Strategic Review of the Feasibility of Seaweed Aquaculture in Ireland

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1.0 Executive summary

The National Seaweed Forum, commissioned by the Minister for the Marine and Natural Resources in 1999, evaluated the current status of the Irish Seaweed Industry, investigated the potential uses of seaweeds and identified measures to be undertaken for developing the different industrial sectors. Seaweed aquaculture was identified as a key area for the development of the Irish Seaweed Industry to meet growing market demands and to create attractive and high–skilled jobs in peripheral communities in coastal areas.

Following these recommendations the Marine Institute commissioned this present study to investigate the feasibility of seaweed aquaculture in Ireland. Its objectives are to:

- Review the current status of seaweed aquaculture worldwide and in NW Europe, identify seaweed species, their potential uses and economic value, which would lend themselves to aquaculture in Ireland.
- Assess Irish expertise capable of supporting a national seaweed aquaculture programme.
- Identify priority RTDI projects necessary for supporting a development programme.
- Assess the availability of suitable sites for seaweed aquaculture.
- Develop an outline strategy for a national seaweed aquaculture programme over the next ten years.

Worldwide seaweed aquaculture is a growing sector. In 2000, seaweed aquaculture production was about 10 million tonnes wet weight with an economic value of US$5.6 billion. The major producer of seaweeds is China, followed by other Japan and Korea. The majority of seaweed produced is used for human consumption and for the extraction of hydrocolloids. In Europe seaweed aquaculture is a relatively new development and still in its infancy with only a small number of commercial seaweed farms. Research is focused on the establishment of low–volume high–value seaweeds, the development of new applications for algae and the identification of specific algal compounds, food supplements, cosmetics, biomedicine and biotechnology. Recent trends in life–style towards natural, healthy products are opportune for advancement in seaweed aquaculture.

The most suitable seaweed species for cultivation in Ireland for the near future are those already used in trials and/or commercial cultivation operations in Ireland and other Western countries and for which a market demand already exists. These include algae for human consumption, nutraceuticals and cosmetics. The introduction of new, high–value species into aquaculture will depend strongly on the development of new value–added applications and markets.

Irish expertise capable of a supporting national seaweed aquaculture programme is available through Third–Level Institutions, Development Agencies, service companies, fishermen and aquaculturists, and the seaweed and other industries. It is seen as essential, however, that the main impetus for development comes from the Irish Seaweed Industry.

The assessment of the current status of the Seaweed Industry and the consultations undertaken have led to the identification of RTDI needs, which are assumed to be necessary to support a national seaweed aquaculture programme. Key areas for R&D projects concern cultivation methods, research in bioactive substances and applications, and research in biomedicine and biotechnology.

The selection of suitable seaweed aquaculture sites depends on the biological requirements of the seaweed species (such as current, water depth, salinity, nutrients) and the availability of space with respect to other coastal resource users and the designation of protected areas (such as Special Areas of Conservation). Assessment of potential sites based on selected criteria revealed that the north, west, and southwest coasts of Ireland offer a range of suitable seaweed aquaculture sites for different species. Although in many of these coastal areas there are aquaculture activities, it is not assumed that situations of competition for space arise. It is however recommended that aquacultural activities be co–ordinated if organisation structures are not already in place (such as Co–ordinated Local Aquaculture Management Systems). Special Areas of Conservation do not necessarily impose an automatic ban on the use of an area, but an environmental impact survey may be required with the application for an aquaculture licence.

Evaluation of aspects investigated in this desk study has led to the development of an outline strategy for the development of a national seaweed aquaculture programme over a ten–year period. The realisation of the seaweed aquaculture programme is divided in three phases. The main objectives are to establish commercial seaweed aquaculture operations, to advance product development in different industrial sectors and to improve marketing structures.

2.0 Introduction

The term "aquaculture" is defined as the cultivation of marine and freshwater organisms. In Western countries the term "aquaculture" commonly comprises finfish and shellfish aquaculture but without reference to seaweed aquaculture. In Asian countries, however, seaweed aquaculture is considered equal or even superior to other aquaculture sectors. The total world aquaculture sector (finfish, shellfish and aquatic plants) is a rapidly growing sector with a total production of 45.7 million tonnes and a total value of US$56.5 billion in 2000 (FAO 2002). This represents an increase of about 64% in quantity and 34% in value compared to 1995. The total global aquaculture production of finfish accounts for more than 50% (23 million tonnes). Proportions, however, vary drastically when species are grouped according to environment. In the marine environment, the main species groups in aquaculture are molluscs (46.2%) and aquatic plants (44%). Reported world seaweed production in 2000 was 10.1 million tonnes with an economic value of US$5.6 billion (FAO 2002). The major producer of seaweed is China, followed by Japan and Korea.

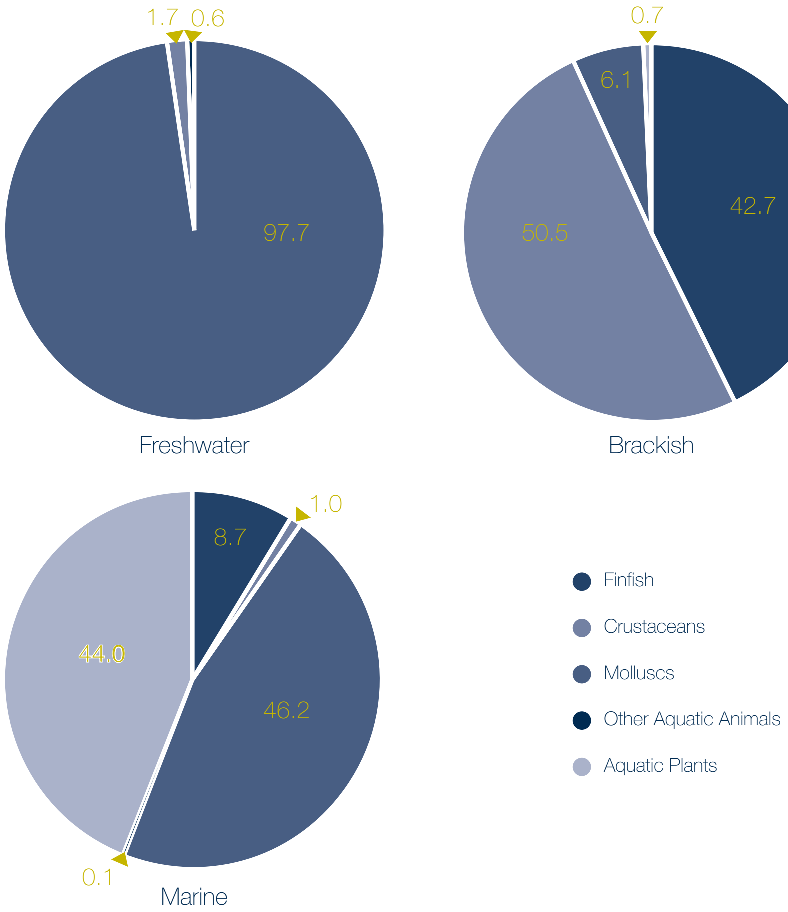


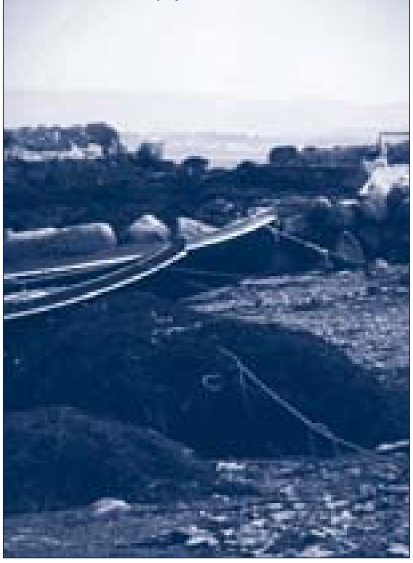
Fig 2.1: World aquaculture production: proportions of species groups by environment in 2000 (FAO 2002).

The concentration of mass production of seaweed in aquaculture in Asia results from specific cultural and historical traditions as well as socio–economic aspects. Moreover, natural conditions with respect to hydrogeography and the abundance of suitable cultivation sites have contributed to this development. In recent years, efforts have been made to establish seaweed aquaculture in North America and Europe. Some of the underlying reasons include: partial substitution of seaweed aquaculture by the more profitable finfish and shellfish aquaculture in traditional producer countries in Asia, environmental pollution, and climate changes (e.g. El Niño phenomenon), which have led to losses in seaweed production. These developments have created bottlenecks in meeting the growing demand mainly of the food sector in Asia, which is consequently considered to be a potential market for seaweeds produced in Europe and North America. Advances in research and technology and recent market trends have led to an increased interest in seaweed aquaculture in North America and Europe, and have created new applications and new demands. In the western hemisphere emphasis is directed towards the cultivation of high–value low–volume seaweed species, and towards more environmental friendly integrated aquaculture systems comprising finfish, shellfish and seaweeds. An important driving force of the industry is the search for new natural chemical substances from marine organisms. Several European countries have an established seaweed industry based on the exploitation of wild stock but efforts are underway to evaluate the potential of seaweed aquaculture.

Ireland has a long tradition in the utilisation of seaweed. For centuries cast seaweed ("blackweed", consisting mainly of *Laminaria* spp., *Fucus* spp. and *Ascophyllum nodosum*) was collected from the beach and used as fertiliser on farmland (Guiry, www.seaweed.ie). Seaweed was also used as fodder for cattle and gathered for human consumption and medical applications. The discovery of soda in burnt seaweed (kelp) in the 18th century, which was essential for pottery glazing and the manufacture of glass and soap, led to a first flourishing period of the seaweed industry in Ireland. When this industry declined in the early 19th century following the establishment of the Le Blanc's soda process, another industry developed, which used burnt kelp as a source of iodine. This industry was sustained over some decades before it declined at the end of the 19th century. The seaweed industry gained some importance at the beginning of the 20th century with the collection, drying and milling of drift weed for the use as fodder. Due to the low nutritional value of the drift weed, the increase of drying costs and the low economical value, the use of drift weed declined sharply in the 1980s, and disappeared in the early 1990s.

Today's seaweed industry in Ireland comprises several sectors including biopolymers, agriculture/horticulture, cosmetics and thalassotherapy, and human consumption. The first two sectors are economically the most important ones. Although about 16 seaweed species are commercially utilised the highest production is presented by only three. Harvested calcified algae, collectively known as maërl, comprises mainly two species (*Phymatolithon calcareum* and *Lithothamnion corallioides*). These are exploited by one company and sold as powder for agricultural, horticultural and food applications and as a water–filtration agent. The other bulk species *Ascophyllum nodosum* is used for alginate extraction and agriculture/horticulture applications. This species sustains an industry, which is an important factor in contributing to the maintenance of coastal communities especially in rural areas along the west coast.

On the beach: Ascophyllum nodosum



Apart from maërl the supply of raw material for this industry as well as for the other sectors relies on harvesters who cut the seaweed sustainably by hand. Although a source of employment this hampers the expansion of the seaweed industry, especially in the light of declining numbers of harvesters due to an increasing age profile and insufficient recruitment. The demand for raw material on the other hand is increasing due to recent developments on the market and industrial side. With respect to these developments and the availability of natural sustainable resources in Ireland the industrial potential including high–value applications has not been fully realised.

Against this background the National Seaweed Forum was commissioned by the Minister for the Marine and Natural Resources in 1999 consisting of 19 members from State Agencies, Third–Level Institutions and the seaweed industry. The objective was to evaluate the potential of the industry and to formulate measures for further development. The results of the assessment were published in the National Seaweed Forum Report in 2000.

The National Seaweed Forum identified seaweed aquaculture as a key area for development of the Irish seaweed industry. It was stated that seaweed aquaculture would provide the most cost–effective method to meet the growing market demand with high–quality seaweed for specific sectors such as human consumption, cosmetics and biotechnology. Additionally, a seaweed aquaculture industry is expected to create attractive and high–skilled jobs especially in peripheral communities in coastal areas.

Other crucial recommendations given from the Forum were successfully implemented, and are of direct relevance for the development of a seaweed aquaculture industry were:

- The establishment of the Irish Seaweed Centre in 2001 as a regionally based centre of excellence for seaweed research with links to the other research institutions, the industry and development agencies.
- The appointment of a Seaweed Research Coordinator by the Marine Institute. The main objectives of the Coordinator are to select and realise R&D based key ideas in the areas of seaweed aquaculture and seaweed harvesting, and to facilitate technology transfer and innovation.
- The appointment of a regionally based Seaweed Development Officer by BIM to promote and assist in the development of seaweed harvesting and aquaculture and to bring projects to a commercial stage.
- The assistance in seaweed aquaculture pilot trials by relevant State Agencies and regulatory bodies and to evaluate the economic feasibility of these projects.

In this context, the Marine Institute commissioned the present study in order to assess the feasibility of seaweed aquaculture in Ireland and provide a conceptual base for the development of a Seaweed Aquaculture Industry. This study includes:

1. A review of the status of seaweed aquaculture worldwide.
2. A review of seaweed aquaculture experiences in NW Europe.
3. The identification of seaweed species, their by–products and economic value, which lend themselves to aquaculture production in Irish waters.
4. An assessment of Irish expertise capable of supporting a seaweed aquaculture development programme.
5. The assessment/identification of priority RTDI needs/projects necessary to support such a development programme.
6. An assessment of availability of suitable sites for seaweed aquaculture.

A final evaluation of all these aspects is leading to an outline strategy for the development of a national seaweed aquaculture development programme over the next ten years.

In connection with this desk study a workshop entitled "Seaweed Aquaculture in Ireland: Opportunities and Challenges; Exploring the potential for Ireland and the Seaweed Industry" which was held on April 10th, 2003 in Galway, was organised by the Irish Seaweed Centre and the Martin Ryan Institute in conjunction with the Marine Institute, the Irish Seaweed Industry Organisation (ISIO), BIM and Taighde Mara Teo. The workshop was funded by the Marine Institute.

3.0 A short review of seaweed aquaculture worldwide

This document was prepared for the Irish Seaweed Centre, Martin Ryan Institute, National University of Ireland, Galway, Ireland, as part of the desk study "Strategic review of the feasibility of seaweed aquaculture in Ireland". The information was produced by Dr Alan T. Critchley*. The personal impressions and opinions are entirely those of the author. They do not represent, and cannot be construed to represent, the opinions and positions of his past or present employers.

3.1 Introduction

This article sets out to highlight some relevant points regarding aspects of seaweed aquaculture. It is a reflection on some factors affecting and developments within the subject area. The intention is to present a realistic approach to the topic and generate informed interest.

The first part of this review deals with the current and most reliable data available on seaweeds harvested and produced in aquaculture by the major producing countries in the world. It can be seen that from the great diversity of seaweeds available, relatively few are used and even fewer cultivated. The second section of this review provides some supplementary information and personal reflections on issues affecting seaweed aquaculture in general. The third part review takes some pointers from a recent analysis of why China is the world's largest producer of aquaculture species (including seaweeds). Seaweeds are to some extent considered low–value biomass when compared to finfish and shellfish aquaculture and there is an increasing trend to value–addition. Seaweed aquaculture at its most basic is promoted as a means of providing employment opportunities in a number of developing/ emerging countries with suitable coastal environments, and at its most advanced a highly technological and controlled enterprise.

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3.2 Seaweed aquaculture production and value data

3.2.1 Background and terms

Seaweed aquaculture, mariculture, cultivation, farming, ranching, phycoculture, marine agronomy

The title given to this short review is that of seaweed *"aquaculture"*. However the term is perhaps synonymous with seaweed *"mariculture"* (the distinction between freshwater and marine cultivation seems to have been blurred in recent years – but obviously seaweeds can only be cultivated in sea water). In addition, these terms may possibly conjure up an image of seaweeds grown in some form of impoundment or tanks/raceways on land. By contrast, the terms seaweed *"cultivation"* and seaweed *"farming"* are also in common usage and may even be used interchangeably, but they are terms which might be most commonly applied to the production of seaweeds in the open sea (on a small scale there are individual plots, increasing to larger–scale applications of such terms as co–operatively operated seaweed "estates" or "plantations"). Seaweed *"ranching"* is an alternative term used to convey the concept of seeding natural or man–made areas/structures to develop "natural" seaweed beds/forests which may then be used either for habitat development (e.g. to attract other commercially important species – abalone/lobsters, etc.) and/or to act as a sustainable resource that can be harvested. *Ranching* is a relatively recent concept which is being applied successfully in Japan. *"Phycoculture"* is a useful term which encapsulates the production of all types of algae (micro and macro–) in any system, using marine or freshwater. *"Marine agronomy"* perhaps takes the subject of marine aquaculture further dealing with the broad–scale, practical methods of field–crop production and also the management and manipulation of factors affecting production.

Seaweed: seaplant, sea vegetable (veggies, sea salad, aquatic plants, etc.)

The title of the short review also includes the term "seaweed". There are many alternatives such as the more scientific, collective term "macroalgae" (singular macroalga – likewise the term "algae" is collective and plural, the term alga is singular). Seaweeds are algae, and all seaweeds are macroscopic and live in marine waters. However, not all algae are seaweeds and (micro– and macro–) algae can be found in many different types of aquatic (and damp) environments.

Unfortunately, the common name combination of the words "sea" and "weed" does not always result in a positive image in the minds of many western consumers (the term rather conjures up images of rotting, smelly masses on the beach!). The Japanese character for seaweed is *"kaiso": kia* (ocean) and so, which can mean water, plant, good, tree, etc. it seems a much more "kindly" term for these beneficial, large photosynthetic organisms from the sea (Nisizawa, 2002). For clarity the term seaweed will be used throughout this document.

In the marketing and value–addition of seaweeds and their products, some producers have found it advantageous or even necessary to try to compensate for pre–conceived ideas that seaweeds are something, nasty, smelly and of little worth. Those fortunate people who study seaweed and marine biology all know how wonderful seaweeds are, but very few consumers actually realise just how common their use of seaweed derived extracts is in the normal daily use of processed foods, cosmetics, etc. To promote the use of seaweeds for food in western diets, there are increasing trends towards calling seaweeds more acceptable names such as, sea plants (seaplants), sea vegetables (veggies), sea salad, and so on.

Of course, the most valuable seaplants are those which are difficult, or presently impossible, to produce by aquaculture (e.g. the red seaweed *Meristotheca* used in seaweed salad, once traded for around the equivalent of several hundred US$ per kg since it was only available by hand collection and in very small volumes – it was difficult to cultivate, however a patent has recently been registered in Japan). Once a seaweed has been domesticated and the volumes available through cultivation increase, then the value will naturally decline. When a product becomes a commodity and there are several producers, then competition for lower prices is inevitable.

Unfortunately, there has been some confusion over the value of seaweed extracts – some of the more common valuable fine–chemicals produced by algae are often actually derived from microalgae (e.g. pigments such as beta carotene, astaxanthin, etc). This is not to deny that some seaweeds contain interesting active compounds (see Nisizawa, 2002).

3.2.2 Seaweed production and value worldwide

The most independent and respected source of data on aquaculture production of seaweeds is the Food and Agriculture Organisation (FAO). They use the collective term "aquatic plants" (sometimes tabulated in Latin *Plantae aquaticae*), the majority of which are seaweeds. They report statistics on use of aquatic plants by collection or capture from wild stocks and also aquaculture. Their figures are reported in metric tonnes wet (fresh) weight and economic values in thousands of US$ ('000). Data are supplied by the national FAO offices to a central database for collation. Sometimes information is obscured under the title "miscellaneous" if the information cannot be defined to the species or category level. In the case where no statistics are returned, FAO make an estimate, based on previous data (and marked "F" in their tables). A report of '0' indicates more than zero but less than half of a tonne. FAO's data are considered to be independent and although absolute values may not always be "spot on", their trends and "ballpark" values are acceptable for comparisons of performances and trends in activities.

FAO publish their annual fisheries statistics and make information available via their web site. Thus in the first half of 2003 the most current information will be from 2000. The 2001 year book will be published in summer 2003 (and the web data updated at that time). In March 2004, a new version of FishStat containing 2002 data will be available.

Table 3.1 shows the volumes of aquatic plants for those countries where both wild harvest and aquaculture are practiced in terms of FAO (2002) data available up to 2000. In terms of collection from wild stocks, China falls just behind Chile, producing 204,290 versus 247,376 metric tonnes wet weight respectively. All the values pale into insignificance when one compares the volume of seaweeds produced by aquaculture by China. Approximately 7.9 million tonnes fresh weight were produced in 2000 (which has increased to 8.2 million tonnes in 2001; supplementary FAO data). This represents approximately 70% (in 2000) and 78% (in 2001) of global seaweed aquaculture production respectively (viz. global totals of 10.1 and 10.5 million tonnes in 2000 and 2001, respectively).

The relative volumes of seaweed capture (wild harvest – 1,219,028 wet tonnes) and aquaculture (10,130,448 wet tonnes) in 2000 can be compared with fish capture (94,848,764 tonnes) and fish aquaculture (35,585,111 tonnes) to show that in 2000 seaweed wild harvest volumes only represented approximately 1.3% of fish caught in the sea, yet seaweeds represent just over 28% of the volume of combined fish species aquaculture.

FAO (2002) report statistics on the world production of aquatic plant material by culture environment. Figure 3.1 shows the volumes and values of seaweeds produced (1991 – 2000) in predominantly marine environments (some minor amounts are produced in brackish waters, viz. mostly *Gracilaria* spp.). The figures are corrected by taking total values and removing quantities attributed to freshwater activities. It can be seen that over this period total volumes increased by more than 100% (from over 4 million to nearly 10 million wet tonnes per annum since 1991).

Table 3.1. Countries involved with both wild collection and aquaculture of seaweeds.

An overview of aquatic plant production by capture (wild stocks) versus aquaculture (*data FAO 2002).

Aquatic plant production (wet weight metric tonnes)

Country	Capture	Aquaculture (2000)
Argentina	3	
Australia	13 650	
Canada	14 790	
Chile	247 376	33 471
China	204 290	7 863 540
China (Taiwan)	125	12 529
Cook Isl.	50	
East Timor	1	
Estonia	201	
Fiji Isl.	67	520
France	70 336	20
Iceland	17 501	
India	100 000	
Indonesia	17 916	205 227
Ireland	36 100	
Italy	2 000	3 000
Japan	119 030	528 881
Kiribati		9 500
Korea DP Rp		401 000
Korea Rep.	13 030	374 648
Madagascar	5 792	
Malaysia	16 125	
Mexico	33 555	
Morocco	6 080	
Namibia	829	20
Norway	192 426	
Peru	1 312	11
Philippines	413	656 631
Portugal	1 224	
Russian Fed	53 653	3 008
South Africa	6 000	157
Spain	14 214	
Tanzania	5 000	7 000
Ukraine	6	
USA	42 058	
Venezuela		160
Vietnam		15 000

The value of the biomass increased in the early 1990s from around US$4 to 5.5 billion, since which the value has remained in the US$5–6 billion range. Thus, whilst volumes have seen large increases, overall biomass value has increased by around 50%.

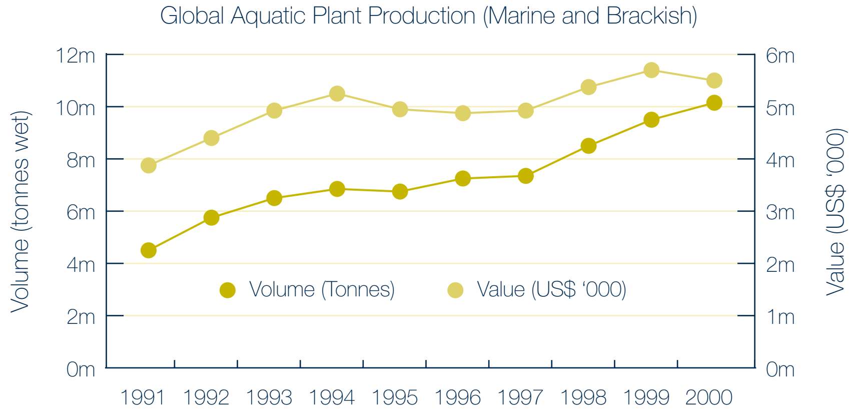

Fig. 3.1: Comparison of volumes (tonnes fresh weight) and value (US$ '000) for marine and brackish seaweeds, 1991 –2000 (data FAO 2002).

Volumes and values of seaweeds showed the greatest increases in the early and late 1990s, with a general increasing trend ending 2000 with a value of around US$6 billion for a wet volume of around 10 million tonnes.

Table 3.2: Most common genera and uses of seaweeds produced in aquaculture.

*Adapted from Wikfors and Ohno (2001).

Class	Genus	Uses
Chlorophyta	Monostroma	edible, human food
	Enteromorpha	edible, human food
Phaeophyta	Laminaria	alginates, edible, human food
	Undaria	edible, human food
	Cladosiphon	edible, human food
Rhodophyta	Asparagopsis	medical applications
	Gelidiella	agar, food and medical
	Gelidiopsis	agar, food and medical
	Gelidium	agar, food and medical
	Gracilaria	agar, food and medical
	Pterocladia	agar, food and medical
	Chondrus	carrageenan, human food
	Eucheuma	carrageenan, human food
	Kappaphycus	carrageenan, human food
	Gigartina	carrageenan, human food
	Hypnea	carrageenan, human food
	Iridaea	carrageenan, human food
	Palmaria	human and horse feed
	Porphyra	carrageenan, human food

FAO (2002) consolidated the data on the global production and value of brown red and green seaweeds used in aquaculture. These data are presented in figs 3.2 and 3.3. The figures show clearly that the most voluminous and valuable seaweeds produced in aquaculture are consistently the brown seaweeds with approximately twice the tonnage and value of red seaweeds. By comparison the green seaweeds are quite minor in importance. The majority of these species are used in some form for food or, in a few cases, for chemical extracts. The costs of production of the biomass tend to exceed the value of the biomass as a raw material for phycocolloid extraction, although it is known that some Chinese kelps produced by aquaculture are used for the production of salts of alginic acid, and applying low–technology extensive forms of aquaculture are used to produce *Gracilaria* for agar extraction (see Tables 3.3 and 3.4).

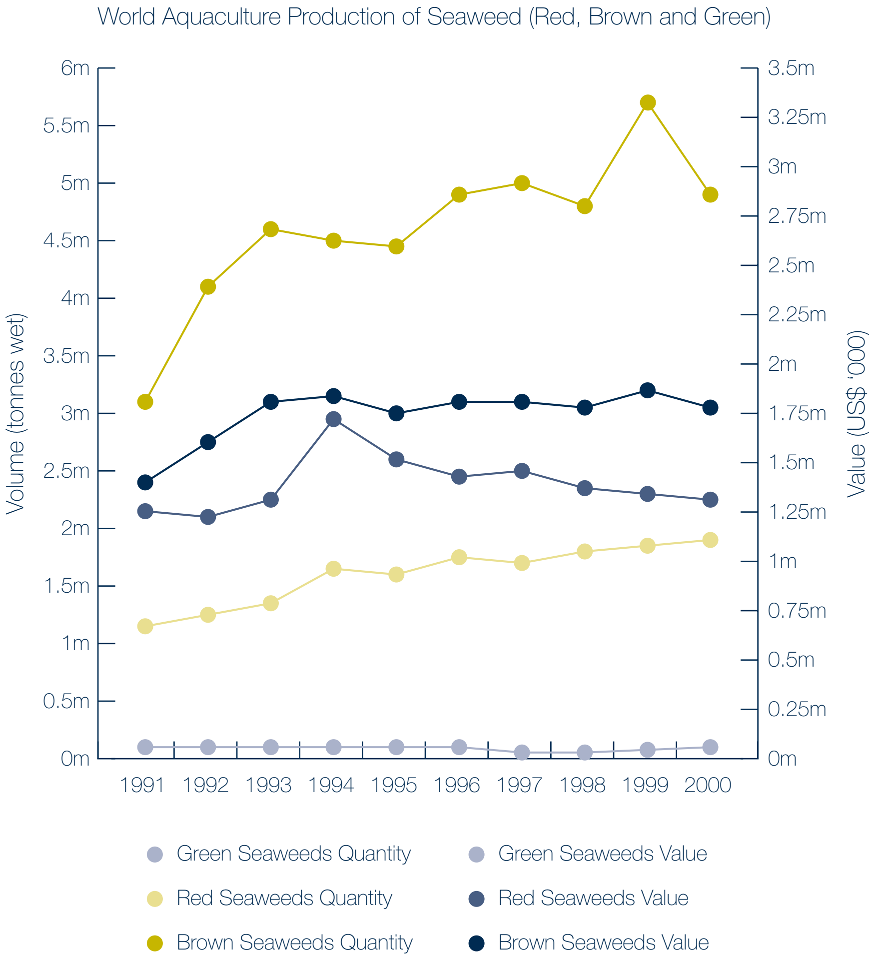

Fig. 3.2: Comparison of brown, green and red seaweed production and values in aquaculture 1991 –2000 (FAO 2002).

Brown seaweed production by aquaculture increased from 1991 – 1993 and remained relatively constant with a tonnage of around 5 – 5.5 million wet tonnes and a value of around US$1.8 billion. By far the largest volumes and value are made up of *Laminaria japonica* (kombu) and *Undaria pinnatifida* (wakame) from China.

Figure 3.2 illustrates that value and volumes of red seaweeds increased until 1994. Quantities show an increasing trend between 1.7 – 1.9 million tonnes fresh weight since 1996. However, from their highest value level of 1994 (US$1.8 billion), the value of red seaweed produced by aquaculture has shown a declining trend to US$1.3 – 1.4 billion over the 1997 – 2000 period. This is probably due to the high volumes of carrageenophytes *Kappaphycus* and *Eucheuma* produced by cultivation in SE Asia and, to some extent, *Gracilaria* cultivated in South America, and as such, showing trends towards commoditisation.

Fig. 3.3: Value and volumes of green seaweeds produced by aquaculture (data FAO 2002).

Green seaweeds produced by aquaculture have relatively minor values and volumes, as compared with the red and brown seaweeds. Between 1991/92 and 1998, values declined, at this time the most common green in aquaculture was *Caulerpa*. Some increasing volume and value is reported from 1998, probably due to the increased cultivation of *Monostroma*, *Ulva* and *Enteromorpha* for aonori or green laver in Japan and the Republic of Korea.

3.2.3 Main species of aquaculture seaweed by country

Tables 3.3 and 3.4 are prepared from data provided by FAO, which will appear in the next (2003) aquaculture handbook.

Table 3.3: Ranking of largest volumes of aquaculture seaweeds and producer countries

Ranking	Country	Seaweed produced by aquaculture	Percentage of global seaweed aquaculture production 2001 (tonnes fresh weight)
1	China	*Laminaria japonica* (P) kombu	38% (3 988 650)
2	China	Red aquatic plants (R) (unspecified – mostly *Gracilaria* (agar) and eucheumatoids)	34% (3 586 810)
3	Philippines	*Kappaphycus alvarezii* (R) (reported as *Eucheuma cottonii* for kappa carrageenan)	6.3% (664 068)
4	China	*Porphyra* (R) nori	5.5% (583 990)
5	Japan	*Porphyra* (R) nori	3.5% (373 121)
6	Korea, Dem. P. Rep.	*Laminaria japonica* (R)	3.3% (350 000)
7	Indonesia	Red seaweeds (mostly eucheumatoids for carrageenan)	2% (212 473)
8	Korea, Rep.	*Undaria pinnatifida* (R) wakame	1.7% (175 490)
9	Korea, Rep.	*Porphyra* (R) nori	1.6% (167 909)
10	Chile	*Gracilaria* spp (R)	0.6% (65 538)

(C) = Chlorophyta; (P) = Phaeophyta; (R) Rhodophyta

The first five ranked categories (Table 3.3) of seaweeds and their countries comprise approximately 87% of all seaweeds produced in aquaculture in 2001.

The data allow some interesting observations to be made:

- The domination of China in global seaweed production by aquaculture is clear (approximately 8.2 million tonnes fresh weight or 77% of global total in 2001). China's production is almost equally split between the brown seaweed *Laminaria japonica* (49%) and undefined of red seaweeds (44%, *Gracilaria* and carrageenophytes). Nori (*Porphyra* spp.) contributes the remaining 7% of China's seaweed aquaculture output. Production of *L. japonica* continued to increase rapidly from just over 1.2 million (1990) to nearly 4.5 million metric tonnes fresh weight (1999). In the years 2000 – 2001 this value declined to about 4 million tonnes. However, this trend is compensated by the almost exponential increase of other unspecified red seaweeds increasing from around 465,000 tonnes (1996/1997) to 3.6 million tonnes (2001). *Eucheuma* seaweeds for carrageenan and *Gracilaria* spp. for agar extraction are included in this group. After some declines in seaweed production due to competition with other forms of marine aquaculture, seaweed farming as a means to address some eutrophication problems is being adopted, which will contribute to overall increases. The production of nori shows a steady increase in China.
- Production in the Philippines is dominated by carrageenophytes. There are some name problems but seaweeds for kappa carrageenan production make up 89% of the seaweeds produced by aquaculture in the Philippines. This is followed by *Eucheuma* for iota carrageenan (8%), with the remaining 3% coming from the production of the green seaweed *Caulerpa* for food. After a rapid expansion of *"E. cottonii" (Kappaphycus alvarezii)* eucheumatoid farming in the first half of the 1990s, the rate of production increased from about 350,000 to around 600,000 tonnes by 1996, subsequently production has increased more slowly to just over 660,000 tonnes in 2001. In comparison, the production of eucheumatoid seaweeds in Indonesia has shown an overall increase to around 200,000 tonnes in 2000/2001. The Philippines produced 7.4% (785,795 tonnes) of the total of all seaweeds produced in the world in 2001.
- Japan has a broad spectrum of seaweeds produced by aquaculture. Their major product is nori (73%), followed by roughly equal amounts of the brown seaweeds kombu (12%) and wakame (11%). There are relatively minor contributions made by aquaculture of other red and some green seaweeds (aonori). Production of nori peaked at around 480,000 tonnes in 1994. Since 1995, nori production has stabilised at around 400,000 tonnes. The overall level of wakame production declined steadily from just over 110,000 tonnes in 1990 to almost half of that in 2001 (57,000 tonnes), possibly in the face of competition by other major producers of wakame (such as North and South Korea). In comparison, the remaining seaweeds produced in Japan have remained relatively stable over the 1990 – 2000 period. Japan produced 4.8% (511,755 tonnes) of the global seaweed production by aquaculture in 2001.

- The Republic of Korea (south Korea) has the broadest range of seaweed production. The kelp wakame (*Undaria*) and the red seaweed nori (*Porphyra*) were roughly equal (at 46% and 45% of total in 2001). In the mid 1990s, the volumes of wakame were almost double that of *Porphyra*. In 2001, the majority of the remaining 9% was made up of *L. japonica* (5%) and 2% for "unspecified brown seaweed" cultivation (which may include some production of *Cladosiphon*) and also the green seaweed *Monostroma*. The production of wakame was greatest in the mid 1990s but volumes have declined significantly. Peaking in 1997 at just over 430,000 tonnes they declined to less than half that value, to about 175,000 tonnes by 2001. Nori production reached a peak of around 270,000 tonnes in 1994, declining with some resurgence in 1998/1999 to a value of nearly 168,000 tonnes reported for 2001. The Republic of Korea produced 4.4% of the global total of seaweeds by aquaculture in 2001 (373,538 tonnes out of a total of 10.5 million tonnes).
- The aquaculture production of seaweeds in the Korean Democratic People's Republic (DPR) is dominated by the brown seaweed *L. japonica* (90%). *Undaria* contributes 8% and the remaining 2% are made up of red seaweeds *(Gelidium, Gracilaria and Porphyra)*. Accurate values are difficult to obtain for the Korean DPR, and FAO have estimated many of the values reported. However, very large swings can be seen as well as overall declining production. In 1992, Korea DPR reported over 940,000 tonnes of *Laminaria japonica*. These values declined to a final value of 350,000 tonnes in 2001. Similarly, wakame peaked in 1994 with an official report of 55,000 tonnes (75,000 tonnes were previously estimated), which have progressively declined to 32,000 tonnes in 2001. Nori production declined from around 20,000 tonnes in the early 1990s to 7,000 tonnes in 2001. Production of *Gelidium* and *Gracilaria* remained unchanged over the reporting period at about 1000 tonnes each. The Korean DPR produced 3.9% of global production of seaweeds by aquaculture in 2001 (estimated values of 39,100 tonnes).

Table 3.4 on the following pages.

Table 3.4. Details of main species produced in aquaculture and their countries pf production. 1990 – 2001 (FAO 2002 and additional data)

Country	Reported identity	Species (Scientific)	TONNES FRESH WEIGHT 1990	1991	1992	1993
Chile						
	Gracilaria (m)	*Gracilaria* spp (R)	38017	57679	47807	48648
China						
	Japanese kelp (m)	*Laminaria japonica* (P)	1221530	1783300	2470645	3009135
	Laver (Nori) (m)	*Porphyra tenera* (R)	52940	116480	158990	193230
	Red aquatic plants nei (m)	Plantae aquaticae (R)	195760	286210	429370	603330
Fiji Islands						
	Eucheuma nei (m)	*Eucheuma* spp (R)	630	345	240	165
France						
	Wakame nei (m)	*Undaria* spp	F 6	F 53	F 52	F 70
	Harpoon seaweeds (m)	*Asparagopsis* spp (R)	0	0	0	0
Indonesia						
	Red seaweeds (m)	Rhodophyceae (R)	F 100000	F 90000	F 95000	F 110000
Italy						
	Gracilaria seaweeds (br)	*Gracilaria* spp (R)	5000	5000	5000	5000
Japan						
	Green seaweeds (br/fr)	Chlorophyceae (C)	327	335	333	376
	Japanese kelp (m)	*Laminaria japonica* (P)	54297	42619	72924	59966
	Wakame (m)	*Undaria pinnatifida* (P)	112974	99092	112302	89581
	Red aquatic plants nei (m)	Plantae aquaticae (R)	10544	10380	10326	13533
	Laver (Nori) (m)	*Porphyra tenera* (R)	387245	403363	382805	362955
Kiribati						
	Eucheuma nei (m)	*Eucheuma* spp (R)	5080	8168	3472	1632
Korea, Democratic People's Republic						
	Japanese kelp (m)	*Laminaria japonica* (P)	F 750000	F 800000	943000	F 973000
	Wakame (m)	*Undaria pinnatifida* (P)	F 75000	F 75000	F 75000	F 75000
	Gelidium (m)	*Gelidium* spp (R)	F 1000	F 1000	F 1000	F 1000
	Gracilaria (m)	*Gracilaria* spp (R)	F 1000	F 1000	F 1000	F 1000
	Laver (Nori) (m)	*Porphyra tenera* (R)	F 18000	F 18000	F 20000	F 20000
Korea, Republic of.						
	Green laver (m)	*Monostroma nitidum* (C)	12463	14367	17248	12053
	Brown seaweeds (m)	Phaeophyceae (P)	23920	11408	18163	27621
	Japanese kelp (m)	*Laminaria japonica* (P)	8084	8938	9560	17180
	Wakame (m)	*Undaria pinnatifida* (P)	269333	266966	371432	372182
	red aquatic plants (br/fr)	Plantae aquaticae (R)	13	12	7	10
	Red aquatic plants nei (m)	Plantae aquaticae (R)	432	2	5	10
	Laver (Nori) (m)	*Porphyra tenera* (R)	97637	143845	163555	235272

1994	1995	1996	1997	1998	1999	2000	2001
65787	49183	105212	102767	68386	31278	33471	65538
3169505	3222230	3719230	3932785	3965145	4474090	4152050	3988650
290000	306150	303680	320230	364450	411370	481590	583990
671620	634240	471015	461675	1946980	2368830	3229900	3586810
				210	1509	520	320
87	100	54	54	50	20	10	10
0	0	8	8	10	0	0	0
102000	102000	148000	115000	117210	133720	205227	212473
5000	5000	5000	5000	3000	3000	3000	3000
201	374	376	305	248	230	307	307
57757	55056	61121	60103	50123	48251	53846	63200
88280	99571	78368	70052	70669	77064	66676	56977
10000	7483	7486	10245	6019	20642	16371	18150
483196	407005	372700	392622	396615	409850	391681	373121
3168	5248	9480	7376	5938	9396	11530	1190
667349	604371	635579	375577	F 370000	F 370000	F 360000	F350000
55000	45000	50000	33433	F 33000	F 33000	F 32000	F32000
1000	1000	1000	1000	F 1000	F 1000	F 1000	F1000
1000	1000	1000	1000	F 1000	F 1000	F 1000	F1000
15000	13000	14000	8137	F 8000	F 8000	F 7000	F7000
6918	4344	8277	7794	5298	5873	5288	5760
31669	37679	23054	34475	25220	22940	12091	6873
30421	27295	35640	33466	7931	25447	14160	17506
411602	386819	305813	431872	239742	213706	212429	175490
6	0	0	0	0	3	7	0
6	2	12	0	0	0	0	0
269581	192960	166199	140236	190979	205706	130488	167909

Table 3.4. Continued

			TONNES FRESH WEIGHT			
Country	Reported identity	Species (Scientific)	1990	1991	1992	1993
Madagascar						
	Red aquatic plants nei (m)	Plantae aquaticae (R)	1025			
Malaysia						
	Red aquatic plants nei (m)	Plantae aquaticae (R)				
Micronesia, Fed. States						
	Eucheuma nei (m)	*Eucheuma* spp (R)	0	0	0	0
Namibia						
	Gracilaria seaweeds (m)	*Gracilaria* spp (R)	0	0	0	17
Peru						
	Gracilaria seaweeds (m)	*Gracilaria* spp (R)	0	0	0	0
Philippines						
	Caulerpa seaweeds (m)	*Caulerpa* spp (C)	F 17471	F 17027	F 20970	25169
	Elkhorn sea moss (m)	*Kappaphy. alvarezii* (R)	F 8735	F 8513	F 10485	9782
	Spiny eucheuma (m)	*Euch. Denticulatum* (R)	F 14559	F 14190	F 17475	18382
	Zanzibar weed (m)	*Eucheuma cottonii* (R)	F 250411	F 244053	F 300575	348215
Russian Federation						
	Brown seaweeds (m)	Phaeophyceae (P)	0	0	0	0
	Brown seaweeds (m)	Phaeophyceae (P)	5388	9742	1300	1500
St Lucia						
	Eucheuma nei (m)	*Eucheuma* spp (R)	0	0	0	0
	Gracilaria seaweeds (m)	*Gracilaria* spp (R)	F 4	F 4	2	1
South Africa						
	Red aquatic plants nei (m)	Plantae aquaticae (R)	260	285	309	300
	Gracilaria seaweeds (m)	*Gracilaria* spp (R)	0	0	0	0
Taiwan, Province of China						
	Aquatic plants nei (br)	plantae aquaticae (R)	1	2	0	0
	Laver (Nori) (m)	*Porphyra tenera* (R)	23	21	16	6
	Warty gracilaria (m)	*Grac. Verrucosa* (R)	10551	9239	11034	7924
	Warty gracilaria (m)	*Grac. Verrucosa* (R)	63	29	0	0
Tanzania, United Republic						
	Eucheuma nei (m)	*Eucheuma* spp (R)	F 1200	F 1800	F 2500	F 2500
Un. Sov. Soc. Rep.						
	Brown Seaweeds	*Phaeophyceae* (P)	0	0	0	0
Venezuela						
	Elkhorn sea moss (m)	*Kappaphy. alvarezii* (R)	101		5	54
Vietnam						
	Gracilaria seaweeds (m)	*Gracilaria spp* (R)	F 2000	F 3000	F 5000	F 5000

(m) = Mariculture, (br) = Brackish, (fr) = Freshwater

A value of "0" indicates that some production occurs (more than 0 but < 0.5 tonnes)

(C) = Chlorophyta; (P) = Phaeophyta; (R) Rhodophyta

Units are metric tonnes wet weight

"F" indicates that the number is an FAO estimate based on available information.

"nei" = not elsewhere included

NB: not included recent developments in carrageenophyte cultivation in India by PepsiCo and *Asparagopsis* in Ireland

1994	1995	1996	1997	1998	1999	2000	2001
				11847	16125	18863	
0	0	0	0	0	0	0	0
17	F 17	F 17	F 17	F 17	F 20	F 20	20
0	2	227	125	125	53	11	12
26787	12863	19826	3718	28704	22751	28910	25843
6847	14649	12903	6236	9463	17464	15324	30502
14039	7995	8551	7864	17425	20084	30320	65382
433822	522763	590107	609287	629744	635813	632485	664068
0	0	0	0	0	100	112	103
2500	6560	410	6595	3035	2900	2896	401
0	0	0	0	0	14	0	3
1	F 1	F 1	0	0	0	0	0
300	300	390	85	120	135	145	140
0	10	32	10	16	5	12	12
0	0	0	0	0	0	0	0
12	7	9	6	4	3	19	17
6104	8254	9924	12576	14766	15324	11325	13607
1	0	0	0	0	0	1185	2004
F 3000	F 4000	F 3000	F 3000	F 5000	F 7000	7000	7000
0	0	0	0	0	0	0	0
15	40	F 32	F 36	160	160	95	25
F 6000	F 8000	F 9000	F 10000	F 12000	F 13500	F 15000	16000

3.3 Short notes on selected seaweeds most commonly produced in aquaculture

3.3.1 Brown seaweeds

- As shown in Fig. 3.2 brown seaweeds account for the most voluminous and valuable production of seaweeds globally. Kelp cultivation includes species such as *Laminaria japonica* (kombu) and *Undaria pinnatifida* (wakame). China, North and South Korea and Japan are the largest producers.
- The kelps are produced by one of the oldest forms of open–water line aquaculture. There is the requirement for the back–up of laboratories and indoor water facilities for the seeding of ropes by manipulation of the (heteromorphic, biphasic) life cycle. Production is very successfully carried out in SE Asia and some material is even grown for alginate production.
- The open water line cultivation can be adopted for use with European and North American kelps and has been trialled for biomass production for biodigestion, even energy production, but none were competitively and economically viable. France began cultivating the introduced wakame in the 1990s but this only continues at a small scale (see Table 3.4). There is some small–scale production of biomass for cosmetics and novelty foods. The use of the biomass in beauty products tends to be cyclical and perhaps even faddish.
- Kelps as bioreactors for the production of useful chemicals is being pioneered in China, some forms are genetically modified.

3.3.2 Red seaweeds

- *Eucheuma/Kappaphycus* – or "eucheumatoids" – are produced as a source of carrageenan and are extensively grown in areas such as Philippines (total about 760,000 tonnes), Indonesia (about 21,000 tonnes), East Africa (Tanzania, about 7,000 tonnes), by poor people relying on this activity as a cash income. They are grown by extensive, floating fixed line cultivation in coastal water areas. This activity has also spread to some Pacific Islands, e.g. Fiji Islands (320 tonnes) and South America (e.g. Venezuela, 25 tonnes). A percentage of the unspecified 3.6 million tonnes of red aquatic plants produced in China is expected to be in this group. The biomass is of relatively low value for the carrageenan extractive industry (*Kappaphycus* spp. for kappa carrageenan and *Eucheuma* spp. for iota carrageenan). The popularity of this biomass has increased because of declining amounts and quantities and increasing prices of other sources of carrageenan (e.g. *Chondrus, Gigartina* etc.), which are mostly only available from wild crops. Eucheumatoids are cultivated by relatively simple methods of seedling production (vegetative and asexual propagation). They are grown largely as monocrops, and as such can experience problems with disease (ice–ice and epiphyte infestations). Reports of alternatives, such as *Sarcothalia* being produced in tanks in Chile, are relatively preliminary.

- *Porphyra* – a red seaweed of immense value due to the traditional value placed on it as a delicacy in eastern cultures. If the total value for all seaweeds is estimated at US$5 – 6 billion, nori alone is valued at around US$1.5 billion. The production is highly specialised requiring collection of “seed” by manipulation of spore producing and sexual reproduction stages (requiring extensive laboratory and greenhouse facilities for seeding spores onto nets). Specialised forms of grow–out are required but there has been some mechanisation allowing for fewer people to be involved with blade production. *Porphyra* spp. are grown as a monocrop and problems with disease are being experienced. Processing requires highly specialised and expensive equipment to produce the sheets which confer the value. Seeded nets have been grown in a number of other parts of the world (e.g. West and East coasts of US). However, production outside Japan, China and Korea remains limited. Some attempts have been made to grow the *Porphyra* blade in tanks for high–value food and progress has been made in the production of blades from monospores thereby removing the need for complicated control of an alternation of generations.
- *Gracilaria* – a mainstay of the agar industry, although there is some minor utilisation as food. Most production for agar comes from wild beds, but impacts of either environmental damage or over–harvesting are significant. *Gracilaria* can be grown in land–based tanks and raceways, but costs of production exceed value of biomass for agar extraction. The most common form of aquaculture is a mixture of ranching and rehabilitation of former wild beds (e.g. Chile and South Africa). Some tank–cultivated *Gracilaria* may find a market as a feed for herbivorous aquaculture species.
- *Chondrus* – can be grown in tanks for food (e.g. in Canada for export to Japanese markets), but the production of biomass by aquaculture for carrageenan is not yet economically viable. There is one example of a microalgal species (*Odontella*) growing with *Chondrus* in tank cultivation. The microalga requires the presence of *Chondrus* and produces polyunsaturated fatty acids which are of more value than the carrageenophyte.
- *Palmaria* – can be produced in tanks on land. It has a good value as a human food (e.g. as bar snacks, but in small volumes) and as an additive for horse feed. However, the required volumes are likely to remain relatively small. Value will decline as more material is produced. The seaweed produces kainic acid, which may contribute to one of its traditional applications as a vermifuge.
- *Asparagopsis* – a relative new–comer to the aquaculture scene. Extracts are used in some skin treatment preparations. Table 3.4 reports that France produced 8 – 10 tonnes by aquaculture 1996 – 1998. More recently, there have been some cultivation trials in Ireland.

3.3.3 Green seaweeds

- Green algae, e.g. *Ulva, Monostroma* and *Enteromorpha* are also relatively new–comers to the scene for human consumption, mostly as a condiment. In spite of these being amongst the most common of the weedy species and present as a pest in nutrient enriched waters, considerable studies have been required (in Japan) to be able to cultivate them reliably, using suspended nets (very similar to *Porphyra* cultivation). Volumes and values outside of Japanese/Korean cuisine would be very limited. Some greens *(Enteromorpha)* can also be grown relatively easily in tanks and of a high quality (clean and good colour). The main market is Japan. Some material might be used as a food for other herbivorous aquaculture species.

Japan produces around 300 tonnes of green seaweeds (some in brackish water conditions – this total value also includes production of *Caulerpa* spp. in southern Japan), with the main production of *Monostroma* (5000 – 6000 tonnes) being in the Republic of Korea (Table 3.4). Although production has been relatively stable in Japan, there has been a steady decline in the Republic of Korea from levels as high as just over 17,000 tonnes in 1992.

This is perhaps a good example of where a huge biomass is available in the west as a consequence of environmental pollution, e.g. green tides. However, in many cases it is being disposed in land–fill waste sites due to the low perceived value. In Japan it is cultivated as a very high value food species. In the west, there has been research to use the biomass for animal feed, composting, biodigestion and methane production, fertiliser applications, etc. but none have been economically cost–effective.

- *Caulerpa* – is grown as a food in suspended cages (southern Japan) and some earthen impoundments in Philippines. It is valued for colour and texture and contains some mild toxic substances (e.g. caulerpicin), which when consumed causes numbing of tongue and lips. The volume of *Caulerpa* in Japan is included with other green algae with a total about 300 tonnes in 2001. By contrast, nearly 26,000 tonnes were produced in the Philippines, where volumes have fluctuated but have remained above 22,000 tonnes since 1998.

3.3.4 Production of seaweeds for "secondary products"

All seaweeds contain secondary metabolites, some of which have anti–herbivore or anti–fouling properties in the natural environment. A number of these compounds cannot be synthesised and some have been shown to have beneficial properties. In general, the brown seaweeds seem to contain more active compounds, followed by the reds, and the green seaweeds have relatively few. The recent interest in *Asparagopsis* is due to the presence of active compounds.

Production of single species seaweed aquaculture is often not profitable. There is the need for exceptionally high–value products (in the realms of pharmaceutical products to cover production costs). Alternatively combining the aquaculture of seaweeds with treatment of nutrient rich effluent from fish farms may result in shared production costs and therefore enhanced economic viability. Some problems exist around the marketing of growing biomass in waste water, also there may be issues over the chemicals used to dose and treat aquaculture animals (e.g. antibiotics etc), which are then readily absorbed and perhaps even accumulated by the seaweeds.

3.4 General comments on seaweed aquaculture: Supplementary information

3.4.1 Seaweed Statistics

It is often difficult to substantiate the production volumes and values of seaweeds produced worldwide. Many import/export statistics are misleading as seaweeds can fall under quite strange registration categories. Probably the most independent, reliable and therefore most quoted figures on seaweeds and their values are provided by the FAO (Food and Agricultural Organisation of the United Nations). They collate and produce Fishery Statistics (seaweeds are considered a fishery). These figures are available in the FAO annual reports and more recently available via the internet. Inevitably, these figures are a few years out of date by the time of publication.

Until relatively recently, FAO published the data on world production of all seaweeds together (no distinction was made between collections from wild stocks as opposed to volumes and values from materials produced by aquaculture).

The fresh weight of seaweeds is generally 75 – 90% water and FAO statistics are given in metric tonnes wet weight. Industry statistics are expressed in dry weight but percentage water content in dry biomass can vary considerably.

As an example and supplement to information provided in Section 1, the following data in table 3.5 were prepared from: Prud'homme van Reine and Trono (2001), after FAO 1996 and 1999 data.

Table 3.5: Comparison of production and value data from FAO until 1997

World Production from natural stocks (excluding seaweed aquaculture)*

	1996	1990–1992	1993–1995	1996	1997
Seaweeds total	1 133 667	1 133 667	1 101 433	1 138 200	1 193 800
Phaeophyta		737 904	716 608	765 914	784 196
Rhodophyta		213 170	176 102	167 236	168 378
Chlorophyta		23 013	22 675	23 409	24 517
Miscellaneous		159 586	185 836	181 646	214 756

World seaweed aquaculture production (MT wet weight)*

	1986	1990–1992	1993–1995	1996	1997
Seaweeds total	3 400 089	4 599 520	6 789 656	7 166 780	7 241 449
Phaeophyta	2 269 880	3 230 676	4 541 362	4 909 269	4 978 402
Rhodophyta	888 246	1 109 761	1 571 875	1 750 505	1 758 348
Chlorophyta	21 476	33 514	29 695	28 479	32 989
Miscellaneous	221 154	314 981	647 047	478 903	472 015

Prices of seaweeds produced by aquaculture (US$ per MT wet weight)*

	1990–1995	1993–1995	1996	1997
Phaeophyta	719	666	626	620
Rhodophyta	1051	1015	803	829
Chlorophyta	608	464	382	335
Miscellaneous	631	627	721	728

The FAO provide global figures; within the categories there are very large ranges in reported tonnage. From the above data it seems a good working statement that in 1997 seaweed aquaculture produced more than three times the amount of seaweed than that taken from natural populations, although it was commonly cited that seaweed aquaculture produces more than half of the world's seaweed crop (rising to > 80% in 2003). The global figures for red algae are influenced by the high prices and large amounts of *Porphyra* spp. produced. The high prices and volumes of miscellaneous aquatic plants cannot be explained on the basis of the available data (Prud'homme and Trono 2001). However, the clear trend towards lower prices and commoditisation of the increased volumes is evident.

FAO statistical databases (FAOSTAT) are available at http://apps.fao.org web site, where FISHSTAT + universal software for fishery time–series analysis is also available (http://www.fao.org/fi/statist/fisoft/FISHPLUS.asp). Clearly this will be a most useful resource to all involved with seaweed aquaculture and monitoring trends.

Access to (including associated factors such as available labour, roads, communications, etc.), and abundance of seaweed resources are critical factors in determining their commercial viability. Costs of seaweed aquaculture, harvesting (labour and equipment), drying, transportation, chemicals, water supply and environmental measures are all important considerations.

3.4.2 Resources for seaweed information

For more general seaweed information, one of the first places to start looking for information should be the excellent site of the MRI, National University of Ireland, Galway: www.seaweed.ie.

This links to another invaluable database of seaweed information, including taxonomy and nomenclature is at: www.algaebase.org.

SeaweedAfrica

Arising from the success of the above seaweed site and AlgaeBase, there is a recently funded EU project entitled: Seaweed Africa (www.seaweedafrica.org). SeaweedAfrica is a project to provide a biodiversity database of seaweed information, to include ecological, commercial and technology information on African Marine Algae. This project is funded by the European Union under the INCO–DEV section of FP5. The project involves scientists from Ireland, Sweden, France, Portugal, Kenya, Tanzania, Moçambique, South Africa, Namibia and Brazil. The database itself will be a state–of–the–art SQL database allowing for fast and easy access to huge quantities of very complex data. At present, the SeaweedAfrica team is designing the screens that the public will use to get information out of the database.

The project is certainly ambitious in scope, but on track to deliver the information. The site is primarily aimed at users in Africa, as an aid to investigate and develop sustainable utilisation of their rich seaweed resources. However, the information is of use to, and will be an important resource for anyone interested in seaweed aquaculture. The SeaweedAfrica team has collated and summarised the recent literature on all conceivably useful seaweeds including their distribution, ecology, uses and detailed methods of production. The site is in a development phase but further to registration, the information is freely accessible and available to all users.

A recent publication by the Seaweed Africa group (Smit et al. 2002) is entitled: Seaweed: some useful "weeds" (an electronic publication at: http://www.scienceinafrica.co.za/2002/october/sweed.htm). This is a useful short summary of the recent (global) literature on applications and methods for the production of seaweeds, obviously access to all of the information when summarised through the database will be of considerable interest. The following table 3.6 is from their assessment of seaweed uses:

Table 3.6: Categories of seaweed uses in the SeaweedAfrica 'Uses Database'

Categories of seaweed uses in the SeaweedAfrica 'Uses Database' (figure represent the number of reported uses)	
Aesthetics	6
Agriculture, horticulture & agronomy	13
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Smit *et al.* (2002) give some examples of potential future applications of seaweeds. It is interesting that many of the more recent applications are in the fields of true pharmaceuticals (drugs from the sea) and also wellness applications such as nutraceuticals (compounds, which are said to provide a human/animal health benefit but which have not necessarily been rigorously tested or registered). In this regard, it would be useful for anyone interested in developments of active compounds from seaweeds to follow progress reported under the tentative EU project NaturaHealth (www.naturahealth.net, where there is an excellent flow diagram of opportunities from seaweed and associated marine organisms).

It seems likely that a continuing trend will be to screen seaweeds for high value applications, but it will be then necessary to produce the required biomass through seaweed aquaculture. The rationale will be first to protect the naturally occurring wild–stock mother crop from possible over–exploitation and secondly to produce the target species under optimal, controlled conditions for the highest purity, quality and therefore value. Just a few recent potential applications for seaweed extracts summarised by Smit et al. (2002) include:

- Brown seaweeds: super clean alginates for body implants, nerve and bone regeneration.
- Red seaweeds: sesquiterpinoids from *Laurencia* spp., for anti–fouling, antibiotic and anti–malarial applications, monoterpenes from *Plocamium* spp., for anti–fungal, anti–biotic and invertebrate toxins, crude extracts from *Polysiphonia* spp. for anti–herpetic and anti–oxidant properties.
- Green seaweeds: crude extracts from *Codium* spp. for anti–coagulants.

Clearly, when completed, the SeaweedAfrica site will be a useful resource and powerful tool of value to all those interested in seaweed aquaculture.

There are many other useful sites on the internet, but three others providing information specific to seaweed aquaculture are worthy of special mention here, viz. CEVA, SuriaLink and the Irish Seaweed Centre.

- CEVA www.ceva.fr/anglais/index.html The European Centre for the Study of Algae, produce a unique, quarterly publication called *Algorythme* available on subscription. It contains recent developments in the field of algal use and production, with updates of patents and applications.
- SuriaLink is a very useful and continually evolving site www.surialink.com. It already contains a considerable amount of information on seaweed (seaplant/sea vegetable) resources with an interesting concept of providing and sharing information. Of particular interest to seaweed aquaculturalists will be the sections on geographic/historical information on where seaplants are produced and also the SeaPlant Handbook, an illustrated guide to the practical production of seaweeds (subtropical, but many good general principles are covered.
- Irish Seaweed Centre www.irishseaweed.com

3.4.3 Methods of seaweed aquaculture

The approaches to seaweed aquaculture are varied. In general terms there are two broad categories, divided into extensive and intensive forms.

Extensive seaweed aquaculture

These are generally large–scale (farming) approaches using low technology in open water situations. There are applications such as the basic fixed bottom or hanging (floating) rope techniques. These techniques were developed in Asia and have spread far and rapidly, with relatively minor modifications for local conditions or types of seaweeds. This activity is promoted in developing countries since there are lower entry barriers for the coastal–dwelling participants who may have little access to other income generating opportunities. The start-up costs of materials are generally low for stakes, ropes and floats, etc; however, even these low costs are sometimes beyond the means of the poorest people, and some form of innovative lending/support is required for them to secure the

Laminaria japonica, China

materials necessary to construct the growth area and purchase the seedlings for cultivation. There are some contentious issues over water property rights, access to the zones managed for seaweed aquaculture and conflicting uses (e.g. other types of fisheries and tourism). There are surprisingly relatively few studies on the environmental and socio–economic impacts of these activities. Extensive seaweed cultivation tends to operate on a batch basis. Seedlings are planted, grown for a set period and then harvested. Selected plants are then chosen to provide the next seedlings or reproductive material to continue the cultivation. The cultivation periods and duration vary; there is a need to establish the optimal conditions at each site. The practice is well established and in need of innovations and possibly some form of mechanisation. An excellent pictorial account of the aquaculture of nori is given at: http://www.seaweed.ie/cultivation/Cultivation Introduction.html.

- *Re–seeding areas:* Inserting plants into former harvest beds has been practiced in Chile in an attempt to re–establish wild populations where over–exploitation has occurred. Plants simply inserted into the soft substratum with a fork or anchored to the bottom with sand–filled plastic bags.
- *Ranching of seaweeds* might be considered a modified form of extensive aquaculture. This is something relatively popular in Japan where new, coastal constructions such as artificial islands and also sea defences are seeded with selected seaweed (e.g. *Sargassum* spp. and kelps). The purpose of this is to reduce the costs of cultivation and establish a natural seaweed bed which will in turn attract other commercially valuable marine species.

Intensive seaweed aquaculture

Generally the more intensive the activity becomes, the more sophisticated the operation and so too the expense of the required equipment and personnel involved.

- At a basic level, intensive cultivation may be just one step up from extensive, open–water farming, e.g. large–scale pond farming. This has been practiced in areas of SE Asia, to utilise purpose–built ponds, sometimes exclusively for seaweeds (i.e. green seaweeds for food – *Caulerpa* in the Philippines), or as part of a “polyculture” system with fish, shrimps or crabs (e.g. *Gracilaria* and milk fish in Taiwan). The ponds used may often only be simple earthen excavations or enclosed coastal lagoons. Water exchange is often facilitated with the rising and falling tides.

- Ponds and tanks for intensive seaweed aquaculture built on land require considerably more attention, expertise and money to operate. Seaweeds can often survive lowered seawater temperatures, but even very brief spikes in high temperature can be fatal. One of the most common ways to regulate temperature in tanks and ponds is to adjust the rate of water flow through the system. As a consequence, pumping is required, and associated with this is the necessary permits for extraction and discharge of seawater. The quality of the discharged effluent is an increasing issue requiring attention.
- Seaweeds in ponds and tanks are often kept at high densities (this helps reduce problems with competing species such as epiphytes). Thus, there is competition for light, dissolved gases, nutrients, etc. Mixing of the seaweeds is very important and a number of methods and designs for the circulation of biomass have been proposed many relying on various positioning of bubble jets and currents. The chemical and physical condition of the water requires constant monitoring, plus the system may either be operated continuously or in batches. In continuous culture, once an optimum stocking density has been established, the new growth of seaweed is periodically cut back and harvested; cultivation continues whilst conditions are favourable. Most factors must be site–specifically determined, i.e. for a given seaweed in a given locality and type of aquaculture system. Control of contaminating species can be achieved by adding required nutrient supplements at night. In particular, this is effective for *Gracilaria* in cultivation and is a strategy for epiphyte control.
- Intensive seaweed aquaculture requires the inputs of a considerable range of expertise, from not only the knowledge of the biology of the target species but to the engineering of the water systems and the practicalities of the artisans, such as electricians and plumbers to realise such. This is without even considering the necessary planning and permits for occupation of land close the sea and extraction and discharge of water.
- Cost is a major factor of intensive cultivation, not least the costs of operation (24 hrs, 7 days per week), plus the necessary skills and training of personnel, the additional pumping and control of nutrients and the factor of land value. A number of researchers have demonstrated that it is biologically and physically possible to produce seaweeds in tanks and ponds, unfortunately, so far, few have shown this to be a profitable enterprise when all costs are considered.

- Seaweeds in ponds and tanks are open to contamination from other species of algae (e.g. microalgae, bacteria, etc.) This can have problems for the quality of the crop (not least if the invasive microalgae might also produce toxins, as occurred with the production of seaweed for salad in Hawaii). In the same way, there is the possibility of contamination of the crop by parts of animals (parts of insect bodies, bird droppings etc.). The more valuable the crop, the less likely that such foreign bodies would be acceptable. To address these problems, there have been some attempts to grow macroalgae in closed photobioreactors (the seaweeds passing through a tubular system, not exposed to the atmosphere). In such cases production costs are very high and it is suggested that the seaweed have to be produced for a fine chemical with a high value to warrant the cost of production.
- In an attempt to reduce the costs of energy required and improve reliability, some forms of intensive cultivation have reverted to more simple methods of production. In some cases seaweeds are being produced in paddle-wheel raceways, very similar to designs for the earliest cultivation of microalgae. Raceway design has received some attention.
- It is possible that the costs of seaweed aquaculture might be shared if the land and operational costs were covered by a dual or integrated use of facilities. The case of using seaweeds as biofilters for fish waste water will be explored a little more later (see www.seapura.com).

3.4.4 Values of seaweeds in aquaculture

Hyperbole surrounding economic value and potential for seaweed utilisation:

There is a pop–science mantra that seaweeds have been used traditionally for thousands of years, that they are full of minerals, vitamins, health and healing properties and that they are eco–friendly, sustainably produced, a renewable resource and fully organic crops. This leads some people to suspect that there is lots of money to be made in their production for consumption.

Seaweeds do have many useful and beneficial properties; seaweed aquaculture is a sustainable activity involving a renewable resource. Indeed seaweeds are very useful and versatile but some caution is required so as not to over-exaggerate their potential. Not wishing to be overly critical or pessimistic, but rather practical and cautionary, it is not the intention of this article to discourage people's interests, but rather indicate that there has been some hyperbole around the values and economic potential for growing seaweeds as a cash crop.

The use of a broad–brush approach such as this review is often difficult, since there will be many exceptions. The following is an attempt to bring a realistic balance to the attention of prospective entrants to seaweed aquaculture activities. Often the uncommon and spectacular values of some of the rarest seaweeds with specialist uses are cited as justification for the overall value of seaweeds. The huge tonnages of seaweeds consumed at high prices for food, or the large amounts of seaweed required for extraction of hydrocolloids, the value of the end products of the gels and, indeed, pharmaceutical companies are screening biologically active compounds from seaweeds as the source of the next generation of drugs, are seen as primary attractions to be involved with the seaweed aquaculture industry. However, in the European (western world) context, the following points are presented to stimulate thought and the option to reflect.

- Seaweeds are consumed in significant quantities as part of the eastern diet. In Japan, some seaweeds indeed command relatively good prices; accordingly, the Japanese consumers demand very high qualities. The criteria used to determine the quality are sometimes difficult to quantify and can be elusive. It may also be true that even the Japanese are not consuming as much seaweed as was once traditionally the case, as they explore western diets and convenience foods.
- Alternatively, seaweeds are also consumed by people in poorer eastern economies, and prices (and often quality) are lower.
- Admittedly the market for fresh and processed seaweeds as a food is growing in western economies (also encouraged by their exploration and appreciation of eastern foods). The market for such products is relatively small (but growing, which is good), hence the reason why consumers are prepared to pay higher prices, perhaps also in part for the novelty and perceived health values.
- Nori is a seaweed often cited as a prime example of seaweeds with a huge value, a market of perhaps US$1.5 billion. However, the major markets are in the east and it is relatively difficult to enter if the material is produced in the west. The machines required to produced and toast the sheets of nori from the blades of *Porphyra* are specialised and as such expensive (ca. US$1 million). The value of the *Porphyra* is directly due to the quality of the processed sheets. *Porphyra* fishermen in Japan are relatively wealthy and are formed into successful co–operatives and marketing organisations.

- The largest percentage of the world's commercial seaweeds is now produced on farms. Much of this production is in developing countries (emerging economies). Seaweed cultivation there (as predominantly open–water cultivation) has been promoted by various development agencies as a means of poverty alleviation and for people more associated with subsistence agriculture and fishing to become involved in a cash economy (they grow seaweeds and sell the biomass for money). It is unlikely that seaweed cultivators in developed countries would be able to commercially and economically produce biomass for the same purposes in competition.

Porphyra cultivation (nursery), China

- Much of the value–addition to seaweed biomass comes after the extraction process (the costs of the establishment of a globally competitive extraction process for agar, carrageenan or alginate is very high). There is also a trend to move the seaweed hydrocolloids from being high–volume low–price commodities to having higher priced, specialist applications. For enhanced profitability, production should be as closely linked to processing as possible (see also the comments of McHugh (2002) in the context of seaweed production for developing countries).
- We should also note that seaweeds are excellent indicators of pollution and readily take up and accumulate heavy metals and radioactive materials. Hence considerable care and vigilance is required and will become increasingly necessary when considering aspects of quality control of the raw materials produced (for whatever purpose) in the near future.

Simplistic comparison of land crops and seaweed crops

In as much as land agriculture is several thousand years old and there are 250,000 or more species of land plants, only a few hundred species are widely (economically) cultivated and only four are in mass production. So too there are many thousands of seaweed species in total, but the number of species of commercial/economic value can be counted are between 10 and 20 and seaweed aquaculture is in its relative infancy (e.g. several hundreds of years with nori and much more recent developments for kelps, eucheumoids and gracilarioids). Land farming has required many adaptations and developments, from the selection of crop species and their improvement to the development of improved farming technique (fallow land, crop rotation, mechanisation, chemical applications, crop improvements, etc.).

In as much as land cultivation has caused considerable changes to the terrestrial landscape, so too seaweed aquaculture, in the sea or on land, cannot be considered to be without consequences. Proponents of seaweed culture will stress the green issues of sustainable activities and renewable resources, even looking to seaweeds as carbon sinks to mop up environmental carbon dioxide. In the same fashion as some wood forest producers, some large–scale seaweed farmers have considered using their crops for carbon credits, although it is not known if any of the carbon emitting countries have taken up this option and actually purchased the credits.

Who makes the advances in seaweed aquaculture?

Whilst many scientists and academics are keen to publish results and share information as soon and widely as possible after development, many commercial concerns view any information about the ways and means their raw materials are produced, and the volumes/values used and products derived, as information not to be shared if, in some way, there is a competitive advantage.

It has been said in several contexts, (and also attributed to Prof Maxwell Doty, recognised to be the father of carrageenophyte farming) that the best fertiliser a (seaweed) farmer can provide is that of his shadow (i.e. continual inspection and care for the crop). If a farmer has good agronomic/ horticultural techniques and is vigilant, the crop will be spared from many common problems. Having said this, with regard to the most commonly cultivated and economically important seaweeds, such as kelps (*Laminaria, Undaria*, etc.), nori (*Porphyra*), eucheumoids for carrageenan (*Kappaphycus* and *Eucheuma* spp.) and perhaps some of the agarophytes (*Gracilaria* spp.), many of the most practical itty gritty advances were made at the coal–face by the actual practitioners of farming (knowing relatively little about the science of seaweeds), and not the theorists and academics. This acknowledges that the science/biology of the seaweed is not necessarily the most important information required to produce a crop and make a profit.

Obviously such a statement requires further clarification. Seaweeds are relatively simple organisms compared to land plants. Their biology is highly complex and their methods of reproduction are fascinating. Indeed, their study and derived understanding of phases and alternation of morphologically dissimilar generations has allowed for great advances to be made in seaweed aquaculture (particularly with nori and kelps). However, for many seaweeds, their multiplication and growth in laboratory conditions (whilst not without some problems) is relatively achievable. It has been this relative ease that has been one of the prime factors in selecting and promotion of crop or target species.

It is obvious that growing a seaweed in a laboratory (generally only changing one variable at a time) is very different from growing seaweed in an aquaculture situation where many variables change over very different time scales. Even so, many of the cultivated seaweeds are grown using relatively simple and basic techniques, so again it might be said that certain forms of seaweed aquaculture are also really not too difficult. Growing seaweeds to make money can be an altogether different proposition. In some cases, the best demonstration seaweed farms have been established to illustrate that on biological and engineering principles seaweeds can be grown, without much consideration to the costs of production and the value of the biomass produced. As a consequence, a number of seaweed production technologies have been devised, such as on–land tanks, and once biomass production has been demonstrated, then there is a need to find some form of elusive extract, fine chemical or biologically active ingredient with a high economic value to warrant the costs of production of that particular seaweed. The most desirable result would be a biologically active compound with proven and clinically tested/approved pharmaceutical properties cynically perhaps, but preferably as an anti–cancer or an anti–HIV agent.

Of course, this is a chicken–and–egg situation, the technology required to produce the seaweeds must exist in order to exploit those seaweeds, which will be required for fine chemicals and pharmaceutical compounds. There are some seaweeds with known activities, which are only available from wild–stock materials, the challenge is now to find ways and means to produce these in an aquaculture situation to produce significant volumes, cost–effectively.

The most expensive seaweeds are those that cannot be cultivated and rely on small, and perhaps dwindling, natural stocks.

Production of seaweeds in aquaculture

Since some seaweeds are relatively easy to grow, these are naturally the target species, the ones which are used most frequently in aquaculture and to some extent they have become bulk produced commodities (as evidenced in the earlier tables of FAO data for volumes and values of seaweed biomass). For someone entering the seaweed aquaculture business, bulk production, of low value biomass, is perhaps not an area to aim for as there is continual pressure on lower prices and competition with large producers.

In addition, and as mentioned above, it should be noted that seaweed aquaculture has been promoted by a several world development agencies (FAO, UNDP, World Bank, etc.) as an economic engine for sustainable development, production of renewable crops and socio–economic upliftment of poor coastal dwellers in developing countries/emerging economies. Seaweed farming has been promoted as an alternative to environmentally damaging styles of fishing (e.g. cyanide and dynamite) and even as an income–generating activity for reformed armed rebels. It should be borne in mind that in many of these regions the cost of land, infrastructure and labour are low. For any person considering entering into a seaweed aquaculture activity, it would be informative to read the article by Dennis McHugh a part of the FAO Corporate Document Repository (available at the search page http://www.fao.org /documents/ – insert 'seaweeds" into the search box), entitled *Prospects for Seaweed Production in Developing Countries*. FAO Fisheries Circular C968. Indeed this FAO site carries a large number of articles on establishing seaweed farms and use of seaweeds, all from the point of view of developing countries in sub–tropical regions, but nevertheless very informative and available freely for download.

3.4.5 Propagation for seaweed aquaculture

Seaweeds can reproduce in a great variety of ways. Although they are also known as sea plants there are a number of significant differences with land plants, not least in the methods of reproduction. Seaweeds do not posses flowers and the traditional methods of cross–pollination are therefore not available to them.

There are those seaweeds, with a normal pattern of multiplication, which includes sexual reproduction (joining together of male and female gametes). Then there are those seaweeds, with a much simpler means of reproduction and do not rely upon sexual reproduction. In this case the seaweed body grows and can be divided (fragmented) into many small pieces, each piece will continue to grow and produce a new individual, this latter form is called asexual or vegetative reproduction.

Sexually reproducing seaweeds

In those seaweeds where male and female gamete structures are found, the sexual phase of the seaweed may be quite different in size and appearance to the phase required for the crop, e.g. the sexual phase for the male and female stages of kelps (e.g. *Laminaria*) are microscopic, the sexual phase for the nori (*Porphyra*) blade can be microscopic and furthermore have an obligate requirement to live inside a matrix structure such as shell or rock (i.e. endolithic phase). Knowledge of these relationships has allowed for control and manipulation of the life cycle, in some cases shortening the required period of cultivation of kelps from two years to one and/or allowing for cross–fertilisation between species as with some European kelps. The manipulations obviously require a high degree of control and sophisticated laboratory equipment/facilities.

- Aquaculture of *Porphyra* for nori and kelps for wakame (*Undaria*) and kombu (*Laminaria*) has made significant developments in this area, and the selection of parents and hybrids has been responsible for production of improved strains for aquaculture.

- Recently, advances have been made such that *Porphyra* can now be cultivated in free–floating suspension in tanks and the need for growing out on nets and even the requirement for an endolithic period have been replaced.

Vegetatively reproducing seaweeds

Some economically valuable seaweeds seem to have lost the ability to reproduce sexually and rely upon vegetative fragmentation to be perpetuated (good examples of this are species of the genera *Eucheuma, Kappaphycus* and *Gracilaria*). Here parent stock is selected from wild populations and grown in the aquaculture system. The starting stock begins as seedlings, chosen from healthy plants in the wild, the adult plants are simply divided into small fragments and the seedlings attached to the ropes of nets for the appropriate grow out period. At the end of this growing period, some of the seedlings will have grown better than others and so these plants will be selected to produce the new seedlings; the remaining biomass is harvested. In most cases, the selection will be made on the basis of, for example, good growth and colour, whereas the crop may be being grown for some form of colloid extraction (the quality of which is not necessarily taken into account).

Vegetative propagation of some seaweeds has been hugely successful and responsible for the boom in seaweed aquaculture. However, since the seedlings are repetitively selected by fragmentation, the genetic base of the crop is rather narrow (in the absence of any genetic exchange via sexual gametes). In addition, the seaweeds are grown as very large monocrops. As has been clearly demonstrated by certain terrestrial plant crops, the use of clonal forms of plants, grown as monocrops is bad practice and can lead to attacks of the crop by pathogens/diseases and in worst cases the entire crop being wiped out (as evidenced by the potato blight and resultant famine, and more recently by concern over commercial banana crops).

Improvement of seaweeds for aquaculture

- Within the seaweeds currently used commercially for aquaculture there are numerous attempts to find and develop new strains, which would then broaden genetic diversity and reduce the impacts of disease in the crops.
- There are searches for new sources of crop plants. This however, is difficult – many of the obvious contenders have been screened – it is unlikely there is a new, as yet undiscovered equivalent to nori.

Eucheuma cultivation, Philippines

- There is also the research into the production of hybrids created by cell – cell fusions (e.g. the combination and fusion of naked cells from different parental stocks of materials) to produce polyploid hybrids.

- Given the sensitivities to genetic engineering, genetic modification should be avoided (GM, i.e. specifically the insertion of foreign genetic material to produce a transgenic form), not least since the resultant material would not be broadly accepted for use within foods or processed materials.
- Novel applications have been found for some species in natural populations, the trend is to find ways and means to produce those seaweeds by means of aquaculture rather than (possibly over–) exploit small, natural beds.

The need to develop new strains and diversification of seaweed aquaculture crops is very important. In as much as many terrestrial crops are supported through large agricultural research bodies and even government bodies, there is by no means the same attention/effort/funding given to improving seaweed species or their methods of production in aquaculture. Hopefully this situation may improve with increased activities and economic returns in seaweed aquaculture (but funding for the research may come through some form of levy/tax on those activities!).

3.5 Selected trends in seaweed aquaculture

Seaweeds as part of an integrated system

Clearly seaweed aquaculture can be achieved in a variety of ways. However, the economies and scale of production may be holding back some developments.

Seaweeds as a source of aquaculture feed

Some developments include production of seaweeds (*Ulva, Gracilaria,* etc.) as feed for high–value grazing animals such as abalone. As such, the purity of the biomass is not critical since some of the other seaweeds, which can be eaten by the molluscs, are harvested from wild stocks.

Seaweeds as a biofilter for nutrient enriched water from fish cultivation

The polyculture of valuable marine animals and seaweeds has been performed for some time: however, recent research has focused on the use of seaweeds as biofilters to clean up effluents from fish farming. In many cases the effluent from a fish farm contains high levels of nitrogen and phosphorus, which can be taken up by the seaweed biomass for growth. Here may be an example where it is necessary to redefine effluent since many people are not impressed by a product grown in effluent even if that is merely a nutrient enriched flow of water. In addition to filtering the nutrients, seaweeds grown as part of the fish farming enterprise can benefit by cross–subsidisation of the energy, manpower and land costs. In a situation where it may not be profitable for seaweed aquaculture for the sole purpose of seaweed production, the scale and economies may be beneficial when the fish waste effluent must be treated anyway (due to legislation) and that the biomass form the seaweed has a value. This elegant system is being carefully considered by another EU supported programme entitled: SEAPURA (www.seapura.com): "Species diversification and improvement of aquatic production in seaweeds purifying effluents from integrated fish farms". Their homepage provides the following statement and rationale: SEAPURA – Sustainable poly–aquaculture systems based on seaweeds (macroalgae) are tested, in which algal growth is integrated with fish farms, in conjunction with different enterprises (SMEs), so that the environmental impact and the costs of fish farms in Europe are reduced. In other sites, seaweed cultures will be used to purify waste waters from domestic sewage works and eutrophic inshore coastal waters. The project is innovative in the following respects:

- High–value seaweed species not used before in poly–aquaculture will be grown as sources of cosmetics, pharmaceutical and fine chemicals, and as fish feed.
- Seaweed production will be improved by controlling day length to induce year–round growth, avoiding unwanted sporulation, seeding somatic cells, and the use of new tank and raceway designs.

The interested reader will find a considerable amount of relevant information on recent developments in applied seaweed aquaculture, including the annual reports for the first two years of activity. The EU project has one more year to run.

China provides an interesting example of a country producing large volumes of seaweeds by aquaculture (see 3.6 of this review). However, some of the seaweed aquaculture became displaced due to competition pressures for area to produce more valuable biomass in the form of molluscs and fin–fish. In some areas (particularly coastal embayments in southern China), the balance of nutrients became disturbed with huge volumes of fish producing exceedingly eutrophic conditions, which then resulted in toxic microalgal blooms, which resulted in fish mortalities. As a consequence, fish/mollusc cultivation has been reduced and the areas given over to seaweed farming have increased and in certain areas taking place side by side with fish/mollusc cultivation with the seaweeds acting as a biofilter.

Seaweeds and pollutants

However in as much as seaweeds are good at mopping up excess nutrients in the environment, so too they can act as sponges for other environmental pollutants. This includes heavy metals, radioactivity and chemicals (e.g. herbicides and antibiotics used in high density fish cultivation). It will become increasingly necessary to screen and certify that these are not present in the crop produced from aquaculture.

Depending on conditions and circumstances, seaweeds themselves may become pollutants. Care must be taken when target species are imported from one geographic area to another, so they do not become introduced and/or invasive species (a whole area of study in itself).

As an example, *Eucheuma/Kappaphycus* spp. have been relocated over large distances in SE Asia and East Africa. Some are now only recently being described as invasives causing environmental perturbations more than 40 years after first being introduced to Hawaii. In the same regard, target species of seaweeds should be screened and quarantined when moved from one seaweed aquaculture area to another since they may be a vector for other (unwanted) marine species, which might be hitching a ride (and themselves become problematic once released in their new environment – the literature is just littered with such examples). Epiphytes on commercial seaweed crops might be just one practical example of this.

Molecules to market

It is necessary to point out that not only must the biology, the engineering and the economics of seaweed aquaculture be well understood and mastered, but in order for the activity to be a success there must be marketing of that product. The marketing can be a considerable cost.

Unrealistic claims

Seaweeds do possess many beneficial properties. Care must be exercised so that unsubstantiated, wild claims are not given credence, thereby giving rise to labelling such as snake oil. This will help to preserve and build up on their true value and properties.

Clinical testing and verification of active compounds from seaweeds will be of tremendous benefit to indicate which seaweeds will have high values as candidates for aquaculture. Marine functional foods for health: http://www.nutrahealth.net/Inicio.htm, is an integrated project application to the European 6th Framework for funding. The homepage has a very interesting graphic linking possibilities of sources of marine organisms (including seaweeds), which would then be screened for pharmacological activity for pre– and clinical testing. Successfully identified seaweed species would need to be produced in intensive aquaculture conditions of the highest standards and levels of control. Presumably entrepreneurial opportunities would exist to produce selected seaweed biomass for such an enterprise (see also Nisizawa 2002).

Quality control issues

- Some of the more simple forms of seaweed aquaculture (e.g. open water, long–line and floating methods) produces biomass to be used for the hydrocolloid extraction industry. In such cases the material is sold on a dry mass basis, not on the content and quality of the colloid contained within. It seems this situation will change and more quality control criteria will be introduced (e.g. checking for metals, contaminating metals, chemicals etc.).
- In terms of traceability of raw materials, more will be required in the form of accurate records for the production of raw materials.
- It is possible that some form of HACCP (Hazard Analysis and Critical Control Point) regulations will be introduced for seaweed aquaculture, particularly for more specialist applications of the biomass.

Selection of seaweeds for aquaculture

- The issue of genetically modification of seaweeds needs to be closely monitored and assessed as a crop, seaweeds used in aquaculture are subject to a constant search for improvements. Modern developments may lead in the direction of genetic modification. As mentioned, strain selection and cell–cell (protoplast) hybridisation are accepted techniques. Transgenic forms are yet to gain acceptance, particularly for applications close to processed foods.
- Some transgenic seaweeds (kelps) have been produced in China as a means of producing valuable fine chemicals. Kelps are used as bio–reactors to biosynthesise valuable chemicals with a benefit for human health. This trend should be monitored. The transgenic seaweeds are kept in laboratory quarantine and isolation to prevent escape into the marine environment.

Seaweed disease

It is often asked "Have you ever seen a sick seaweed"? Seaweeds are remarkable in that they live in an environment where they are continually abraded by sand and shell particles in the water, plus they may be grazed upon by fish and molluscs. These points of damage rarely become infected. Where seaweed disease is a problem it is often under the conditions where seaweed crops are stressed due to too little water exchange, over–crowding, lack of light, nutrients etc. The fact that many systems of seaweed aquaculture rely on clonal monocrops is cause for concern. The options for selection and use of new strains need to be carefully considered.

Deep water mariculture of seaweeds

There have been relatively few innovations made in traditional seaweed aquaculture. One seems to be the use of deep seawater. The application of this technique is limited to very few places where the coastal shelf is relatively narrow and water can be abstracted form great depths (ca. 500m). It has been possible (at great expense) to pump water from these depths in the past; however, in a relatively recent development, water may be siphoned using relatively little power. The advantages of using deep water are that seawater temperatures are relatively low, constant and not subject to great seasonal shifts. The nutrients are fully mineralised, plus the water is taken form well below the photic zone which is free of contaminating propagules, hence the seaweeds in cultivation remain clean and healthy. This system is patented in Japan for the production of high value food seaweeds such as *Ulva* and *Meristotheca*. Having said this there are some attempts to see if the system could also be practiced in areas of the world also with a narrow coastal shelf and access to deep seawater, relatively close to shore, but with lower costs (labour and land, e.g. volcanic islands in the Pacific).

Final comments

As indicated, the foregoing text attempts to assimilate the varied impressions of the author on seaweed aquaculture and generate consideration of general trends and issues. Indeed seaweeds are valuable and useful and there are a number of possible methods of seaweed aquaculture. The value of seaweeds is sometimes over–exaggerated and the situation can be blurred when comparing eastern and western economies and cultures and also the practicalities of operating in developing and developed countries.

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Note:

FAO (2002). The following links point to summary tables from the 2000 Aquaculture Yearbook. FAO are in the process of producing the 2001 Yearbook but it is not available yet.
ftp://ftp.fao.org/fi/stat/summ_00/a–5_table.pdf
ftp://ftp.fao.org/fi/stat/summ_00/b–1_table.pdf
(includes seaweeds at the bottom of the table)
See http://www.fao.org/fi/statist/summtab/default.asp
for the complete list of yearbook tables available.

FAO State of World Fisheries and Aquaculture is available and downloadable at: ftp://ftp.fao.org/docrep/fao/005/y7300e/y7300e01.pdf

FAO 2002. The State of World Fisheries and Aquaculture. FAO Fisheries Department. Available: http://www.fao.org/docrep/005/y7300e/y7300e00.htm

Global trends in aquaculture and production and harvests

FAO have made available 10 year data for volumes and values of world fisheries. These data can be accessed via: FAO Global Production Figures. http://www.fao.org/fi/statist/summtab/default.asp

The FAO make general references to aquatic plants and in some data sets differentiate between fresh, marine and brackish water sources. The majority of the volumes are for seaweeds.

3.6 Examples from China – Pointers for the Irish situation

The FAO have produced the most recent State of World Fisheries and Aquaculture (SOFIA) 2002, which is available at: http://www.fao.org/sof/sofia/index_en.htm.

The interested reader is recommended to read the whole report. It is highly informative and covers fisheries and all aquaculture activities. Seaweed aquaculture is only a small part, but some of the over–riding principles are the same independent of the target species. The following includes some abstracted points which relate to aquaculture and would be true for all species.

It can be difficult to de–couple data of marine plants at the species level. The examples most cited are the most voluminous and valuable seaweeds such are nori and kombu. FAO discusses the difficulties in obtaining accurate and reliable statistics, suffice to say the picture they present is perhaps the best and most balanced available for decision making purposes.

The values cited are given as good examples of trends, some of the statements made about aquaculture (the majority of which is now non–seaweed based) are applicable to those considering principles and trends in seaweed aquaculture. Trends in economies of scale and applications with regard to eastern/western culture and developed/developing economies impact on aquaculture of seaweeds as well as to any other target species and should be considered carefully when a new enterprise is in the planning stages.

- With regard to the reported total (all species), global aquaculture production was 45.7 million tonnes by weight and US$56.5 billion by value. China produced 71% of the total volume and 49.8% of the total value.
- More than 50% of the total world aquaculture production in 2000 was finfish.
- In 2000, the total production of seaweeds (as World aquatic plant production) was approximately 10 million tonnes of which 7.9 million tonnes (with a value of US$4 billion) originated in China.
- FAO considered that more than 9.7 million tonnes of global aquaculture production was not reported at the species level in 2000 (however the majority of this is likely not to be seaweed material). Many of these might be organisms in the experimental stage and pilot–scale trials of aquaculture (and thus likely to increase potential number of species which can be cultured in the future).

- In 2000, more than 50% of global aquaculture production came from marine and brackish coastal waters comprising mainly finfish and high value crustaceans. Although brackish water production represented only 4.6 % of the total global production by weight – it comprised 15.7% of total value. Finfish predominate in brackish waters, molluscs and aquatic plants predominate in marine waters (aquatic plants 44%, molluscs 46%).
- In general, aquaculture has been growing at a rate of 3.7% in developed countries since 1970, with even a small decline to 2.4% in 1999 – 2000. In developing countries (and low income food–deficit countries) it has been growing steadily at about 10% per annum.
- During the past 30 years aquaculture expanded, diversified, intensified and made technological advances. One important contribution of the potential for this development is to improve rural livelihoods, food security and alleviate poverty.
- FAO 2000 estimated that farmed seaweed production reached 10 million tonnes in 2000 (10.5 million in 2001), and represented 88% of total seaweed supplies. Most output is used domestically for food, but there is growing international trade. China (the main producer) has started to export seaweed as food to the Republic of Korea and Japan. The Republic of Korea exports some quantities of *Porphyra* and *Undaria* to Japan (together about 23,500 tonnes in 2000).
- Significant quantities of *Eucheuma* are exported by the Philippines, Indonesia and Taiwan. The total European Community imports of seaweed in 2000 amounted to 21,000 tonnes. Chile is an important extractor, processor and exporter of agar and carrageenan.
- Policy makers and development agents are increasingly viewing aquaculture as an integral part of the search for global food security and economic development.
- Mainland China is the world leader in aquaculture production, following steady development over 30 years.

FAO 2002 states that an identification and analysis of the factors and issues, which motivated aquaculture development in China, could play a critical role not only in understanding the future of aquaculture in China but also in shaping aquaculture development in many parts of the world.

The report considers important questions regarding China such as:

- Why did aquaculture develop so sustainably?
- What is the current development level?
- How was development achieved?
- Where is aquaculture heading?

Before 1980, three species, i.e. kelp (*Laminaria japonica*), laver/nori (*Porphyra tenera*) and blue mussel accounted for about 98% of their total marine aquaculture output in China. Currently, shrimp, oyster, razor clam, scallops, abalone and finfish are added to the list of all species produced by aquaculture. The relative importance of seaweeds has declined.

In the southern part of China, more than 90% of farms (all types) belong to individuals and private corporations. In some regions (e.g. Zheijang Province) joint ventures and co–operatives account for all aquaculture business. In the north, 80% is under the control of corporations (for comparison, in–land aquaculture is 90% family and individually owned).

Research education and extension has also been cited as being important. In 1999, there were 210 fisheries research institutes in China (all aspects of fisheries). Local institutions focus on solving the technical problems affecting local aquaculture development. These institutions are more producer-orientated and often a step ahead of the national institutions and Universities in terms of practical advances. They are also funded by provincial and/or municipal governments. In addition, commercial and private companies also sponsor research. Education and on–job training are sponsored by central and local government.

Thirty universities enrol 1000 undergraduates in aquaculture annually and these students can study all the way through to doctorate degrees. In addition, there are about 20 technical secondary schools producing skilled workers for the aquaculture industry. Furthermore, aquaculture extension is strongly supported by the Chinese Government.

The FAO SOFIA 2002 report points out some specific points regarding China:

Major strengths

- *Supportive government policies.*
- *Well established seed production technologies.*
- *Strong research and development infrastructure.*
- *Solid extension service.*
- *Relatively high profit and net income per unit of labour.*
- *Strong domestic and international demand.*

Constraints

- *Threats of environmental degradation and disease outbreaks.*
- *Little improvement in seed supply.*
- *Limited suitable land for expansion of on land based aquaculture.*
- *Poor infrastructure in many areas (transport and communication).*

FAO (2002) further stresses the emphasis on research, technological development and information dissemination. The rapid development of aquaculture of all species in the past two decades has been dependent on scientific research, which contributed to 50% to the growth of aquaculture output from 1979 – 1999. In addition, there has been the promotion of species of high value, e.g. prior to the 1970s the main species were seaweeds and molluscs.

The Chinese government addressed specific issues, such as seed, feed, technology, land and marketing. They also promoted diversification of species, especially through introduction of foreign technologies and exotic species with good commercial aquaculture potential.

Since 1979 the Chinese government has been reforming the policy and marketing system, which is providing incentives for aquaculturalists. There is also a Government established seafood market information network, which collect and disseminate information thereby improving transfer of information and knowledge.

There are some land issues, which requires the structural reform of farm ownership and property right policies. Since the 1980s the Chinese government supported transfer of farm ownership from the public to private sector.

The Chinese government has the intention that aquaculture should be environmentally friendly, rational, healthy and sustainable. They appreciate that there is the need for sound management to safeguard the environment. To address this they are developing management strategies, through adoption of the precautionary principle approach as embodied in the FAO's Code of Conduct for Responsible Fisheries.

Aquaculture is a high priority in China. There is government commitment and there is more interest of the Private Sector in aquaculture than any other agricultural sub–sectors of the national economy.

Future prospects

FAO cautions optimism over future demands for seaweeds in Japan (as traditional large user), e.g. over the period 2000 – 2030, the Japanese demand does not look set to increase. The model demand does not exceed 800,000 tonnes and this assumes a 1% annual increase in GDP and that the demand is for food use. This demand is around that of 2000 levels.

At present more than 90% of aquaculture production comes from Asia. There is no reason why it could not also be a common and sustainable activity outside of Asia. The legal framework for most modern aquaculture is known and generally in place in rich economies. FAO (2002) expects that the real costs of transport and communications will probably fall, if only slowly. As a result, the aquaculturalists in rich, temperate zone economies will be exposed to competition with producers from increasingly distant areas. Temperate region aquaculturalists will be able to compete on the platform of technological development and application. FAO (2002) also touches on the impact which subsidies might have if extended to aquaculture activities could generally curtail future growth.

For potential entrants into a European scenario of seaweed aquaculture, the above summaries something of what they are up against long term investment and expertise, niche and high value species markets, plus extensive support of government and research institutions.

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4.0 Seaweed aquaculture experiences in NW Europe

In NW Europe there has never been an incentive for the development of seaweed aquaculture at an industrial scale. Reasons for this include:

a) The North Atlantic as a cold–temperate region with extensive rocky shorelines has a rich algal flora and is one of the most productive areas with respect to macroalgal biomass. The development of the seaweed industry in Europe has traditionally been based on harvesting wild stock.

b) Expansion of the European industry in the 20th century (mainly the hydrocolloid industry, but also other industries such as agriculture/horticulture) led to a growing demand. This was met by mechanisation of seaweed harvesting in parts of Europe and during the last decades by the importation of raw material from Asia, Africa and South America where seaweeds are produced at relatively low–cost.

c) Due to relatively low market prices for raw material paid by the hydrocolloid industry, large–scale seaweed production in Europe would not be competitive on the world market because of high labour and production costs (e.g. drying costs).

d) The demand for seaweeds for utilisation in new developing sectors, such as cosmetics, thalassotherapy, and healthcare, is still met by harvesting natural stocks.

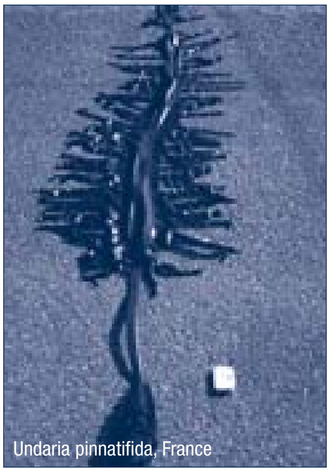
e) Although in several European countries seaweeds were traditionally collected for human consumption, the usage of seaweed was always minor and locally restricted to coastal areas. In Asia, however, seaweeds are an important component of the daily diet. The high demand for raw material initiated the large–scale cultivation of seaweeds, e.g. *Porphyra* spp., *Laminaria japonica* and *Undaria pinnatifida* in China and Japan in the mid 1950s. Concomitantly to the development of large–scale cultivation of brown, red and, to a lesser extent, green algae, cultivation techniques have been improved and strain selection and genetic manipulation have been applied.

The objectives for the development of seaweed aquaculture in Europe have not been to produce bulk biomass for the hydrocolloid industry, but rather low–volume high–value raw materials for novel applications. This also includes the production of sea–vegetables for the food market, which, compared to Asia, is still a niche market.

4.1 First commercial cultivation trials in Europe

4.1.1 Undaria pinnatifida cultivation in France

Cultivation trials were initiated in the early 1980s in Brittany by IFREMER using the edible seaweed *Undaria pinnatifida* (wakame). This species of Japanese origin was introduced to France in the early 1970s via spores attached to imported oyster spat. Since the quality and taste of this seaweed is superior to the European *Laminaria* species and *Alaria esculenta*, by Asian standards, it was the species of choice for cultivation. Chinese cultivation techniques were adopted but were adapted for local conditions in Brittany. In China cultivation ropes are seeded with spores released from mature plants in May/June and then pre–cultivated over a period of four months in tanks before being transferred to the sea in September. This is necessary to circumvent heavy fouling in summer. The maintenance of seeded ropes indoors is very labour intensive. In order to avoid this lengthy pre–cultivation period a special method, the so–called free–living technique, was developed by IFREMER (patented), which is the cultivation of the microscopic gametophytes, arrested in a vegetative stage due to a high temperature – low light regime. By changing the culture conditions the gametophytes become fertile and ropes can be seeded. This technique enables the seaweed farmer to choose the time of maturation of spores and the subsequent process of seeding the cultivation ropes. Consequently, the time for offshore cultivation can be manipulated and the number of growth cycles per year can be increased. Moreover, seed in non–limiting amounts can be produced, which is ideal for mass cultivation (Kaas 1998; R. Kaas, 2003, pers. comm.). As a result, by shifting the time of spore release to August, the subsequent pre–cultivation time of *Undaria* sporelings was reduced to three weeks. Ropes were transferred to the sea in September and harvested in February. A second artificial fertilisation of gametophytes was induced in January with transfer of the germlings in February and harvest in May.


Undaria pinnatifida, France

To reduce the risk of spreading of this alien species the first cultivation trials were carried out on the Île d'Oussant, an island, located about 40 km off the mainland coast in NW Brittany. Although *Undaria pinnatifida* has been cultivated at other sites along the mainland coast and is growing and reproducing freely in the environment, its distribution is restricted to the vicinity of the cultivation sites and no mass propagation or displacement of native kelp species has been observed yet (Floc'h et al. 1996).

At present, *Undaria* is commercially cultivated by at least two companies in Brittany with a production of 5–8 t wet weight per year. It is sold dried as sea vegetable on the French food market. The production has remained more or less stable over the last decade reflecting the limited demand for this species on the French market.

4.1.2 Laminaria saccarina and Alaria esculenta cultivation in England

Laminaria saccharina and *Alaria esculenta* were cultivated at the Isle of Man/England during the 1980s. Asian cultivation methods were adopted and improved. The procedure included seeding of ropes, pre–cultivation under laboratory conditions and transfer to the sea. Initially, *Saccorhiza polyschides*, a fast–growing annual kelp, was also used, but was found not suitable for cultivation, because it detached easily from the ropes in strong water movement. With the establishment of the commercial seaweed farm for *Laminaria saccharina* and *Alaria esculenta* cultivation, a specific end product for the food market was developed. The crop was dried, flavoured and sold as a snack. The cultivation operation and the food processing company were in business for only a few years. It is likely that the lack of acceptance of the market rather than the cultivation itself led to a failure of the combined business (Kain & Dawes 1987, Kain 1991; T. Hold, 2003, pers. comm.).

4.2 New forms of application

Since the 1980s several cultivation trials have been carried out in different countries, mainly by third–level institutions alone or in cooperation with Small to Medium Enterprises on a pilot–scale. The objectives of these cultivation trials differed considerably; however, several species used for these trials were already under cultivation elsewhere. The growing interest in seaweed aquaculture reflects the development and advances in fundamental research carried out by universities as well as by the industry committed to the search for new applications and products. Key areas of research are directed towards:

- Algae for human consumption.
- Functional principles of algae for agriculture/horticulture applications, cosmetics, nutraceuticals, bioactive molecules for pharmaceutical use.
- Seaweeds in integrated polyculture, i.e. seaweed aquaculture in combination with finfish and shellfish aquaculture to remove inorganic nutrients released by these forms of aquaculture.
- Algae in bioremediation, i.e. as scavengers of inorganic nutrients and/or heavy metals in urban sewage and industrial effluents.

4.2.1 Algae for human consumption

Mariculture of the edible red alga Palmaria palmata in Northern Ireland

As part of an EU FAIR project, which commenced in 1998 with partners in Norway, Spain and Ireland and supported by the Department of Agriculture and Rural Development, Northern Ireland, *Palmaria* cultivation trials were conducted at the Marine Laboratory Portaferry, Queen's University Belfast. The objective was to test three different offshore cultivation methods and assess their economical feasibility. Two approaches were based on the harvest of whole young plants with intact stipe and holdfast from the wild. These were either attached to polypropylene culture ropes by passing the plants through the lay of the rope or were put directly into polypropylene bags. The ropes and bags were attached to a long–line culture rig in Strangford Lough, a fjord, which extends ca. 60 km inlands in south–north direction and has a rigorous water exchange due to strong tidal current. In a third approach, spores were obtained from fertile plants, which were collected from the Lough, for the seeding of culture strings. These were pre–cultivated in the laboratory under optimum tested culture conditions for two months. The strings with plantlets of ca. 2.5 mm were cut into pieces of 3m lengths and transferred into the field, where they were attached to the long–line. Growth rate of the plants directly attached to the rope and those seeded on strings were comparable, whereas plants cultivated in the bags showed significantly smaller growth rates. In an economic assessment, a 5–year business plan showed that only an approach 3, in which culture strings were seeded was viable with a profit of almost £60,000 (≈ €90,000). The other approaches would lead to a substantial loss, mainly due to high labour cost and relatively low value of the product (Browne 2002; L. Browne, 2003, pers. comm.).

In another EU funded project (SEAPURA, see below and previous chapter) methods for *Palmaria* offshore cultivation were further investigated. Pieces of 3 mm culture string with pre–cultivated *Palmaria* plants were either attached directly to the long–line as drop–lines or wrapped around 3 m long pieces of polypropylene line prior to attachment to the long–line. Whereas the latter method proved not suitable because of high epiphyte development on the ropes out–competing the *Palmaria* plants, the plants on the strings directly attached to the long–line were healthy and reached a length of 20 cm after 45 days and 77 cm after 90 days (Browne 2003; L. Browne, 2003, pers. comm.).

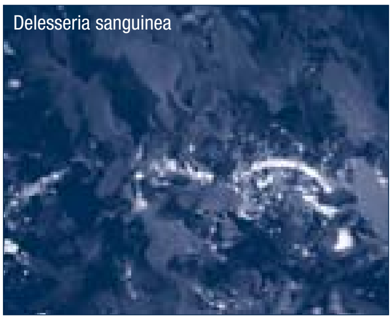
4.2.2 Seaweeds in integrated polyculture

European SEAPURA project

In 2001 the EU funded SEAPURA project (acronym for: Species diversification and improvement of aquatic production in seaweeds purifying effluents from integrated fish farms; www.seapura.org) commenced its work. Eight participants in five countries are involved (Spain, Portugal, Germany, France, United Kingdom). The objectives of the project are to:

1) Develop and test high–value algal species, not used before, to integrate them into finfish aquaculture and thereby increase the diversity of algae used in integrated poly–aquaculture systems (IPAS), to assess nutrient uptake efficiencies for the IPAS and to use part of the harvestable algal biomass as fish–food.
2) Improve seaweed production to provide seed stock of the species used in the IPAS.
3) Develop informative health assays for the farmed seaweed species.
4) Screen cultivated seaweed species for potential fish–pathogenic antibiotics.
5) Conduct an economic evaluation of the IPAS (see SEAPURA 2002, 2003).

The seaweeds used in cultivation trials are mainly red algae of warm–temperate waters (Grand Canaria, Spain and Faro, Portugal) and cold–temperate waters (Porto, Portugal, Sylt, Germany and Portaferry, Northern Ireland).



At the Marine Laboratory, Portaferry, trials have been carried out using the red algal species *Palmaria palmata, Dilsea carnosa, Chondrus crispus* and *Delesseria sanguinea.* Young plants were collected from the intertidal and cultivated in in–door and out–door tanks at different times of the year. The species showed good growth rate during a three–month period. However, due to high irradiance the algae in the out–door tanks started to deteriorate after a certain time (Browne 2003; L. Browne, 2003, pers. comm.).

At the Wadden Sea Station Sylt/Alfred–Wegener Institute, Germany, intensive tank cultivation is taking place in the scope of the SEAPURA project and a DBU project (Deutsche Bundesstiftung Umwelt, German Foundation for the Environment), the latter with the objective to produce sea–vegetables for the food market in France and Germany.

The seaweeds are cultivated in 2000 L tanks and the species used include *Palmaria palmata, Laminaria saccharina, Chondrus crispus, Ulva lactuca* (as sea–vegetables and for the SEAPURA project), the *Falkenbergia* (gametophytic) phase of *Asparagopsis armata* and *Hypoglossum hypoglossoides*. Cultivation on a larger scale has been undertaken using *Palmaria palmata* and *Laminaria saccharina*. *Palmaria* is cultivated by making use of both vegetative propagation (fragmentation) and sexual reproduction. The yield varies between 200–600g fresh weight (FW) m–2 day–1. New tank cultivation methods are being tested for *Laminaria* and *Ulva*. To prevent the summer–drop of growth, *Laminaria saccharina* is grown in tanks with an automatic blind. With this technique short day conditions can be simulated to achieve constant growth. The same principle already successfully applied previously for the cultivation of *L. digitata* (Gómez & Lüning 2001). Tank cultivation of *Ulva* spp. is critical because the frequently occurring sporulation events result in loss of algal tissue. To overcome this problem, lamps were installed in the tanks giving low light illumination throughout the dark–phase. Sporulation still occurs but is restricted to small portions of the blades (K. Lüning & S. Pang, 2003, pers. comm.).

At CIMAR (University of Porto, Portugal) different species, indicating *Chondrus crispus, Gracilaria* spp., *Gelidium sesquipedales* and *Palmaria palmata*, are cultivated in the effluent waters of tank–cultivated turbot and seabass (*Scophthalmus maximus* and *Dicentrarchus labrax*, respectively). Different water exchange rates and stocking densities are being tested. In parallel, algal–based fish feed preparations are being used in feeding experiments (I. Sousa Pinto, 2003, pers. comm.).

Similar experiments were conducted at CCMAR (Centre of Marine Science of the University of Algarve, Faro, Portugal). Here, run–off water from fish ponds, containing *Sparus aurata* (bream) is used for the cultivation of a range of different seaweeds in aerated tanks. The species tested comprise red algae, such as *Hypoglossum rhizophorum, Falkenbergia rufolanosa* (gametophytic life stage of *Asparagopsis armata*) and *Gelidium sesquipedale*, brown algae (*Ectocarpus* spp. and *Dictyota* spp.) and some green algae (*Ulva rigida* and *Cladophora* spp.; R. Santos & A. Schünhoff, 2003, pers. comm.). At the University of Algarve successful trials have been already conducted using *Ulva* for purifying the effluent from pond cultivation of *Sparus aurata* (Mata & Santos 2003).

The SEAPURA project is still ongoing. Therefore detailed data, with particular respect to the economical feasibility of tank cultivation, are not yet available.

Integrated mariculture in Scotland

In 2003, a three–year project entitled "Reducing the environmental impact of sea–cage fish farming through cultivation of seaweeds in Scotland" began. It is conducted by the Scottish Association for Marine Science (SAMS) and Queen's University Belfast with industry partners Loch Duart Ltd. (salmon farmer, Scotland), Dolphin Sea Vegetables (Belfast, NI) and Xplora (aquaculture gear manufacturer, Scotland) and is funded by Highlands and Islands Enterprise, the Highland Council and the project's industry partners. Its aim is to assess the potential of commercially important seaweeds cultivated in the immediate vicinity of salmon cages to reduce the impact of nutrients released by fish and unused fish feed. The algae cultivated in this nutrient rich environment will be analysed for their protein content and tested as a potential food source for human and shellfish consumption (M. Kelly & C. Anderson, 2003, pers. comm.). The data will contribute to a model of the distribution of dissolved inorganic nutrients from sea–cage fish farms and will help to develop a predictive tool for assessing the impact of introducing algal cultivation at a site.

In the first year it is intended to use *Palmaria palmata* in cultivation trials. Cultivation techniques, including the seeding of culture ropes and indoor pre–cultivation, developed at the Marine Laboratory Portaferry/Queen's University Belfast (see above) will be applied. As the project progresses, other species such as *Porphyra* spp. and *Laminaria* spp. will be used (M. Kelly & C. Anderson, 2003, pers. comm.).

This is the first project in Europe to evaluate the potential of seaweeds to reduce the impact of nutrients released by cage–farmed fish. Offshore finfish aquaculture is a fast growing sector in Europe with proven significant environmental impacts (Persson 1991; Chopin & Yarish 1999). The idea of using seaweed aquaculture to counteract the resultant effects from finfish aquaculture is not new. Efforts are being made, especially in Eastern Canada, to promote and establish sustainable integrated mariculture. The outcome of the Scottish project is therefore of particular interest for further directions of integrated aquaculture in Europe.

4.2.3 Seaweed in bioremediation

Seaweed cultivation for bioremediation of urban sewage in Northern Ireland

In 1999 a project entitled "The use of seaweed as biofilters for inorganic nutrients and heavy metals in effluent from sewage treatment works" was carried out at the Marine Laboratory Portaferry, Queen's University Belfast (funded by NERC, Natural Environment Research Council, UK, DRD Water Service Northern Ireland and Kirk McClure Morton; GR3/CO032). The scope of the project was to study the feasibility of using seaweed as biofilters to remove inorganic nutrients (nitrogenous and phosphorus compounds) from secondarily treated effluent.

Fucus serratus cultivation
for bioremediation of urban sewage

In collaboration with the Northern Ireland Water Service a pilot plant has been built at a sewage treatment works on the shores of Strangford Lough. The perennial alga *Fucus serratus* was collected from the Irish Sea and cultured in aerated raceways (6000 L holding capacity). A 1:1 mixture of secondarily treated effluent and seawater flowed through the raceway with the water being exchanged 2–3 times per day. The initial biomass used varied between 36–140 kg wet weight per tank (2.5–9.5 kg m–2). The experimental algae were cultivated for up to 8 weeks. Algal growth, inorganic nutrient concentrations of the inflow and outflow and of algal tissue were monitored frequently. The relative growth rate of *Fucus serratus* varied between 1% and 4% d–1 in autumn/winter and spring/summer, respectively. The removal rates for nitrate, ammonium and phosphate varied from 20% to 60%, independent of the season. This reached values of 80% when the effluent was pre–filtered in order to reduce the high particle load which led to high turbidity, coverage of algal surface and consequently deterioration of the tissue. Analysis of nutrient concentrations in algal tissue showed that a high proportion of nutrients, removed from the effluent, were channelled into growth, the surplus of nutrients, mainly phosphate, were internally stored (Werner et al. 2003).

This project showed the feasibility of using macroalgae in tertiary treatment of urban sewage. The situation for the seaweed used as biofilters for the treatment of sewage compared to seaweed used as biofilters in integrated polyculture systems is different in several respects:

- For sewage treatment the effluent has to be mixed with seawater, which means a maximal reduction of ambient salinity by 50%. Therefore the choice of species is restricted to intertidal ones, which tolerate low salinity.
- The average inorganic nutrient concentrations and the ratios in the effluent vary significantly not only over the course of the year but also over the day. In a 1:1 mixture of effluent and seawater the concentrations of nitrate, ammonium and phosphate are up to 200 times higher than in seawater. The seaweed must be efficient in removing not only nitrogenous compounds from the effluent but also phosphate.
- The seaweed must be easy to collect from the shore and be abundant the whole year.
- It must provide a sustaining efficiency as a biofilter the entire year.

Fucus serratus was chosen for this purpose because it fulfilled the requirements mentioned above and showed a high potential for removing inorganic nutrients despite its low growth rate. An essential step towards optimisation of the system is the integration of an efficient pre–filtration unit for the effluent. Reduction of the particle load, as it was shown, had a significant influence on the longevity and health of the plants and, consequently, on the removal rates of nutrients.

The project clearly showed feasibility of utilisation of seaweeds as biofilters from the technical and biological point of view. For commercial establishment, however, the economical feasibility still has to be assessed including the evaluation of a value–added use of the biomass produced as, for example, fertiliser in horticulture or extraction of certain algal compounds.

Algal material for heavy metal absorption

In the early 1990s pilot–scale offshore cultivation of *Laminaria saccharina* was tested around the island of Helgoland in the North Sea. The raw material was used to study the potential of dried material as a matrix for biosorption of heavy metals. This project was funded by the BMBF, Federal Ministry for Education and Research. Floating ring–shaped structures, suspended at 1.2m below the water surface, were used as supporting structures for the trials. Ropes were seeded in the laboratory and pre–cultivated in tanks during the early development of sporophytes. This was followed by a 6–month cultivation period offshore. A biomass of 300 kg wet weight per ring structure with 80m of seeded ropes (3.75 kg per m rope) was harvested. The biomass was air–dried and further used for the investigations of heavy metal absorption.

Although in principle the cultivation itself was successful, it was evident that cultivation on a commercial scale would not be viable. The test area was too exposed and prevailing weather conditions made frequent access to the farm impossible. Moreover, pre–cultivation of juvenile sporophytes under laboratory conditions proved too expensive in terms of labour intensity.

In connection with the cultivation trials, the induction of sporangium formation and subsequent spore production was investigated in *Laminaria digitata*. The results suggested that a substance is released from the meristematic region, the transition zone between the stipe and the blade, which inhibits sporangia formation in spring and summer during the period of rapid growth (Buchholz & Lüning 1999; Lüning et al. 2000).

4.3 Present commercial seaweed cultivation

Laminaria saccharina cultivation in Germany

In 1999 a pilot–scale seaweed farm was set up in the Baltic Sea near Kiel/Germany by the research company CRM (Coastal Research & Management) for the cultivation of *Laminaria saccharina*, based on the experiences obtained during the *Laminaria* project on Helgoland ten years before. This three–year pilot project was funded by the DBU (German Foundation for the Environment). The seed material was obtained from fertile Laminaria saccharina plants collected in the Baltic Sea. Two approaches were followed: spores were either seeded directly on culture lines or kept as free–floating cultures until the development of small plants. These were then attached to the culture lines prior to out–planting. After several weeks of pre–cultivation under laboratory conditions the culture ropes were transferred to the sea using a long–line system. An area of 40 m2 was used for cultivation. After three months of cultivation (winter to spring) the yield for both methods was 0.5 kg/m culture rope with the algae pre–cultivated as floating culture prior to attachment to the ropes reaching an average length of 90 cm compared to the algae of the seeded ropes with a lengths of 20–40 cm. The small growth rate of the latter was due to over–seeding of the ropes and consequent effects of shading and nutrient competition whereas the other plants were attached to the ropes at 10 cm distance from each other and showed better development.

After the two–year trial it was planned to extend the farm. For 2002 it was aimed to harvest 360 kg wet weight from 1800m of culture ropes and 480 kg wet weight from 2400m of culture ropes. Through optimisation and rationalisation of the cultivation process the production cost could be reduced to achieve a price of ca. 25 per kg dry weight of *Laminaria saccharina.*

Along with the cultivation trials extensive market research was conducted to identify target markets for the raw material. Markets with different potential were identified as follows:

a) The main potential for markets in the short to medium term were in the cosmetic, wellness and health food sectors.

b) In the medium to long term the main potential were in the sectors waste water treatment, anti–fouling paints, and bioactive substances from *Laminaria saccharina* for pharmaceutical uses.

c) The utilisation of algae for human consumption, algae as biofilters in re–circulation systems for finfish and shellfish aquaculture were considered to be niche markets.

The company O'Well – Ocean Wellness GbR was founded in 2001 with the aim to develop and market algal products using the raw material produced from the *Laminaria* farm. A series of six products for the wellness sector and cosmetic centres have been developed so far. In addition, an algal drink based on *Laminaria* has been developed in collaboration with a laboratory in Mecklenburg, East Germany. Further diversification in the utilisation of raw material produced at the farm is under way (Piker 2001).

The development of this seaweed farm in the Baltic is remarkable for different reasons: The Baltic Sea is a semi–enclosed water body with limited water exchange with the North Sea which leads to reduced salinity. In the German part of the Baltic Sea salinity is about 16–20% compared to 32% in the North Sea. As a consequence, algal diversity and growth rates are significantly reduced. Moreover, several areas of the Baltic are at risk of eutrophication as indicated by the high number of annually occurring microalgal blooms. Natural resources of *Laminaria saccharina* are small due to several factors, such as low salinity, high water temperatures in summer, limited availability of rocky substratum for settlement, shallow coast lines, virtually no tidal current and relatively high turbidity. This has implications for the seaweed farm with respect to the acquisition of plants for spore release to seed the culture ropes, the finding of suitable farming areas, and the relatively slow growth in comparison to growth rates which can be achieved in a full marine environment. On the other hand, the benefits of a seaweed farm in these waters are significant with respect to environmental issues. Piker (2001) stated that there is a substantial potential to increase biodiversity around the seaweed farm. An attraction of local fauna from small crustaceans to fish was observed seeking shelter and prey. Additionally, an increased number of *Laminaria* plants in the vicinity of the farm was recorded, which probably were dislodged from the cultivation lines and consequently settled on the substrate available. The development of natural standing stock would have consequences in providing areas for colonisation, breeding–grounds and shelter for accompanying flora and fauna.

Farming of Asparagopsis armata in Brittany/France

A commercial seaweed farm was set up on the Île d'Oussant in the mid 1990s by Jean–Yves Moigne, Algues et Mer, to cultivate the red alga *Asparagopsis armata*, a new species in aquaculture. Today, this alga is farmed on an area of 2 ha, comprising 14 km cultivation rope with an annual yield of 8 tonnes wet weight. Mr Moigne, who was involved in the first *Undaria* cultivation trials carried out on the island and mussel farmer since then, developed a patented cultivation technique, which is based on vegetative propagation of the alga, and the use of a special type of rope. The growth cycle is restricted to the winter–spring period and two harvests are carried out until April/May. The seed stock is collected from the wild and pre–cultivated in the sea to increase seed stock biomass because the natural resources are very limited. Approximately two months after seeding the culture ropes the first harvest is carried out. A second harvest follows about two months later. At the beginning of summer, the growth rate of *Asparagopsis* declines and the substances extracted from the algae lose their bioactivity.


Asparagopsis armata cultivation, Ireland

Prior to the set–up of the farming operation, Mr Moigne conducted an extensive search for potential bioactive compounds in the alga in collaboration with a cosmetic company, and potential products and markets were assessed. The bioactive compound from this alga is a mixture of substances, mainly sulphated polysaccharides with iodine and bromine groups. Algues et Mer developed a special solvent–free technique to extract the substances, which is also patented. The process comprises cellular breakdown by cold grinding, clarification by tangential micro–filtration and concentration of the substances by freeze–drying. The end product, called Ysaline 100, shows strong anti–bacterial properties and is used as a natural preservative in cosmetics, as anti–dandruff and scalp cleanser and as anti–acne treatment.

In addition to the production of Ysaline 100, *Ascophyllum nodosum* is used for the extraction of other bioactive compounds. These are polyphenols and depolymerised fucoidans. For the extraction of polyphenols, Algues et Mer uses an innovative extraction methods without solvents. The final product, free of any preservatives shows anti–oxidant properties and finds its application as a cosmetics and health food ingredient.

Fucoidans constitute a heterogenous population of high molecular weight compounds (100,000 – 800,000 g/M), mainly composed of polymers of sulphated L–fucose. A new method was developed by IFREMER using free radical depolymerisation in the presence of a metal catalyst and hydrogen peroxide to produce oligosaccharides with a molecular weight of 5000 – 15,000 g/M with an increased biological activity. Algues et Mer has set up the complete process of extraction, depolymerisation and purification of standardised LMW – FS (low molecular weight fucoidan sulphate), having the exclusive licence from the IFREMER – CNRS patent. Since the LMW fucoidans have properties as microcirculation enhancers, connective tissue rebuilders and defence mechanism enhancers, they are used by the pharmaceutical and cosmetic industry (J.–Y. Moigne, 2003, pers. comm.).

The company Algues et Mer is unique in its profile, structure and success in NW Europe. Five people are employed; two of them in full–time positions, and one position is partially funded by a national grant. The company conducts the process from production of raw material to production of the end product and marketing. Focus is set on high–value products. The company works closely together with the industry for the development of new products. Vital for the success were and is the application of innovative techniques, the observation of new developments in research and market demands and good marketing strategies.

4.4 Seaweed aquaculture experiences in Ireland

4.4.1 Research and development projects

Alaria esculenta cultivation

A thesis, entitled "A routine method for mass cultivation of *Alaria esculenta* (Greville 1830)" carried out by J.–F. Arbona, was undertaken to establish methods for commercial sea–based cultivation of *Alaria esculenta*. Vegetative large–volume cultivation of the microscopic gametophytes, obtained from wild fertile plants, fertilisation of gametophytes, seeding of ropes and pre–cultivation of juveniles under laboratory conditions were successfully established. The pre–cultivated ropes were then attached to long–lines transferred to three different sides at the West Coast. Growth rates of plants from different sites were compared and yield ranged between 3–5 kg wet weight per linear metre of culture rope after 4–5 months of offshore cultivation. The procedure from fertilisation to offshore cultivation was shown to be reproducible (Arbona 1997).

This study was of far–reaching importance because it resulted in the successful establishment of cultivation and control methods for both life stages of *Alaria esculenta*. It also showed the importance of technology transfer and adaptations of existing methods for related seaweed species for the requirements of the target species. For the cultivation of *Alaria* the Korean technique for commercial cultivation of Laminariales and the methods developed by IFREMER for large–scale vegetative gametophytic growth have been adopted and successfully modified.

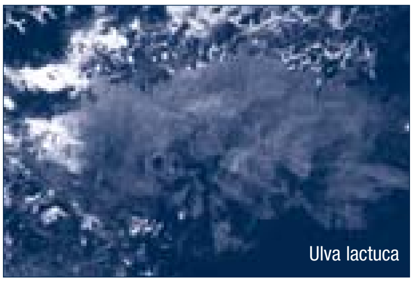
Strain improvement of the Alaria esculenta

In view of the economical importance of *Alaria esculenta* as a value–added sea vegetable two Marine Institute R&D projects have been undertaken since 1995 by the Irish Seaweed Centre (ISC), Martin Ryan Institute, National University of Ireland, Galway. These projects were entitled: “Strain selection of the edible seaweed *Alaria esculenta*: genetic fingerprinting and hybridisation studies under laboratory conditions” and “Strain hybridisation field experiments and genetic fingerprinting of the edible brown seaweed *Alaria esculenta*”. Genetic studies and hybridisation experiments were conducted using five species from the Atlantic and Pacific, and six geographically isolated populations around Ireland (Kraan & Guiry 2000a; Kraan *et al.* 2000). The hybridisation–experiments revealed that all Atlantic isolates were interfertile albeit to varying degrees of success. Self–crosses and hybrids from Irish isolates showed significant differences in morphology and growth rates implying that some strains are more suitable for commercial cultivation than others.

These findings are of particular interest with respect to improving strains for aquaculture to achieve maximal yield. Fast growth of the target species may increase the number of growth cycles performed during the year. Additionally, quality with respect to vitamin, mineral and protein contents, and taste may differ in strains. It was shown that protein levels in *Alaria* hybrids from cross experiments of Irish and foreign Atlantic species differ significantly (Kraan & Guiry 2000b). Therefore studies on growth as well as protein and mineral content of different Irish *Alaria* populations should be further investigated.

Marine algae as a novel, sustainable organic supplement in fish feed for salmonid aquaculture

This R&D project, conducted by the ISC, Martin Ryan Institute and funded by HEA PRTLI, Cycle 3, commenced in 2002. It combines two important aspects: tank cultivation of different seaweed species in effluent waters from cultured sea trout, and development of fish feed formulations using algal raw material, which will be tested on sea trout.


Ulva lactuca

Different species, such as *Ulva* spp. and *Palmaria palmata*, are cultivated vegetatively in tanks through which the effluent water from sea trout tanks is flowing. This provides a nutrient rich environment for the algae, with the potential to promote growth and increase internal protein content. Algal material will be analysed for its nutritional value, e.g. proteins, amino acids, fatty acids, carbohydrates and vitamins. The raw material of different algal species will then be tested in different fish feed formulations to partly replace components, such as fishmeal (A. Soler, 2002, pers. comm.).

Finfish aquaculture is a fast growing sector worldwide. Consequently the demand for fish feed is rising. Fishmeal is an important protein source in feed for fish but also for livestock. The production of fishmeal has not increased over the last years, therefore the utilisation of other protein sources is essential to maintain the supply of high quality feed.

Other relevant R&D projects

There are several other projects of importance. One project, which was initiated by the Waterford Institute of Technology and will commence soon, is aimed at investigating the potential of seaweeds in bioremediation, i.e. to remove heavy metals in the effluent of tanneries and the glass industry discharged into the river Suir.

In a recently completed 5th framework EU project, undertaken by eight participants from four countries, including the ISC and Slogeisc Mhic Dhara Teo in Ireland, research was conducted to develop a surfactant (surface–active agents), derived from kelps. Biochemical research with potential implications for the seaweed aquaculture sector, are focusing on investigations of algal polysaccharides (e.g. laminarans from brown algae) and their potential application for therapeutic use. These include research on key enzymes in the carbohydrate biosynthesis to investigate the potential for their use as biocatalysts (e.g. to modify algal polysaccharides for specific applications) and iodine metabolism in *Laminaria* species (i.e. chemical composition of iodine containing molecules, iodine content in algae, uptake mechanisms and their control).

Studies on *Porphyra linearis*

At the MRI, comprehensive research has been conducted on *Porphyra linearis.* The life cycle of this species was examined over growth and reproduction in the field and cultivation of the conchocelis phase under laboratory conditions were undertaken (Varela 2002). A prerequisite for commercial cultivation of indigenous *Porphyra* species is the ability to control the whole life cycle and have substantial knowledge of optimal conditions for growth and reproduction. The studies were the first on an indigenous Irish species and it would be essential to conduct research on other *Porphyra* species to be able to select the most suitable species for aquaculture.

4.4.2 (Pre–) Commercial cultivation of seaweeds

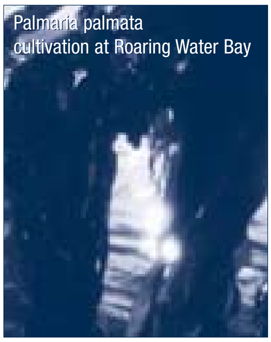
Farming of *Asparagopsis armata* in Ard Bay

A project to commercially cultivate *Asparagopsis armata* in Ireland was initiated in 1996 after an establishment of contact with J. Y. Moigne of the company Algues et Mer in Brittany (see 4.3). This project was mediated by Taighde Mara Teo as support agency, facilitating the liaison between an Irish contract producer (Sliogéisc Mhic Dara) and J.Y. Moigne as Technology Holder. Technology transfer and intensive training for the cultivation of *Asparagopsis* were conducted by Taighde Mara Teo, as well as assistance in the licensing process and the development of the business structure. In 1998 the farm was constructed and first cultivation trials took place. It became obvious that, although the cultivation sites and environmental conditions in Brittany and Ireland are relatively similar, cultivation methods had to be adjusted to local Irish conditions, especially with respect to the timing and duration of the growth period. After harvesting, the biomass was frozen for preservation of the bioactive compounds of interest, and sent to Algues at Mer where it was processed (M. Norman, Taighde Mara Teo, 2003, pers. comm.). It is expected that contracted production of *Asparagopsis* will expand due to the continuous demand for raw material by Algues et Mer and the expression of interest by some Irish promoters.

Seaweed cultivation trials in South West Cork

Innovative strategies with respect to the cultivation of different seaweeds, evaluation of marketing and processing possibilities have been followed by the company Seaweed South West with assistance of BIM and external expertise from J.–F. Arbona in 2000–2003. Several seaweeds for human consumption, such as *Alaria esculenta, Palmaria palmata, Ulva* spp. and *Porphyra* spp. have been tested in pilot trials for the feasibility of farming. Hatchery methods as well as sea–based cultivation *(Alaria, Palmaria)* and tank cultivation *(Palmaria, Ulva, Porphyra)* have been investigated. Concomitantly to these trials, extensive market research was carried out. Seaweed South West made contact with several companies in Europe for quality analysis of the produced crop and for the evaluation of market opportunities. Market research was also carried out in

Japan, a major market for sea vegetables, especially for *Porphyra* (nori). Analyses showed that the quality of all tested species was good. The demand for sea vegetables on the European market, however, is limited. Due to encouraging results of the quality analysis of *Porphyra* in Japan, the possibility of buying a nori machine to produce nori sheets was evaluated (M. Sammon, Seaweed South West, 2003, pers. comm.).



The strategy for a holistic approach including cultivation trials, quality analysis, processing of raw material, production of a value–added end product, and intensive market research is essential to fully evaluate the feasibility and viability of seaweed farming. When attempting to enter the Asian market, detailed knowledge of the quality demands and market opportunities are important. Depending on the final use, refinement of algal raw material by the producer should be considered. In the case of *Porphyra* production, high capital investment is necessary to buy a nori machine. With respect to investment amortization it might exceed the capacities of a single company. Therefore joint capital investment by a producer association might be an alternative.

Seaweed cultivation in Roaring Water Bay

A pilot project was developed by the Roaring Water Bay Seaweed Co–operative Ltd. (RWB Co–op) with assistance of BIM and the Irish Seaweed Centre to cultivate *Palmaria palmata* and *Alaria esculenta* for sale as sea vegetables. The project commenced in 2001. Both seaweeds were grown at a 1.75 ha site on long–lines. Technology transfer was facilitated through the Irish Seaweed Centre. For *Palmaria* cultivation, young intact plants were collected from the sea and inserted into the lay of the culture rope before transferred to the sea. *Alaria* sporelings were obtained through fertilisation of gametophytes and consequent seeding of ropes with released spores. After a time of pre–cultivation in the laboratory the plants were transferred to the farming site. The success of the trials was partly impaired by a number of factors including adverse weather conditions in winter, plant losses and plant bleaching. Trials were carried out over one season only; however, substantial progress was achieved which has provided valuable lessons for the optimisation of the cultivation processes. (D. Pitcher, J. Morrissey, 2003, pers. comm.).

In a new project the feasibility of offshore *Chondrus crispus* cultivation will be investigated by the RWB co–op with assistance of the Irish Seaweed Centre (funded by Enterprise Ireland RIF award). *Chondrus* is an economically important species for human consumption and the cosmetics industry is a novel species for cultivation in Ireland (see Chapter 5.3).

The RWB are interesting as they were developed and conducted by a co–operative. As an initiative of a Parish consisting of about 300 people a co–op was formed. Shareholders were recruited, of whom 95% are from the Parish, management structures were established, including a committee of 15 members, and aims were formulated. Before the seaweed cultivation project was developed the RWB co–op was already engaged in seaweed harvesting for several end–uses and market connections therefore were already established.

The co–op approach is advantageous in several aspects:

- Capital investment for business development (and consequently risk) is distributed among the shareholders.
- Expertise of different areas is brought in by the diversity of professions of the members and can cover a range of essential functions, such as research, marketing and sales and administration.
- Labour input for the individual on average is minor, because it is divided between several members (part–time activity).
- During labour intensive periods (bringing out seed stock, harvesting, processing) additional labour can be recruited more easily.

This example of a co–operative may serve as a model for small communities, where members are willing to engage in additional activities to increase their income or are interested in aquaculture but are not capable to take a financial risk to set up a business on their own.

4.5 Conclusion

Recent developments in seaweed aquaculture in NW Europe with respect to research projects and the establishment of a small number of commercial farms, are promising for the future. In recent years, more comprehensive approaches in R&D projects were undertaken to investigate new species, cultivation methods and new applications. Increased emphasis has been placed on the evaluation of the commercial feasibility of seaweed farming. However, the development of seaweed aquaculture can only be successful when appropriately supported by national and EU policies.

5.0 Identification of seaweed species, their by–products and economic value, which lend themselves to aquaculture production in Irish waters

Northwestern European countries, Atlantic Canada and the Atlantic coast of United States show comparable conditions with respect to climate and algal flora, as well as economical conditions and standards of living. Therefore trends and developments in seaweed aquaculture in each of these countries are of relevance for the other countries and may be adopted to a certain degree. The review of the current status of seaweed aquaculture in NW Europe and North America (see Chapters 3 & 4) revealed that commercial seaweed aquaculture operations produce predominantly for the food market and, to a smaller extent, for the cosmetic sector and some biotechnological applications. Ongoing research and development is focusing on novel applications of seaweed derived substances and new species for aquaculture.

5.1 Seaweed species and applications

In Ireland, seaweeds used in human consumption, animal feed, health and cosmetics have been established in pre–commercial aquaculture (*Alaria esculenta, Palmaria palmata* and *Asparagopsis armata*) and/or are being tested for possible applications (*Chondrus crispus, Porphyra* spp., *Ulva* spp. and *Laminaria saccharina*). The primary use for species cultivated in Irish waters at present is for human consumption and, in the case of *Asparagopsis*, for cosmetic applications. Applications will certainly diversify when species are fully established in commercial aquaculture and other sectors will additionally be supplied, for example the Irish cosmetic sector which currently sources its seaweed from wild stock. The utilisation of some of these algae as a supplement in fish feed is under investigation only the development of nutraceuticals using seaweeds, such as *Alaria, Palmaria, Laminaria saccharina, Chondrus* and *Porphyra* is realistic for the future.

The introduction of new seaweed species depends strongly on advances in research, product development and the economical feasibility of cultivation of particular algae. Various examples, given in Table 1, (marked red) have been shown to have valuable properties with potential applications in different sectors.

Sulphated oligo– and polysaccharides are of major interest for pharmacological applications, cosmetics and nutraceuticals. Carrageenan, heparin–like polysaccharides, laminarans and fucoidans have shown, for instance, anti–inflammatory, anti–bacterial, anti–viral and immuno–stimulant activities. These properties are already exploited by the cosmetic industry and for the production of food supplements/nutraceuticals (Neushul 1990, Noda et al. 1990, Carlucci et al. 1997, Vlachos et al. 1999, Xue et al. 2001, CEVA 2002, 2003a).

Table 1. Seaweed species established in aquaculture and their utilisation, and new potential species with novel applications under investigation in NW Europe and North America

Sector	Applications	Seaweed species utilised at present or investigated for their potential use	Cultivation established as sea–based (S) or tank (T) cultivation
Human consumption	Sea–vegetables	*Alaria esculenta*	S
	Food ingredients	*Laminaria saccharina*	S
		Undaria pinnatifida	S
		Palmaria palmata	S, T
		Porphyra spp.	S, T
		Chondrus crispus	S, T
		Ulva spp.	T
Animal feed	Food additive	*Alaria esculenta*	S, T
	Protein source for fish, shellfish, poultry, cattle	*Palmaria palmata* *Ulva* spp.	S, T T
	Antibiotics against fish pathogenes	Red algae	
Health	Nutraceuticals (functional food, food supplements)	*Alaria esculenta* *Laminaria saccharina*	S S S, T
	Para–pharmaceuticals	*Palmaria palmata* *Porphyra* spp. *Chondrus crispus*	S, T S, T S, T
Cosmetics	Seaweed (extracts) as additives with claimed function	*Palmaria palmata* *Chondrus crispus*	S, T S, T
	Bioactive algal compounds with proven effects (e.g. anti–wrinkle, anti–acne, anti–dandruff)	*Asparagopsis armata* Red & brown algae	S
Agrochemicals	Growth enhancer	*Laminaria digitata*	Harvested, cultivation not likely
	Stimulants for plant defence system ("plant vaccine")	*Ascophyllum nodosum* *Fucus* spp.	
	Fungicides		
	Bactericides	Red & brown algae	

Table 1. Continued

Sector	Applications	Seaweed species utilised at present or investigated for their potential use	Cultivation established as sea–based (S) or tank (T) cultivation
Biotechnology	Surface protecting substances	*Laminaria* spp.	Harvested, cultivation not likely
	Enzymes for specifically modifying chemical compounds	*Fucus* spp.	
	Food engineering	Red algae	Cultivation?
	Biomedicine (surgery, transplantation, encapsulation, etc.)	Brown algae	
	Environmental technologies	Specific life stages of certain algae	
Biomedicine	Bioactive substances with proven activities, such as:	*Laminaria digitata*	Harvested, cultivation not likely
	Anti–viral	*Delesseria sanguinea*	
	Anti–bacterial	*Dumontia contorta*	Cultivation?
	Anti–tumor	*Ceramium* spp.	
	Anti–inflammatory	*Laurencia* spp.	
	Anti–coagulant	*Gracilaria* spp.	
	Immuno–stimulant	Specific life stages of certain seaweeds	

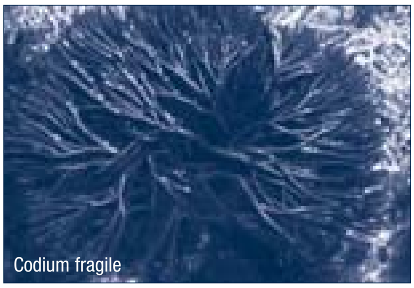
Despite comprehensive research on bioactive substances from seaweeds and the broad spectrum of proven efficacy of carbohydrates, almost no approved seaweed derived pharmaceuticals are on the market yet (Colwell 2002). This might be because the raw material is not considered to be available in sufficient quantities (with respect to rarer species) and, even more importantly, in standardised high quality. Another reason might be the complex nature of oligo– and polysaccharides. These polysaccharides, although general constituents of the different algal groups, show species-specific and life–phase dependent characteristics. This makes some seaweed species more suitable for utilisation than others. The molecular complexity of these sulphated carbohydrates makes it difficult to develop synthetic analogues. In the process of manufacture, in some cases chemical or enzymatic depolymerisation techniques are applied to obtain smaller sized oligosaccharides with increased bioactivity, such as low molecular weight fucoidans and carrageenans, (see Chapter 4.3; CEVA 2001).

The therapeutical properties of algal polysaccharides could also be exploited for the development of drugs for animals and could be applied in agriculture/horticulture as plant vaccines. Extensive research on algal oligosaccharides and their effect on plants have been conducted by the United Research Unit, which affilitates research groups of the CNRS (Centre National de la Recherche Scientifique) Roscoff and the company Goëmar (Brittany/France). Laminarans and other oligo– and polysaccharides influence numerous functions in terrestrial plants, such as growth, development and reproduction. The most important aspect of the research conducted is the function of algal oligosaccharides as elicitors. Elicitors are signal molecules, which are recognised by the plant and trigger the activation of the plant defence systems. As a consequence the plant is prepared for potential pathogen attacks (CEVA 2001; J.–C. Yvin, Goëmar, 2003, pers. comm.). It is estimated that the administration of elicitors to plants can reduce the use of fungicides for crop by 25%. A product of an algal elicitor has been developed by Goëmar and has been approved recently for utilisation in wheat cultivation (CEVA 2003b).

Beside the importance of seaweed derived polysaccharides as bioactive substances they are of major importance as gelling and viscosifying agents in various industrial sectors (e.g. food, textile, medicine, biotechnology). The utilisation of biopolymers, such as carrageenan, agarose/agar and alginates, for medical applications is of increasing importance.

In addition to polysaccharides a variety of other bioactive substances from seaweeds have been characterised and tested for potential applications. Observations of natural seaweed systems, such as self–protection against biofouling and damaging ultra–violet (UV) radiation, has initiated research into the underlying mechanisms and potential applications for human use. Chemical compounds with anti–fouling activity are present in many algae; however, considerable differences in the level of bioactivity are seen. There is a potential for the development of an environmentally friendly algal anti–fouling substances with no toxicity on, for example, fish larvae, for replacing common toxic anti–fouling paints (e.g. TBT coatings; Hellio *et al.* 2001, De Nys & Steinberg 2002). The development of sunscreens using seaweed derived chemical compounds is a focus of research with two major groups of substances being examined: mycosporine–like amino acids (MAAs) and polyphenols from seaweeds. These act as UV filters and as anti–oxidants to prevent skin–cell damage caused by photo–oxidation and the production of free radicals when the skin is exposed to UV radiation (De Nys & Steinberg 2002, CEVA 2003a).

There is a broad spectrum of potential applications for seaweed derived substances, based on extensive research conducted in various fields. The crucial step is to bring a potential application to the stage of commercialisation. For a viable Irish Seaweed Aquaculture Industry it is essential that the industry invest in such developments. The transfer and exploitation of the extensive knowledge available is necessary. It is essential that local seaweed species are tested for potential bioactive substances as species of one genus show significant differences in biochemical properties between populations and between isolates. In addition, cultivation methodology has to be developed for potential species, which are known to be difficult to cultivate (e.g. where the life cycle is not fully known, where there is small growth rates of the species of interest, or the ecophysiological requirements are not known). It also has to be verified that a particular species can be produced in sufficient and reliable quantities in an economically viable way.



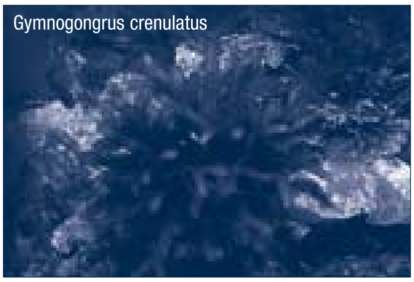
Codium fragile

5.2 Economic value of seaweeds and markets

The economic value of a seaweed is determined by the final product and by market demand. In general, with increasing refinement of the raw material the economical value increases, and consequently also capital investment and time necessary for product development rises (i.e. final products of the sectors, listed in Table 1, section 5.1, increase in value in descending order). Additionally, the market demand is crucial for the value of the end products.

A key factor for the development of a viable Irish Seaweed Aquaculture Industry is the evaluation of sustainable markets. Irish seaweed products applied in different sectors are well established at national and international markets with considerable potential for expansion. In the food, health and cosmetic sector there is still an increasing demand for “natural” and “healthy” products. This general trend for “green” products is not new but is still gaining significantly broader acceptance by the public. The consumer today is more critical with respect to product quality, ingredients, environmentaly friendly processing of products and the origin of raw materials. The market for nutraceuticals and para–pharmaceuticals is still expanding. In the United Kingdom, for example, the market for vitamin and mineral supplements was worth 576.7 million (£395 million) in 2002 according to the research group Euromonitor (Pratley 2003). The figure remained relatively stable in comparison to figures 5 years ago, which is due to a decline in retail prices when supplements entered super markets and became a commodity. However, this masks the significant growth in quantities being used.

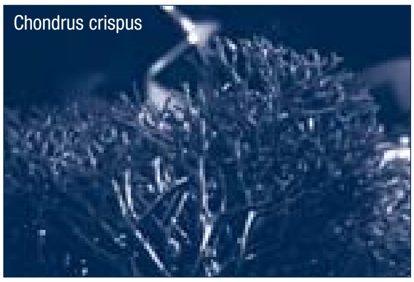
Today, around 10 million people in the UK use dietary supplements (one in three women and one in four men). Due to the beneficial properties of seaweeds and their high contents in vitamins and trace minerals there is a significant potential for the development of seaweed derived nutraceuticals.



The search for new bioactive substances in marine organisms for biotechnological and medical applications has been adopted by the cosmetic sector. Claimed and proven beneficial effects of seaweed compounds in cosmetics and corresponding marketing strategies have created a new trend for "ocean–derived" products, which are readily welcomed by the consumer. For France algal extracts were used since 1990 in over 65% of cosmetic products. The latest records of products launched on the market between 2001 and 2002 showed that 85% of claimed activities in cosmetics are attributed to bioactive substances from seaweeds (CEVA 2003a). In accordance with these general market trends, the Irish Seaweed Industry may particularly benefit from the perception of Ireland as "natural, green and clean". In Ireland several cosmetic companies have responded to these trends and have successfully established seaweed based products on the market. With ongoing research for new algal substances and their efficacy in dermatological applications, this sector is considered to have considerable growth potential.

The profit margins for seaweeds as food vary significantly depending on the importance of particular seaweeds for the consumer and consequently on the markets. In Asia, seaweed is a common constituent of the daily diet. The diversity of seaweed food products as well as the quality range is high. In Japan high quality nori (*Porphyra*) fetches prices of up to €500 per 300 gram (R. Kaas, IFREMER, 2003, pers. comm.). Due to a steady demand for seaweeds, especially for nori, and relatively high prices for algal food products, the Japanese market in general is considered to be a main target market for seaweeds produced in aquaculture. However, entry to the Japanese food market requires careful market evaluation, local contacts for marketing and high quality products. One example for successful development of a seaweed product for and marketing on the Japanese market is presented by the Canadian company Acadian Seaplants Ltd., based in Dartmouth, Nova Scotia, Canada (www.acadianseaplants.com). The company has developed a method of cultivating *Chondrus crispus* in outdoor and indoor tank facilities producing 10,000 – 60,000 kg per year. The raw material is processed by removing pigments of *Chondrus crispus* from intact plant tissue. The final unique product is *Chondrus* in three colours, green, yellow and pink, with a specific texture, which is well accepted by the Asian market.

Seaweed food products on the European market, and particularly on the Irish market, have gained an increasing acceptance, the growing demand for *Palmaria palmata* shows frequent inquiries from abroad for substantial volumes of biomass of Irish seaweeds also reflect a growing demand. Improvements in quality, packaging and labelling, and a more reliable supply are needed to increase sales along with greater promotion of seaweeds as a delicacy and for use in restaurants. For seaweeds produced by aquaculture in Ireland, the food market is certainly of major importance.


Chondrus crispus

As seaweed aquaculture in Ireland is at a very early stage of development, it is advisable to strengthen and expand existing markets, like food, health and cosmetic markets. However, for the development of a viable and sustainable seaweed aquaculture industry in the long–term, it is essential to also evaluate high–value markets of other sectors, such as biotechnology and biomedicine.

5.3 Seaweed species with priority for aquaculture in Ireland

The seaweeds with priority for aquaculture in Ireland are those, which have been cultivated at a pre–commercial scale or are being investigated for the feasibility for aquaculture (see Table 2). These species are already used as sea vegetables, food ingredients and in cosmetics and the markets are well established. They can be used for a range of applications and therefore provide the potential for further product diversification as well as market expansion.

Table 2. Commercially important seaweed species in Ireland and their current status with respect to aquaculture methodology, applications and markets

Seaweed species	Aquaculture	Aquaculture methods	Application	Markets	Demand
Palmaria palmata	established	Sea based cultivation	Human consumption	established	yes
		Out–growth of small plants collected from the wild & Spore seeding	Cosmetics	developing	yes
Alaria esculenta	established	Sea based cultivation	Human consumption	established	yes
		Spore seeding			
Laminaria saccharina	established	Sea based cultivation	Human consumption	established	yes
		Spore seeding			
Porphyra spp.	feasible	Tank cultivation	Human consumption	developing	yes
		Vegetative propagation			
	not tested	Sea based cultivation			
		Spore seeding			
Chondrus crispus	developing	Sea based cultivation	Human consumption	established	yes
		Vegetative propagation	Cosmetics	established	yes
	not tested	Tank cultivation			
Asparagopsis armata	established	Sea based cultivation	Cosmetics	established	yes
	(contracted cultivation)	Vegetative propagation		(contracted production)	

For successful commercial cultivation of seaweeds, biological and ecophysiological knowledge of the target species is essential including knowledge of the life cycle, propagation methods, nutritional requirements and growth conditions. This enables the seaweed farmer to control and optimise cultivation effectively.

Current status of cultivation methods for priority species

Palmaria palmata (life cycle: see Appendix 1)

This species has been extensively tested in cultivation trials (see Chapter 4, section 4.2.1) and has entered pre–commercial cultivation in Ireland. At present young plants of *Palmaria* are collected as seed stock, attached to culture ropes and transferred to the sea for out growth. As a comparison between different culture methods has shown, seeding of ropes is the most economically method, especially in view of expanding *Palmaria* cultivation (L. Browne 2002;). Methods for spore release from fertile plants, seeding of cultivation ropes and pre–cultivation under controlled laboratory conditions have been developed and technologies can be transferred. There is potential to develop methods for the artificial induction of spore maturation of mature plants and controlled spore release to seed ropes at times when naturally grown plants in the wild are not fertile. This would help to extend the growing period and allow multiple harvests through the year.

Alaria esculenta and Laminaria saccharina

For both species the feasibility of their use in aquaculture have been shown (Arbona 1997; Piker 2001; see Chapter 4, section 4.3 & 4.4.1). The life cycle of these species is understood and cultivation is relatively simple compared to many red algae (Appendix 1). It is possible to keep stock cultures of the gametophytes, the microscopic life–phase of these species, for extended times in the laboratory. Artificial induction of reproduction makes seed stock available at any time of the year although for the manipulation of the growth periods. Strain selection studies on *Alaria* have been carried out (Chapter 4, section 4.4.1) showing significant differences in growth rates between different Irish populations. These investigations provide a good basis for further studies on strain improvement.

Porphyra spp.

China, Japan and Korea have developed an extensive, highly sophisticated and economically very important *Porphyra* aquaculture industry. In Asia *Porphyra* is a traditional and valuable constituent of the normal diet, known as “nori”. *Porphyra* is processed in various ways with a range of different quality grades and prices accordingly. Demand and high prices for *Porphyra* have attracted attention in Western countries and initiated attempts to adopt cultivation methods and adjust them to the local conditions. However, there are some constraints for the cultivation of this alga.

- *Porphyra* has a complicated life cycle, which includes a life–phase, in which the microscopic plant, called *Chonchocelis*, develops in shells. The spores released by this life stage develop into the leafy *Porphyra thalli* (Appendix 1).
- During cultivation in the sea *Porphyra* can release monospores which settle on the culture ropes and can increase the yield significantly; however this species is dependent and not all *Porphyra* species exhibit this feature.
- In Asia two species are used for cultivation due to their characteristics with respect to production and taste: *Porphyra yezoensis* and *P. tenera*, both of which are indigenous to Asia. However, *P. yezoensis* was introduced to North America and cultivated in the United States (see below; Levine 1998).
- In Japan, where there is a high demand of *Porphyra*, quality standards are very high and markets need to be evaluated carefully.

Under Irish conditions tank cultivation of *Porphyra* spp. has been shown to be feasible and may be an alternative for open–sea cultivation.

In 1991 nori cultivation was initiated by the company Coastal Plantations International Inc. (CPI) at the northeast coast in Main, United States. Transfer and modification of cultivation and processing technologies from China, Korea, Japan, and research programmes of Washington State led to the first internationally certified, organically cultivated and processed nori. In 1998 *Porphyra yezoensis* was cultivated on an area of 47.75 hectares. The cultivation programme was backed by strong research on the improvement of strains (Levine 1998, Yarish *et al*. 1998). CPI developed a range of *Porphyra* products including nori, condiments, vitamin supplements, animal feeds, and r–phycoerythrine, a red pigment used as a fluorescent tag in medical diagnostics. CPI pursued new approaches for *Porphyra* cultivation, such as integrated polyculture with salmon farms. Productivity of *Porphyra* depends strongly on nutrient supply and integrated polyculture provides a means for increased nutrient supply for the algae. The algae simultaneously function as a biofilter by removing nutrients released by the fish aquaculture (Chopin *et al.* 1999b).

For the initiation of *Porphyra* cultivation in Ireland comprehensive research on indigenous species is essential to investigate their potential in aquaculture and to develop adequate cultivation methods. Five *Porphyra* species have been reported for Ireland (Hardy & Guiry 2003) and these may have different potential for seaweed aquaculture. An initial step was undertaken by Varela (2002) who performed comprehensive investigations on *Porphyra linearis* (see Chapter 4, section 4.4)

Chondrus crispus

Chondrus crispus has not been cultivated in Ireland yet. First sea–based cultivation trials will be conducted by the Roaring Water Bay Seaweed co–operation with assistance of the Irish Seaweed Centre under Enterprise Ireland funding. For seeding ropes a similar method as used for *Palmaria* will be applied, i.e. the collection of seed stock from the wild and insertion of plants into the lay of the rope before transfer of culture ropes into the sea.

Sea–based *Chondrus crispus* cultivation is a new approach. Trials have been carried out in Canada and Mexico (Chopin et al. 1999a; Zertuche–González et al. 2001) but have not been carried further to a commercial stage. Also in these trials plants from the wild have been used as seed stock. Depending on the results of the cultivation studies in Ireland, sexual propagation methods may be investigated to allow seeding of culture ropes via spores.

The example of *Chondrus crispus* cultivation by Acadian Seaplants verified that tank cultivation is economically feasible if the final product is of high value. Detailed investigations of optimal tank design and growth requirements for *Chondrus* were first conducted by Bidwell *et al.* 1985.

Asparagopsis armata

The cultivation of *Asparagopsis armata* in Ireland is a special case and has some restrictions. As described in Chapter 4, section 4.3, the cultivation techniques for *Asparagopsis* have been developed and patented by the company Algues et Mer in Brittany, France, as well as the extraction process of and the bioactive compounds themselves. This company has contracted cultivation in Ireland, and technology transfer of cultivation methods took place accordingly. The raw material was exclusively for the use by the company, where the extraction process of bioactive substances is taking place. Aquaculture of *Asparagopsis* therefore may further be conducted either as contracted production for Algues et Mer or other cultivation techniques and applications have to be developed independently.

6.0 Assessment of Irish expertise capable of supporting a national seaweed aquaculture programme

For the successful realisation of a national seaweed aquaculture programme, expertise in three areas is needed:

- Seaweed aquaculture for high–quality raw material production.
- Processing industry for the development of high–value end products.
- Structures for successful marketing.

Irish expertise in each of the three areas identified is available and will certainly be improved with further development of the Irish Seaweed Industry and by adjusted to arising needs. Taking into account the knowledge available in closely related sectors, such as shellfish and finfish aquaculture, aquaculture engineering, and marketing expertise of seafood, more expertise can be mobilised and drawn upon by the emerging seaweed aquaculture sector.

6.1 Expertise in seaweed aquaculture

6.1.1 Universities and Institutes of Technology

Scientific expertise on seaweed research and application of novel developments with respect to seaweed aquaculture, is mainly centred at the Universities, whereas engineering and management knowledge derives predominantly from Institutes of Technology.

Among the Universities the major centre of expertise for seaweed research with its various disciplines is the Martin Ryan Institute (MRI) of the National University of Ireland, Galway, including the Irish Seaweed Centre (ISC). Basic and applied research includes genetic studies, seaweed physiology and ecology, and aquaculture studies. The Irish Seaweed Centre was established to liase with research institutions, the seaweed industry and State Agencies and to develop and realise R&D projects. An excellent source for information about seaweed is provided by AlgaeBase (www.algaebase.org) a database of taxonomic, distributional and ecological information, housed at the Martin Ryan Institute. Scientists from the ISC and the Department of Botany at the MRI provide an important source of expertise for the development of seaweed aquaculture. Additionally, close links between the MRI and ISC with other universities in Ireland and abroad facilitates technology transfer and recruitment of scientists for a range of projects.

6.1.2 State Agencies

The Marine Institute, BIM and Taighde Mara Teo are responsible for the development and support of seaweed aquaculture. Substantial expertise is accessible through these State Agencies as has been shown by several seaweed aquaculture projects, in which technology transfer had been carried out either directly by Agency personnel or by contracted external experts. The implementation of the recommendations of the National Seaweed Forum (i.e. appointment of the Seaweed Research Co–ordinator by the Marine Institute, appointment of a regional Seaweed Development Officer by BIM; see Chapter 1) has been a crucial measure for the development of the Seaweed Aquaculture Industry. At present, there is a relatively small number of seaweed aquaculture projects at the stage of commercialisation. An increase in the number of seaweed aquaculture operations will need continued support. BIM and Taighde Mara Teo have established regional offices to facilitate the provision of assistance for finfish and shellfish farmers in different coastal areas. This network of expertise and support has played, and still plays, a crucial role in the development of these aquaculture sectors and has also facilitated the existing seaweed aquaculture projects. This will be of increasing importance as the seaweed industry expands.

6.1.3 Other relevant expertise

Fishermen and aquaculturists

Valuable practical experience and expertise is available from fishermen, finfish and mussel farmers with respect to technical and operational knowledge. This includes essential know–how of installing and maintaining moorings and aquacultural structures, rope work, boat handling and important knowledge of local conditions of bays (e.g. site exposure, tidal currents, substratum, benthic flora and fauna).

Service companies

There are many service companies in Ireland, which offer services relevant to seaweed aquaculture. These include companies offering physical, chemical and biological surveys, environmental impact assessments, project planning and management, financial projection, and licenses preparation and submission (e.g. Aqua–Fact International, EcoServe, Waterborne Geophysics, Watermark).

6.2 Expertise in product development

6.2.1 Irish seaweed industry

The Irish seaweed industry has accumulated extensive expertise in product development in different sectors (e.g. agriculture/horticulture, cosmetics). Seaweed aquaculture offers the opportunity to increase the quality of raw material and select seaweed species and suitable cultivation methods for the production of specific substances. Such a development in the aquaculture sector should be followed in the development of novel applications and new products to guarantee a viable seaweed industry. Small and medium sized enterprises (SMEs) may not have the capacity to carry out extended research on new products to compete with larger enterprises. Therefore close collaboration with third level institutes is required through R&D projects.

6.2.2 Third level institutions

As an important step to facilitate interaction between the industry and academia, the Technology Transfer Initiative (TTI), which is an innovative support structure, was formed in 2002 involving the three universities of the Atlantic University Alliance: the National University of Ireland, Galway, the University of Limerick and the University College Cork. Combining resources and complementing capabilities in research, innovation and development, a broad pool of expertise has been created by these universities to assist indigenous industries in the West, Midwest and South in product development and technology transfer. The TTI concentrates on four key growth sectors, of which two are of immediate relevance for the Seaweed Industry. These are the biomedical and healthcare sector, and the food sector.

Other relevant centres of expertise are Institutes of Technology, which are performing training and research in specific sectors, such as food science (e.g. IT Letterkenny), and are essential for the development of new products. Technology transfer is also facilitated by Marine Institute, BIM and Taighde Mara Teo.

6.3 Marketing expertise

Marketing is of crucial importance for the development of the seaweed aquaculture industry. At present marketing is mainly directed by individual companies and BIM has expertise in marketing, which is applicable to the seaweed sector. The impetus, for co–ordinated marketing efforts and promoting campaigns must come from the Seaweed Industry.

At present the availability of statistical information on production and markets in Ireland and Europe is very limited. Mechanisms should be put in place to monitor seaweed production and markets and to make information accessible to stakeholders. A marketing infrastructure similar to that for Irish Seafood should be developed, taken into account the diversity of market sectors for seaweed products.

7.0 Assessment/identification of priority RTDI needs/projects necessary to support a national seaweed aquaculture development programme

Following the consultation process and evaluation of the current status of the Seaweed Industry, in comparison with developments in other European countries priority R&D projects have been identified for six main areas:

- Cultivation techniques for selected seaweed species.
- Tank cultivation techniques.
- Bioactive substances and their utilisation for nutraceuticals, cosmetics, and biomedicine.
- Seaweed in fish feed.
- New applications for seaweed derived substances in biotechnology.
- Processing of seaweed raw material.

7.1 Seaweed cultivation techniques

7.1.1 Propagation methods and seed stock provision

The establishment of a commercial seaweed hatchery is strongly recommended (see Chapter 9) to supply seaweed aquaculture operations with high–quality seed stock (seeded ropes with pre–cultivated plants). It is essential to develop efficient and reliable methods to produce sufficient seed stock for the main species of interest (*Palmaria palmata, Chondrus crispus, Alaria esculenta, Laminaria saccharina*) at times appropriate for out–growth in the sea. Research should focus on large–scale gametophyte cultivation methods of kelps, artificial induction of sexual reproduction in red seaweed species, and improvement of pre–cultivation methods of seeded ropes. Principal techniques for several species are already well developed and can be adopted and adjusted for the target species to be used in Ireland (e.g. the free–living technique for *Undaria*, which can be adopted for other kelp species; see Chapter 4, section 4.1.1).

7.1.2 Optimisation of cultivation techniques to extend growth periods

Cultivation techniques for economically important species, which are already under cultivation in Ireland (for food and cosmetics), should be optimised to allow an extension of the growing period. The cultivation of most seaweeds is restricted to a growth period from autumn to spring. During the summer months, high light intensities, elevated water temperatures and rapid growth of fouling organisms on culture ropes limit the cultivation of target species.

7.1.3 Development of cultivation methods for new species

Several seaweed species, which are known to synthesise bioactive substances of interest for specific applications, are difficult to cultivate. Appropriate methods need to be developed for these species, (e.g. *Delesseria sanguinea, Dumontia contorta, Dilsea carnosa, Codium fragile*), to make large–scale sea–based or tank cultivation feasible. Research should include life–cycle analysis, sexual and vegetative propagation methods, artificial spore induction and release, evaluation of optimal growth conditions, and assessment of the feasibility of cultivation at pilot and commercial scale.

7.1.4 Integrated polyculture of salmon and seaweed

The feasibility of integrated aquaculture should be investigated. Cultivation trials should be carried out in collaboration with salmon farmers to grow seaweed in the direct vicinity of salmon cages to investigate the potential benefits of co–cultivation (enhancement of seaweed growth, beneficial effects on salmon) and evaluate potential negative effects (potential fouling on cage structures, impact on water current). Research should include an assessment of the economical feasibility, the possibility for sharing work facilities and infrastructure.

7.1.5 Co–cultivation of seaweed and mussels

The co–cultivation of seaweed and mussels should be investigated to enable mussel farmers to have an additional crop in the event of mussel farming closure due to harmful algal blooms. An objective should be to develop structures for seaweed aquaculture as an extension of already existing structures to minimise investment. Focus should be directed towards mutual effects of combined seaweed–mussel farming (e.g. effects on growth rates, impact of fouling by mussels settling on seaweed culture ropes and *vice versa*).

7.2 Tank cultivation techniques

In comparison to sea–based cultivation, tank cultivation offers the opportunity of closely controlling and consequently optimising cultivation conditions. It is therefore especially advantageous for algal species, which are propagated vegetatively (e.g. by thallus fragmentation, tissue culture), and for obtaining highly homogenous and high–quality raw material. For the cost–efficient cultivation of seaweeds in land–based systems, it is essential to develop tank systems that meet the needs for optimal production of seaweeds at lowest costs with respect to energy input and space required. Different aspects need to be covered in R&D projects:

- Biological aspects: optimal growth conditions with respect to nutrient supply, light, stocking densities.
- Technical aspects: tank shape, aeration to allow optimal movement of unattached algae, re–circulation systems vs. flow–through systems, optimal temperature control.

Research should be conducted to develop tank systems for large–scale algal production in view of different physiological requirements of different species. Additionally, research should focus on integrated polyculture. The underlying principle is that the "waste" produced by one species is utilised by another species (see Chapter 4, section 4.2.2). Beside the potential positive effects for each species, it may be economically advantageous for sharing facilities, running costs, and labour.

7.3 Bioactive substances and their use in nutraceuticals, cosmetics, and biomedicine

Efforts should be directed towards the complex area of bioactive substances and their applications in nutraceuticals, cosmetics and biomedicine. Research should focus predominately on seaweeds which are already utilised in Ireland, and those with known valuable properties. Comprehensive screening programmes should be established and potential bioactive substances analysed in detail.

Several chemical compounds, which are general constituents of specific algal groups, have been shown to exert multiple effects on, for example, the immune system of humans and animals and the defence system of plants. These substances are mainly poly– and oligosaccharides, which are common in brown and red algae (e.g. laminarans and fucoidans from brown algae, carrageenan from several red algae). Additionally, there is a wide range of other substances of potential interest, e.g. polyphenols with antioxidant properties, and mycosporine–like amino–acids as UV–protection agents.

In order to advance the area of bioactive algal compounds both fundamental and applied research is needed to increase the understanding of underlying mechanisms of biological functions exerted by specific bioactive substances on human health and consequently to utilise these substances and to develop novel applications.

7.4 Seaweeds in fish feed

Fish aquaculture is a growth industry worldwide. Consequently the demand for fish feed is increasing. Fishmeal as a protein source is an essential constituent of fish feed as well as in feed for livestock. The production of fishmeal in recent years has remained stable but larger portions were diverted from agricultural uses to the use in fish feed. It is predicted that the intensification of freshwater fish aquaculture in Asia alone may absorb at least 50% of the world fishmeal production at the end of the decade, not considering expansion of aquaculture in other parts of the world, which will create problems of supply (Commission of the European Communities 2002). To meet the growing demand for fish feed, producers are searching for alternative protein sources from plants.

Seaweeds may offer such an alternative protein source for partial fishmeal substitution. (see Chapter 4, section 4.2.2 & 4.4.1). Compared to some land plants the average protein content is not very high in seaweeds but can be increased by growing seaweeds in nutrient–rich environments, in, for example the effluent of land–based fish farms. Research should be conducted to search for suitable algal species and for methods to enrich their protein content. These algae should be tested in fish feed formulations.

Algal compounds may also have a beneficial effect on fish health, similar to the positive effects on the human immune system and the plant defence system. Therefore the development of "nutraceuticals" or "parapharmaceuticals" for fish should be investigated.

7.5 New applications for seaweed derived substances in biotechnology

An emphasis on the development of innovative R&D projects in the biotechnology sector is required. This sector comprises a wide range of areas and offers the greatest challenges for developing innovative technologies and applications. Relevant research areas include:

- Algal substances as anti–fouling substances and surfactants.
- Specific highly purified and/or modified polysaccharides for applications in the food industry, the cosmetic and medical sector.
- Algal enzymes as biocatalysts.
- Algal polysaccharides, fibres or material left after extraction processes, could be used for the development of novel biomaterials (e.g. biodegradable packing materials).
- Application of algal material as sustainable energy source (e.g. biodiesel, methanol production).
- Seaweeds and seaweed derived materials in bioremediation.

Certain biotechnological applications require specific types of polysaccharides, e.g. specific forms of carrageenans, which are predominantly produced by a particular life phase of certain red algae. Therefore screening programmes should be conducted to investigate the chemical composition and contents of polysaccharides in the different life phases of seaweeds. Cultivation methods for potential seaweed candidates should be evaluated accordingly.

7.6 Processing of seaweed raw material

Storage and processing of algal raw material is of particular importance and innovative, cost–efficient methods are needed. These include drying and freezing techniques with respect to the preservation of high quality material including bioactivity of algal compounds of interest. Processing techniques should be investigated for, for instance, the preparation of nori–sheets and extraction methods for particular algal constituents.

8.0 Assessment of the availability of suitable sites for seaweed aquaculture development in view of competition from salmon / shellfish and other coastal resource uses, including SAC (Special Areas of Conservation) designations

For the selection of the most appropriate seaweed aquaculture sites two key areas of consideration must be balanced:

1) Suitability of a site with respect to requirements of the target seaweed species.
2) Feasibility of aquaculture development with respect to availability of space and competition with other interest groups and coastal resource users (e.g. shellfish and finfish farmers, fishermen, shipping, yachting, tourism, protected areas).

8.1 Biotic and abiotic factors for site selection

Natural, high abundance of a particular species is the best indicator for the suitability of a potential cultivation site for that species. In most cases, these sites, for different reasons, would not be the first choice for an aquaculture operation. Often farming is conducted at sites where the target species is not highly abundant due to a lack of suitable substrata (e.g. sandy or muddy bottom substrata). The primary environmental factors, which have to be considered for successful growth of seaweeds, are the following:

Light

Light is essential for photosynthesis and consequently growth. The quantitative light demand for photosynthesis and growth depends on the algal species, its morphology and adaptation mechanisms. Species inhabiting the upper euphotic zone (intertidal) are well adapted to exposure to high irradiances and are referred to as "sun plants". Species of the deeper euphotic zone (subtidal) lack adequate adaptation mechanisms but have developed strategies to cope with low light intensities and overall annual quantities (Lüning 1990). The type of seaweed (sun plant or shade plant), the season (light intensity), the turbidity of the water body all must be considered during the design of a cultivation system.

Nutrients

Nutrients determine productivity and biomass yield but also the abundance of epiphytes in aquaculture systems. Nutrients essential for growth are divided into three main categories: macronutrients (e.g. nitrogen, phosphorous, carbon; N, P, C, respectively), micronutrients or trace elements (e.g. iron, zinc, selenium, copper, manganese, molybdenum) and vitamins (vitamin B12, thiamine and biotin), which are required in different concentrations (Lobban & Harrison 1994). Micronutrients and vitamins are rarely a limiting factor for seaweed production in coastal waters. The most important nutrients for high productivity are nitrogen (ammonium, NH4, and nitrate, NO3) and phosphorus (orthophosphate, PO4). In coastal waters the concentrations of N and P can become limiting for seaweed growth. They vary significantly during the year with highest concentrations in autumn/winter and lowest in spring/summer. In many coastal areas (e.g. semi–enclosed bays, estuaries, inlets with restricted water exchange) the concentrations of inorganic nutrients are increased by anthropogenically derived inputs of nitrogen and phosphorus from urban sewage treatment works, intensive agriculture and aquaculture plants and run–off from agricultural land.

Seaweeds differ in their response to elevated N and P levels. The uptake efficiency depends on the form of N (NH4 vs NO3) available in ambient waters and the N:P ratio. Some seaweeds (especially kelps) are able to take up NO3 and NH4 simultaneously and at the same rate. By contrast, other seaweeds (e.g. *Ulva* spp.) take up NH4 preferentially over NO3.

The application of seaweeds as biofilters for removing inorganic nutrients from effluents of finfish and shellfish aquaculture systems, or from urban sewage, requires a good knowledge of the ecophysiological demands of a species to identify one with a potential for maximum nutrient removal efficiency that are additionally, commercially valuable species for aquaculture.

Salinity

Fluctuations in salinity can be a critical factor for aquaculture sites located in bays with restricted water exchange and high fresh water inflow, in estuaries and in shallow areas. Most seaweed species grow optimally at salinities around 30% but tolerate some fluctuations in salinity. Some intertidal algae however, such as *Ulva* and *Enteromorpha*, show optimal performance at lowered salinities (e.g. sites with small fresh water inflow).

Temperature

Each seaweed species has an optimal temperature range for growth and reproduction. For most native species the average optimal range for growth is between 10ºC and 15ºC with a survival temperature range between 0ºC and 25ºC (Lüning 1990). This is well within the range of average sea surface temperature of the west and south coast of Ireland, which is 6–8ºC in February /March and 14–17ºC in August. In certain shallow areas, however, summer temperature may well rise over 20ºC. Elevated temperatures, especially in connection with high irradiance, can be critical for some seaweeds (e.g. kelps and *Palmaria palmata*) and may lead to deterioration and bleaching of the thalli. To avoid this aquaculture sites should be located in areas with a minimum depth of 4–6 metres and good water exchange.

Exposure and tidal currents

The demands of the commercially important seaweeds with respect to exposure and tidal current vary considerably. Whereas Alaria esculenta inhabits very exposed sites, *Palmaria palmata* grows on less exposed sites with a good tidal current. Other algae such as *Laminaria saccharina* and *Porphyra* spp. are found in more sheltered areas. The demands have to be balanced with the feasibility for an aquaculture operation to work efficiently at any season and weather condition and to avoid damage to the farm. Therefore very exposed sites have to be excluded. Semi–sheltered areas with a strong tidal current (up to 3 knots) can significantly increase growth rates of *Alaria* and *Palmaria* in comparison to sites with prevailing currents of 0.5–1 knots as shown in cultivation trials (J. Morrisey, 2003, pers. comm.). An increased water velocity at the algal surface enhances nutrient uptake and algal productivity (Hurd 2000). (Water motion is an essential factor for algal growth has also to be considered in tank cultivation).

Pollution

Seaweeds have the ability to remove nutrients from surrounding waters and also internally accumulate heavy metals (e.g. mercury, arsenic, cadmium, copper, lead, zinc), radionuclides (e.g. Caesium–137 and Technetium–99) and other contaminants (Schramm 1991). Therefore potential pollution of certain areas has to be considered especially with respect to the production of sea vegetables.

In Ireland, assessments of water quality data of estuarine and coastal waters have indicated generally satisfactory conditions. Overall inputs of effluent containing chemical contaminants other than inorganic nutrients are moderate with few cases with serious pollution. (Marine Institute 1999; Smith & O'Leary 2000). In general, the Irish Sea and Celtic Sea are loaded with more contaminants than the Atlantic Seaboard. On the west coast the main centres of antropogenically derived inputs are Shannon Estuary, Galway Bay, Sligo Bay and Donegal Bay.

Table 1: Some Commercially important seaweed and their requirements for optimal growth

Commercially important species	Light	Salinity	Temperature optimum (ºC)	Exposure /tidal current
Alaria esculenta	medium	normal	10–12	high
Laminaria saccharina	high	normal	10–15	medium
Palmaria palmata	low–medium	normal	10–15	high
Porphyra spp.	high	low–normal	Depending on species 5–20	low–medium
Chondrus crispus	high	low–normal	12–15	low–medium
Ulva spp.	high	low	Depending on species 10–20	low–medium

The effect of the environmental factors on the productivity and biomass yield of cultivated seaweeds mean that potential aquaculture sites should be examined with these criteria. Preferably, trials should be conducted first to verify if the site is suitable for production of a target species.

8.2 Availability of suitable aquaculture sites

Several other criteria have to be met for selection of an aquaculture site with respect to logistical operation of a farm. These criteria include exposure of a site, pier access, access to the hinterland and other activities in the potential area. In Table A4.1 (Appendix 4) some potential seaweed aquaculture site are listed and generally described according to certain selection criteria. Some examples are given interpreting the selection parameters and implications, which can be drawn from them. In the table only major bays, Loughs etc. are considered.

The highest potential for seaweed aquaculture development is clearly on the west coast, followed by the north, southwest and south coasts. In contrast to the coast of the Irish Sea these coasts provide:

- A large number of sheltered to semi–sheltered sea Loughs, bays, inlets and estuaries.
- Good water exchange and different strength of tidal currents.
- Generally unpolluted water.
- Different degrees of nutrient enrichment.
- On average, lower water turbidity than at the east coast due to different bottom substrata.

With respect to the availability of space and competition with other coastal resource users, two major issues are highlighted: the opportunity for a close link of seaweed, shellfish and finfish aquaculture, and the implications of the presence of Special Areas of Conservation (SACs) and Special Protected Areas (SPAs).

8.2.1 Co–ordination of aquaculture operations

Shellfish and finfish aquaculture operations are well established in the north, west and southwest coast of Ireland. Under the NDP 2000–2006 programme it is stated that all sectors of aquaculture are to be further developed and will be supported by grant aid. Seaweed aquaculture at present is at the very beginning of development and is occupying a negligible area for farming in comparison to areas used by mussel and salmon farmers (at present licenses for seaweed aquaculture comprise 2–4 ha per farm, salmon farms have 30–50 ha per farm under license). If seaweed aquaculture gains a foothold, as expected, it will consequently need space for extension and a situation of conflict of interests may arise. Therefore at this early stage of seaweed aquaculture development a dialogue between stakeholders of the different aquaculture sectors should take place to exchange information and redirect competition into coordinated management. A necessary prerequisite, however, is dialogue by seaweed farmers to define their objectives and concepts. The latter could be facilitated by the ISIO and with the assistance of State Agencies and the Irish Seaweed Centre.

8.2.2 Co–ordinated Local Aquaculture Management Systems

The Co–ordinated Local Aquaculture Management System (CLAMS) process is a nationwide initiative to manage the development of aquaculture operations in bays and inshore waters at a local level. CLAMS have evolved from the Single Bay Management, which was initially introduced as an initiative for co–ordinated salmon farm management to efficiently enter lice–control on farmed fish. CLAMS incorporates and builds upon the Single Bay Management concept embraces the interest of other groups using bays and inshore waters and integrates Coastal Zone Management Policy and County Development Plans. As part of its concept, CLAMS provides a comprehensive compilation of relevant data of the bay (hydrophysical characteristics, aquaculture operation data, infrastructure, socio–demographic data etc.). This allows a holistic approach to coastal management.

Co–ordinated Local Aquaculture Management Systems have been launched in nine major bays in recent years. Eight additional projects are planned and will follow soon. These projects are very useful and proved to be successful in bringing together the different interest groups, exchanging information and thereby increasing mutual acceptance, and coordinating activities. The final success, however, depends on the engagement of all stakeholders.

8.2.3 Integrated polyculture

Integrated polyculture is an approach for the advancement of sustainable aquaculture, which brings the coordination of aquaculture activities to a stage of close collaboration between finfish, mussel and seaweed farmers. The underlying rationale brief is:

- Fish consume oxygen and release substantial amounts of nutrients (mainly NH4) and organic matter (faeces). Significant concentrations of N and P are also released by non–consumed feed.
- Molluscs as filter–feeders take up organic matter, but also consume oxygen and excrete NH4.
- Seaweeds remove nutrients released by fish and molluscs from the system and channel them into enhanced growth. They produce oxygen and therefore contribute to balance the dissolved oxygen levels of the system. The biomass produced in turn can be used to feed fish and/or herbivorous molluscs, or other value–added applications.

In a well balanced system, the nutrient release into the environment is minimal and the integration of fish, molluscs and seaweed can increase the economic output.

The first successfully developed polyculture systems were land based cultivation systems, using fish, abalone and seaweed (e.g. Jiminéz del Río *et al.* 1996; Neori & Shpigel 1999; Neori *et al.* 2000; Shpigel & Neori 1996; see also SEAPURA, Chapter 4, section 4.2.2). There is an increasing effort to apply the same principles in open sea aquaculture operations against the background of the rapid expansion of salmonid aquaculture worldwide, and Atlantic salmon in Norway, Chile and United Kingdom in particular (FAO, 2002). There is growing concern about the continuing deterioration of coastal ecosystems and intensive fish cage cultivation may contribute to the degradation of the environment. It is estimated that 9.5 kg P and 78 kg N per tonne of fish per year is released to the water column. For nitrogen, which is the nutrient of major concern in marine environments, there is a consensus that at least 80% of total losses (dissolved and organically bound) from fish farms are plant available and are potentially eutrophicating substances (Persson 1991). In the worst case, they can generate severe disturbances, including eutrophication, toxic algal blooms and green tides (Chopin & Yarish 1999). However, only a few cases of increased primary phytoplankton production in the vicinity of marine cage farms have been reported. This is not surprising considering the water exchange rate in relation to the doubling time of phytoplankton. Due to time lags and the buffering capacity of ecosystems, the eutrophication process in an area may be slow, acting over time scales of several years (Wulff & Stigebrandt 1989).

In order to utilise the nutrients released from fish farms, several studies have been conducted where seaweeds were grown in the direct vicinity of salmon cages. In Chile, for example, rope cultures of *Gracilaria chilensis* were co–cultivated with a coastal salmon cage farm. The growth rate of *Gracilaria* cultivated at 10 m from the farm was up to 40% higher than those of plants cultivated 150 m and 1 km away from the farm (Troell *et al.* 1997). In other pilot trials different *Porphyra* species (Chopin et al. 1999b), and *Laminaria saccharina* and *Nereocystis luetkeana* (Pacific kelp species) have been tested showing that the co–cultivation of seaweed and salmonids can be feasible.

Is there a need for integrated polyculture in Ireland?

In Ireland, salmon production was about 23,000 tonnes in 2002, which is significantly lower than the tonnage produced in Scotland and Norway (Salmon Conference, Furbo, 2002). The majority of Irish farming sites are located in moderate to exposed areas which a good water exchange by strong tidal flushing resulting in high dilution effects of released nutrients. Extensive environmental monitoring of the water bodies around the farming sites and the seabed below the cages confirmed that the impact of organic nutrient enrichment due to farming activity is minor (O'Connor 2002). Additionally, the application of novel fish feeding techniques is contributing substantially to the reduction of nutrient release from unused fish feed into the environment (R. Flynn, 2003, pers. comm.). To ensure the maintenance of the healthy status of seabeds around farming sites, the Department of Communications, Marine and Natural Resources (DCMNR) has recently defined acceptable levels of impact and has introduced annual benthic surveys monitoring protocols for all finfish farms. If impact levels are breached the DCMNR has the option to take action against the operation (R. Flynn, 2003, pers. comm.).

If the concept of integrated polyculture is defined in a very narrow sense, i.e. to counteract potential eutrophication caused by offshore fish farming, then there would be no immediate need for application in Ireland as the data of environmental monitoring are showing. However, integrated polyculture is not just a tool for reducing potential or existing pollution:

- It has been shown that algal growth rates are enhanced, when seaweeds are cultivated in the direct vicinity of salmon cages, due to the inorganic nutrients released by the fish. The availability of nutrients at times when concentrations in ambient seawater are naturally low (spring/summer) may be advantageous to prevent a drop in growth rate.
- Seaweeds produce oxygen through photosynthesis and therefore increase levels of dissolved oxygen in the water, which may have beneficial effects for the fish.

- From a practical point of view, the co–cultivation of seaweed and finfish could lead to a share of infrastructure, labour and licensed aquaculture sites.

In seaweed cultivation a similar approach could be applied connecting seaweed aquaculture and mussel farming. Interest has already been expressed by several mussel farmers and existing structures could be used for seaweed aquaculture. The productivity of a licensed area could be increased and income improved through species diversification.

8.2.4 Special Areas of Conservation

In recent years a substantial number of designated marine Special Areas of Conservation (SACs) have been implemented and candidate SACs drawn up (see Appendix 3). Within these areas:

- Existing traditional activities (e.g. seaweed cutting) may be continued but a substantial increase of harvesting seaweed and any new activities must be approved by the Minister.
- Any mechanisation of seaweed harvesting within the designated areas would be questioned by the National Parks & Wildlife Service (NPWS), Department of the Environment, Heritage & Local Government.
- Seaweed aquaculture is permitted subject to the usual licensing considerations but the NPWS has to be consulted by the Department of Communication, Marine and Natural Resources for approval.

According to the statement there is no obligatory hindrance as such for the establishment of seaweed aquaculture in a Special Area of Conservation. Although the applicant for an aquaculture licence may have to prove that the construction of the farm will not have adverse impacts on the habitat. Therefore an environmental survey may need to be conducted before license issue.

8.2.5 Special Protection Area (SPA)

Special Protection Areas have been designated and are implemented in Ireland in accordance with EU directives for the protection of particular wild birds. The existence of a SPA does not affect the establishment of seaweed aquaculture (see Appendix 3).

9.0 An outline strategy for the development of a national seaweed aquaculture development programme over ten years

From this desk study five key areas of strategic importance have been identified. These are:

1) Supporting structures
2) Facilities and technical capability
3) New Applications
4) Quality
5) Marketing & awareness

These areas form the framework of the proposed outline strategy for a national seaweed aquaculture development programme. The recommendations given for these key areas are a conceptual approach to realise the objective to develop a viable seaweed aquaculture industry.

9.1 Supporting structures

- The relevant State Agencies should give further technical assistance and financial support for pilot seaweed aquaculture projects, bring these to a commercial stage and enable the development of new seaweed aquaculture operations.
- The Irish Seaweed Centre should get further confirmed support by the Marine Institute to initiate and provide R&D, to strengthen the existing alliances between research centres, development agencies and the industry, and to develop new ones.
- The Seaweed Development Officer of BIM should continue to play a major role in facilitating grant aid and assisting in the development of seaweed farms.
- Collaborations between research institutes and SMEs should be intensified and adequately funded by the relevant State Agencies.
- The ISIO as the representative organisation of the seaweed industry should be strengthened. Members of the ISIO should engage more actively and should develop a strong network to facilitate information exchange. Producer associations for certain seaweeds (e.g. *Porphyra*) may be organised to strengthen competitiveness at the international market. Co–ordinated promotional campaigns for seaweed products should be supported by the ISIO.

- Aquaculture licences should be approved within a regulated period of time if all requirements for licensing process are fulfilled to allow efficient planning by the applicant and avoid costly delays. Additional resources may be committed by the Department for Communication, Marine and Natural Resources to speed up the application process for trial and full aquaculture licences.

9.2 Facilities & technical capability

- A seaweed hatchery should be established for economically important species, such as *Palmaria palmata, Alaria esculenta* and *Laminaria saccharina* (and new species, if required) to facilitate the supply of high–quality seed stock for seaweed farms. The hatchery should be established in collaboration with seaweed farmers and BIM, Taighde Mara Teo and the ISC. To alleviate capital investment, the hatchery could be integrated into existing facilities such as the MRI Carna Laboratories, shellfish hatcheries or land–based seaweed aquaculture operations.
- Comprehensive training courses in seaweed aquaculture should be held and manuals for the cultivation of seaweed species of interest should be made available. Frequent updating of existing manuals and the publication of manuals for newly established species should follow accordingly.
- Cultivation techniques for new promising species for aquaculture should be developed on the base of research projects with the support of State Agencies and the Seaweed Industry.
- Tank cultivation techniques should be developed for species, which are otherwise difficult to cultivate at sea, preferentially in connection with finfish and shellfish tank cultivation as integrated polyculture operations. These R&D based projects should concentrate on biological aspects (i.e. optimal growth conditions of seaweeds, propagation) and innovative technology in tank design.
- Finfish, shellfish and seaweed growers should be encouraged by the ISIO, BIM, Taighde Mara Teo and the ISC to co–operate in investigating the feasibility of integrated offshore polyculture in Ireland. Funding should be made available for these R&D projects.
- Analytical laboratories should be selected by producers of sea vegetables and State Agencies to conduct frequent analysis of vitamin, mineral, protein contents and potential contaminants (e.g. heavy metals, organic compounds) in seaweeds.
- The establishment of local drying and freezing facilities for commonly used seaweeds should be considered to reduce costs for individual enterprises.

9.3 New Applications

- Research programmes should be initiated to search for new bioactive substances and their potential applications in cosmetics, biomedicine and biotechnology. These R&D projects should be developed in close collaboration with the seaweed industry, and development agencies.
- Extensive fundamental research is needed to investigate functional principles of bioactive substances, e.g. to verify claimed effects of algal substances in cosmetics and health care.
- Irish universities should co–ordinate their efforts and resources for conducting research on algal bioactive substances. Alliances with international research institutions should be strengthened.
- R&D projects should be developed for the utilisation of seaweed aquaculture for bioremediation applications and their feasibility should be evaluated.

9.4 Quality

- The ISIO should initiate and co–ordinate the frequent analysis of mineral, vitamin and heavy metal content in seaweeds used for human consumption. On this basis, quality standards and appropriate labelling of products can be developed.
- The status for organic production should be clarified, and quality standards and standardised labelling of products should be established within the existing support structure in conjunction with BIM.

9.5 Marketing & Awareness

- Seaweed aquaculture should be recognised as a third aquaculture sector along with finfish and shellfish aquaculture and be promoted accordingly.
- Statistical information on production and markets in Ireland and on an international level should be made available to the domestic industry on a frequent basis by BIM. Similar to the finfish and shellfish sector, market reports should be published. The ISIO should assist in providing relevant information to BIM.
- The national and international perception of Ireland as a “green, clean and natural” should be capitalised upon by the Irish seaweed industry and Irish quality products should be promoted accordingly.
- Public awareness should be raised regarding the value of seaweed products in nutrition, health and body care, agriculture, horticulture, biomedicine, and biotechnology. Environmental benefits of sustainable aquaculture and the potential of seaweeds in bioremediation should be highlighted.

The realisation of the development programme depends strongly on the implementation of the recommendations given above. The development of the Seaweed Aquaculture Industry is outlined below.

9.6 Outline strategy for a national seaweed aquaculture development programme over ten years

Present day	Year 1–3	Year 4–6	Year 7–10
	Objectives		
Current State	Aquaculture:	Aquaculture:	Aquaculture:
Pre–commercial aquaculture: • 3 operations (*Palmaria, Alaria, Porphyra, Asparagopsis*) **R&D projects:** • *Chondrus* cultivation • Integrated tank cultivation, seaweed as fish feed **Applications:** • Sea vegetables, food ingredients, cosmetics **Markets:** • Established for products above • Marketing by SMEs	• 3 commercial operations • 2 pilot scale operation **R&D projects:** • Cultivation methods (including propagation techniques, integrated polyculture, tank cultivation) • Seaweed hatchery • Product development: food ingredients, nutraceuticals, cosmetics, fish feed • Research in bioactive substances (cosmetics, agrochemicals, biomedicine) and biotechnology • Seaweeds in integrated polyculture and bioremediation **Quality issues** **Marketing:** Market information and promotion by BIM & ISIO Delivery mechanisms • Funding under NDP and EU (MI, BIM, TMT, HEA, EI, EU) • Private investment (SMEs) • Technology transfer by State Agencies & third level institutions • Product development by SMEs in conjunction with research institutes • Coordinated support by ISIO and finfish & shellfish farmers for R&D	• 5 commercial operations • 3 pilot scale operation (including tank cultivation) • Pre–commercial seaweed hatchery **R&D projects:** • Cultivation methods: optimisation, strain improvement & new species • Integrated polyculture (sea–based and tank systems) • Product development: food & health, fish feed, biotechnology • Research in bioactive substances (cosmetics, agrochemicals, biomedicine) and biotechnology **New products:** Food, nutraceuticals, cosmetics **Quality:** Frequent quality analysis & labelling of products **Marketing:** Information network, marketing and promotion by BIM & ISIO • Funding under national grant schemes and EU programmes • Private investment (SMEs) • Technology transfer by State Agencies & third level institutions • Product development by SMEs in conjunction with research institutes	• 8 commercial operations (incl. 2 integrated tank cultivation systems) • 3 pilot scale operation (including new species) • Commercial seaweed hatchery **R&D projects:** • Cultivation methods: optimisation, strain improvement & new species • Integrated polyculture (sea–based and tank systems) • Product development: all sectors • Research in bioactive substances (agrochemicals, biomedicine) and biotechnology **New products:** Food, nutraceuticals, fish feed, fish health, biotechnology **Marketing:** Marketing and promotion by BIM & ISIO • Funding under national grant schemes and EU programmes • Private investment (SMEs) • Technology transfer by State Agencies & third level institutions • Product development by SMEs in conjunction with research institutes

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11.0 Appendix 1. Glossary and life cycles of selected species

11. 1 Glossary

Agar: Commercially important polysaccharide extracted from different genera of red algae, such as *Gelidium* and *Gracilaria*. It has gelling properties and is widely used in the food industry and as microbial culture matrix.

Alginate: Commercially important hydrocolloid extracted from brown algae (salt of alginic acid) extensively used for food, cosmetic, medical, and other industrial applications.

Carposporangium (carposporangia): Carpospore–producing cell cluster of red algae.

Carpospore: A spore released from a carposporangium of a red alga.

Carposporophyte: Microscopic life phase of red algae, which develops attached to the female gametophyte.

Carrageenan: Commercially important phycocolloid extracted from different genera of red algae, such as *Chondrus*, *Gigartina*, *Eucheuma* and *Kappaphycus*. Different forms of carrageenan (κ, |, λ, μ, ν) exist, which are species specific and life phase dependent in different ratios. Carrageenans are widely used by the food industry as gelling and viscosifying agents.

Conchocelis phase: Microscopic filamentous life phase of *Porphyra*. Grows inside calcareous shells.

Diploid: Each cell of an organism contains two sets of chromosomes (2n).

Euphotic zone: Upper layer of a water body, which is inhabited by autotrophic plants. This zone provides sufficient light to satisfy the photosynthetic requirements of plants.

Eutrophication: Process in which a water body becomes overloaded with inorganic nutrients, such as nitrate, ammonium and phosphate. This can cause planktonic blooms and massive growth of certain seaweeds (e.g. green tides), and consequently oxygen depletion of the water body.

Fucoidan: Sulphated polysaccharide present in cell walls of brown algae (e.g. *Laminaria, Fucus* and *Ascophyllum*). It shows biological activities as, for example, an anti–thrombotic, anti–coagulant or anti–viral agent.

Gamete: A cell capable of fusing with another cell to form a zygote. (sperm or egg).

Gametophyte: Haploid phase of the life cycle of a seaweed that produces gametes.

Haploid: Each cell of an organism contains one set of chromosomes (n).

Hydrocolloids: Generic term for commercially important polysaccharides extracted from seaweeds (phycocolloids) and higher plants.

Laminaran: Storage carbohydrate of certain brown algae. It shows immuno–stimulating effects in humans.

Oligosaccharide: Medium–sized carbohydrate composed of simple sugar molecules.

Phycoerythrin: A red, water–soluble pigment in red algae. It is used as a fluorescent tag by the medical diagnostic industry.

Phycocolloids: Economically important polysaccharides extracted from seaweeds with gelling properties (agar, carrageenan, alginates; see also **Hydrocolloids**). These are widely used by the food and pharmaceutical industry.

Polysaccharide: A large carbohydrate polymer built of simple sugar molecules, to which specific chemical groups may be attached.

Sporangium (sporangia): A cell that divides to form spores.

Spore: An asexual reproductive cell produced by sporangia.

Sporophyte: Diploid phase in the life cycle of a seaweed, producing spores for reproduction.

Tetrasporophyte: Life phase of red algae, which produces tetraspores for reproduction.

Thallus (thalli): The entire body of a seaweed.

11. 2 Life cycles of selected species

Life cycle of *Laminaria hyperborea*

This life cycle is typical for members of the family Laminariaceae, such as *Laminaria saccharina* and *L. digitata,* and members of the Alariaceae (*Alaria esculenta*), although in the latter the sporophyte develops special reproductive organs, the sporophylls.

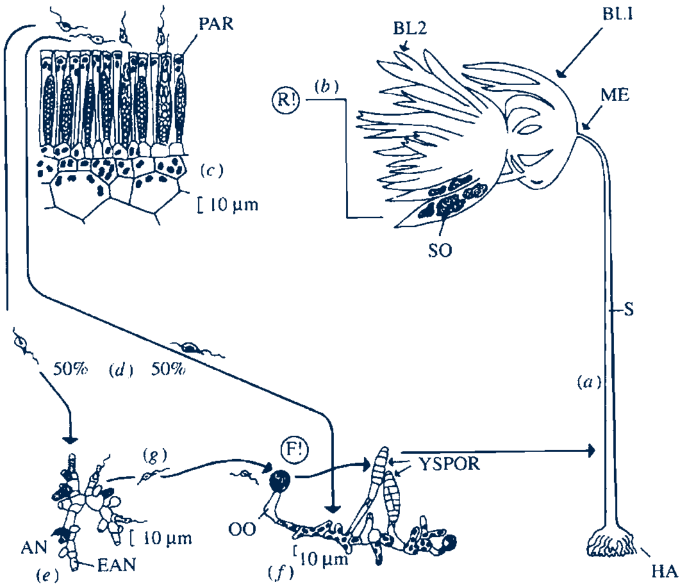

Figure 1. Life cycle of *Laminaria hyperborea* (from van den Hoek et al. 1995). a) Sporophyte (2n). b) The reduction division (meiosis) occurs during the first division within each unilocular sporangium. c) Cross section through a sorus containing unilocular sporangia. d) Haplogenotypic sex determination.
e) Microscopic male gametophyte (n). f) Microscopic female gametophyte (n). g) Spermatozoid.

AN = antheridium; BL1 = blade of the current year; BL2 = blade of the previous year; EAN = empty antheridium; F! = fertilisation; HA = haptera; ME = meristem; OO = oogonium; PAR = paraphysis; R! = reduction division (meiosis); S = stipe; SO = sorus; YSPOR = young sporophyte.

Life cycle of *Porphyra*

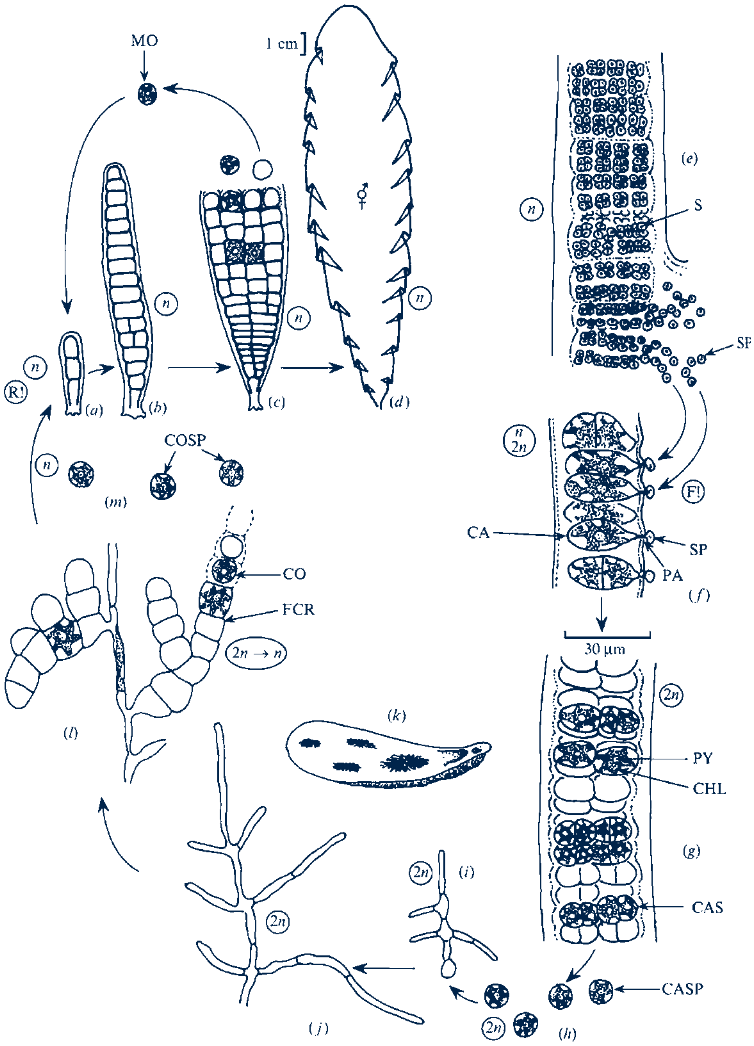

Figure 2. Life cycle of *Porphyra tenera* (from van den Hoek et al. 1995). (a–c) Stages in the development of a young blade, including the production of monospores (in c), which grow into new blade–like germlings; d) A full–grown monoecius blade. e) Cross section through a male portion of a blade: the spermatangium mother cells have divided into packets of spermatangia and, at the lower end, are releasing spermatia. f) Cross section through a female portion of a blade: the carpogonia are being fertilised by spermatia, while two fertilised carpogonia (top and bottom) have divided into two cells; this division being the first in a series leading to the formation of diploid carpospores. g) Formation of the carpospores from the fertilised carpogonia. h) Carpospores. (i–j) The *Conchocelis* phase. k) *Conchocelis* phase growing in an oyster shell. l) *Conchocelis* phase with fertile cell rows producing conchospores; one conchospore is produced by each conchosporangium. m) Conchospores.

CA = carpogonium; CAS = carposporangium; CASP = carpospore; CHL = chloroplast; CO = conchosporangium; COSP = conchospore; F! = fertilisation; FCR = fertile cell row; MO = monospore; PA = papilla on carpogonium; PY = pyrenoid; R! = reduction division (meiosis), during germination of the conchospore; S = spermatangium; SP = spermatium.

Life cycle of *Palmaria palmata*

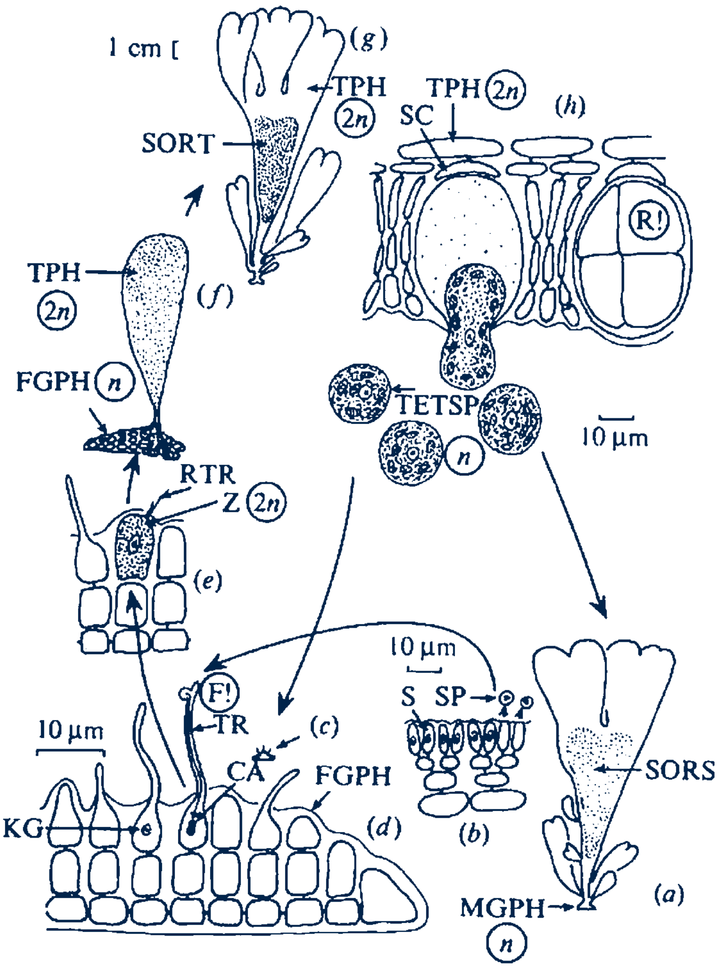

Figure 3. Life cycle of *Palmaria palmata* (from van den Hoek et al. 1995). a) The blade–like gametophyte (n). b) Cross section through the cortex of a male gametophyte, showing the spermatangia. c) The tiny (ca 0.1 mm diameter) crustose female gametophyte (n). d) Cross section of a female gametophyte and fertilisation of a carpogonium by a spermatium (n). e) Cross seaction of a female gametophyte, with zygote (2n, stippled). f) Young blade–like tetrasporophyte (2n). This grows directly from the zygote, which is retained in the gametophyte. g) Fully grown tetrasporophyte. h) Cross section through the cortex of a tetrasporophyte, showing tetrasporangia; one tatrasporangium is releasing its four tetraspores (n).

CA = carpogonium; F! = fertilisation; FGPH = female gametophyte; KG = karyogamy; MGPH = male gametophyte; R! = reduction division (meiosis); RTR = remnant of the trichogyne; S = spermatangium; SORS = sorus of spermatangia; SORT = sorus of tetrasporangia; SP = spermatium (n). TETSP = tetraspore; TPH = tetrasporophyte; TR = trichogyne; Z = zygote.

12.0 Appendix 2. Useful web sites

In the following web sites are listed, which provide useful information about seaweeds, seaweed aquaculture and seaweed related issues. In addition, web sites of relevant development agencies and research institutions in Ireland and other European countries are given.

- www.algaebase.org: information about seaweed taxonomy, nomenclature, utilisation and publications.
- www.aquaflow.org: European network for the dissemination of aquaculture R&D information.
- www.awi–bremerhaven.de/benthic/coastaleco/: Wadden Sea Station Sylt of the Alfred–Wegener Institute for Polar and Marine Reseach, Germany. The Wadden Sea Station is a centre for seaweed research, focused on tank cultivation of marine algae. Prof. K. Lüning (head of the phycological research group) is co–ordinator of the SEAPURA project.
- www.bim.ie: Bord Iascaigh Mhara, Irish Sea Fisheries Board, Ireland.
- www.cambiaip.org: intellectual property resource, worldwide data base for patents.
- www.ceva.fr: Centre d'Etude et de Valorisation des Algues (Seaweed Manufacturing Technology Centre). CEVA is a unique centre for algal research providing service in seaweed analysis, product development and feasibility studies for aquaculture, and market analysis.
- www.fao.org: Food and Agriculture Organisation.
- www.ifremer.fr: French Research Institute for Exploitation of the Sea. Fields of activities are coastal environment management, marine living resource management, ocean research, engineering and marine technology, and managing ocean research vessels and tools for underwater invention.
- www.irishseaweed.com: Irish Seaweed Centre, Ireland.
- www.marine.ie: Marine Institute, Ireland.
- www.marlin.ac.uk: Marine Life Information Network for Britain and Ireland, provide information about taxonomy, biology and habitats of seaweeds, and their importance.
- www.seapura.com: information about the EU–funded SEAPURA project.
- www.seaweed.ie: source for general information about seaweed species, their utilisation and cultivation.
- www.surialink: information about species, uses, production worldwide.
- www.taighdemara.ie: Taighde Mara Teo, Ireland.

13.0 Appendix 3. Legislation consulted

Special Area of Conservation (SAC)

The EU Habitats Directive 92/43/EEC of 1992 obliged all member states to protect certain types of habitats, which were identified as being of European importance. The relevant legislation implementing the habitats directive in Ireland is the European Communities (Natural Habitat) Regulations, 1997 (S.I. No. 94 of 1997). SACs are identified as outstanding examples of selected habitat types or areas important for the continued well–being or survival of selected species other than birds. The Government is obliged by EU law to protect these habitats.

Marine habitats recognised and assigned:

Marine Habitat no.	Habitat Description
1.1	Open marine waters, inlets and bays, tidal rivers and estuarine channels, marine caves, reefs, submerged sandbanks
1.2	Mudflats and sandflats, sandy coastal beaches, shingle beaches, boulder beaches, bedrock shores, marine caves
1.3	Saltmarshes
1.4	Sand dunes and machair
1.5	Brackish lakes, lagoons
1.6	Rocky sea cliffs, clay sea cliffs, sea stacks and islets (stacks, holms and skerries)

Special Protection Area (SPA)

The EU Directive 79/409/EEC of 1979 on the Conservation of Wild Birds obliges member states to take measures to protect bird species which require habitat conservation because of their rarity or vulnerability to habitat change. The designation is implemented in Ireland by the Conservation of Wild Birds Regulations, 1995 (S.I. No. 291 of 1985). Marine habitat types of designated SPAs are the following: estuaries, marine islands, lagoons, sea cliffs, coastal lakes, sand dunes and polder.

Aquaculture Licences

For seaweed aquaculture (sea and land based) aquaculture licences and trial licences are required and must be applied for by the Coastal Zone Management Division of the Department of Communications, Marine and Natural Resources. The relevant legislation comprises:

- Foreshore Act, 1933
- Fisheries (Amendment) Act, 1997
- Aquaculture (Licence Application) Regulations, 1998 (S.I. No. 236 of 1998)
- Aquaculture (Licence Application and Licence Fees) Regulations, 1998 (S.I. No. 270 of 1998)

14.0 Appendix 4. List of potential aquaculture sites

Table A4.1

Sites	coast type	depth (metre)	current (knots)	bottom type	exposure	salinity	nutrient load	pier access	SAC
Co. Donegal									
Lough Foyle									no
outer L.F.	sea lough	5-10	2-3	G/S	2-3	4	1-2	2	
inner L.F.	sea lough	0-5	1-2	S/SI	2	2-3	3	2	
Lough Swilly									yes
outer L.S.	sea lough	5-20	2-3	G/S	4	4	2	2	
middle L.S.	sea lough	1-12	2-3	S/SI	2-3	3-4	2-3	3	
inner L.S.	sea lough	1-16	1-2	M	1-2	3	2-3	2	
Mulroy Bay	deep inlet	1-5/5-19	2-3	S/SI	2	4	1	2	yes
North Water	deep inlet	5-47	2	M	1	4	2-3	3	
Broad Water	deep inlet	3-20	2-3	M	1	3-4	2	3	
Sheep Haven	bay	0-5/5-20	1	M/S	3-4	4	1	1	yes
Cruit Island, East	sound	1-5	2	S/R	3	4	1-2	2	no
Sound of Aran	sound	5-20/1-5	2	M/S/R	2-3	4	1-2	3	yes
Rutland Island Sound	sound	4-14/1-6	2	M/S/R	1	4	2	3	yes
Donegal Bay									
Fintraugh Bay	bay	11-24	1	S/R	3	4	1	2	no
Mc Swynes Bay	bay	1-5/11-24	1	M/S	3	4	2	2	no
Inver Bay	bay	1-4/5-24	1	M	2-3	4	1-2	2	no
Donegal Harbour	bay	1-5/5-20	1	M/S	3	4	2-3	3	yes
Co. Sligo									
Sligo Bay									
Coney Island, North	bay/sound	5-10	1	M	3	4	2-3	2	no
Co. Sligo/Co. Mayo									
Killala Bay, West	estuary	1-6	1	M/S	3-4	4	2	2	yes
Co. Mayo									
Broad Haven Bay	bay								yes
inner part		1-10	1	M/S	1-2	3	1-2	3	
Blacksod Bay	bay	0-5/5-20	1	M/S	2-3	4	1-2	2	yes
Achill Island									
Bull's Mouth	bay/sound	0-3/3-10	3-4	M/S	2	3-4	2	2	no
Clew Bay	bay	1-5/5-27	1.5	M/S	3	3-4	2-3	3	yes
Co. Galway									
Killary Harbour									no
inner part	fjord	1-38	1	S/R	2	4	2		
outer part	bay	5-29	1	S/R	3-4	3-4	1		
Ballynakill	bay	1-11	1	M/S	3	4	2		no
Clifden Bay									no
inner part	fjord	1-12	1-2	M/S	1	3-4	2-3	2	
outer part	bay	4-15	2	S/R	2	4	2	2	
Mannin Bay	bay	0-4/5-10	2	S	2	4	2	1	no
Roundstone Bay	bay	0-4/5-13	1-2	S	1	4	1-2	1	no
Bertraghboy	bay	0-5/5-23	2	S	1	4	1-2	2	no
Kilkieran Bay	bay/sound	0-3/5-12	2	M/S	1	3-4	1-2	3	yes
Greatman's Bay	bay/sound	0-4/5-10	2	M/S	1	3-4	1-2	3	yes
Cashla Bay	bay	1-4/5-14	0.5	M/S	1	3-4	2	3	no
Inishmore									yes
Killeany Bay	bay	1-9	1	M/S	1	4	1-2	2	yes

SPA	shellfish class	salmon & seatrout	scallops	mussels	oysters	clams	CLAMS	other
yes							no	cross border fisheries board
	B	no	no	3*	yes	no		
	B	no	no	3*	yes	no		
yes							yes	
	A	yes	no	3*	yes	no		
	A	yes	no	yes	yes	no		
	A	no	no	yes	yes	no		
no	A/B	2	nursery	2	yes	yes	no	
		3	nursery	2	yes	no		
		2	nursery	2	yes	yes		water quality poor (MI 1999)
no		no	no	no	yes	no	no	
no	A	no	no	no	no	no	no	
no	A	no	no	2	yes	no	no	
no	A	no	no	no	yes	no	no	shipping way
							yes***	
no		no	no	no	no	no		
no	A	yes	no	yes	no	no		
no		yes	no	no	no	no		
no	A	no	no	yes	yes	yes		
no		no	no	no	yes	yes		
yes		no	no	no	yes	no	no	
yes							no	
		no	no	no	yes	no		
yes	B	no	no	yes	yes	yes	no	
no		no	no	yes	yes	no		
no	A,B	yes	yes	3	3	yes	yes	
no							yes	
	B	no	yes	3	no	no		
	B	yes						
no	B	yes	no	no	yes	no	yes***	
no							no	
	B	yes	no	no	yes	no		
	B	yes	no	no	no	no		
no	B	yes	no	no	yes	no	no	
no	B	3	no	yes	yes	no	no	
no	B	3	no	yes	yes	no	no	
no	A	3	no	yes	no	no	yes	
no	A	2	yes	yes	no	no	no	
no		no	no	no	no	no	no	ferries
no							no	
no		no	no	no	no	no		

Table A4.1: Continued

Sites	coast type	depth (metre)	current (knots)	bottom type	exposure	salinity	nutrient load	pier access	SAC
Co. Clare									
Galway Bay									yes
Doorus Strait	bay	1-4/6-11	1-2	M/S	2	2-3	2	2	yes
Co. Limerick									
Shannon River									
outer (K. Head-Kilc. P.)	bay	5-37	1.5-4	S	3-4	2	2	2	no
middle (Kilc. P. - Tarbert)	estuary	1-5/5-30	2-3	M/S	3	3	3	3	no
inner part (Tarbert -)	estuary	1-5/5-30	2-3	M	2	2-3	3	3	yes
Co. Limerick									
Tralee Bay	bay	0.5-4/5-12	0.5-1	M/S	2	4	2	2	no
Brandon Bay	bay	1-4/5-20	0.5	S	2	4	1	2	no
Smerwick Harbour	bay	1-30	0.5-1	M/S	2	4	1	3	no
Dingle Bay									no
Ventry Harbour	bay	1-20	0.5	M/S	1-2	4	1	3	
Valentia Island									
Valentia Harbour	sound	1-3/5-13	1-2	S/R	1	3-4	2-3	2	yes
Portmagee Channel	sound	0-4/4-12	1-2	M/S	1	3-4	2-3	2	no
Co. Kerry/Co. Cork									
Kenmare River									yes
inner & middle part	estuary	1-4/4-30	2	S/M	1-2	3-4	2	2	
Co. Cork									
Bantry Bay									no
Bearhaven	sound	1-4/4-21	1	S/R	2	4	2-3	3	
Bantry Harbour	bay	0-4/4-12	1	M/S	1	3-4	3	3	
Dunmanus Bay									no
inner part	bay	1-33	1	M/G	2	3-4	2	3	
Long Island Bay									
Roaring Water Bay	bay	1-5	1	M/S	2	4	2	2	yes
Baltimore Harbour	sound	1-6	1	M/S	1	3-4	2-3	2	no
Castle Haven	inlet	1-15	1	S/R	2	3-4	3	2	no
Glandore Harbour	inlet	1-4/5-16	1	M/S	1	3-4	3	2	no
Cork Lower Harbour	estuary	1-4/5-26	1	M/S	1	3-4	3	3	no
Co. Waterford									
Dungarvan South Bank	estuary	1-3	1	M/S	2	4	2	2	no
Co. Louth									
Carlingford Lough	lough	1-4/4-36	2-3	M/S	2	4	2	2	no

Current: in knots (kn), data derived from Admiralty and Imray charts; Depth: metres below lowest astronomical tide, data derived from Admiralty and Imray charts; Bottom type: M = mud, S = sand, G = gravel, Sl = silt; Exposure: exposure of a site with respect to prevailing winds and swell, relative units from 1–5, 1 = lowest degree of exposure; Salinity: relative units: 4 = full salinity, 3 = low salinity, 2 = brackish, 1 = fresh water; Nutrient load: estimates, relative units, 3 = high, 2 = medium, 1 = low, natural oceanic concentrations; Pier access: estimates, 3 = good, 2 = reasonable, 1 = sparse; Aquaculture activities: * = ground fisheries / extensive fisheries, 3 = high activity, 2 = moderate activity; CLAMS: ** = being drawn up, *** = plans to be formed in 2003; Blue background indicates Special Area of Conservation (SAC).

SPA	shellfish class	salmon & seatrout	scallops	mussels	oysters	clams	CLAMS	other
yes							no	
yes		no					no	
no		no	no	yes	3	no	North Bank	
no	B/NC	no	no	no	yes	no	South Bank in 2003	
yes		no	no	no	yes	no		
yes		no	no	no	yes*	no	no	water quality poor (MI 1999)
no		no	no	no	no	no	no	
no		no	no	no	no	no	no	
no							no	
	A	no	no	no	no	no		
							no	
no	NC	no	2*	no	yes	no		high boat traffic
no	NC	no	no	no	yes	yes		high boat traffic
no								
	A	3	yes	3	yes	no	Ardgroom in prep.	
no							no	
	B	no	no	yes	yes	no		jurisdiction-BHA, shipping way
		2	no	3	no	no		oil terminals, potential spill, shipping
no							yes**	
	B	no	no	yes	yes	no		
no	A	no	yes	3	yes	no	yes	
no		no	no	yes	yes	no		boat traffic
no		no	no	no	no	no	no	
no		no	no	no	no	no	no	
yes	B	no	no	no	no	no	no	boat traffic, industry
yes	B	no	no	no	yes	no	yes	
yes	A, C	no	no	2,2*	2	no	yes**	

Current: in knots (kn), data derived from Admiralty and Imray charts; Depth: metres below lowest astronomical tide, data derived from Admiralty and Imray charts; Bottom type: M = mud, S = sand, G = gravel, SI = silt; Exposure: exposure of a site with respect to prevailing winds and swell, relative units from 1–5, 1 = lowest degree of exposure; Salinity: relative units: 4 = full salinity, 3 = low salinity, 2 = brackish, 1 = fresh water; Nutrient load: estimates, relative units, 3 = high, 2 = medium, 1 = low, natural oceanic concentrations; Pier access: estimates, 3 = good, 2 = reasonable, 1 = sparse; Aquaculture activities: * = ground fisheries / extensive fisheries, 3 = high activity, 2 = moderate activity; CLAMS: ** = being drawn up, *** = plans to be formed in 2003; Blue background indicates Special Area of Conservation (SAC).

14.1 Potential seaweed aquaculture sites

Table A4.1 gives a general overview of potential sites for seaweed aquaculture. Within a listed area, such as a bay or a sound, conditions may vary significantly depending on the dimension and type of the water body. Therefore not the entire bay may considered to be suitable but certain areas within. This list provides an approximation, as it is explained below, but cannot substitute for a more detailed assessment of a particular area. Small scale cultivation trials should be conducted in any case before establishing large–scale cultivation.

Some examples are given as to how to interpret the information given in Table A4.1.

14.1.1 Example 1: Clew Bay

Site	Clew Bay
coast type	bay
depth (metre)	1–5/5–27
current (knots)	1.5
bottom type	M/S
exposure	3
salinity	3–4
nutrient load	2–3
pier access	3
SACS	yes
SPA	no
shellfish class.	A, B
salmon & seatrout	yes
scallops	yes
mussels	3
oysters	3
clams	yes
CLAMS	yes
Other	–

14.1.1 Description of Clew Bay

Clew Bay has a dimension of 31,250 hectares (ha) with 25 km in length and 12.5 km in width. The inner part of the bay is a drumlin landscape.

- Depth given in the table (1–5/5–27; in metres below lowest astronomical tide) points on extended shallow areas (1–5 metres) and deeper water (5–27 metres) further away from the coast.
- The bay is relatively exposed to westerly winds and swells (3 units; see legend of Table A4.1).
- The major part of the bay has full salinity, with low to full salinity in the shallow parts due to the inflow of several rivers.
- Nutrient load is expected to be medium to high due to the inflow of a number of rivers and waste water inputs from Newport and Westport, the main urban centres in that region, which discharge their sewage after primary treatment and no treatment, respectively (Smith & O'Leary 2000).
- Aquaculture activity is high in Clew Bay. The total area (including Clare Island) under aquaculture and foreshore licences is 274 ha, with 70 ha under licence for finfish and 177 ha for shellfish.
- Clew Bay has an established Co–ordinated Local Aquaculture Management System, which facilitates the introduction and integration of new aquaculture activities.
- Clew Bay is a designated Special Area of Conservation. This does not necessarily impair the establishment of a new aquaculture activity, but may require an environmental survey for the licences application.

14.1.2 Potential areas within Clew Bay and seaweed species for cultivation

Sites with potential for aquaculture are located at the inner bay. This area is relatively sheltered through the small islands. With respect to the conditions described above and the biological requirements of particular seaweed species (see Chapter 8.1), the following species are presumed to be suitable for cultivation in the inner part of Clew Bay:

- *Porphyra* spp.
- *Laminaria saccharina*

At more exposed sites of the inner bay or those with a higher tidal current also Palmaria palmata and *Chondrus crispus* may be cultivated.

The northeast and east coast of Clare Island may also provide potential sides for seaweed aquaculture, although these areas are relatively exposed and direct access from the shore of the island is restricted. Most suitable species would be *Alaria esculenta* and *Palmaria palmata.*

14.2 Example 2: Kilkieran Bay

Site	Kilkieran Bay
coast type	bay/sound
depth (metre)	0–3/5–12
current (knots)	2
bottom type	M/S
exposure	1
salinity	3–4
nutrient load	1–2
pier access	3
SACS	yes
SPA	no
shellfish class.	A
salmon & seatrout	3
scallops	no
mussels	yes
oysters	no
clams	no
CLAMS	yes
Other	–

14.2.1 Description of Kilkieran Bay:

The bay stretches from a southeastern direction 13 km inlands and has a width of about 2 km. To both sides of the entrance of the bay and at the eastern side there are several small islands and the large islands of Gorumna and Lettermore. The bay is connected with Greatman's Bay in the east through narrow sounds.

- The inner part of Kilkieran Bay is shallow with a depth of 1–5 metres. The outer part shows depths between 5–12 metres with maximal depth of 21 metres.
- There is a good tidal current. Due to the orientation of the bay and the islands the bay is relatively sheltered.
- The major part of the bay has full salinity; in shallow areas at the end of the bay the salinity may be lowered due to fresh water inflow from rivers.

- Nutrient load is expected to be low to medium (in the inner shallow part). The shellfish classification (A) points on good water quality (i.e. low microbial load).
- Salmon farm activity is high at the outer part of Kilkieran Bay.
- The bay is a designated Special Area of Conservation.

14.2.2 Potential for seaweed aquaculture

Kilkieran Bay offers a good area for seaweed aquaculture. The inner shallower part could be used for *Porphyra* cultivation. The deeper parts northwest of Lettermore Island may be suitable for *Chondrus crispus, Asparagopsis armata, Laminaria saccharina* and *Palmaria palmata* aquaculture. These sites are sheltered but show a good current which is favourable especially for *Palmaria* cultivation. As mentioned above, at the outer part there are several salmon aquaculture operations. This area is highly suitable for *Palmaria* and *Alaria* cultivation. It is deep, has a good water exchange but the exposure is moderate. Therefore it would be advantageous to link both seaweed and salmon farming and investigate the potential of integrated polyculture.

14.3 Example 3: Cork Lower Harbour

Sites	Cork Lower Habour
coast type	estuary
depth (metre)	1–4/5–26
current (knots)	1
bottom type	M/S
exposure	1
salinity	3–4
nutrient load	3
pier access	3
SACS	no
SPA	yes
shellfish class.	B
salmon &seatrout	no
scallops	no
mussels	no
oysters	no
clams	no
CLAMS	no
Other	boat traffic, industry

Clew Bay and Kilkieran Bay present favourable conditions for the cultivation of several seaweed species for human consumption and cosmetics due to clean water. Cork Lower Harbour is given as an example for a potential aquaculture site for the production of seaweeds for other than food applications, because of potential load of pollutants due to inflow of industrial effluents.

Lower Cork Harbour presents an area with high nutrient input from the river Lee, Cork city (no sewage treatment; Smith & O'Leary 2000) and industrial effluent inflow. Due to the importance of Cork Harbour there is high boat and ferry traffic, which restrict the space of potential aquaculture operations.

Favourable factors for seaweed aquaculture are depth, current, exposure and good pier access. Nutrient enrichment of the estuarine would be positive for growth enhancement of seaweeds.

Seaweed aquaculture could be conducted pursuing the following aims:

- Bioremediation: improvement of the water quality through removal of inorganic nutrients and other potential contaminants.
- Production of seaweeds for biotechnological applications (e.g. extraction of chemical compounds).

15.0 Acknowledgements and picture credits

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