceland	22563	21014	15737	18079	17168	-24%	1.35%	92.38%
9 Indonesia	3030	2697	5479	7641	17136	466%	1.35%	93.72%
10 Canada	43300	43431	14824	13833	14842	-66%	1.17%	94.89%
11 South Africa	10748	11821	10901	16234	12583	17%	0.99%	95.88%
12 USA	8207	9027	9614	9382	11388	39%	0.90%	96.77%
13 Mexico	5152	1128	5072	5725	10122	96%	0.80%	97.57%
14 South Korea	10843	13043	14787	10123	8566	-21%	0.67%	98.24%
15 Morocco	10368	7405	5797	5150	6138	-41%	0.48%	98.73%
Rest of the world	14980	12432	15462	16100	16192	NA	1.27%	100.00%
Total	**1091751**	**1049150**	**1097558**	**1109408**	**1271787**			

The main type of aquatic plants harvested in the wild globally is brown seaweeds (60% in 2013; Figure 6), followed by miscellaneous aquatic plants (25%) and red seaweeds (15%). Global production of aquatic plants from wild harvest appears to have been relatively stable between 2000 and 2013 (Figure 6).

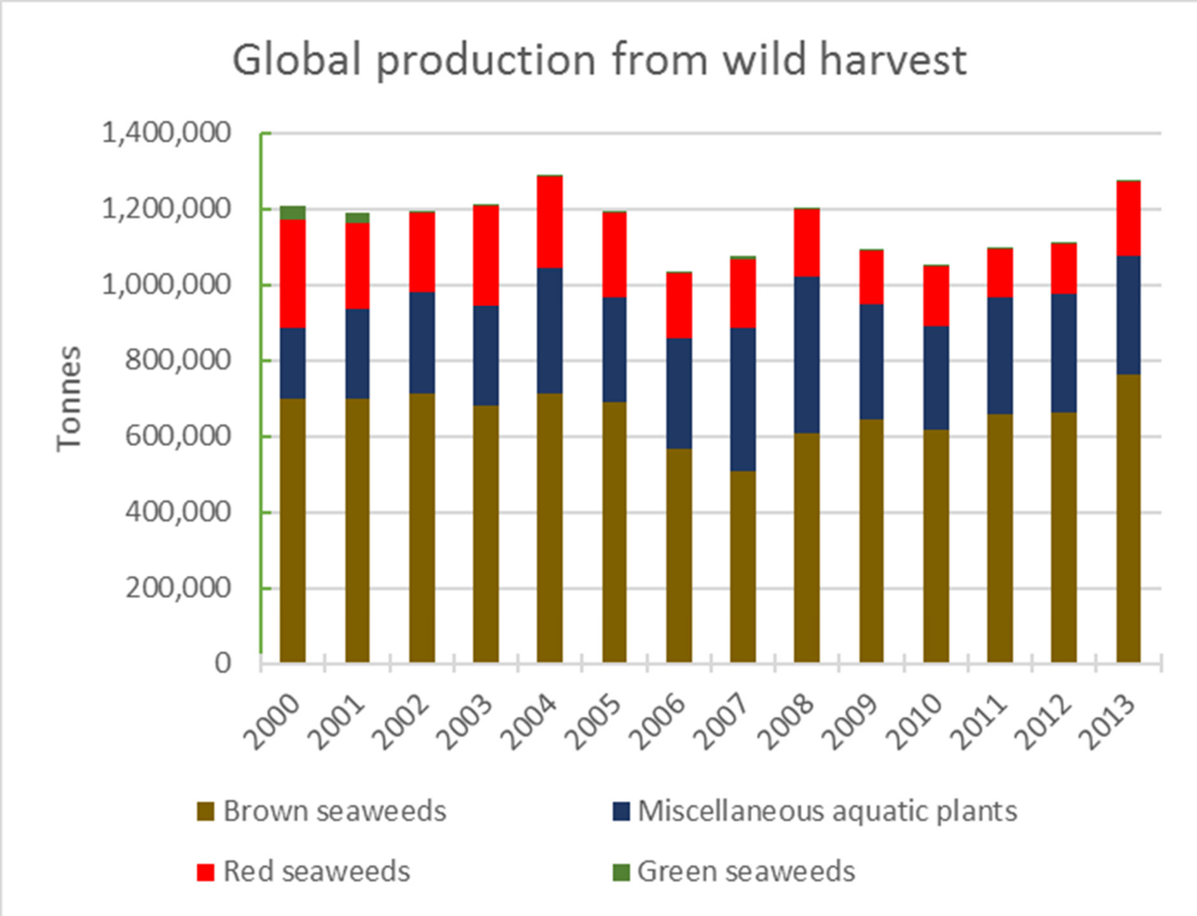


Figure 6. Global cumulative annual production (tonnes) from wild harvest of the different types of aquatic plants (brown, green and red seaweeds, miscellaneous aquatic plants).

Almost all countries from Table 2 (except China, Peru, Indonesia, Morocco and Canada) harvest mainly brown seaweeds (Annex 3). Peru, Indonesia and Morocco only harvest red seaweeds from the wild, while China produce miscellaneous aquatic plants (i.e. unspecified aquatic plant; Annex 3). Production from wild harvest in Canada was dominated by brown seaweeds up to 2002, then by red seaweeds (Annex 3).

2.2.1 Production from wild harvest in the UK

There are no records of macroalgae production for the UK in the FAO database although harvesting of wild seaweeds occurs in various parts of the UK (Figures 7-8). Reports by Netalgae (www.netalgae.eu) indicate that seaweeds (brown, red and green) are gathered by hands in the UK (Figure 7). James (2010) indicated that approximately 5,000 tonnes per year of *Ascophyllum nodosum* (a brown seaweed) are harvested in Scotland; in addition, unknown quantities of subtidal kelp and storm-cast seaweeds are also collected. In 2012, Viking Fish Farms Ltd[10] estimated that annual production of wild harvested seaweeds in the UK was around 6,000 wet tonnes. According to Viking Fish Farms Ltd, the UK macroalgae industry (constituted by 15 small medium enterprises - SMEs) had an estimated value of £1-1.3 million (in 2012). The majority of wild seaweeds were harvested in the Outer Hebrides (approximately 5,500 tonnes), while the remaining was harvested (mainly for food and agriculture) in the Orkney and Shetlands Islands and Northern Ireland (Viking Fish Farms Ltd. 2012). Harvest in South Wales (of *Porphyra* species) is carried out for preparation of food such as laverbread (Figure 8). A more recent estimate of seaweed production in the UK is of 2,000-3,000 dry tonnes (AB-SIG 2013), which could be roughly considered equivalent to 20,000-30,000 wet tonnes[11].

To our knowledge, there are no recent estimates of the wild seaweed standing stock of the UK nor of the potential stock that could be sustainably harvested. An exception is the investigation of the intertidal seaweed resources of the Outer Hebrides, which was carried out by Burrows and co-authors, in 2010. Based on this study, the biomass of *Ascophyllum nodosum* for the Outer Hebrides was estimated at 170,500 tonnes of which 15,000-25,000 tonnes could be sustainably harvested annually (Burrows et al. 2010).

For the rest of Scotland, it was suggested (Kelly and Dworjanyn 2008) that the most accurate estimates of macroalgae standing stock are still the ones calculated more than 60 years ago by Walker and co-authors in a series of surveys from 1946 to 1953 (Walker 1954). Walker (1954) estimated a standing stock of 10 million tonnes of algae, although Kelly and Dworjanyn (2008) highlighted that this estimate should be increased to 30-50 million tonnes (due to underestimation of algal biomass during sampling).

[10] www.netalgae.eu

[11] Assuming that 1 tonne of dry seaweed *S. latissima* is equivalent to 10 tonnes of wet seaweed as suggested by Hughes et al. 2012

Species	Gathered by hand on shore (drift and attached)	Mechanical harvesting	Diving	Farming (including trials)
Alaria esculenta	UK			France, Ireland, Norway
Ascophyllum nodosum	UK, France, Ireland, Norway, Spain	Norway		
Asparagopsis armata			Spain	France, Ireland
Chondrus crispus	UK, France, Ireland, Spain, Portugal		Spain	France
Codium sp.	Spain, Portugal		Spain	
Corallina officinalis	UK	Ireland		
Dilsea carnosa	Ireland			
Fucus ssp	UK, France, Ireland, Spain, Portugal		Spain	
Gelidium corneum			Portugal	
Gelidium sesquipedale	France, Spain	France	Spain, Portugal	
Gigartina pistillata	Spain, Portugal			
Gracilaria spp.				Portugal
Himanthalia elongata	UK, France, Ireland, Spain			
Laminaria digitata	UK, France, Ireland, Norway	France	Norway	UK, France, Ireland
Laminaria hyperborea	UK, Ireland, Norway	France, Norway	Norway	UK
Mastocarpus stellatus	UK, France, Ireland, Spain, Portugal			
Palmaria palmata	UK, France, Ireland, Portugal, Norway			France, Ireland
Porphyra umbilicalis	UK, France, Spain			France, Ireland, Norway
Saccharina latissima	UK, France, Portugal, Norway	Ireland	Spain, Norway	UK, France, Norway, Spain
Ulva sp.	UK, France, Ireland, Norway, Spain, Portugal		Spain	France
Undaria pinnatifida				France, Spain

Figure 7. Species harvested and harvesting technique in Europe, from report by Netalgae (2012) on the seaweed industry in Europe (www.netalgae.eu).

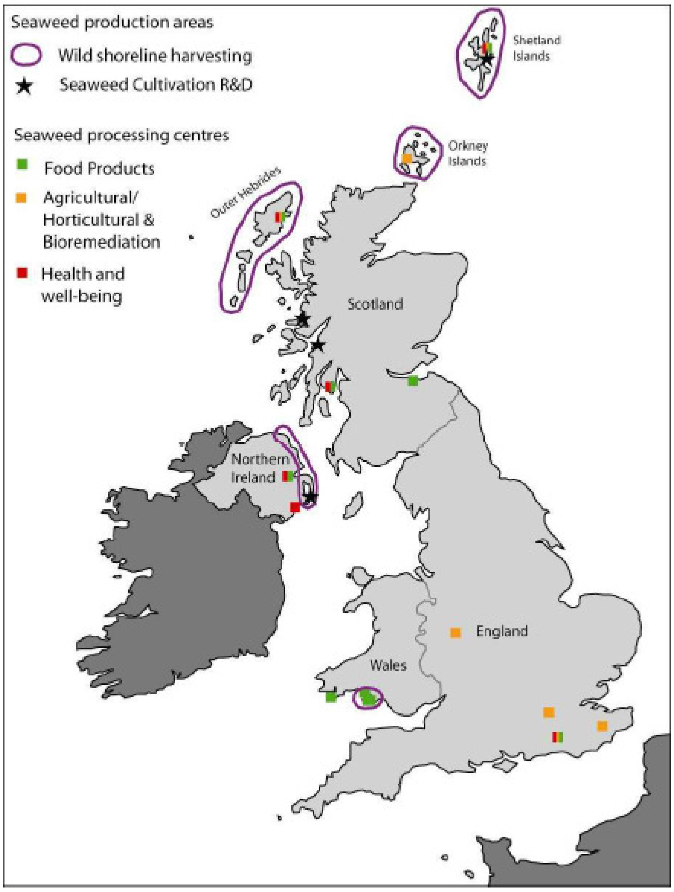


Figure 8. Seaweed production areas in the UK and uses as in 2012 (from Viking Fish Farm Ltd, 2012, Netalgae).

2.3 Production of marine aquatic plants from aquaculture

There are 35 countries in the world that farm marine aquatic plants. However just 7 (China, Indonesia, Philippines, South Korea, North Korea, Japan and Malaysia) accounts for 99.3% of the world production (Table 3). China and Indonesia alone produce 84.5% of world production of marine aquatic plants (52.2 and 32.3% respectively in 2013; Table 3). World production of farmed seaweeds almost tripled between 2000 and 2013 (2.8-fold increase; Figure 9). Particularly strong expansion has been observed in Indonesia (42-fold increase in production between 2000 and 2013; Annex 4) and further expansion is anticipated in this country as the Government embraces a "blue growth" policy (see Annex 5 for further details on the seaweed industry in Indonesia). China also saw a near doubling in production between 2000 and 2013 (1.94-fold increase).

Other countries have seen a positive increase in production such as South Korea, Malaysia, Zanzibar, Tanzania and Solomon Islands (Table 3). The latter, although representing a small proportion of the global aquatic plant production (0.06%), has seen marked increase in production (Table 3 and Annex 4), mainly for the export market (FAO 2014). Of the major producers of aquatic plants, Philippines and Japan showed a reduction in production from aquaculture in the period 2009-2013, as well as Vietnam, Chile, India and Madagascar (Table 3). For Japan, the reduction in production has been offset by imports of marine aquatic plants from other countries (FAO 2014).

The FAO (2014) has also recognized that several countries (including India, Madagascar, Fiji, Kiribati, East Timor, and Mozambique) have potential for significant increase in production of seaweeds. Mozambique represents an exception, as seaweed farming has stopped in this country due to non-technical reasons such as marketing (FAO 2014).

Considering the type of marine aquatic plants produced, red seaweeds have been representing the majority of the production in recent years (e.g. 57% of global marine aquatic plant production in 2013); while, up to 2008, brown seaweeds were the main type of aquatic plant produced (Figure 9). As a result, up to 2010 the main species of algae produced globally was the brown seaweed Japanese kelp, while after 2010 it was *Euchema*, a red seaweed, farmed in tropical and subtropical waters. This expansion in production was driven by the growth of the Indonesian red seaweeds industry as well as of other countries (FAO 2014).

In particular, red seaweeds production increased 7.6-fold between 2000 and 2013, while brown seaweeds production doubled. In the same period of time, production of miscellaneous aquatic plants has maintained approximately constant while production of green seaweeds has halved (Figure 9).

Table 3. Production of marine aquatic plants (tonnes) from **aquaculture**, by country in the period 2009-2013 and summary statistics: per-cent 5-year change in production (green – increase; red – decrease); share of country production in 2013; cumulative country share production for 2013. Figures for North Korea are in grey-italic as they are not reliable.

Country - tonnes	2009	2010	2011	2012	2013	5yr change	2013 % world prod	2013 % world prod - cumul
1 China	10424865	10995210	11476535	12751810	13479355	29%	52.23%	52.23%
2 Indonesia	2791688	3399436	4539413	5738688	8323263	198%	32.25%	84.48%
3 Philippines	1739995	1801272	1840833	1751071	1558378	-10%	6.04%	90.52%
4 South Korea	858659	901672	992283	1022326	1131305	32%	4.38%	94.91%
5 North Korea	*444300*	*444300*	*444300*	*444300*	*444300*	*0%*	*1.72%*	*96.63%*
6 Japan	456426	432796	349737	440754	418365	-8%	1.62%	98.25%
7 Malaysia	138857	207892	239450	331490	269431.2	94%	1.04%	99.29%
8 Zanzibar	102682	125157	130400	150876	110438	8%	0.43%	99.72%
9 Solomon Islands	5100	8000	8000	12850	16700	227%	0.06%	99.79%
10 Vietnam	15000	18221	14019	18544	13561	-10%	0.05%	99.84%
11 Chile	88152	12162	14469	4111	12460	-86%	0.05%	99.89%
12 Tanzania	5520	6885	6600.8	6510	6689	21%	0.03%	99.91%
13 India	6920	4240	4500	4500	4500	-35%	0.02%	99.93%
14 Madagascar	3600	4000	1699	1400	3575	-1%	0.01%	99.94%
15 Papua New Guinea	0	100	250	1400	2500		0.01%	99.95%
Rest of the world	9589.4	13567.75	14715.64	19927.33	11966.3		0.05%	100.00%
Total	**17091353**	**18374911**	**20077204**	**22700557**	**25806787**			

If we consider the type of algae produced by the main countries in Table 3, Indonesia, Philippines, Malaysia, Zanzibar, Solomon Islands, Vietnam, Chile, Tanzania, India, Madagascar and Papua New Guinea farm exclusively red seaweeds (Annex 4). Only China, South Korea and Japan farm various types of seaweeds; Japan produces brown and red seaweeds with the red as the dominant crop. China and South Korea are the only countries farming green seaweeds but for both the dominant type of aquatic plant produced is brown seaweeds (Annex 4). In particular, the main brown seaweed species produced is the Japanese kelp, the most-farmed cold-water seaweed (FAO 2014). The culture of Japanese kelp has become more established with the development of high-yield and warm-water tolerant strains. The result is that recently more Japanese kelp is produced in the south than in the north of the country (FAO 2014). Furthermore, increased in production has also resulted from the promotion of seaweed farming as a way to bio-extract nutrients in seawater released from fish/crustacean/shellfish aquaculture (FAO 2014).

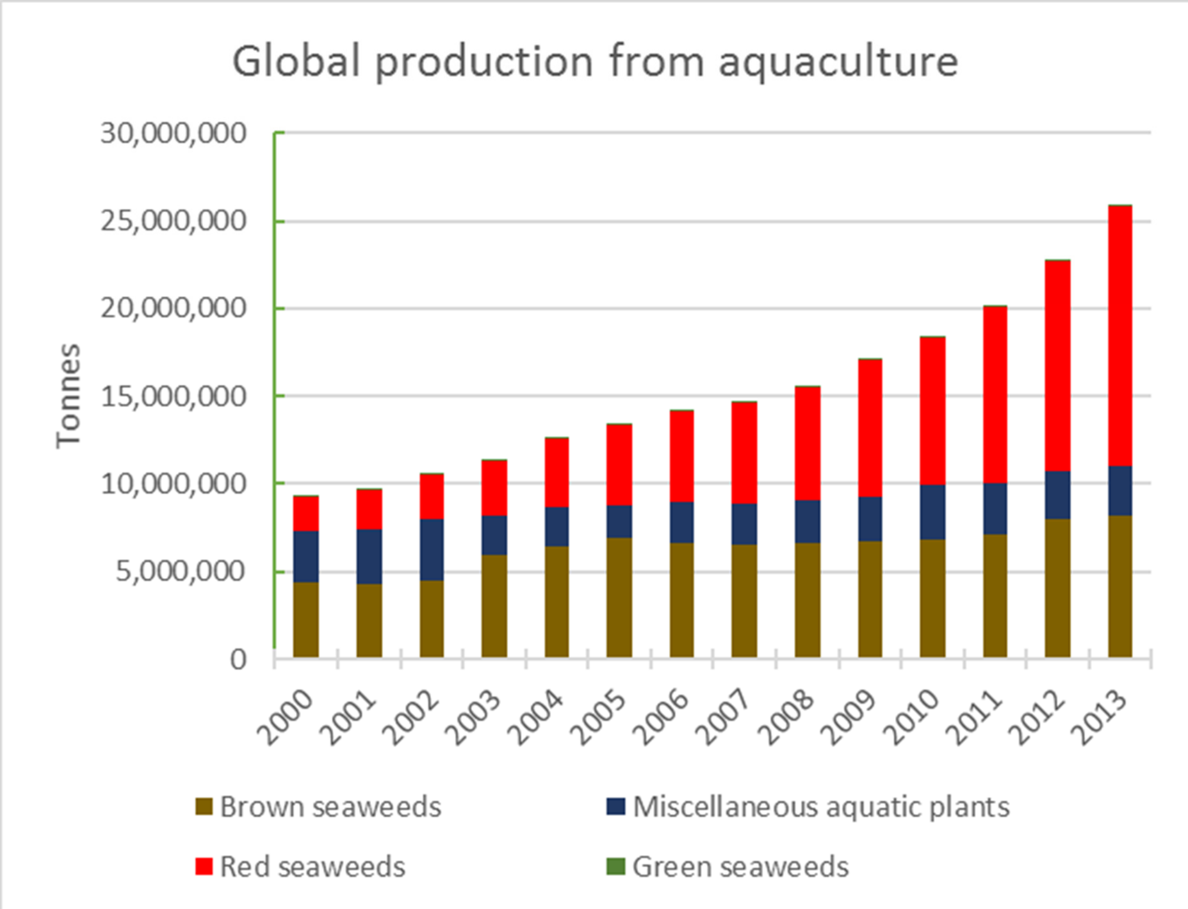


Figure 9. Global cumulative annual production (tonnes) from aquaculture of the different types of aquatic plants (brown, green and red seaweeds, miscellaneous aquatic plants).

European countries do not appear between the main producers of farmed aquatic plants as the main source of marine aquatic plants produced in Europe is from harvest of wild resources (Figure 4). Of the 35 countries farming marine aquatic plants, Denmark ranks 18th, France 25th, Ireland 28th, and Spain 32nd (based on 2013 production figures). In these countries seaweed farming started in the last 10 years except for France (Figure 10). Brown seaweeds are the main type of aquatic plants farmed except for France that since 2009 has been farming miscellaneous aquatic plants (Figure 10). Both Denmark and France has seen an increase in production in the period 2009-2013, although production seems to have been decreasing for France since 2011 (Figure 10). The Netalgae website reports there are 6 seaweed farms in

Brittany (France), 2 farms in Galicia (Spain), and pilot farms in Ireland, Asturias (Spain), Norway and the UK (from www.netalgae.eu). Netherlands has also started showing commercial interest in seaweed farming[12], as also suggested by the completion of the NIOZ (Royal Netherlands Institute for Sea Research) Seaweed Centre in 2014[13].

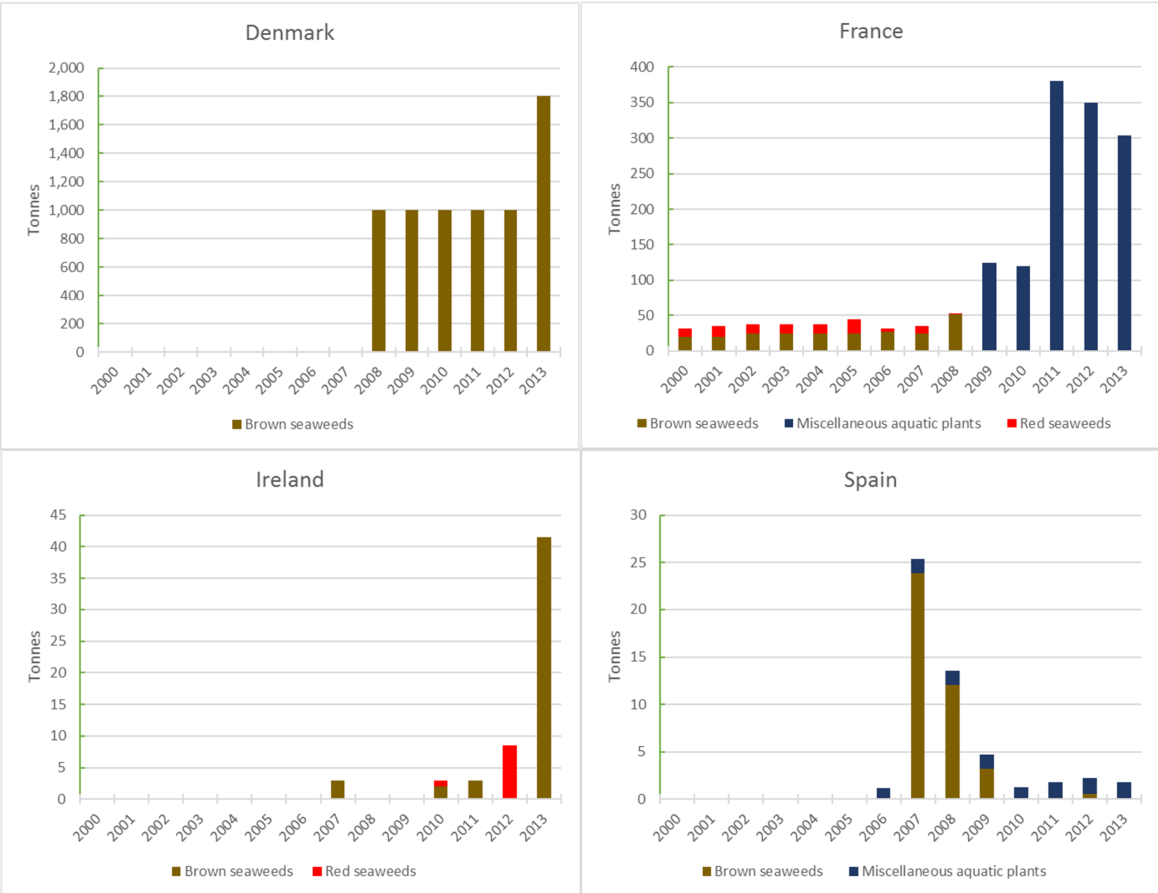


Figure 10. Cumulative annual production (tonnes) from aquaculture of the different types of aquatic plants (brown, green and red seaweeds, miscellaneous aquatic plants), for Denmark, France, Ireland and Spain.

2.3.1 Production from aquaculture in the UK

There is currently limited cultivation of seaweeds in the UK although pilot seaweeds farms are currently developing for R&D. Pilot facilities are established in Northern Ireland (Queen's

[12] http://www.dutchnews.nl/features/2015/07/pioneering-dutch-enterprise-sets-out-to-put-seaweed-on-the-table/

[13] https://www.nioz.nl/seaweedcentre

University, Belfast), Scotland (SAMS), Shetlands (University of Highlands and Islands) and, from this year (2016), Wales (Swansea University). Locations of farms in Scotland and Northern Ireland are marked in Figure 8. These pilot farms have been producing seaweeds (mainly brown seaweeds such as *Saccharina latissima*, sugar kelp) as part of different projects (e.g. SeaGas[14], MacroFuel[15], MacroBioCrude[16]) to investigate the potential use of seaweeds as source for biofuel, chemicals, speciality products, etc. The latest pilot farm, developed by SAMS has a 100x100 m grid and could provide up to 25 tonnes of seaweeds per year, starting in 2016[17].

[14] http://www.seagas.co.uk/

[15] http://www.macrofuels.eu/

[16] http://community.dur.ac.uk/p.w.dyer/page2/styled-2/index.html

[17] http://www.scotsman.com/news/environment/seaweed-farm-to-begin-production-off-argyll-coast-1-3847291 and from P. Kerrison's -SAMS- presentation at the International Conference on Marine Biomass as Renewable Energy, Glasgow 3-4 March 2016.

3 What are the main products from seaweeds in the UK?

There is evidence that seaweeds have been used for centuries in different parts of the world, for example France and Europe (see review by Mesnildrey et al. 2012), Chile (Dillehay et al. 2008), and Japan (see review by Buchholz et al. 2012). Traditionally, seaweeds have been used as a food source, as animal feed, soil enricher, and as fuel. In Europe, seaweeds have played an important socio-economic role through the years particularly for Ireland, Wales, Scotland, Brittany, Iceland and Norway (Mouritsen 2013). In the 17th and 18th centuries, brown seaweeds were burned in Europe for production of potash and soda, used, for example, in the glass industry, and for soap production (Mesnildrey et al. 2012; Mouritsen 2013; Netalgae 'Seaweed Industry in Europe' report 2012). From the start of the 19th century, macroalgae were used for extraction of iodine and production of tincture of iodine (Mesnildrey et al. 2012). After the 2nd World War, seaweeds were mainly harvested in Europe for production of hydrocolloids, particularly alginic acid (gelling and thickening agent in food and non-food applications), with the alginate industry becoming established from the 1950s (Mesnildrey et al. 2012, Netalgae 'Seaweed Industry in Europe' report 2012).

3.1 Overview of uses of seaweeds

Based on McHugh (2003), Mouritsen (2013) and AB-SIG (Algal Bioenergy Special Interest Group) Roadmap (2013)[18] current uses of seaweeds (and associated industries) can be divided into the following categories (Figure 11):

1. Food (human consumption as sea vegetables and premium condiments) and animal feeds and supplements;
2. Chemicals production (hydrocolloids, organic fertilisers, ethanol etc.);
3. Bio-actives used in the cosmeceuticals and nutraceuticals industries;
4. Bioenergy and biofuels (e.g. bio-methane production);

[18] 'A UK Roadmap for algal technologies' https://connect.innovateuk.org/documents/3312976/3726818/AB_SIG+Roadmap.pdf

5. Bioremediations (for example for removing heavy metals and/or nutrients from water bodies or from waste water);
6. Algal knowledge and technologies industries (although this is not a 'use' of seaweeds *per se*, consultancies, suppliers and other business have developed around the other uses of seaweeds listed from 1 to 5).

Seaweeds are also used for preparation of paper[19] and for fabrics[20]. The former use was developed in Italy in the early 1990s as a way of using excessive sea lettuce biomass that was clogging the Lagoon of Venice as result of eutrophication.

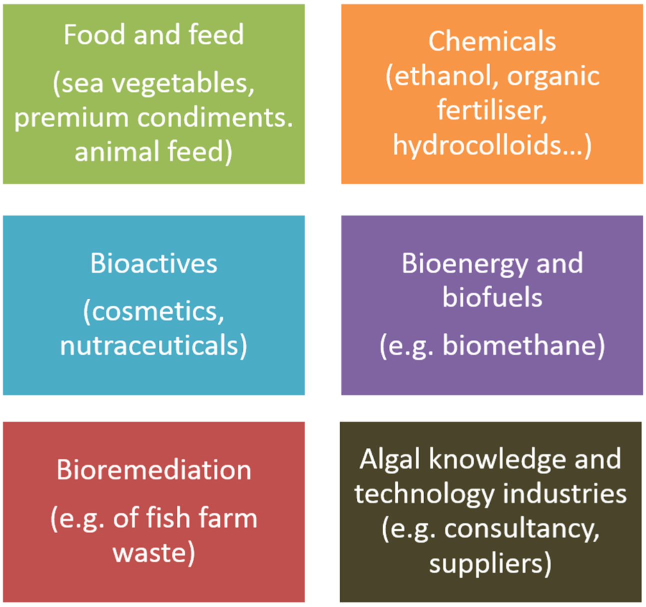


Figure 11. Main uses (and associated industries) for seaweed biomass (based on AB-SIG Roadmap 2013).

3.1.1 Seaweeds as human food source and animal feed

Macroalgae play an important role in human nutrition as their composition is particularly different from the composition of terrestrial plants. In particular, seaweeds have 10-time higher mineral content of plants growth on soils, have a wide range of trace elements and vitamins, and low calories count (Mouritsen 2013).

Countries such as China, Japan and Philippines are the largest consumers of seaweed as food, however seaweeds are also used as food source in different other countries (McHugh 2003).

[19] http://www.favini.com/gs/en/fine-papers/shiro/features-applications/
[20] http://www.smartfiber.info/seacell

The main types of brown algae used as food are *Laminaria*, *Undaria* and *Hizikia* while *Porphyra* (nori or laver) is the most commonly used red seaweed e.g. laver-bread (McHugh 2003). Dulse (*Palmaria palmata*), another red seaweed, is used, on a smaller scale, as food and condiment. Between the green algae, *Ulva* and *Monostroma* are used in salads, soups or additive to enhance food flavours. Mouritsen (2013) provides a detailed description of various edible seaweeds and recipes for using them.

In Europe, a market analysis conducted by Organic Monitor in 2014 indicated that the wholesale value for sea vegetables was approximately 24 million euros (in 2013), with France being the larger consumer market.

France, the UK, Germany and Spain comprised approximately 80% of the European revenues for sea vegetables in 2013 (Organic Monitor 2014). The market of seaweeds as sea vegetables is growing around 7-10% per year following demand from catering and foodservice companies, retail market and food processors (Organic Monitor 2014).

European producers (mainly from France and Spain) supply 25% of the market, however nori, the dominant product, is almost entirely imported into Europe with the UK having the biggest market. Dulse, the second largest product, is mainly produced at regional scale, with imports constituting a small portion (10%) of the market. France is the major producer of dulse (90% of European market) while Spain is the leading producer for wakame (*Undaria pinnatifida*; Organic Monitor 2014).

The report by Organic Monitor (2014) identified the following as main drivers of the growth of the European sea vegetables market:

- high demand from the Catering and Food service (CFS), particularly for nori, for production of Asian food;
- growing number of sea vegetables used in food products (not only Asian food but also in European cuisine);
- specialist retailers (e.g. health shops) are now offering a range of sea vegetables;
- consumers have become aware of health and nutritional benefits of sea vegetables.

Seaweeds have been used as fodder for domestic animals such as sheep, cows, pigs, horses, for centuries; on the Orkney Islands there is still a native breed of sheep feeding on seaweed on the shore (see review by Mouritsen 2013). Interestingly, this breed of sheep was important for the development of another use of seaweeds (production of biomethane) as the microbes used for anaerobic digestion in AD plants of seaweeds were extracted from these sheep stomachs and faeces[21]. Seaweeds are also added to animal feed in forms of granules or powder.

3.1.2 Chemicals

Hydrocolloids are used in the food, cosmetic and medical industries (see review by West et al. 2016). Alginates and fucoidan are extracted from brown seaweeds, while carrageenan and agar from red seaweeds (McHugh 2003). These three components (polysaccharides) can bind water and form hydrogels which are then used as additives and stabilizers in different sectors (Mouritsen 2013).

Alginates are derived from brown seaweeds and are produced mainly in the USA, Norway, China, Canada, France and Japan. They are used in food as thickeners, gelling and stabilizers for different products from ice cream, to beers (review by Mouritsen 2013).

Carrageenans are extracted from red seaweeds and, as seen in Section 2 and in Annex 5, Indonesia is the main producer of farmed red seaweeds. Carrageenans have protein-binding properties therefore it is used in the dairy sector as stabilizer; for example, 0.02% of carrageenan in ice cream will ensure slower melting (review by Mouritsen 2013). Other industrial uses of this hydrocolloid are in shampoos and toothpastes.

The global demand of agar (another hydrocolloid extracted from red seaweeds) is mainly covered by Chile, India, Mexico, California, South Africa and Japan. It is a versatile food addictive (thickening and emulsifying agent) as it has no taste, smell or colour; and it is also used as cultivation medium for bacteria in laboratories (review by Mouritsen 2013).

Various studies (Eyras *et al*. 1998; Alm *et al*. 2013; Bernstein *et al*. 2004) indicate that seaweeds, added to soil as compost, or dried as amendment, or with no pre-treatment, are beneficial to the growth of plants (e.g. tomatoes, corn). Macroalgae have higher concentration of Ca, K, Mg, Na, Cu, Fe, I and Zn compared to terrestrial plants, and their organic compounds can be used as energy source for microbes (see Alm *et al*. 2013 and

[21] From Michele Stanley's presentation at MBRE conference, Glasgow March 2016

reference within). Seaweeds as soil conditioners have the ability to make the soil more porous which allow water and air to penetrate through (Mouritsen 2013).

3.1.3 Bio-actives (cosmetics, nutraceuticals, biomedicals and pharmaceuticals)

A number of studies have been carried out to investigate how seaweeds components (for example, sulphate polysaccharides or iodine) interact with cancers, immune system, inflammation, viruses, pathogenic fungi and bacteria (see review by Mouritsen 2013 and by Chiellini and Morelli 2011).

Some of the chemical substances developed by seaweeds for protection against grazers are important bio-actives also for human, such as iodine. However, there are other secondary metabolites of seaweeds which can have potential beneficial effects such as anti-cancer, anti-viral and antibiotics applications (Mouritsen 2013 and reference within). For example, fucoidan, a sulphated polysaccharide, has shown to inhibit herpes simplex virus in mice, by direct inhibition of viral replication and by stimulating immune defence functions (Hayashi et al. 2008).

Hydrocolloids from seaweeds are used in cream to treat skin diseases, in the fabrication of capsule for medicines, for making plasters and bandages, while mannitol (extracted from seaweeds) is a less caloric alternative to normal sugar as sweetener (Mouritsen 2013).

Seaweeds and seaweed components are used in beauty treatments for example thalassotherapy (seawater and algae) or ‘algotherapy’ which should have different beneficial effects, for example on the skin, and are adopted in spas and beauty clinics around the world (Mouritsen 2013).

3.1.4 Bioenergy and biofuels

As highlighted in the introduction seaweeds could become an important source for third generation biofuels production. In fact, macroalgae have advantage over traditional biomass for biofuels production of not competing for land and freshwater with food crops. Furthermore, seaweeds have high productivity, fast growth rate and high polysaccharide content (Hughes et al. 2012; Kerrison et al. 2015). The latter is particularly important as seaweeds can be fermented to produce bioethanol or butanol, or used for generation of biomethane via anaerobic digestion (Bruton et al. 2009). An example of the products obtained from anaerobic digestion, sugar fermentation and hydrothermal conversion of seaweeds biomass is shown in Figure 12 (courtesy of Michele Stanley, SAMS).

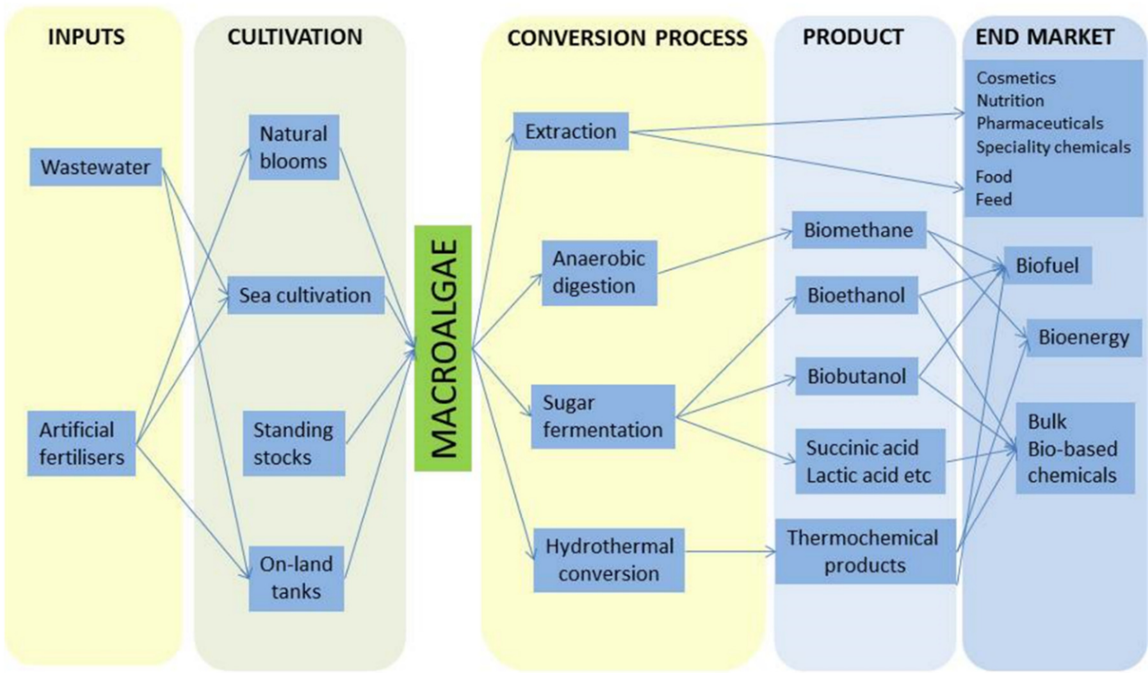


Figure adapted from the Report for the Algal Bioenergy Special Interest Group: *Research needs in ecosystem services to support algal biofuels, bioenergy and commodity chemicals production in the UK*, February 2012

Figure 12. Production chain from cultivation to end-market products of seaweed biomass for production of biofuels (courtesy of Michele Stanley, SAMS).

In order to reduce costs for production of algal biomass, there should be minimal waste and all algae biomass should be developed into a product that can be sold (AB-SIG 2013). This could be achieved with integrated bio-refinery (schematically represented in Figure 13). Following this approach seaweed growth would be fed, for example, by waste water (bioremediation); the harvested biomass would be stripped of all the important components (e.g. carbohydrate, protein) which could be used for different products, and only the residual biomass would be used for generation of biogas via AD (from AB-SIG 2013). The potential uses of seaweeds for bio-refinery is indicated also in the recent 'Biorefinery Roadmap for Scotland'[22] (2015).

[22] http://www.sdi.co.uk/~/media/sdi_2013/chemical%20sciences/biorefineryroadmapforscotland.pdf

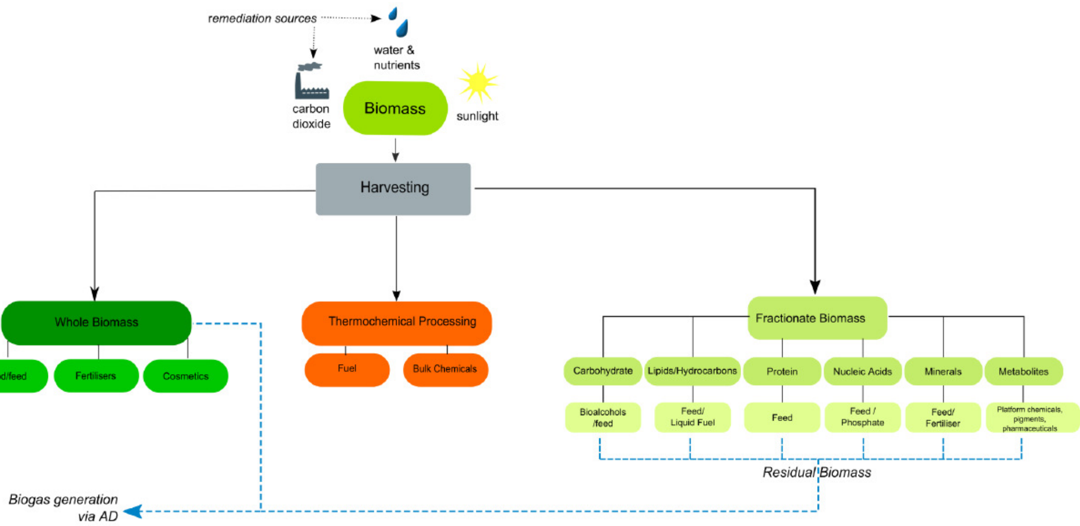


Figure 13. Schematic representation of integrated biorefinery for algal biomass (from AB-SIG 2013).

Biofuels production from macroalgae is still under development; in fact, aspects such as storage and pre-treatment of seaweeds, or economic viability of the supply-production chain, need further investigation. Example of currents projects in UK which are addressing these aspects are given in Table 6.

3.1.5 Bioremediation

As efficient absorbers of dissolved nutrients, macroalgae can act as biofilters, reducing nutrient released from fish and crustacean farms (Ahn et al. 1998; Bouwman et al. 2011; Buchholz et al. 2012; Sanderson et al. 2012; Chopin et. al 2001), as well as from other sources, helping reducing the effects of anthropogenic nutrient-enrichment in coastal waters (e.g. He et al. 2008).

Integration of seaweed farms with fish/crustacean farms (Integrated Multi-Trophic Aquaculture or IMTA) has the dual effect of offsetting the waste nutrient produced by the fish farm while increasing growing rates and yields of seaweeds. There are various examples in literature of applications of IMTA such as the one described by Sanderson et al. (2012) in northwest Scotland with *Palmaria palmata* and *Saccharina latissima*. The authors showed that growth rates of seaweeds increased near the salmon farm (48% for *P. palmata* and 61% for *S. latissima*), removing up to 12% and 5% of waste nitrogen from the farm for *P. palmata* and *S. latissima* respectively (Sanderson et al. 2012).

With increased fish demand and finfish production, IMTA could become a good way of offsetting the nutrient released by farmed fish however there are a number of unknowns which would need resolving. For commercialisation of IMTA, various aspects such as integration of infrastructure for seaweeds, evidence of economic viability of IMTA and biosecurity should be further investigated (AB-SIG 2013).

3.1.6 Knowledge industry for consultancy and algal know-how

Knowledge industries is required to develop the macroalgae business and to complement technical research. Consultancy is needed at different levels; for example, market intelligence can help commercialisation of products, while consultancy on minimal environmental impacts and responsible use of resources is important for the survival of the business. Innovation and sharing algal know-how on yields, economics, productivity, and technology influence the speed of development of the industry (AB-SIG 2013).

3.2 Main products from seaweeds in the UK, seaweed-related businesses and projects

The previous section highlighted the importance of applying a bio-refining approach to seaweed production to reduce waste and obtaining various products from algal biomass. Bio-refining seems even more a reasonable approach of using seaweed biomass when considering the pricing of products produced from seaweeds (Figure 14). In fact, production of fuels, energy, feed and bioremediation require big volumes of algae but the economical return for the biomass is small around <£1/kg. Contrarily, when algal components are used in speciality products, nutraceuticals and cosmeceuticals, the value of algal biomass become substantially higher at >£2000/kg, up to >£5000/kg for special applications (Figure 14). A bio-refining approach would allow production through the range of products of the pyramid of Figure 14, allowing to access different markets.

Currently UK capacity for seaweed production is 'positioned' between the 'added value commodities' and 'speciality products' sections of the pyramid of Figure 14, with values between £1-1000/kg. In particular Figure 15 indicates the timescale for commercialisation in the UK for the various uses of seaweeds described in section 3.1 (AB-SIG 2013).

Uses of seaweed biomass for production of bioactives for cosmetics, or as sea vegetables, fertilizers or for extraction of hydrocolloids, are currently deployed and widespread uptake is expected in the short-medium term (e.g. 5 years; note Figure 15 was prepared in 2013). Seaweed biomass for bioremediation, for preparation of animal feed, for anaerobic digestion or development of knowledge industries (e.g. consultancy and equipment) are at the development stage, with deployment expected in the short term and mid-term (5-10 years; Figure 15). Finally, other uses of seaweed biomass such as for production of some bio-actives (e.g. terpenoids), ethanol, or bioenergy through thermal conversion are still at a research stage, with deployment expected in the medium-long term (10-15 years; Figure 15).

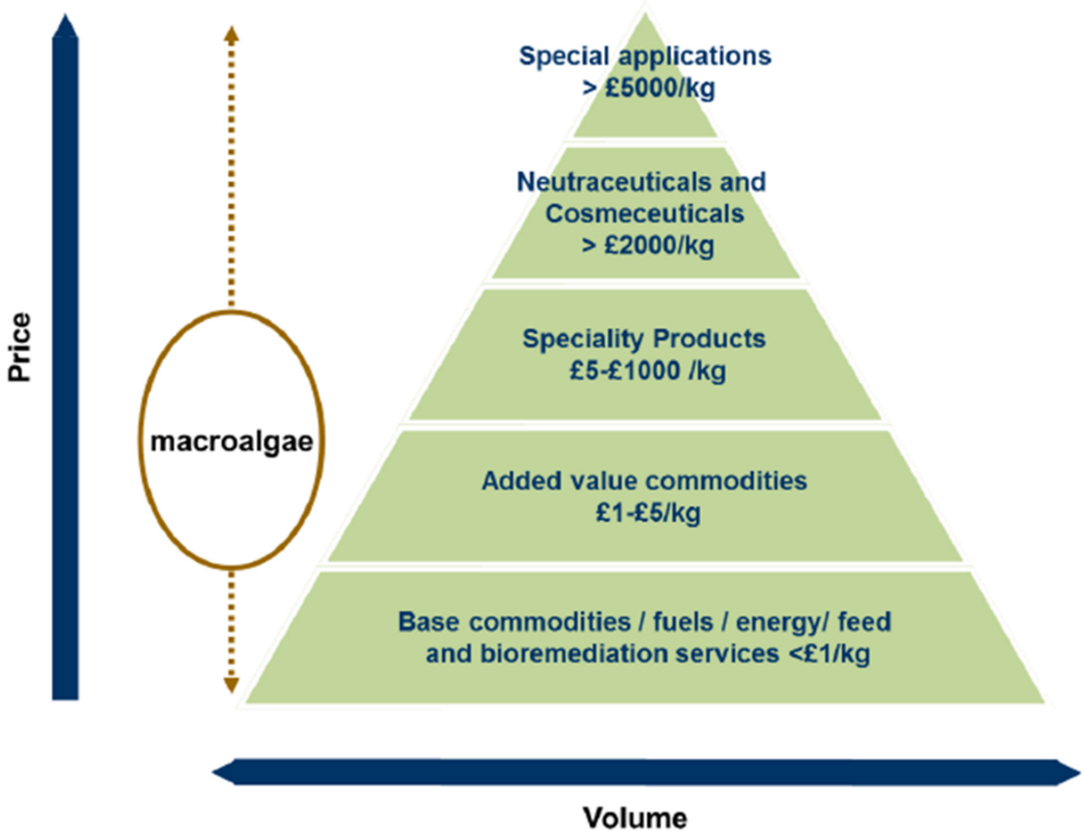


Figure 14. Pricing of products from macroalgae and current capacity for macroalgae production in the UK.

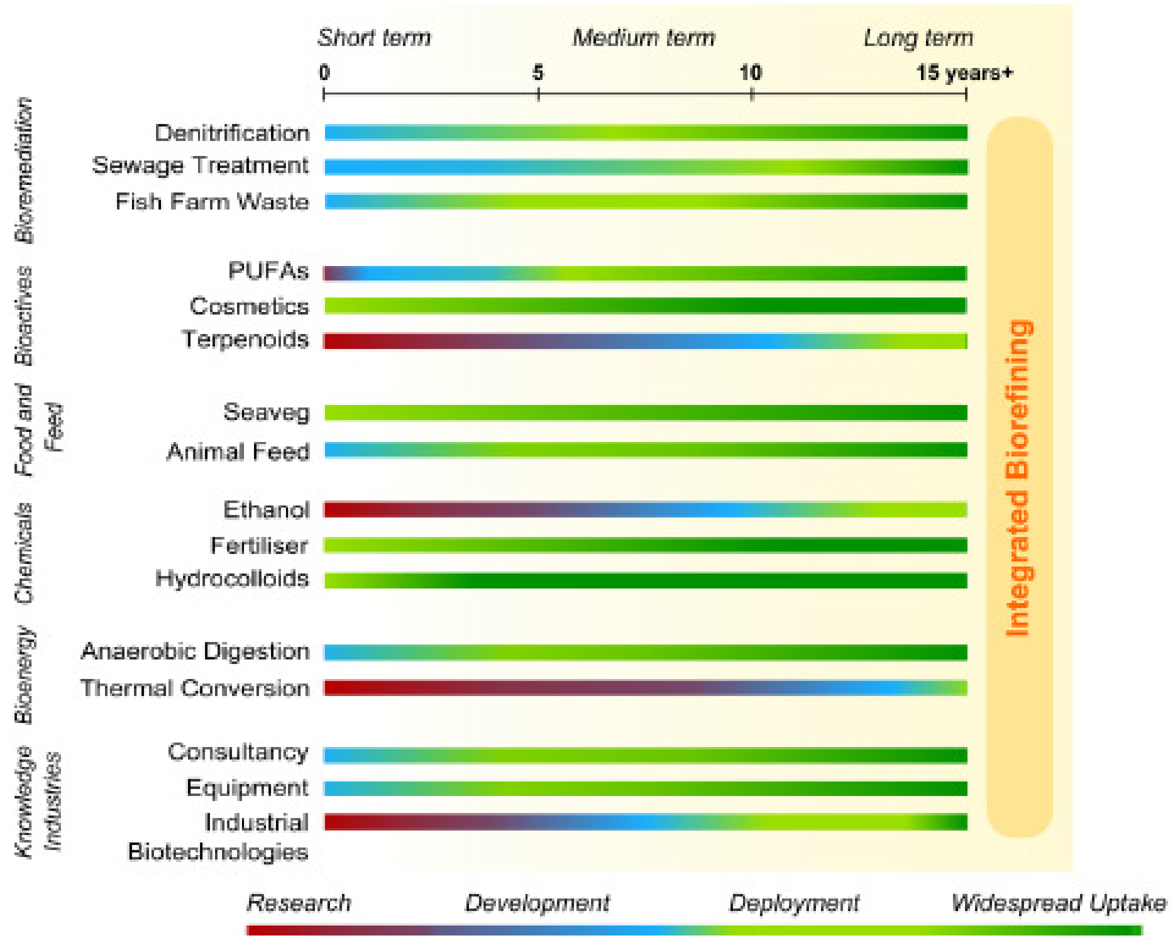


Figure 15. Timescale to commercialisation of different uses of seaweed algal biomass in the UK (from AB-SIG 2013).

Based on web searches, we identified the main UK businesses that are currently (as January-March 2016) producing seaweed-related products. In particular, the UK businesses were grouped as businesses using UK seaweeds for their activities (Table 4), and businesses where seaweeds were sourced outside the UK or seaweed origin was not specified (Table 5).

Based on our results, 16 ‘*UK businesses using UK seaweeds*’ were identified (Table 4); the majority of companies (8) produce seaweeds for food or condiments. The second most common use of seaweeds was for production of cosmetics and nutraceuticals, followed by animal feed production and fertilizers. It appears just two businesses produce alginate and there is only one commercial seaweed hatchery (Table 4). The majority of the businesses are based (and harvest their seaweeds) in Scotland and near Islands, with a couple of businesses set up in Wales and the south west coast, one business in Northern Ireland (Irish Seaweeds) and one in Essex (Neo Argo Ltd; Table 4).

We then identified 11 '*UK businesses using non-UK seaweeds*' (Table 5); of these, 4 focused on cosmeceuticals production, 3 on chemical production from seaweeds (e.g. hydrocolloids), 2 on animal feed/supplements and 2 on human food.

Table 4. Overview of **UK companies** which currently are producing **seaweed-related products from UK seaweeds**. For each company identified, website, date of foundation, number of staff members, products type and comments are provided.

UK companies using seaweeds from the UK					
Name	**Website**	**Founded**	**Staff**	**Products**	**Comments**
Mara Seaweed (registered as Celtic Sea Spice Co)	http://maraseaweed.com/	2011	<50	Condiments	Harvests at four locations in East Neuk of Fife and Argyll. Supply M&S across UK, Ocado, Harrods, Harvey Nichols, and circa 60 locations across UK - indirectly overseas.
Seagreens	http://www.seagreens.co.uk/	1998	51-200	Condiments, animal feed, nutraceuticals, cosmetics	Organic seaweed from UK and Norway. Sells to health stores across UK and Ireland. Ingredients are also used in products branded by Waitrose, Pukka, Bart, and Artisan Bread Organic
Atlantic Kelp Co	http://www.atlantickelp.com/	2009	<10	Condiments	Sell through Ebay store, and other stockists. UK (Wales) company but process and distribute organic seaweed from Canada and UK.
Pembrokeshire Beach Food Company	http://www.beachfood.co.uk/	2010	<20	Food products and condiments	Sell sea-foraged seaweed condiments and snacks to 100 independent retailers across the UK.
Marine Biopolymers (MBL)	http://www.marinebiopolymers.co.uk/	2009		Chemicals (alginate)	Based in Ayr, extracting alginates from Scottish seaweeds but planning to extract high value components from seaweed for food, and pharmaceuticals, (e.g. improved alginates) but also industrial applications such as natural polymers.
Hebridean Seaweed Company	http://hebrideanseaweed.co.uk/	2005	<10 (+30 cutters)	Animal feed, chemicals (fertilizer, alginate), cosmetics, nutraceuticals	Based near Stornoway. Uses services of manual harvesters in the Western Isles; have their own mechanical (Canadian) harvester. Aim to cut up to 6,000 tonnes/year. Also class

UK companies using seaweeds from the UK

					themselves as oil/energy sector on Linkedin.
Just Seaweed	http://www.justseaweed.com/	2007	<10	Food products (fresh&dry) and cosmetics (bath)	Run by Iain & Yvonne Mckellar, have been harvesting and selling seaweeds from the Isle of Bute on the west coast of Scotland. Harvest (by hand) wild, edible seaweed, packaged then posted to customers all over the world.
Cornish Seaweed Company	http://cornishseaweed.co.uk/	2012	<10	Food (dry) and condiments	Based in Falmouth. Harvest for Tesco including fresh seaweed.
Viking Fish Farm Ltd	www.ardtoemarine.co.uk	1965	10-50	Knowledge industries / hatchery	Ardtoe Marine Laboratory (Argyll, Scotland) - research facilities, fish and shellfish production, including commercial seaweed hatchery
Böd Ayre Products Ltd	www.seaweedproducts.co.uk	2003	<10	Food, condiments, animal feed and fertilizers	From Shetlands - Wholesalers of seaweeds, seaweeds harvested locally
Kilmacolmloch Developments Ltd	www.kilmacolmloch.com		10-50	Bioenergy	According to Netalgae - boat and manual harvest of seaweeds as well as imported.
Irish Seaweeds	www.irishseaweeds.com/	1990		Food, cosmetics, nutraceuticals	Family run business based in Belfast (NI), harvest seaweeds from around NI and Irish coast.
Seaweed organics (previously Diana Drummond Ltd)	www.seaweedorganics.co.uk/			Cosmetics (skin care)	Based in Argyll. Seaweeds hand harvested from Outer and Inner Hebrides and Shetlands Isles and products made in workshop kitchen in Argyll.
Orkney Seaweed Company	http://www.orkneyseaweed.co.uk/index.htm	1988		Fertilizers	Range of products based on liquid extraction from seaweeds harvested off Orkney (Scotland). Extract are used in horticulture and agriculture.
Neo Argo Ltd	No website available	2009	<10	Biotechnologies	Based in Essex – are using macroalgae to filter out microalgae in ecologically sensitive areas.
Uist Asco	Website in construction – www.uistasco.com	2012		Fertilizer, animal feed, chemical (alginate)	Process and dry *Ascophyllum nodosum* for various uses (based in Scotland)

Table 5. Overview of **UK companies** which currently are producing **seaweed-related products made with seaweeds sourced outside UK or with not specified origins**. For each company identified, website, date of foundation, number of staff members, products type and comments are provided.

UK companies using seaweeds from outside UK or not specified origins					
Name	**Website**	**Founded**	**Staff**	**Products**	**Comments**
Faith in Nature (register as Millar & Bryce)	https://www.faithinnature.co.uk/shop	1974		Cosmetics	Manufacture in Bury. sell to Holland & Barret across the UK, and Oxfam stores. No indication that seaweeds is sourced from UK.
Dorwest	http://www.dorwest.com/PRODUCTS/MK/MALTED-KELP-TABLETS	1948	11-50	Animal (pet) supplements	Not all products use seaweed. No indication that seaweeds is sourced from UK - only that it meets UK standard for contaminants
Atlantic Kitchen	http://atlantickitchen.co.uk/	2012	<10	Food (supply different type of seaweeds)	1200% year on year growth (2015). UK company but organic seaweed from Ireland, France and Spain. Supplies stores mainly in London – e.g. Selfridges but also over 140 health food stores and convenience stores (Spar, Budgen) as well as online via Amazon, Ocado.
Clearspring	http://www.clearspring.co.uk/	1993	11-50	Food and condiments	£750K turnover. Sells organic products including seaweed from Japan and North Atlantic. Sells to organic food stores, wholesalers, and also Waitrose, Sainsbury's, Asda, Booths, M&S and overseas online sellers, and food halls such as Harrods, Fortnum and Mason, Selfridges, John Lewis.
FMC Biopolymer	http://www.fmcbiopolymer.com/FMCBiopolymer/Locations/tabid/4116/Default.aspx?&regionName=Europe		73	Chemical (alginate)	Part of an American firm - who took over ISP in 2009, resulting in the Girvan factory becoming a blending plant rather than extract production (now in Norway). Sourcing is from Iceland via Norway.
Shropshire Seaweed	http://www.shropshireseaweed.co.uk/	2011		Chemical (fertilizers and cleaning products)	Organic plant feed (liquid kelp extract) Ascophyllum nodosum from Ireland, sold through Amazon, and small independent traders.
Cybercolloids	http://www.cybercolloids.net/	2002	12	Chemicals (hydrocolloids)	Founded by Ross Campbell. Science Co - based in Cork, Ireland but with some members based in UK. Conducts research/analysis re hydrocolloid process implementation but not only from seaweeds. Clients worldwide.

UK companies using seaweeds from outside UK or not specified origins					
REN Skincare	http://www.renskincare.com/uk/	2000	51-200	Cosmetics	No indication of where seaweeds are from. Not all products are seaweed specific. Sell to dept. stores, pharmacies and Spas in over 50 countries
Base Formula	http://www.baseformula.com/	1996	11-50	Cosmetics	Based in Melton Mowbray. Importers, exporters and analysers of essential oils and absolutes. Not all is seaweed; no indication of where the seaweeds are from.
Bentley Organic	http://www.bentleyorganic.com/products/body-care/bar-soap.htm	2006	<10	Cosmetics (e.g. soap)	Manufacture in England. Sell a range of cosmetics particularly soaps, including with seaweed. No indication of where seaweeds are from. Available through Ocado and other - circa 30 online sellers.
Equimins	http://www.equimins.com/	1992		Animal (horse) supplements	Family business, manufactures in Devon, UK and exports to over 40 countries. Use Scandinavian seaweed (kelp).

The potential of seaweeds as biomass for renewable energy has driven national and international interests and funding, as highlighted by the number of recent projects carried out in UK (or with partners in the UK), some of which listed in Table 6. An extensive list of national and international projects and initiatives in relation to macroalgal biomass and biofuels can be found in James (2010).

Some of the existing pilot seaweed farms in the UK (see Section 2.3 for details) have been developed and are producing seaweed biomass to support research under these projects (Table 6). For example, seaweeds growth in Scotland at the SAMS pilot farm are used in the SeaGas and Macrofuel projects.

Table 6. Overview of the main current and recent projects related to seaweeds where all or some of the project partners are UK organisations. For each project identified, website, type of fund, and aims are provided. *denotes an ongoing project.

Project	Website	Fund	Aims
EnAlgae	http://www.enalgae.eu/	INTERREG IVB North West Europe	To develop sustainable technologies for algal production, bioenergy and greenhouse gas mitigation, from pilot facilities to products and services. Development of 9 pilot-scale farms across 7 EU states.
At~Sea	http://www.atsea-project.eu/	EU FP7 Programme	To develop and advance technical textiles for demonstrating technical and economic feasibility of off shore cultivation of seaweeds.
BioMara	http://www.biomara.org/	INTERREG IVA / Highlands and Islands Enterprise / The Crown Estate / The Scottish Government / DETI / DCENR	To demonstrate the feasibility and viability of producing third generation biofuels from marine biomass. Joint UK and Irish project. Aim to engage with wider community.
Netalgae	http://www.netalgae.eu/index-en.php	Atlantic Area Transitional Programme / Innovation network / European Regional Development Fund	To create a European network of stakeholders within the seaweed sector. Establish best practice model and policies for sustainable utilization of seaweed resources. Baseline study of national algae industries. Develop EU algal industry database.
SeaGas*	http://www.seagas.co.uk/	Innovate UK	To develop a process using seaweeds for generation of sustainable energy by anaerobic digestion. To investigate storage of seaweeds, AD process development, economic modelling, environmental and social impact assessment and supply chain.
MacroFuel*	http://www.macrofuels.eu/	EU H2020	To produce advance biofuels from seaweeds (i.e. ethanol, butanol, furanics and biogas). Develop rotating scheme for seaweed cultivation, improve pre-treatment and storage seaweeds, develop novel fermenting organisms, develop thermochemical conversion, perform sustainability and risk assessment of seaweed-biofuel chain.
MacroBioCrude*	http://community.dur.ac.uk/p.w.dyer/page2/styled-2/index.html	EPSRC	To establish an integrated supply and processing pipeline for the sustainable manufacture of liquid hydrocarbon fuels from seaweeds (high energy density liquid transport fuels). To explore methods of seaweed gasification, overall process footprint of this novel biofuel supply chain,
Miscellaneous	http://www.thecrownestate.co.uk/energy-and-infrastructure/research/energy-research/reports/	The Crown Estate	Various projects carried out by different UK companies, university and organisations investigating wider impacts of large scale seaweed farms, potential locations of seaweed farms, carbon footprint of seaweed as biofuels, production options for seaweeds.

4 What are the main issues/barriers in the UK and abroad associated to seaweed production and market?

There are numerous issues and barriers limiting or affecting the development of seaweed production and market; some of these issues are global and apply to all countries (e.g. price volatility), while others are country-specific (e.g. diseases or national 'taste' for sea vegetables). This section summarises the main issues/barriers for development of the seaweed industry at different levels, firstly at a global scale, then at European scale, ultimately focusing on the national UK scale.

Web forum, social media, news and internet searches, in combination with FAO reports (e.g. Neish 2013; Valderrama et al. 2013), were used to investigate the issues/barriers at the global scale. Reports prepared by the Netalgae network (www.netalgae.eu) were useful for identifying issues in the European market. For the UK, 'A UK Roadmap for Algal Technologies' by AB-SIG (2013) provided a unique perspectives of issues in the seaweed market as perceived by stakeholders in this sector.

4.1 Issues/barriers in the global seaweed market

The main issues/barriers identified for the global seaweed market are listed below and grouped under 3 main categories.

Setting up of activity

- Regulatory/licensing (unclear process for obtaining licence, lack or unfit regulation specific to seaweed); this appears to be a widespread issue, for the Asian production, as well as for European and UK production;
- Determination of suitable locations for farm sites or harvesting which could also lead to potential conflicts with other uses of the coastal area; for example, in Asia seaweed farms may compete for shallow coastal areas with tourisms;
- Potential impacts of farming/harvesting (and related activities) on the surrounding environment (e.g. direct impact on corals, competition with other plants, loss of equipment and debris in the water);
- Lack of information on productivity and yield (this can limit scaling-up of activities);

- Requirement of robust algal cultivar (for example the development of algal strains with higher growing rates or resistant to higher water temperatures);
- Infrastructure (facilities, storage, distribution for raw and finished products); storage is needed for surplus of products and for maintaining a consistent supply of materials to processing plants (see for example Jakarta Post article on Indonesia being unable to store the surplus of production[23]);
- Capital (setting up costs) and/or lack of investors; as with all business ventures, financing can be a major issue, whether it be small scale low-tech equipment in the developing world or large scale high tech production methods;
- Lack of markets for end-products;
- Lack of promotion and marketing of the industry (e.g. lack of national and international funding);
- Available and shareable technical know-how and skills on seaweeds farming; this has been identified as a key issue by Valderrama et al. (2013) for seaweed farming in India, Indonesia, Mexico, Philippines and Solomon Islands, by Netalgae for the European Industry and by AB-SIG for the UK industry.

Operational

- Natural risks (which can affect productivity or yield, damage equipment/farm or result in a loss of resources):
    - geological instabilities, earthquakes, tsunamis, storms;
    - climatic variability and global warming (variability in weather and increased sea surface temperature; extreme storms);
    - grazers (e.g. herbivorous fish);
- Diseases; for example, control and prevention of diseases such as "ice-ice" for Asian countries;
- Potential introduction of alien species;
- Seasonality (variation in yields can affect price of products; see Vanderrama et al. 2013 for the Asian carrageenan industry);

Global/external factors

[23] http://www.thejakartapost.com/news/2015/11/14/farmers-struggle-amid-declining-seaweed-exports.html [November 201]

- Volatility in price; particularly where seaweed farming is done at a small-family scale, and it is the main revenue, changes in price can impact significantly on the livelihood of the people involved in the seaweed production. Volatility in price would likely have implications throughout the supply and production chain;
- Competition with other countries (see section 4.2. for price competition between European and Asian products);
- Size of market and location of market of seaweed-derived products; this can attract or deter entrants. Seaweeds are used in a variety of products, some of which have a global market, whilst other have more localised markets. Size and location of markets are not static and, particularly in relatively new areas or sectors, lack of market knowledge may be an obstacle to development;
- Restrictions (banning) on seaweed derived ingredients (see for example the Cornucopia Institute that considers carrageenan as an unsafe substance[24]);
- Consolidation of large scale production/processing;
- Countries preventing imports and/or stockpiling (see example of reduced Chinese seaweed import from Indonesia[25]);
- Countries preventing exports of product (see example of Morocco limiting export of *Gelidium*[26]);
- National 'tastes' (countries with no tradition of using seaweeds; see Section 4.2);

[24] The Cornucopia Institute believes that carrageenan is an unsafe food additive, and have called for its removal, although the U.S. Food and Drug Administration (FDA) have not been swayed by their argument. http://www.cornucopia.org/carageenanfda/; this has been a persistent issue according to Vanderrama et al. 2013.

[25] http://www.thejakartapost.com/news/2015/11/14/farmers-struggle-amid-declining-seaweed-exports.html [November 201]

[26] On Linkedin (in 2015), Pedro Sanchez (Commercial Director of Industrias RoKo, Gijon, Spain) has referred to issues with *Gelidium* supplies (a red algae used for agar production) as Morocco, the main producer, has stopped exporting this alga. Ricardo Mello (Aquaculture Marketing Manager of InVivo, Vannes- Brittany, France) agreed with Pedron Sanchez comment and flagged that the supply is dependent on few source countries. Actions such as these may also contribute to price volatility.

4.2 Issues/barriers in Europe

Focusing on the European market, Netalgae (in the report on 'Seaweed industry in Europe' 2012) identified the key enablers for further development of seaweed industry in Europe as:

a. a stable access to seaweed biomass (resulting in lower cost for raw materials);
b. development of value added products for different market sectors;
c. transfer of expertise between regions where production is developed to regions that wish to promote the industry.

According to the Netalgae's report, alginate production is the main end product of seaweeds in Europe, however there is currently substantial competition with Asia as provider of raw seaweed biomass. Local seaweed production in Europe is not enough to meet the high demand of processing industries, particularly for alginates. In fact, existing processing industries in France, Norway and Ireland use local raw materials but need to import dried seaweeds when local supplies are out of season or not enough to meet demand.

This may result in processing industries moving to countries where they can access cheaper raw materials and also labour (e.g. Chile, Philippines, China); it is likely this is one of the reasons why seaweed processing industries in Europe have reduced (Netalgae report on 'Seaweed industry in Europe' 2012). Furthermore, "Seaweed.ie" (an Irish website providing information on seaweed products, farming and industry) suggests that it is unlikely the European alginates and carrageenan industries will look to algae biomass from seaweed farmed in Europe when wider (and cheaper) resources are available in South Africa, Chile, Argentina, and Asia[27].

Another issue of the European seaweed industry is the lack of a diversified market for seaweeds; opening of new markets (e.g. sea vegetables, biotech or biofuels) may help pushing forwards and reinvigorating the European seaweed production. Importantly, development of the sector should be towards a sustainable seaweed production (Netalgae report on 'Seaweed industry in Europe' 2012).

Some of the constrains highlighted by the Netalgae report for the seaweed processing industries (e.g. for alginates) can also be applied to the sea vegetable market in Europe (as summarised by Organic Monitor's market analysis, 2014). The undersupply of European sea

[27] http://www.seaweed.ie/uses_ireland/irishseaweedaquaculture.php

vegetables is leading interested companies to buy their products from Asia, North and South America. A greater European seaweed supply would lead to wider retail product ranges and processed food products, as well as to a reduction in price. In fact, another limitation of European seaweeds in the food market is the higher price compared with Asian products (Organic Monitor 2014). Specific to the sea vegetable industry, other market restrains are the lower consumer awareness of sea vegetables (there is limited tradition of eating seaweeds in Europe) and the relative low demand from food processors (as there is limited knowledge of how to use type of algae different from nori; Organic Monitor 2014).

4.3 Issues/barriers in the UK

AB-SIG run a series of workshops in October/November 2012 attended by various UK stakeholders in the algal technologies sector, from academia, industry and the public sector. Based on the outcome of the different workshops the following were identified as key enablers for commercialisation of seaweed technologies in the UK.

a) **Technical** - need to:
   I. have access to **pilot / demonstration facilities to get data on ecological impacts, operation costs, yields**; important for developing scenarios and scaling up;
   II. define **potential sites for cultivation** across UK (considering Integrated Multi-trophic Aquaculture and/or co-location with other activities);
   III. determine **potential for sustainable harvest** of wild resources in the UK (how much can be harvested sustainably and from where?);[28]
   IV. conduct **R&D into seasonality and storage** of algal biomass;
   V. develop **expertise in algae strain** development;
   VI. encourage **interdisciplinary skills development** and training in this area;

b) **Financial** – need of:
   I. **security of funding for R&D**;

[28]In March 2016, ABPmer has been contracted by Marine Scotland to provide input on the environmental assessment for wild harvest of seaweed for ensuring sustainable use of this resource: http://www.abpmer.co.uk/news-desk/news-archive/abpmer-provides-technical-input-to-wild-seaweed-harvesting-strategic-environmental-assessment/

II. **investments** on scale-up facilities, downstream processing, and strain development (seaweed farms have big set up costs and requires long business plans);
III. **successful examples** of algal biotechnology applications (to improve confidence in the sector);
IV. attribute a **value to bio-remediation** (e.g. with incentives or penalties);

c) **Services** – need of:
I. **closer interaction and knowledge transfer** between academia, chemical and pharmaceutical industry;
II. development of **algal bio-business incubators and clusters**;
III. **development of supply chains** matched to production capacities;
IV. **increase visibility of UK expertise and products** at global level;
V. **increase public awareness** and acceptance;

d) **Regulation**: need to **provide clarity about the regulatory context**, in particular, clearer **marine licensing** procedure for offshore cultivations.

Furthermore, James (2010) identified the **lack of relevant trade bodies** as another potential aspect limiting the development of the seaweed industry.

Currently, in the UK, there is a bottleneck in the seaweed supply chain in terms of production capacity; companies are interested in algal biomass but they are held back by high costs and/or by shortage of supply (AB-SIG 2013). This is a similar situation to the one observed in Europe, resulting in a reduction of processing industries for seaweeds (Section 4.2). In recent years, large multinationals (who dominate alginate and carrageenan production in the UK) have sourced factories in developing world countries or, as in the case of the ISP factory in Girvan (Scotland), downgraded it from production to product blending/finishing, with production moved to Norway and with raw material supply coming from Iceland.

Considering the length of its coastline, the UK has a great potential to extend the macroalgae industry. Currently, seaweed biomass produced in UK is mainly collected from natural resources; wild harvest could potentially be increased or extended to new sites however studies should be carried out to define how much wild seaweeds are available and how much could be harvested sustainably.

A substantial increase in seaweed production could be achieved through farming near shore (in the short-medium term) and offshore (in the long term). The expansion of the industry should move in parallel with product development, from products not requiring intensive or novel processing to bio-refining (AB-SIG 2013). The AB-SIG (2013) workshops concluded that the '*largest market pull is found for products and services that in the current techno-economic assessments are most challenging to achieve: biofuels, bulk feed and chemicals, and large scale bio-remediation, e.g. for CO_2 capture and storage"*.

The Biotechnology and Biological Sciences Research Council (BBSRC) investigated the level of algae-related expertise in biological and environmental sciences and engineering in the UK in 2011[29]. The investigation highlighted that UK has expertise in the environmental and ecological sector for macroalgae. Algal culture collections in the UK are highly regarded internationally and UK experience in algal taxonomy, physiology, metabolism, biochemistry and molecular biology is a key strength. In addition, UK is well places to produce technologies associated with the scaling up of algal growth (e.g. optimizing productivity, lowering costs for growth, harvesting and processing; AB-SIG 2013).

The AB-SIG report (2013) concluded that:

> *"The UK therefore has a highly valuable base of expertise […]. However, continuity of funding is essential to maintain this advantage: both R&D funds to attract and retain academic excellence, and resources to provide continuity and expansion of the support network that facilitate successful project development between academia and industry, will be essential if the UK is to establish a globally competitive algal commercial sector".*

[29] http://www.bbsrc.ac.uk/about/policies/reviews/scientific-areas/1107-algal-research/

5 Are there any gaps in regulations/ directives/ licensing in relation to seaweed farming?

As indicated in the previous section of the report, lack of clarity in the legislation and licensing process for seaweed harvesting/farming can limit development of the seaweed industry.

An example of the difficulties associated with obtaining a licence for seaweed harvesting is presented in the website of the Cornish Seaweed Company (one of the business described in Table 4), where the founders summarised their experience as follow[30]:

> "[in 2012] *It was just so new, I remember calling IFCA, the MMO, NE, The Crown, The Duchy, the Council, National Trust and so many others trying to work out who would be responsible for licensing (seaweed harvesting)' Caro said. 'No-one seemed to know anything about it".*

During the Netalgae project, Viking Fish Farm Ltd. (2012) summarised the licensing process as shown in Figure 16. The two main stages of the process are broadly similar for both wild harvest and farming of seaweeds:

a) application for a **lease from The Crown Estate** (or a private landlord);

b) application for a **seaweed harvesting licence or a marine licence** (for farming) to the relevant regulators (which will vary based on whether the activity will take place in Scotland, Wales, Northern Ireland or England).

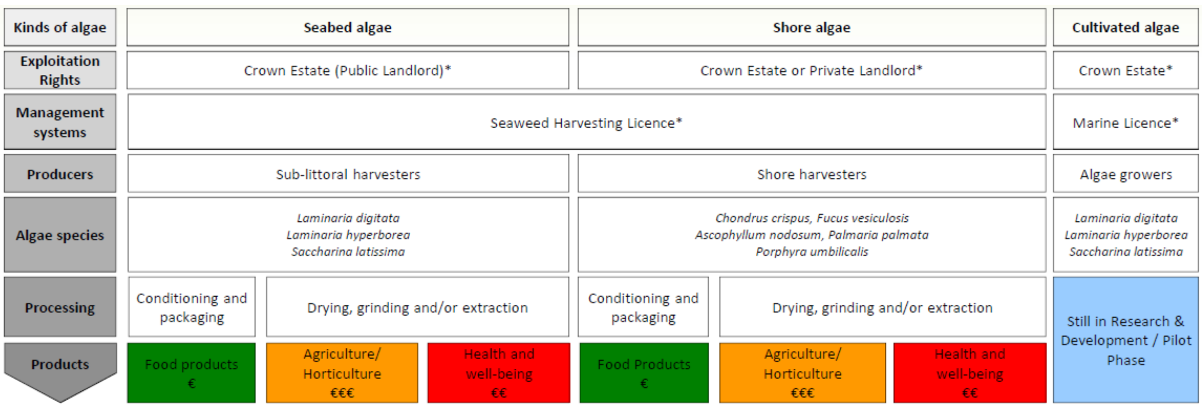


Figure 16. Overview of the licensing process for seaweeds in the UK for harvest of wild resources and farming (from Viking Fish Farm Ltd, 2012, Netalgae).

[30] http://cornishseaweed.co.uk/getting-intimate/the-founders/

Under the SeaGas project (Table 6), Cefas, SAMS, Queen's University (with support from The Crown Estate) have been reviewing the current status of legislation and marine licensing procedure for macroalgae farming, highlighting the current knowledge gaps. In relation to the latter, it was concluded that the processes necessary to obtain lease and licence are established and generally straightforward. However, **these processes, designed for fish and shellfish farming, are not always applicable to the establishment of a seaweed farm** (Wood et al., in preparation). It is also true that seaweed farming is at its infancy in the UK (with currently no commercially operating seaweed farms), therefore licensing and regulations for seaweeds should develop with the industry.

A summary of the review on current legislation and licensing process for seaweed aquaculture, carried out by Wood and co-authors, is given below and summarised in Figure 17.

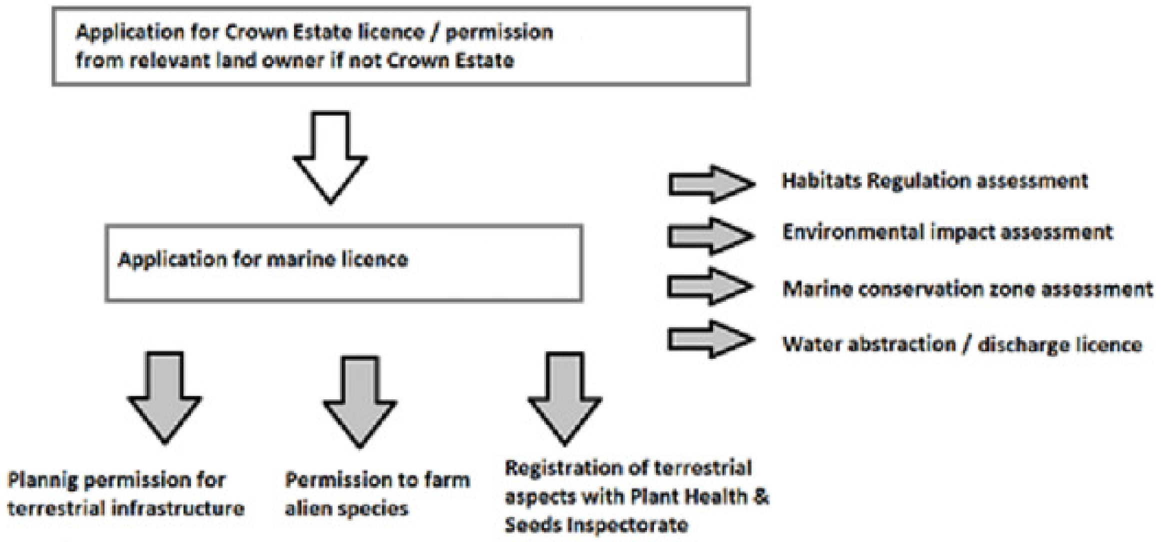


Figure 17. Overview of the licensing process for seaweed farming. Arrows with solid fill indicate stages that may or may not be required, while stages contained within rectangles are compulsory (from Wood et al., in preparation).

5.1 Lease from The Crown Estate

For licensing of seaweed farms, The Crown Estate does not have a regulatory role; however, a lease must be obtained from them for farming activities in UK territorial waters (up to 12 nautical miles from the coast). In particular, the lease (obtained for a designated number of years and paid yearly) requires information on the area planned for the farm, cultivation equipment, and outline of the business plan (including decommissioning). For privately own areas, permission should be sought directly with the landowner (see Wood et al., in preparation, for further details).

5.2 Marine licensing

Although seaweed farming is categorised as a licensable activity under the Marine and Coastal Access Act (MCCA, 2009), there is currently no specific legislation for farming seaweeds (Wood et al., in preparation). The organisation responsible for granting the licence is the Marine Management Organisation (MMO) for inshore and offshore areas in England, and for offshore areas in Wales and Northern Ireland, while Marine Scotland is the agency responsible for licensing in Scotland (for further details on the relevant regulators in the UK for seaweed farming licensing, see Table 7). For the licensing process, additional information on the size, nature and location of the proposed activity may be required by the regulator who should advise on what is required to support the application. In particular, in Scotland, the marine licensing for seaweed farm is covered by Part 4 of the Marine (Scotland) Act 2010; a number of organisations (e.g. Maritime and Coastguard Agency, Scottish Environmental Protection Agency) may be consulted during the licensing process (Wood et al., in preparation).

Table 7. Overview of the marine licence regulation in Northern Ireland, Scotland and Wales (from Wood et al., in preparation).

Country	Regulator	Remit
Northern Ireland	Department of Environment (inshore waters) Marine Management Organisation (offshore waters)	The Department of Environment (DOE) is responsible for marine licensing under the Marine and Coastal Access Act (2009), supplemented by the Marine Licensing (Civil Sanctions) Order (Northern Ireland) 2011 which came into operation in April 2011.
Scotland	Marine Scotland	Under the Marine (Scotland) Act 2010 Scottish Ministers are responsible for marine licensing system and enforcement in the Scottish inshore region from 0-12 NM and under the MCAA 2009 Scottish Ministers have responsibility for licensing and enforcement in Scottish offshore region from 12-200 NM. Marine Scotland Licensing Operations Team (MS-LOT) act on behalf of Scottish Ministers in processing and assessing applications for marine licences. Seaweed

Country	Regulator	Remit
		farms located in Shetland and certain parts of Orkney will also require a works licence from the relevant Harbour of Port Authority.
Wales	National Resource Wales (NRW) (inshore waters) Marine Management Organisation (offshore waters)	NRW Marine Licensing Team (MLT) is responsible for the determination of marine licence applications, ensuring compliance with all relevant legislation in Welsh inshore waters.

5.3 Other potentially relevant legislation

There is a lack of information on the potential environmental effects that seaweed farming could have in European waters (see Section 4.3). It is therefore likely that the regulators would apply a conservative approach (until quantitative information are available), towards the required assessments of the potential impacts of the farm under various legislations (Wood et al., in preparation).

If the location of the potential farm is near or within a designated protected area (e.g. Ramsar Site, Natura 2000, Special Areas of Conservation – SACs, Special Protection Areas – SPAs), the regulator may require assessments such as the Habitat Regulations Assessment (HRA). Similarly, if the proposed farm may affect a Marine Conservation Zone (MCZ), an assessment may be necessary. Within 1 nautical mile from the coast, assessment under the Water Framework Directive (WFD, Directive 2000/60/EC) may be requested if the farm has the potential to deteriorate or affect the ecological status of the water body (Wood et al., in preparation).

Under the Environmental Impact Assessment Directive (97/11/EC), a commercial seaweed farm could be considered falling under Annex II and would require an Environmental Impact Assessment (EIA). However, due to the novelty of commercial seaweed farming in the UK (and the current lack of commercial farms), **it is not currently clear under which circumstances an EIA would be required** (Wood et al., in preparation).

Another aspect to consider is the potential farming of alien species. Currently farming of non-native species is allowed after receiving a permit from the relevant regulator (Fish Health Inspectorate - Cefas - in England and Wales, DARD in Northern Ireland and the Fish Health Inspectorate Scotland for Scotland). A risk assessment under the European Non-native

Species in Aquaculture Risk Assessment Scheme (ENSARS) may be required in order to receive the permit (Wood et al., in preparation).

The seaweed farm will need navigation marks and the regulator issuing the licence (normally Trinity House) will provide details of number, position and character of the buoys required. Furthermore, the Admiralty should also be informed as the farm would need to be added to navigation charts. To prevent accidental collisions and damages, local mariner's and fisherman's organisations should also be made aware of the farm (Wood et al., in preparation).

5.4 Gaps

As previously mentioned **regulation and licensing processes, designed for fish and shellfish farming, are not always applicable to the establishment of a seaweed farm**.

In addition, there is a **lack of information on the potential effects of seaweed farms** on the surrounding environment (see Section 4.3), **resulting in uncertainties for the regulator on how to interpret requirements under the various UK laws and EU directives** (Wood et al., in preparation).

Assessments before farming is commenced and during the farming activities may be requested by the regulator to understand some of the potential effects/impacts of seaweed farming. However, this would be expensive and time consuming for the developer resulting in limited capacity of predicting costs of the farm, increasing level of risk, and deterring potential investors (Wood et al., in preparation). This issue could be solved, for example, supporting pilot/demonstration facilities which would provide (much needed) data on ecological impacts, operation costs, and yields (Section 4.3).

The Scottish Government is currently working on a seaweed policy which should provide information and guidance for licensing requirements for seaweed farming in Scotland. **Knowing what the regulators are expecting and the prerequisite needed for receiving a licence would facilitate the development of the seaweed industry in the UK** and would allow the developers to determine the viability of the investment (Wood et al., in preparation).

6 What could Cefas do for this sector?

Cefas has been carrying out a number of projects on macroalgae since 2003. In particular, earlier projects (2003-2009[31]) focused on modelling distribution, growth, nutrient uptake and controlling factors of wild (not farmed) seaweeds, at different locations along the UK coastline. The driver of these projects was the investigation of nutrient dynamics in coastal and inshore waters in the context of eutrophication assessment.

Since 2011, the focus of seaweed-related projects[32] carried out in Cefas has moved to modelling the potential environmental effects of large-scale seaweed farms, nutrient competition of farmed seaweed with wild seaweed populations, and site selection of seaweed farms. These projects were the results of a growing interest in seaweeds as a potential source of biomass for biofuel production (see for example the current project SeaGas; Table 6).

Through these numerous projects Cefas has been developing various services/products/skills which are listed in Table 8. Particularly, Cefas has developed capability in modelling growth and production of wild and farmed seaweed populations as well as their interactions with the surrounding environment (Table 8).

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[31] Cefas projects C1642, C1882, C2116, funded by the Environment Agency; see also Aldridge and Trimmer (2009).

[32] Cefas projects C5567, C5567C, C6311, funded by The Crown Estate, and C6627 (Innovate UK).

Table 8. List of seaweed-related service/product/skills, and associated desirability in the UK and Cefas capability. The perceived current (as for April 2016) desirability of each service/product/skill was ranked on a scale from 1 to 3; where 1 (red) indicates limited desirability in the current market; 2 (amber) refers to a service that is desirable in the current market, and 3 (green) indicates a service highly desirable in the current market. Cefas capability has been classified as 'Developed[33]' (green) and 'Not developed' (red), indicating whether previous or current projects have been carried out on this topic.

Service/product/skills	Desirability of this service in the UK	Cefas capability	Comments
Modelling growth and production of farmed seaweed	2 (would become more important with growing sector)	Developed in previous/current work	1D model at the farm scale; 3D model (ERSEM with seaweed module)
Modelling farmed seaweed environmental impacts	3 (lack of information on potential environmental effects of large-scale seaweed farms)	Developed in previous/current work	Impacts on phytoplankton, natural seaweed, nutrients concentration, etc.
Seaweed farms site selection	2 (would become more important with growing sector)	Developed in previous/current work	GIS based approach for spatial planning
Natural seaweed distribution and standing stock	3 (importance of sustainable harvest of wild resources)	Developed in previous/current work	GIS/model approach
Modelling of natural (not farmed) seaweed environmental impacts	2 (relevant for transitional/coastal areas with high concentration of green seaweeds)	Developed in previous/current work	Competition with phytoplankton Eutrophication Associated to changes on benthos/sea birds/human uses of coastal areas, etc.
Modelling of seaweed nutrient uptake (nutrient management)	2 (important for areas with high nutrient concentration)	Developed in previous/current work	Phytoremediation Co-location with fish farms

[33] It is important to note that application of a developed service/products (e.g. a model) to different locations will likely require knowledge and information of the in situ environmental conditions and algal physiology, and therefore an adaptation of the product to the specific local conditions.

Service/product/skills	Desirability of this service in the UK	Cefas capability	Comments
			Eutrophication Relevant for Nitrates Directive, WFD, MSFD
Regulations/licensing	3 (one of the issues highlighted in the previous section);	Developed in previous/current work	Not just in relation to farming but also food security
Seeding and growth rates of seaweed (laboratory)	1 (currently limited application) 2 (would become more important with growing sector)	Not developed but there are facilities in house	Provide local seedling for seaweed farms; Verifying seaweed growth rates in North Sea
Economics of seaweed farming	2 (would become more important with growing sector)	Not developed but there is expertise in house	Currently investigated under SeaGas
Ecology / biodiversity / fish nurseries / invasive species	1 (would become more important with growing sector);	Not developed but there is expertise in house	
Integration of seaweed aquaculture with other uses	1 (would become more important with growing sector);	Not developed but there is expertise in house	Multitrophic aquaculture Co-location with other sectors e.g. offshore wind

Considering the issues/barriers to the development of the seaweed industry in the UK, identified in Section 4.3, current Cefas capability can contribute significantly towards:

- investigation of the ecological impacts of seaweed farms;
- determination of potential yields of seaweed farms;
- identification of potential sites for seaweed cultivation;
- determination of natural seaweed availability;
- clarification of the regulatory/licensing context in relation to seaweeds.

For example, under the SeaGas project (see Table 6), Cefas, in collaboration with SAMS and Queen's University, is currently investigating the potential environmental effects of large-scale seaweed farms at different locations in the UK and reviewing the legislation/licensing process for seaweeds.

Furthermore, Cefas has facilities and expertise to develop other services/products/skills which would be relevant for the commercialisation of the seaweed sector. These include, for example, laboratory and field investigations of growth rates of seaweed strains, as well as the economics of the seaweed industry. Expertise is available for investigating potential effects of seaweed farms on ecology and biodiversity of the marine environment, and for investigating the integration of seaweed aquaculture with other uses (e.g. fish/shellfish farming, wind sector; Table 8). Furthermore, Cefas can contribute towards creating roadmaps to identify and prioritise activities and policies to accelerate blue growth.

7 Conclusions

The aim of this report was to provide an overview of the national and international seaweed sector and products, as well as the constraints to further development of the sector, especially in the UK.

Global seaweed production has more than doubled from 10.5 to 28.4 million tonnes between 2000 and 2014. China and Indonesia have the largest global markets for seaweed production, with China alone accounting for 50.8% of production. Production of seaweeds in Asia and Africa is mainly from aquaculture sources, while in America and Europe production of seaweeds is almost entirely from harvest of wild plants. As Asia accounts for the majority of world marine plant production, it follows that almost all of the world production (95%) is from aquaculture. Indonesia, Peru, and France have shown the biggest growth in production of seaweeds from wild harvest in the period 2009-2013, while Solomon Island and Indonesia have shown the biggest growth in seaweed production from aquaculture within the same period.

Seaweed production from wild harvest in the UK, in 2013, has been estimated around 2,000-3,000 dry tonnes. In addition, unknown quantities of subtidal kelp and storm-cast seaweeds are also collected. To our knowledge, there are no comprehensive estimates of macroalgae production in the UK, as also suggested by the lack of data in the FAO database for the UK. Furthermore, there are no recent estimates of the wild seaweed standing stock of the UK, nor of the potential algal stock that could be sustainably harvested (with exception of *Ascophyllum nodosum* stocks in the Outer Hebrides, which have been investigated in 2010).

The majority of UK seaweed-related businesses (a total of 27 were identified based on a web search) produce seaweeds for human consumption as food ("sea vegetables") or condiments (10 out of 27 businesses identified), and for cosmetics (e.g. skin care; 9 out of 27 businesses). Other products, based on seaweeds and produced in the UK, include animal feed and supplements, chemicals (e.g. hydrocolloids), fertilizers and nutraceuticals (e.g. dietary supplements). Production of seaweed for bioremediation, or as biomass for biofuel production via anaerobic digestion, is at the development stage. Furthermore, there is currently limited cultivation of seaweeds in the UK although pilot seaweed farms are developing at different sites for research and development, mainly on biofuel technologies.

There are various issues and barriers limiting or affecting the development of the seaweed production and market; some of these issues are global and apply to all countries (e.g. price volatility), while others are country-specific (e.g. diseases or national 'taste' for sea vegetables). Currently, in the UK and Europe, there is a bottleneck in the seaweed supply chain in terms of production capacity; companies are interested in algal biomass but they are held back by high costs of seaweed production and/or by limited (seasonal) supply of algal biomass.

Seaweeds aquaculture could contribute to meet the demand for algal biomass; however, factors such as lack of knowledge on operational costs, yields and potential ecological impacts of seaweeds farms, as well as unclear regulatory context (particularly marine licensing), are perceived to limit the development of the industry.

In fact, it was highlighted that there is currently no specific regulation for seaweed farming in the UK and the established licensing procedure for fish/shellfish farms would not always be applicable to seaweed farms. The lack of information on potential environmental effects of seaweeds farms results in uncertainties for the regulator on how to interpret requirements under national and international regulations (for example, under which circumstances an EIA would be required).

Cefas expertise can contribute to clarify the potential for sustainable harvest, and the potential environmental effects of large-scale seaweed farms. In addition, we can help developing the marine licensing procedure for offshore cultivation and, more generally, Cefas can contribute towards creating roadmaps to identify and prioritise activities and policies to accelerate blue growth.

Concluding, to enable further development of the seaweed industry in the UK further work and investments should be directed at:

- determination of the algae standing stock in the UK and of the amount of seaweeds that could be sustainably harvested;
- development/update of regulations/licensing procedure, to account for seaweed aquaculture;
- development/maintenance of pilot farms for investigating seaweed species/strains and growth rates; yield; costs (setting up and running a farm); potential environmental effects; farm locations; storage of surplus algal biomass;

- Life Cycle Analysis of products (e.g. is economically viable to produce seaweed as biomass for biofuels?), and development of supply chains;
- knowledge transfer between research and industry, with development of algal-business clusters.

It would also be important to obtain and record comprehensive figures of annual seaweed production for the UK (which could then be submitted regularly to the FAO).

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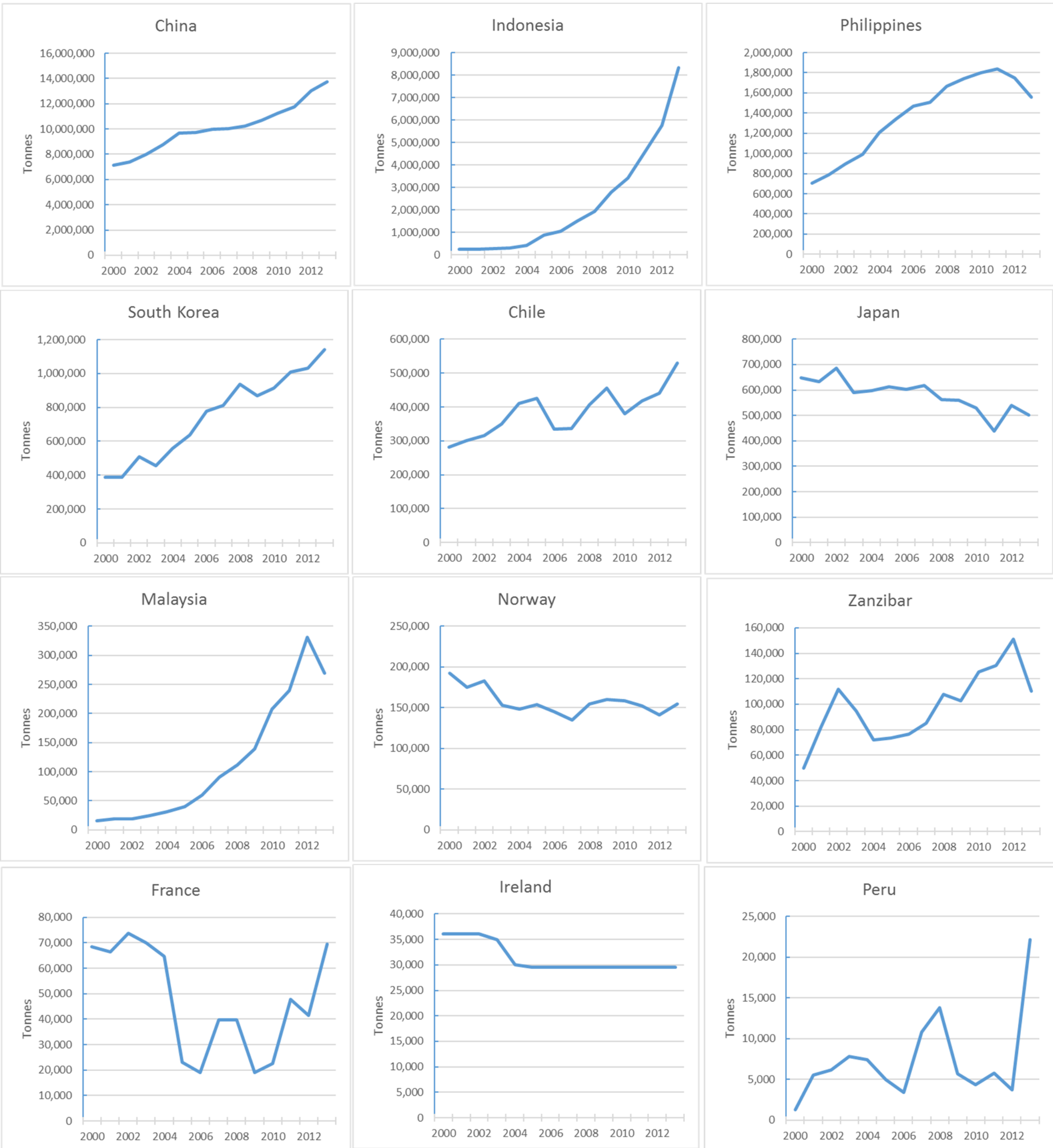
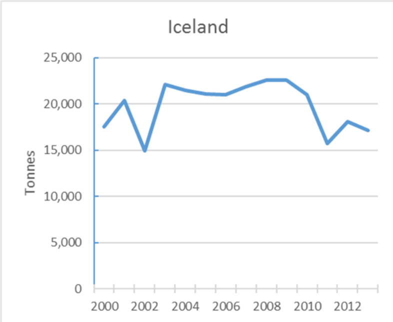
9 Annexes

9.1 Annex 1

Production of marine aquatic plants (tonnes) in the period 2000-2013 for countries listed in Table 1, excluding North Korea and Vietnam, due to unreliable production estimates. Note the different scales in the various plots. Data from FAO database (March 2016).

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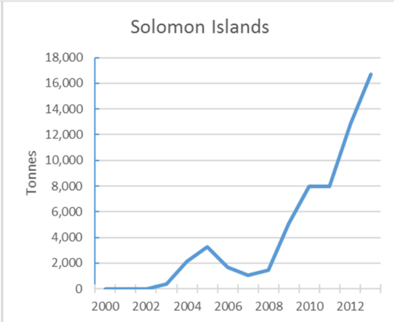
Solomon Islands
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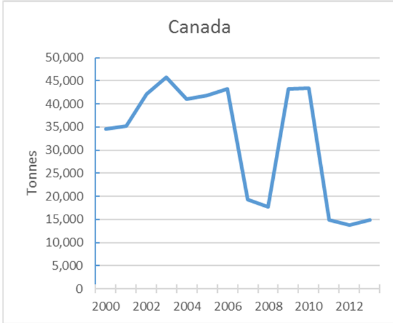
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Tonnes
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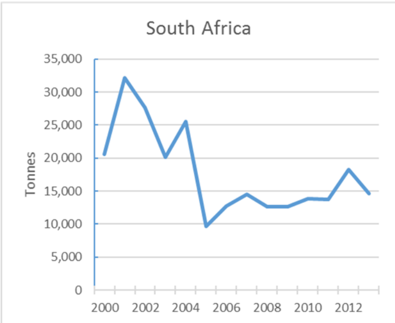
2000 2002 2004 2006 2008 2010 2012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Tonnes
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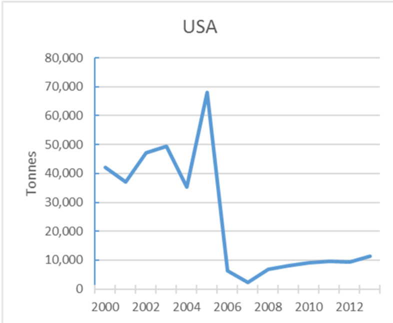
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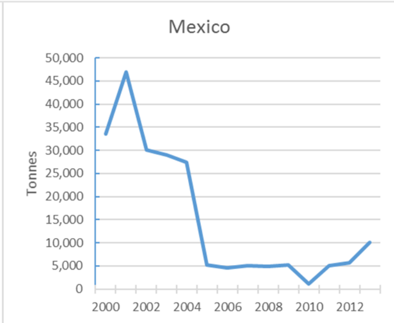
2000 2002 2004 2006 2008 2010 2012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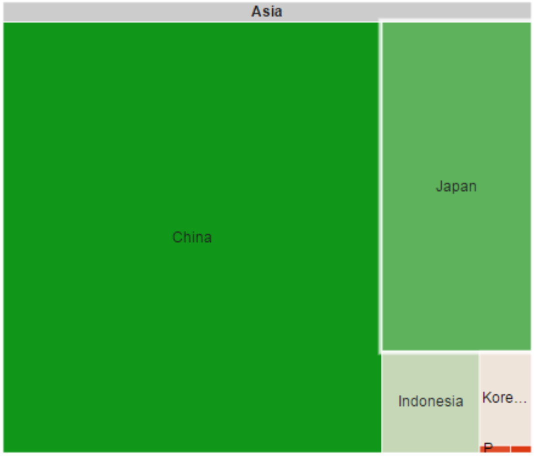
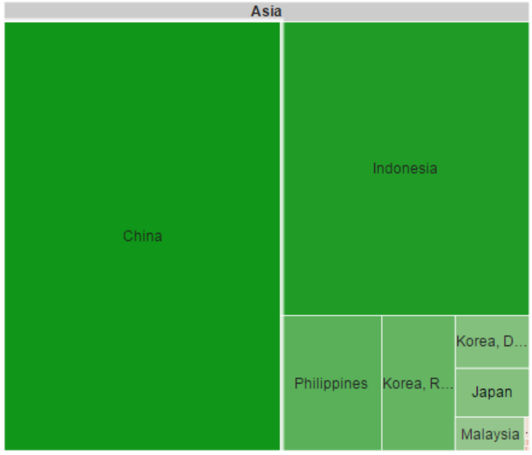
2000 2002 2004 2006 2008 2010 2012

9.2 Annex 2

Relative proportion of marine plant production by country in 2013, divided by source of production (harvest of wild plants or aquaculture), and continent (rows). Data from FAO database (March 2016).

<table>
<tr><th></th><th>Wild harvest</th><th>Aquaculture</th></tr>
<tr><td>Asia</td><td>
</td><td>
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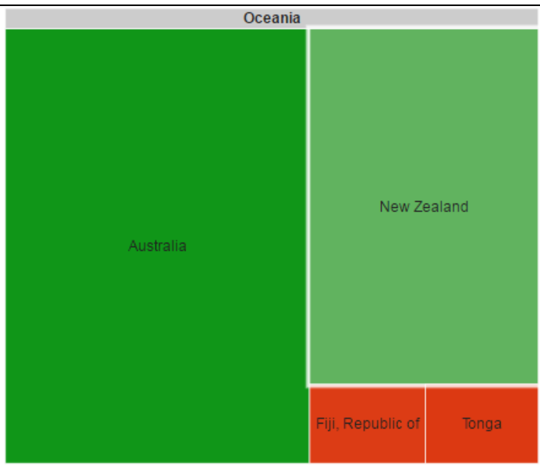
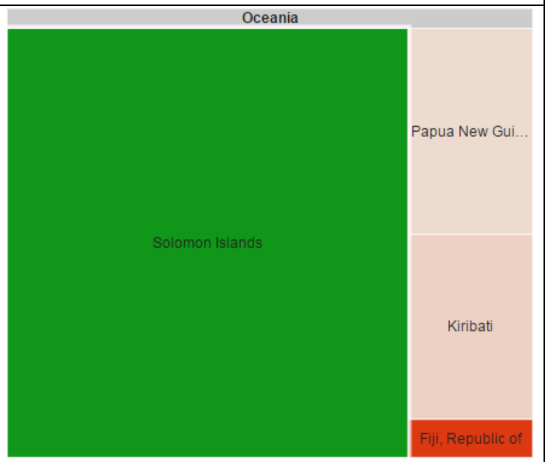
<tr><td>Oceania</td><td>
</td><td>
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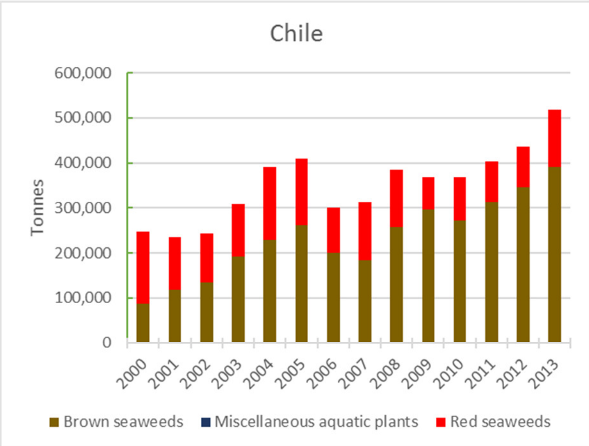
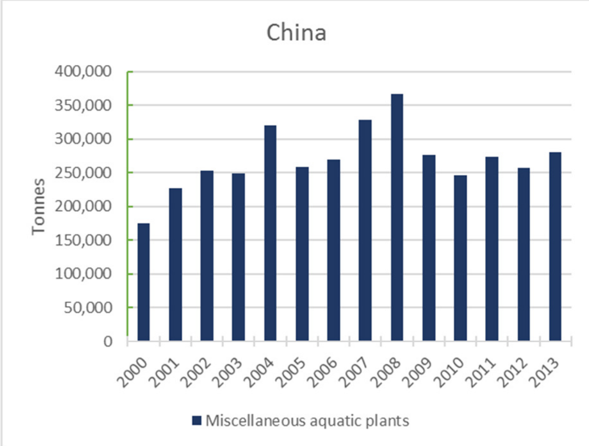
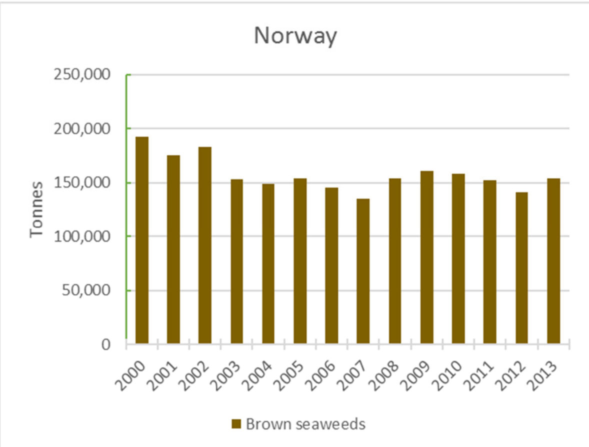
</table>

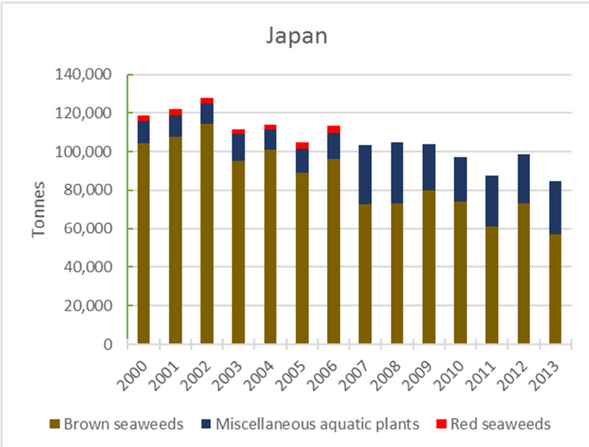
9.3 *Annex 3*

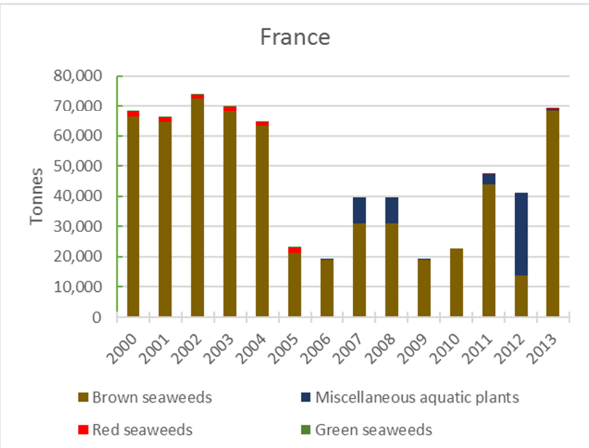
Annual production of marine aquatic plants from 2000 to 2013 from **wild harvest**, by country (Table 2) and by type of plant (i.e. brown, red, green seaweeds and miscellaneous of aquatic plants). Data from FAO database (March 2016).

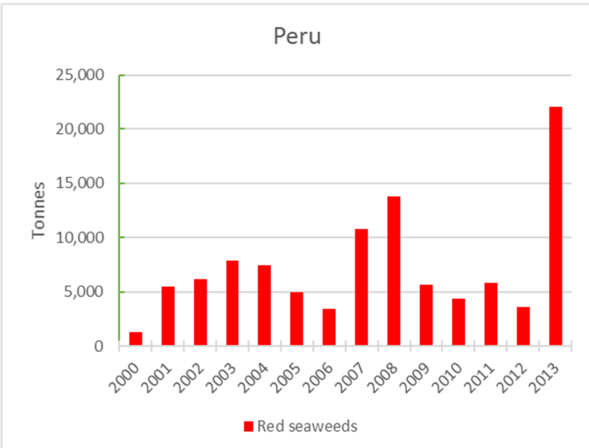


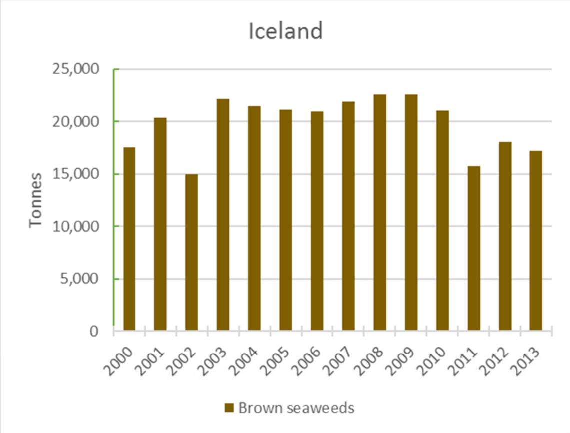











Iceland
Tonnes
25,000
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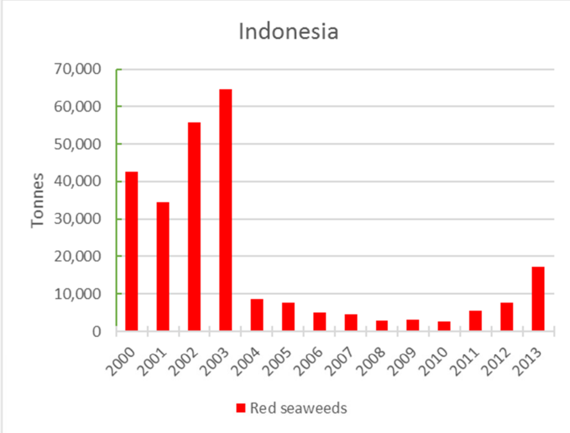
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Brown seaweeds


Indonesia
Tonnes
70,000
60,000
50,000
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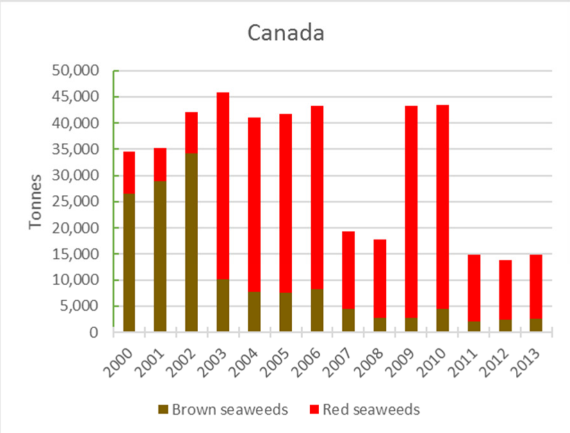
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Red seaweeds


Canada
Tonnes
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30,000
25,000
20,000
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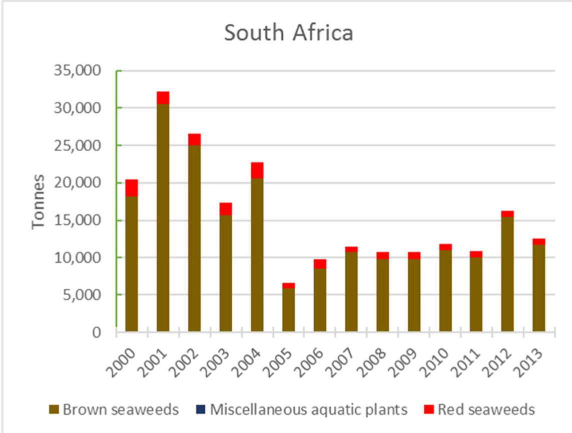
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Brown seaweeds
Red seaweeds


South Africa
Tonnes
35,000
30,000
25,000
20,000
15,000
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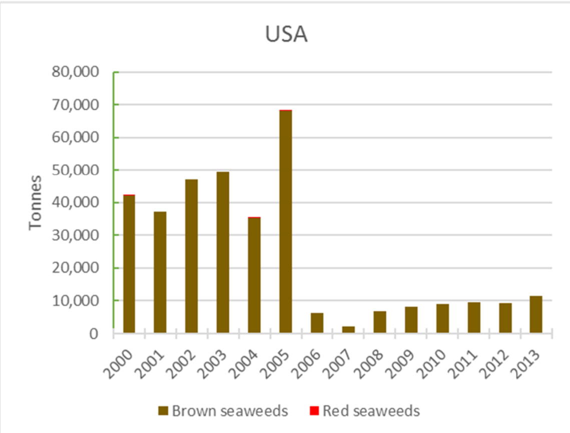
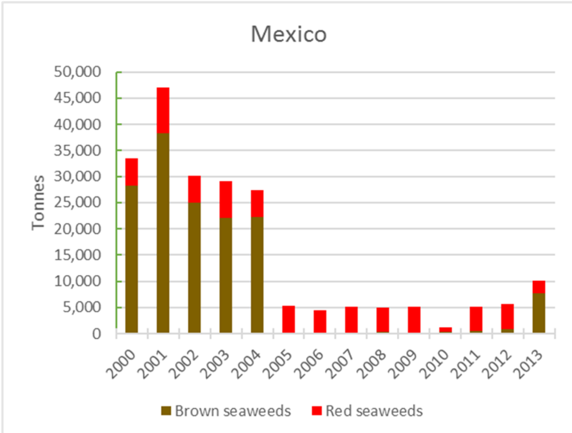
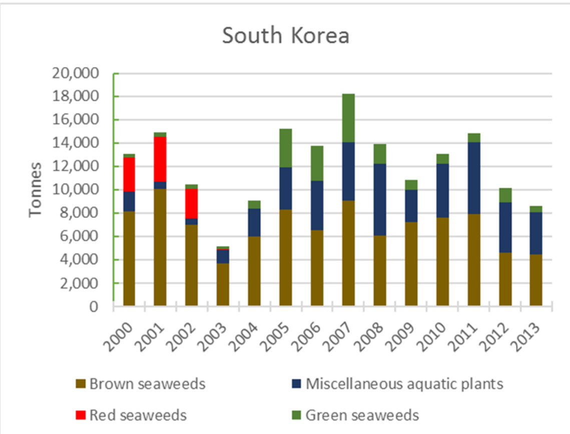
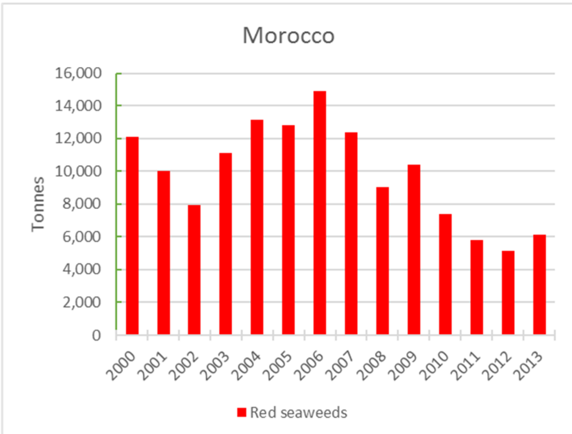
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Brown seaweeds
Miscellaneous aquatic plants
Red seaweeds


USA
Tonnes
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Brown seaweeds
Red seaweeds

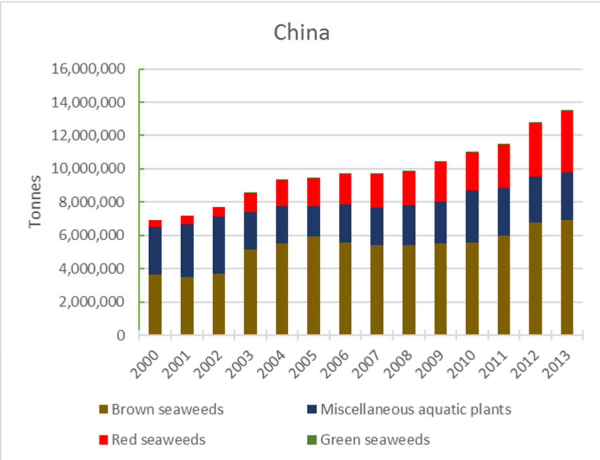

Mexico
Tonnes
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Brown seaweeds
Red seaweeds

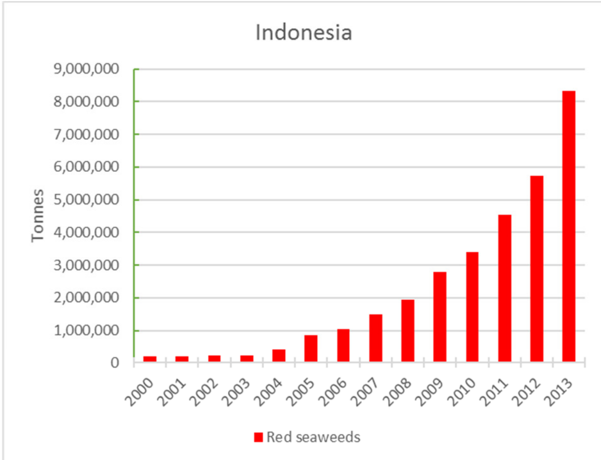

South Korea
Tonnes
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Brown seaweeds
Miscellaneous aquatic plants
Red seaweeds
Green seaweeds

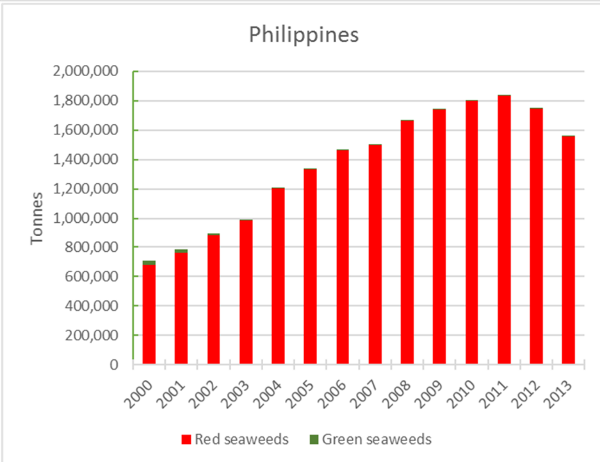

Morocco
Tonnes
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Red seaweeds

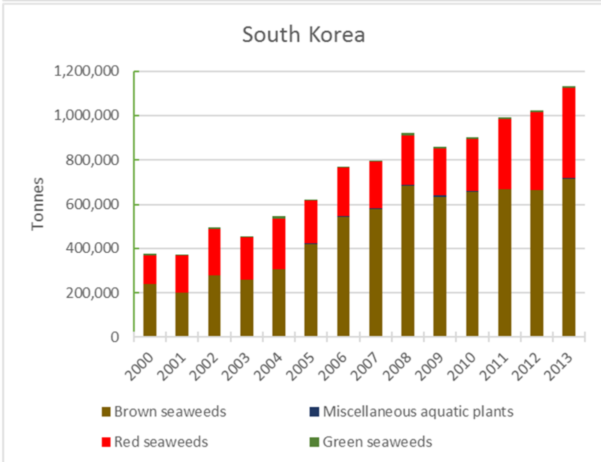
9.4 *Annex 4*

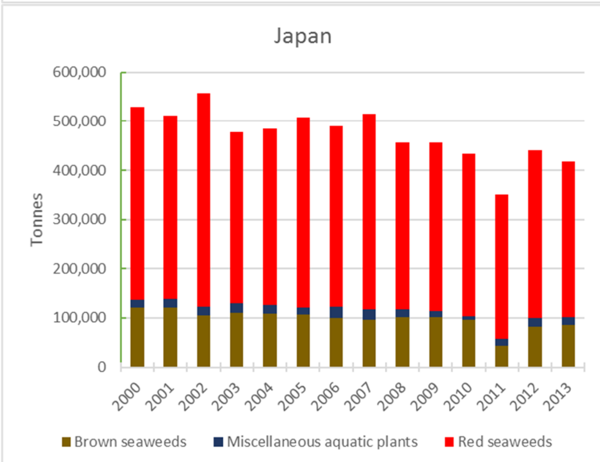
Annual production of marine aquatic plants from 2000 to 2013 from **aquaculture**, by country (Table 3) and by type of plant (i.e. brown, red, green seaweeds and miscellaneous of aquatic plants). Data from FAO database (March 2016).

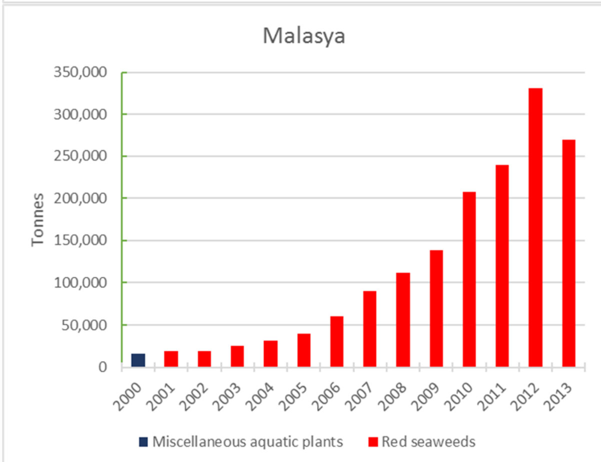


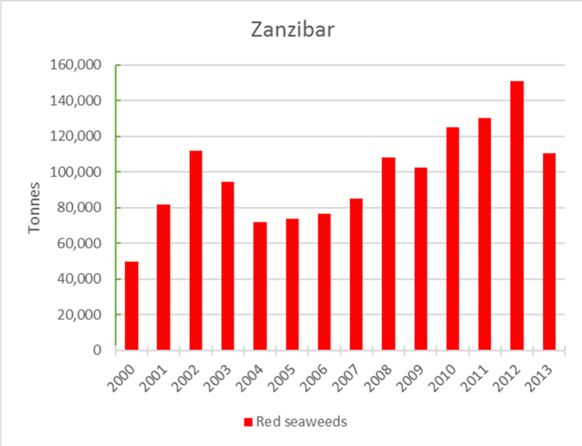


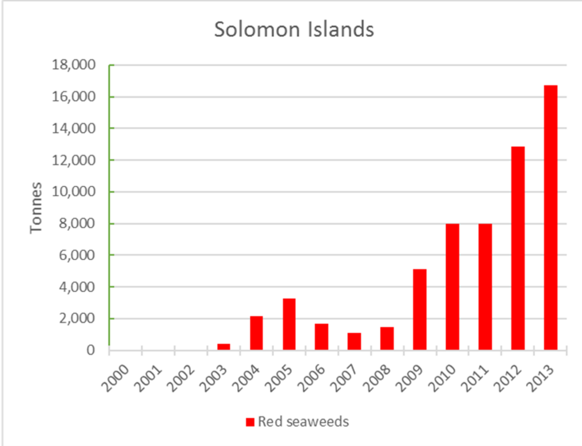


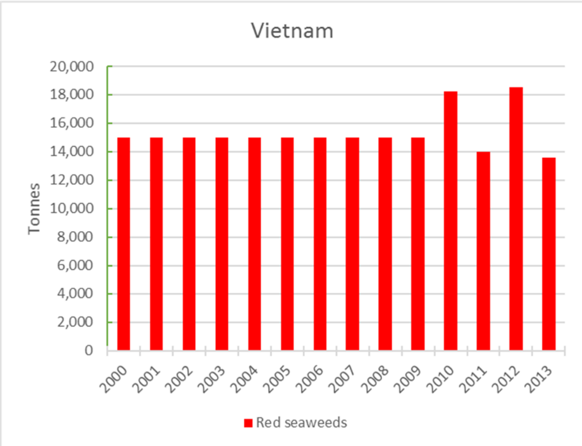


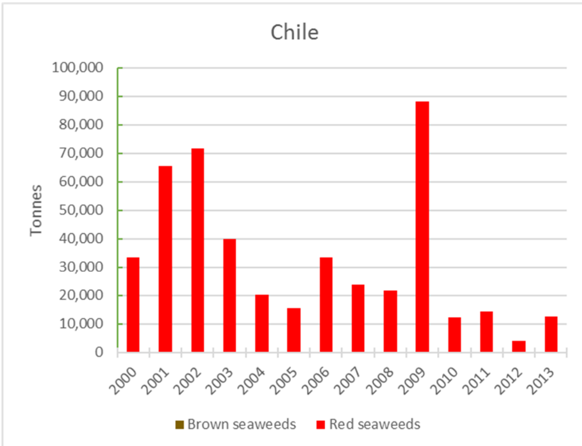


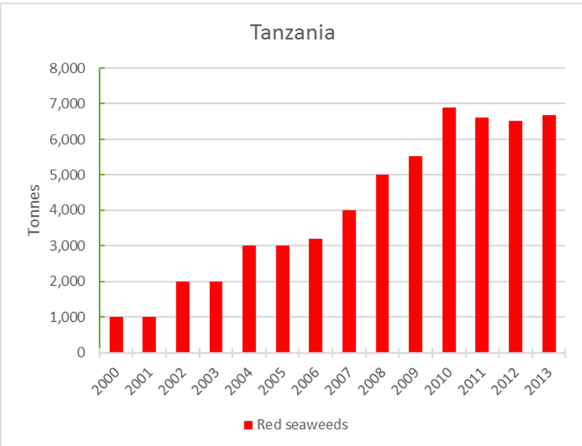


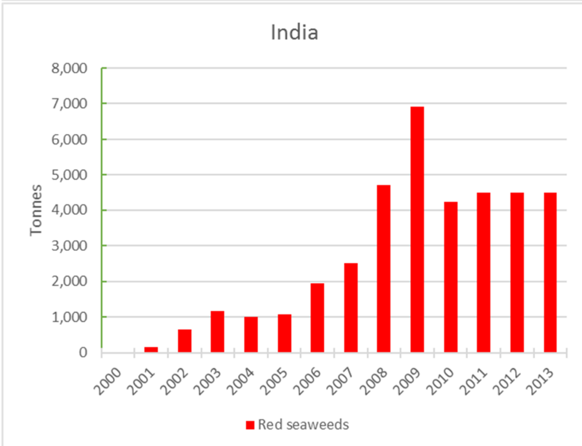

Zanzibar
Tonnes
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Red seaweeds

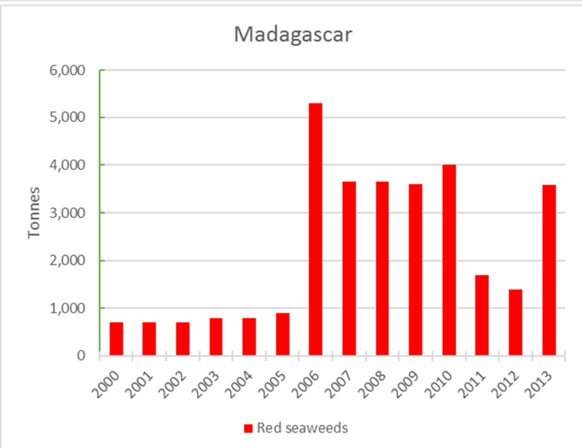

Solomon Islands
Tonnes
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Red seaweeds

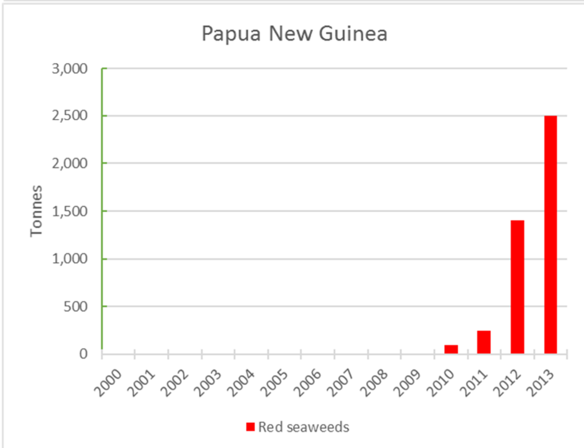

Vietnam
Tonnes
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Red seaweeds


Chile
Tonnes
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Brown seaweeds
Red seaweeds


Tanzania
Tonnes
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Red seaweeds


India
Tonnes
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Red seaweeds


Madagascar
Tonnes
6,000
5,000
4,000
3,000
2,000
1,000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Red seaweeds


Papua New Guinea
Tonnes
3,000
2,500
2,000
1,500
1,000
500
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Red seaweeds

9.5 *Annex 5*

Case study: Aquatic plants aquaculture in Indonesia

- Indonesia was the 2nd world producer of farmed aquatic plants in 2013, with 8.3 million tonnes of seaweeds produced, equivalent to 32.3% of the total world production of farmed aquatic plants (FAO statistics). For comparison, in the same year, China produced 52.2% of the total world production, while Philippines (3rd world producer) accounted for 6%.
- Indonesia was the world largest seaweed farming country for carrageenan production in 2010, accounting for 61% of world production (Valderrama et al. 2013).
- Production of farmed aquatic plants in Indonesia more than doubled between 2010 and 2013. "*Further rapid development there is expected as the national policy is to embrace "blue growth", and the country has vast areas of sunlit shallow sea as suitable culture sites]*" (FAO 2014).
- Farming of seaweeds is done at small-scale (family operations rather than corporate, plantation-style farms). Seaweed aquaculture is undertaken in remote areas where there are reduced economical alternatives and it is a major source of income for coastal areas (Valderrama et al. 2013).
- Aquaculture of seaweeds in Indonesia uses simple technologies, as well as easy and accessible materials. Seaweed farm development in Indonesia has been bottom-up driven, by farmers and local collectors (Neish 2013).
- The government perceives seaweed farming as a sustainable activity however due to the decentralize nature of farms (small-scale, family run) information on crop production and statistics cannot be collected and disseminated comprehensively (Neish 2013).
- Most cultivated seaweeds in Indonesia are red seaweeds, in particular *Eucheuma* sp. (or spinosum), *Kappaphycus alvarezii* (or cottonii) and Gracilaria (Neish 2013) for carrageenan producing.
- 68% of Indonesia's seaweed was exported to China and 22% to other Asian countries, in 2011. The majority of the product is exported as raw materials (i.e. sundried algae) therefore most of the value added to the seaweed processing is not captured in the country.
- Local newspapers (Jakarta Post, Nov 14th, 2015) indicated that in 2015 China reduced its imports of red seaweeds, leading to Indonesia being unable to absorb the resulting surplus in seaweeds. This, in turn has led to calls for infrastructure development and storage facilities for seaweed in Indonesia.
- From international press, it appears Indonesia plans to process half of its seaweeds domestically by 2020, instead of exporting raw material to China and Philippine. Indonesia is aiming to add value to seaweed (processing) locally; Switzerland Global Enterprise is endorsing the project (FoodNavigator.com, December 2015[1]). A way to achieve this target could be for Indonesia to restrict the export to raw seaweeds in order to support development of local processing plants (FoodNavigator.com, June 2015[2]).

[1] http://www.foodnavigator.com/content/view/print/1024878

[2] http://www.foodnavigator.com/Policy/What-will-it-take-to-make-Indonesian-seaweed-competitive

About us

Cefas is a multi-disciplinary scientific research and consultancy centre providing a comprehensive range of services in fisheries management, environmental monitoring and assessment, and aquaculture to a large number of clients worldwide.

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We have a long and successful track record in delivering high-quality services to clients in a confidential and impartial manner. (www.cefas.defra.gov.uk)

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CTL systems and services are developed by teams that are experienced in fisheries, environmental management and aquaculture, and in working closely with clients to ensure that their needs are fully met. (www.cefastechnology.co.uk)

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With our unique facilities and our breadth of expertise in environmental and fisheries management, we can rapidly put together a multi-disciplinary team of experienced specialists, fully supported by our comprehensive in-house resources.

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- the European Commission
- the World Bank
- Food and Agriculture Organisation of the United Nations (FAO)
- oil, water, chemical, pharmaceutical, agro-chemical, aggregate and marine industries
- non-governmental and environmental organisations
- regulators and enforcement agencies
- local authorities and other public bodies

We also work successfully in partnership with other organisations, operate in international consortia and have several joint ventures commercialising our intellectual property

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