Part 2

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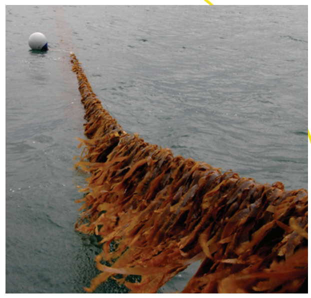
Business Plan for the Establishment of a Seaweed Hatchery & Grow-out Farm



Marine Institute
Foras na Mara
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NDP
National Development Plan 2007 - 2013

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Part 2

Business Plan for the Establishment of a Seaweed Hatchery and Grow-out Farm.

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This document is an output of the project, PBA/SW/07/001 (01), 'Development and demonstration of viable hatchery and ongrowing methodologies for seaweed species with identified commercial potential'. This project is carried out under the Sea Change Strategy with the support of the Marine Institute and the Marine Research Sub-programme of the National Development Plan, 2007-2013.

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Executive Summary

Limited seaweed farming activity has been taking place in Irish coastal waters over the last ten years. This has involved the species *Alaria esculenta* and only one licensed site in the south-west. Now, with funding provided under the Sea Change Strategy (2006) for the project, 'Development and demonstration of viable hatchery and ongrowing methodologies for seaweed species with identified commercial potential', it has been possible to dedicate three and a half years to the development of culture techniques for two identified species, *Palmaria palmata* and *Laminaria digitata*. Three hatcheries have been used to establish the early stages of these species and material has been grown out at five sea sites around Ireland. The need for seaweed product has been identified as significant. Feeding abalone and urchins in culture in Ireland would require 2,000 tonnes of raw material per year at full capacity. Ireland's existing seaweed and biotechnology sector is based on wild product and is worth of the order €18 million per annum (Morrissey et al., 2011). This sector is largely based on high volume, low value product, however there are a significant number of smaller processors working with higher value products. This sector has not yet reached its potential value and it is hoped that, by identifying more products of higher value, greater returns will be realised from this raw material. Areas that are under investigation include seaweed use in pharmaceuticals, foods and cosmetics. Farming seaweed allows for production of a standardised product in a controlled environment. Sites must be licensed and generally are near-shore and adjacent to a pier and access roads. Seaweed can be farmed at mussel longline sites. In this analysis, four case studies for a *Laminaria digitata* long line production unit with a capacity of 100 tonnes per year are presented (1) a new seaweed hatchery and grow-out farm, (2) a new seaweed hatchery with grow-out at an existing mussel site, (3) a new scallop and seaweed hatchery and a new seaweed grow-out site and (4) a new scallop and seaweed hatchery with grow-out at an existing mussel site. A 3-year break-even price is calculated and, not surprisingly, the seaweed and scallop hatchery using an existing mussel site offers the lowest break-even price for *Laminaria digitata* at €1.12/kg wet weight. This price is still deemed to be on the high side, however seaweed buyers have indicated a willingness to pay up to €1.50/kg for good quality product for manufacture into such high value products as health drinks aimed at the functional food market. A preliminary economic assessment of tank cultivation trials of *Palmaria palmata* is presented. The culture technique for *Palmaria* at hatchery sporulation stage is still not fully understood. Small scale trials of vegetative growth of *Palmaria* in on-shore tanks were also carried out. This approach appears to offer a greater potential for an economic return than ongrowth of *Palmaria* at sea.

1 Introduction

This document is written to complement the document, 'Part 1 A market analysis towards the further development of seaweed aquaculture in Ireland'. Ireland's seaweed and biotechnology sector is currently worth €18 million per annum, it processes 36,000 tonnes of seaweed (wild product) and employs 185 full time equivalents (Morrissey et al., 2011). The product source is currently limited to the wild resource and Ireland's product range is limited in the main to high volume, relatively low value products such as animal feeds, plant supplements, specialist fertilisers and agricultural products. More recent developments include the use of seaweed products in pharmaceutical and cosmetic products, which is a higher value area. This document, 'Part 2 Business plan for the establishment of a seaweed hatchery and grow-out farm', presents an economic assessment of seaweed production in Ireland. This assessment uses data and results from the Project, PBA/SW/07/001(01), 'Development and demonstration of viable hatchery and ongrowing methodologies for seaweed species with identified commercial potential', which took place from January 2008 to May 2011. In addition to the work undertaken on this project, the assessment looks at work previously undertaken on *Palmaria palmata* culture at Queen's University Belfast. It is advised that the two documents, Part 1 and Part 2, are considered at the same time.

1.1 Project PBA/SW/07/001(01)

The direction of research funding towards sustainable seaweed development activity involving aquaculture, through projects such as this, is invaluable. The project, PBA/SW/07/001(01), 'Development and demonstration of viable hatchery and ongrowing methodologies for seaweed species with identified commercial potential' is a landmark project. The project is carried out under the Sea Change Strategy with the support of the Marine Institute and the Marine Research Sub-programme of the National Development Plan, 2007-2013. The project which aimed to commercialise techniques for hatchery production and ongrowing of the two identified species, *Palmaria palmata* and *Laminaria digitata,* ran over three and a half years, 2008-2011, and represented a unique blend of industry participants and academic institutions. The research providers, Queen's University Belfast (QUB) and National University of Ireland, Galway (NUIG) provided key knowledge to the project in the form of scientific know-how and experience in seaweed research. The industry associates comprised six small and medium sized enterprises (SME's). The industry associates were Cartron Point Shellfish Ltd., Tower Aqua Products Ltd., G and B Barge Ltd., Cleggan Seaweed Ltd., Roaringwater Bay Seaweed Co-operative Society Ltd. and Dolphin Sea Vegetable Company (now called Irish Seaweeds Ltd). Other interested groups who had been issued with licences during the lifetime of this project accessed the information arising from the work of the project team and were offered seaweed collectors for ongrowing seaweed at sea. The industry associates could be categorised as (1) active aquaculturalists - these are individuals with licensed sites for seaweed culture, individuals involved in aquaculture (abalone farmers) who wish to start seaweed culture to feed farmed abalone and urchins; and (2) processors - individuals who were involved in processing wild seaweed for the food sector. Because of the mix of personnel and their specialities within the project team, there was a unique learning opportunity created for both industry and academics alike.

1.2 Seaweed Farming – What has to happen

In order for seaweed production from aquaculture techniques to become a reality there are a number of identified needs that first must be addressed. Hatchery capability must be established. In its simplest form a seaweed hatchery must have cold room capacity, an autoclave, a well equipped laboratory and tankage with plenty of clean running seawater. In Ireland, there are numerous licensed shellfish hatcheries that could provide this service. It is envisaged in the first instance, as the seaweed aquaculture sector becomes established in Ireland, that these existing hatchery units will provide this service to the sector. The second requirement for seaweed culture at sea is a Foreshore Licence and an Aquaculture Licence. According to the most recent data supplied by DCMNR and DAFF to BIM, there is one algal aquaculture licence in Waterford, two in Cork and one in Galway. Having said that, at least three other licences have been applied for since then, and one has been approved in Kerry.

2 The Demand for Seaweed

2.1 The Irish Seaweed Industry

The current requirement for raw seaweed product for processing in Ireland is 36,000 tonnes and all of this is wild sourced. The value of the product after processing is €18 million. Seaweed does have huge potential in a variety of value added areas. This opportunity has been identified in the Sea Change Strategy (2006) which describes a set of guiding principles for the Irish seaweed sector. It is envisaged that seaweed from aquaculture production will form the basis for downstream processing of value added biopharma and nutraceutical products and that seaweed will regularly be used in biotechnology. This vision for the future is positive and it is stated that by 2020, the seaweed production and processing sector will be worth €30 million per annum and it will play an increasing socio-economic role as part of the mosaic of marine resource utilisation, in the context of marine spatial planning and the coastal zone.

2.2 Case Study. Macroalgal Requirements for the Irish Aquaculture Industry.

This project's team comprised both academic and industry practitioners. Two of the industry associates were abalone farmers and both intended to farm seaweed to satisfy the dietary needs of their abalone. The cultivation of molluscan species which graze on macroalgae has come to the fore in Irish aquaculture in recent years with the development of a number of recirculating aquaculture systems. Such systems permit greater control of water parameters than traditional flow-through or sea-based culture environments. In this regard, temperature, salinity, feeding rate and spawning are controlled by the farmer. For a valuable product such as abalone which is worth of the order €56/kg ex-farm, seaweed farming allows for continuous supply of high quality diet to the farm. Ideally, a seaweed farm should be located adjacent to the abalone unit to facilitate the feeding of fresh weed to abalone on a daily basis.

Abalone and urchins

Three species of grazer are currently grown in fish farms in Ireland, the abalone *Haliotis discus hannai* and *Haliotis tuberculata,* and the sea urchin *Paracentrotus lividus.*

The abalone, *H. discus hannai* and the sea urchin have a preference for brown macroalgae and commonly eat *Laminaria digitata,* whereas the abalone, *H. tuberculata* has a preference for red weed most notably, *Palmaria palmata.*

Dietary needs

There are currently two formulated diets that are readily available for the purposes of abalone aquaculture, the Skretting Halo diet and Le Gouessant. There are alternative international suppliers from outside Europe including Adam and Amos and Abfeed, but these diets are designed for the Australian and South African abalone, respectively, and their efficacy has not been proven for *H. discus hannai* or *H. tuberculata*. The formulated diet from Skretting comes in only one size and is therefore not useful for all sizes of abalone. The diet from Le Gouessant comes in multiple sizes from powder to large chip but has been designed specifically with *H. tuberculata* in mind.

The protein percentage in the formulated diets can vary from 24% to 35% and the protein source is mostly provided by fish meal. Because production of these foods is small on a global scale, the prices fluctuate with the prevailing fishmeal price. Other protein sources are being investigated. Due to its higher protein content, the Feed Conversion Ratios (FCR's) tend to be better than in macroalgal diets (i.e. more animal is produced per kilogram of formulated feed than of seaweed). The price of proprietary abalone feed delivered to Ireland varies between €1,500 and €3,000 per tonne.

Seaweed requirements

At full production capacity, the estimated wet weight of *Laminaria* required for the Irish abalone industry growing *H. discus hannai* is between 645 and 860 tonnes based on an FCR of 15-20:1 and an annual harvest of 43 tonnes of abalone. For an estimated annual harvest of 37 tonnes of *H. tuberculata,* the volume of *Palmata palmata* required would be between 555 and 925 tonnes based on FCR's of 15-25:1

With a predicted annual harvest of 27 t of sea urchins, the algal requirement is 400 to 540 t based on an FCR of 15-20:1. The species requirement is approximately a 50:50 split between *Laminaria* and *Palmaria*.

The nutritional qualities of macroalgae change throughout the season. The protein content of *Laminaria* can vary from 8-14% and that of *Palmaria* from 12-21%. The protein energy ratio affects the FCR's and consequently the amount of algae required to get animals to market size.

Assuming the above abalone seed inputs are realised and the predicted tonnage is harvested in Ireland, utilising an all-macroalgal diet, the tonnage of *Laminaria* required in Ireland will be between 850 and 1,130 tonnes per annum. Between 750 and 1,200 tonnes per annum of *Palmaria* will also be required.

3 Project PBA/SW/07/001(01) Research Findings

3.1 Work Package 1 *Palmaria palmata*

The project Work Package 1 entitled, 'Development of viable, industry-scale hatchery and ongrowing methodologies for *Palmaria palmata'* had four tasks as follows: (Tasks 1.1 to 1.3 were specified in the original approval, the fourth Task 1.4 was added in August 2010).

Task 1.1: Optimisation of seeding and hatchery techniques

- Optimisation of spore harvesting methodology
- Development of active seeding techniques
- Spore collector substrate: materials and design
- Development of spore/plant storage methodologies.
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Task 1.2: Optimisation and refinement of ongrowing strategies

- Optimise deep-water longline system
- Development of shallow water system
- Monitoring of plant production, yield and quality
- Chemical analysis of plant material

Task 1.3: Optimisation of harvesting technology

- Harvesting strategies
- Determination of vessel requirements
- Mechanisation of harvesting

Task 1.4: In-tank cultivation trials

- Optimise culture parameters
- Monitoring plant production, yield and quantity
- Chemical analysis of plant material

Work Package 1 was led by QUB with assistance from BIM and NUIG. This document deals with the Deliverable 14, 'Business plan for the establishment of a full-scale *Palmaria* farm in Irish waters'. In the analysis undertaken as required in the terms of reference, the Project Team looked at the existing economic model for *Palmaria* production already developed at QUB by QUBIS, Dr Lynn Browne and Dr Maeve Edwards with financial assistance from Dolphin Sea Vegetables (DSV) (now called Irish Seaweeds Ltd). In using these models the IPR of QUB and DSV was fully respected.

Work Package 1 Results

The results of all the work carried out by the scientific partnership on Work Package 1 have been substantially reported in the Interim Technical Reports. In addition, oral presentations of the work undertaken and the ensuing results have been recorded at the biannual meetings of the project team since the project started in February 2008. The reader is respectfully requested to read the Interim Technical Reports for a full analysis of the findings of the work. Summary reports taken from the five Interim Technical Reports are presented below. Importantly, due to the lack of success with conventional methods of grow–out of product at sea, a new Task 1.4 was added to the programme of work from August 2010.

Reporting period 1/01/08 to 31/07/2008

All tasks identified in the project were carried out except T3.1 because *Palmaria* deployed in May was not yet ready for harvest at the end of July. Ideally, *Palmaria* will be put to sea earlier and harvested earlier (for 2009 and 2010). It was not possible to do this in 2008 because of the timing of the project approvals and the given start date of February 1st. Another issue that was encountered as a result of late deployment was fouling of the lines at sea.

Reporting period 01/08/2008 to 31/01/2009

Numerous *Palmaria* sporulation trials were carried out in all three hatchery sites (i.e. DOMMRS, MRI Carna Laboratories and QUB Portaferry) in order to build up stocks of seeded string during the period of optimal spore production (which was missed in 2008 because of the delay in the start of the project), and to test the ongrowing potential earlier in the year than during 2008. Good growth of *Palmaria* from all three hatcheries was observed in Strangford Lough. By early February 2009, the strings deployed in July with spores from both QUB Portaferry and MRI Carna were yielding over 200 g m^{-1}, and those from DOMMRS approximately half this amount. At this harvest, the largest thalli were between 40 and 60 cm in length, and the mean length was 10-16 cm. *Palmaria* grow-out trials at the other sites, Roaringwater Bay, New Quay and Ard Bay were less encouraging.

Reporting period 01/02/2009 to 31/07/2009

From February to May fertile tetraspores were found in abundance at DOMMRS, Carna Research Facility and Portaferry. Spore release was excellent in most cases but often spores did not survive the first week of settlement and development. In total 50-60% of sporulations were unsuccessful due to heavy mortality. A crisis meeting was held in the summer to discuss possible explanations. Deployment in November/December with on-growth during the winter resulted in dense growth of *Palmaria* on string (droppers) without bad fouling at all three sites. At Ard Bay growth of 750g per metre of string dropper was achieved after 151days. This was the best grow-out yield achieved. Material deployed at sites between January and April became heavily fouled and in most cases did not thrive. In Strangford Lough, material put out in February became heavily fouled but then developed to produce a crop in July.

Reporting period 01/08/2009 to 31/01/2010

Since reproductive material was not available through most of this reporting period, discussion was focussed on ways to avoid spore crashes following settlement, and an experimental programme was agreed and implemented from January 2010. A limited amount of string that had been successfully seeded with *Palmaria* spores in spring 2009 was deployed in 3 sites during the summer or autumn, and good growth was recorded at all sites after about 3 months in the sea. Harvesting of this material commenced in early 2010.

Reporting period 01/02/2010 to 31/07/2010

The intensive work designed to avoid spore crashes was completed without providing clear guidance on how to avoid the problem. However, this problem was largely overtaken by another because the majority of the seeded material that was deployed in the sea during the winter season failed to grow satisfactorily, and the ongrowing techniques that have resulted in good growth in previous years seemed not to work this year. Consequently, it was decided to test a new approach to the aquaculture of *Palmaria* in the final year of the project, and to set up tanks on land, which are stocked with small thalli from culture or natural populations. This would be in addition to a further attempt to grow good crops in the sea.

Reporting period 01/08/2010 to 31/05/2011

Tank trials were established at three hatcheries (DOMMRS, MRI Carna and QUB Portaferry) and at Cartron Point Shellfish Ltd. to see how *Palmaria* would perform. Different tank sizes were used, and growth in both natural and nutrient enriched water was compared. The advantage of this cultivation method is that the nursery phase is omitted because harvestable biomass of *Palmaria* is grown vegetatively from an initial stock of *Palmaria* collected from the shore. Once the initial biomass is growing in tanks the surplus material is harvested at frequent intervals throughout the year. High growth rates were observed between early Spring and Autumn resulting in high biomass production per unit of tank surface area. Addition of fertilisers was found to enhance the growth of *Palmaria.* Trial results indicate that, at a stocking density of 4 kg m^{-2}, *Palmaria* doubles in weight every four weeks.

3.2 Conclusions from work undertaken on *Palmaria palmata*

In conclusion, in the time that the Project Team had (i.e. 2008 to mid 2011), it was not possible to demonstrate a consistent year-on-year successful culture methodology to achieve *Palmaria* sporulation – settlement on string – sea deployment – grow-out to harvest. Tank cultivation provides another means of cultivating *Palmaria*. Higher growth rates are observed with increasing light. Addition of fertilisers improves growth rate but may also encourage fouling. The main advantage of this cultivation method is that a hatchery is no longer required and biomass can be produced continuously at an accessible land based site.

3.3 Work Package 2 *Laminaria digitata*

The project Work Package 2 entitled 'Investigation of pilot-scale hatchery methodologies and implementation of a programme of on-growing trials for *Laminaria digitata'*. had three tasks as follows:

Task 2.1 Seeding and hatchery techniques

- Review of techniques used in other countries
- Maximising spore release from fertile thalli
- Establish and propagate cultures of Laminaria

Task 2.2 Ongrowing Strategies

- Optimise 'deep' water longline systems for Laminaria
- Development of 'shallow' water systems for Laminaria. (inappropriate and not carried out)
- Monitoring of plant production, yield and quality
- Chemical analysis of plant material

Task 2.3 Harvesting technology

- Harvesting strategies
- Determination of vessel requirements
- Mechanisation of harvesting

Work Package 2 was led by NUIG with assistance from BIM and QUB. This document deals with Deliverable 15, 'Report on the economic viability of establishing a farm for *Laminaria* in Irish waters'.

Work Package 2 Results

The results of the work carried out by the scientific partnership on Work Package 2 were substantially reported on in the Interim Technical Reports. In addition, oral presentations of the work undertaken and the ensuing results were recorded at the biannual meetings of the project team since the project started in February 2008. The reader is requested to read the Interim Technical Reports for a full analysis of the findings of the work. Importantly, this work package was extremely successful. Summary reports taken from the five Interim Technical Reports are presented below.

Reporting period 1/01/08 to 31/07/2008

WP 2 on *Laminaria digitata* for this period involved a thorough literature review of all available data on seeding and hatchery techniques for this species. Dr Maeve Edwards compiled this information and it was made available to other members of the group. Test sporulations of *Laminaria* were carried out in Carna and at the Daithi O Murchu Marine Research Station (DOMMRS) in Bantry. A sporulation 'demonstration day' was organised at the DOMMRS for group members. There was some success, but it was not possible at this early stage to determine a protocol for successful sporulation of *Laminaria*.

Reporting period 01/08/2008 to 31/01/2009

Gametophyte cultures of *Laminaria* were established in Cork and Galway, and despite the cultures not being axenic, they developed well. These cultures became reproductive, and the fertilised gametophyte culture was sprayed onto 12 collectors. Five of these collectors were deployed in Roaringwater Bay and New Quay during December to February.

Reporting period 01/02/2009 to 31/07/2009

Ripe sori were not available on the Gearhies coastline until June 2009. From this date, monthly sporulations were performed at the lab and continued for the remainder of the year. In Portaferry, cultures from the DOMMRS lab were maintained, and additional cultures from local *Laminaria* populations were established and held in similar conditions to those in DOMMRS and Carna. Cultures in NUIG (Carna) were maintained in several different media in preparation for a further experiment to look at the survival and development of the sporophyte stage of the kelp in each of these media (F/2, Provasoli, Algoflash).

From November 2008 to June 2009 a total of 20 collectors were sprayed with fertile *Laminaria* gametophytes and subsequently grown in the DOMMRS lab. Twelve of these collectors were deployed to sea from December 2008 to June 2009: seven collectors to Roaringwater Bay, four collectors to New Quay and one collector to Carna. Collectors deployed at Roaringwater Bay and New Quay in mid December outperformed all subsequent deployments.

The only deployment *of Laminaria* during this period in Ard Bay (Galway) was made at the end of March. Subsequent monitoring showed that sporophyte juveniles on both cultures were overwhelmed by a large number of epiphytes on the header rope, most likely due to an unusually fast increase in water temperature early in the season. Similarly, a deployment made in May at the Jackdaw Island longline in Strangford Lough was heavily fouled after deployment. The deployment in June fared better, with a high density of 3-cm plants measured after one month. A further deployment in July was also heavily fouled by epiphytes.

Reporting period 01/08/2009 to 31/01/2010

Establishment of gametophyte cultures at the three labs continued successfully as in the previous year's trials, with cultures developed in most months. Much of this material was used (mainly in the Gearhies lab) to establish seeded string which was deployed later at a variety of sites around Ireland, but with the bulk deployed at Roaringwater Bay and New Quay. Several interesting developments emerged in relation to the *Laminaria* deployments. For example, deployments were made earlier than usual in Roaringwater Bay and New Quay with good results (deployments in early October instead of November). After 123 days at sea, plants were approximately 26 cm long, with an estimated biomass of 833 g m^{-1} longline. It was also possible to deploy *Laminaria* in the summer in Strangford Lough (deployments in July and August), indicating that, for some sites at least, it might be possible to have year-round production. The trip to Grenaa, Denmark to visit another kelp hatchery demonstrated new techniques, in particular, deployment of *Laminaria digitata* directly onto other substrates, than the culture string currently used.

A second kelp species, *Saccharina latissima* was introduced for cultivation alongside *Laminaria.* Cultures were set up in NUIG and QUB.

Reporting period 01/02/2010 to 31/07/2010

Gathering of reproductive material, release of zoospores and culture of gametophytes proceeded smoothly from May to July. Cultures developed in time for use in October. Both *Laminaria digitata* and *Saccharina latissima* were in culture. Seeded material deployed in the previous season (October 2009 to February 2010) was successful at all sites used, with most of the material deployed at Roaringwater Bay. Two types of deployment were trialled, using the standard horizontal deployment along header ropes, and 3-m droppers deployed vertically.

The largest yields were produced from deployments in October to December. Yields were 6.4 to 8.1 kg m^{-1}, which equates to a harvest of 1.06 tonnes (wet weight) of *Laminaria* on a 150m header rope for these particular deployments. The first successful trial of *S. latissima* occurred in Strangford Lough on droppers. Yields of 6 kg m^{-1} were reported. Further trials would begin alongside the *Laminaria* in the autumn.

Reporting period 01/08/2010 to 31/05/2011

The final co-ordinated deployments of *Laminaria* were made at multiple sea sites from all three hatcheries during this period. Hatcheries produced seeded culture string from mid-August until December 2010. String was deployed horizontally (across header ropes) and vertically (on 3-m droppers) on longlines in October, November, December and January. Sites where deployments were made included Roaringwater Bay, New Quay, Ard Bay and Strangford Lough. Seeded culture string was also deployed at a new site in Ventry Harbour. This site included a 220-m longline (which supported ~100-m *Laminaria* and ~100-m *Alaria esculenta*) and a 30 x 30-m grid that supported 450-m seeded rope. A new species of kelp – *Saccharina latissima* - was also deployed in Ard Bay and Ventry Harbour for the first time. Harvesting of biomass samples began in February or March and continued until the end of May or early June. Overall, all deployments increased in biomass over time, but those deployments that were made earlier (October and November) produced the greatest amount of biomass by May/June 2011. Although the replicate biomass samples varied somewhat at each site, a maximum average yield of 7.2 kg $m^{-}1$ *Laminaria* was obtained from an October deployment in Roaringwater Bay. Yields for *Saccharina latissima* were also variable, but at least matched, if not exceeded the yields for *Laminaria*. Growth of both kelps on the seaweed grid in Ventry was poor, most likely due to the time of deployment (January). The grid itself was structurally successful, therefore more deployments should be trialled in the future.

3.4 Conclusions from work undertaken on *Laminaria digitata*

In conclusion, in the time that the Project Team has had (i.e. 2008 to mid 2011), it has been possible to establish a sound methodology for *Laminaria* sporulations, seeding on to collectors and deployment to sea for grow-out to harvest. A yield of 6.4 to 8.1kg/m has been achieved.

4 A seaweed production model

The setting up of a seaweed hatchery and a seaweed grow-out farm using the best results of the work undertaken by the Project Team is now described. This analysis necessarily takes into account the hatchery costs and the set up of the farm at sea. It is obvious that the tonnage of *Palmaria* required to satisfy Ireland's needs for abalone and urchin feed will never be achieved from seaweed aquaculture unless techniques are developed to overcome the problems currently encountered. *Laminaria digitata* is more easily cultivated and the amounts required for macroalgivore diets could theoretically be provided by aquaculture.

To illustrate this, the amount of *Laminaria* and *Palmaria* required to feed Ireland's macroalgivores at full production has been estimated. Full production capacity will be met in five years time. If the predicted abalone and urchin tonnage is harvested (27 t of sea urchins, 43 t of *H. discus hannai* and 37 t of *H. tuberculata*), utilising an all-macroalgal diet, the required tonnage of *Laminaria* will be between 850 and 1,130 t per annum and the requirement for *Palmaria* will be between 750 and 1,200 t per annum

4.1 Measured Yield of *Palmaria palmata* achieved during the project

A yield of 0.321kg/linear metre was achieved on nets (1.3x3 m with 10-cm mesh) in Ard Bay by June 2010 (Ref Interim Technical Report No 5). Also in previous work, Edwards (2007) demonstrated growth of 0.583 kg *Palmaria*/linear metre on droppers by day 150 in Strangford Lough. A superior growth rate to that has been achieved on string droppers during the current project (Ref. Interim Technical Report No 3). At Ard Bay growth of 0.75 kg per metre of string dropper was achieved after 151days in April 2009.

Edwards (2007) measured an actual yield of 1.724 kg/linear metre, based on 4 croppings of *Palmaria* on droppers. It was decided that, as this project had never achieved this, it would not be possible to use this production yield.

Assumptions

Assumption 1: *Palmaria* grow-out on nets

A 100-m longline can hold up to 70 nets (1.3 m wide with 12 cm between nets for attachment). Since the nets are 3 m long and have a 10-cm mesh, the total length of string per net is 82.3 m [1].

Assuming a yield of 0.321 kg/m, each net will yield 82.3 x 0.321 = 26.4 kg.

A 100-m longline with 70 nets will produce 1.8 tonnes using this technique.

Assumption 2: *Palmaria* grow-out on droppers

Using 3-m droppers, an average coverage of 0.75 kg/m has been achieved, so that the total potential yield from a 3-m dropper is 2.25 kg. It is possible to deploy up to 80 droppers on a 100-m longline, allowing space for tying and buoyancy (Freddie O' Mahony pers. comm). A 100-m longline with 80 droppers will produce only 180 kg of *Palmaria* using this technique.

Conclusion

It is quite apparent that the use of nets results in much higher potential yields of *Palmaria* than the use of 3-m droppers based on the best results obtained during the current project.

4.2 Economic Analysis

The results to date have indicated a very poor survival of spores in the hatchery and this was the subject of much intensive analysis. Taking the results achieved thus far, there is an average requirement of 1.875 kg of wet *Palmaria* raw material to provide enough ripe material for one seeded net of the size 3x1.3 m with 10-cm mesh. Only 8% of that amount will be usable for sporulation work which is 150 g ripe material per net. On this basis, there will be a need for 10.5 kg of ripe material to seed a 100-m longline with 70 nets. This will mean that 131.25 kg of material will need to be gathered during the correct period for sporulation.

As the analysis demonstrates above, the yield from one 100-m longline containing 70 nets is only 1.8 tonnes. Therefore, the complete cultivation process is increasing the starting material by only 13.7 times. Unless sporulation success can be improved and yields improved, there appears to be little point in culturing *Palmaria* in the hatchery for deployment to sea on nets for grow-out.

[1] To calculate the amount of string in a net of 1.3x3 m with a 10-cm sq mesh, it is necessary to count the vertical string and the horizontal strings making up the mesh. **Vertical strings:** to encompass 1.3 m there are 14 strings 10 cm apart, each string is 3 m long = 14x 3 m of string which is 42 m. **Horizontal string:** in a net 3 m deep, there are 31 strings at 10-cm intervals, each one 1.3 m long. The amount of horizontal string is 31 x 1.3 m = 40.3 m. Therefore the total amount of string in the net is 82.3 m.

4.3 Seaweed Hatchery (*Palmaria* or *Laminaria*) set-up costs

Quite obviously, there is an absolute requirement for certain pieces of equipment regardless of the species to be cultivated or the level of production i.e. a cold room, autoclave and microscope. In the current analysis It is envisaged that the hatchery will be multi-disciplinary with bivalve production likely taking place and other seaweed species being produced. The hatchery unit costs include a cold room capability in an insulated container with all the equipment items required. A laboratory, office, toilet and canteen are not costed. The cold room (12.19 x 2.7 x 2.43 m) is tanked at floor level only to provide 24 tanks with a total tank volume of 16.2 m^3. This tankage can be used to supply *Laminaria* collectors (30 m long) and also *Palmaria* seeded nets. The total production capability from this size of unit is 240 *Laminaria* collectors (240x30 m=7,200 m string). The 24 rectangular tank set up allows 10 *Laminaria* collectors to be held per tank and makes good use of the space. In contrast to this, folded nets (3x1.3 m) for *Palmaria* do not make efficient use of the available space, since only two nets could be placed per tank. Therefore, if all 24 tanks in this cold room were used for *Palmaria*, only 48 nets could be held in the system, and these would cover only 70% of a 100-m longline. Because *Palmaria* must be maintained in the hatchery through the summer for sea deployment in the autumn, culture of this species will involve the complete hatchery tankage until deployment. Forty eight nets deployed at sea would yield 1.26 t of *Palmaria*.

Alternatively this system could be used for *Laminaria* work as already mentioned. *Laminaria* hatchery work starts in June and goes on to October with deployments taking place in October, November and December. The system has a capability to hold 240 collectors at a time with 7,200 m of seeded *Laminaria* lines. The harvested yield identified per metre is 7 kg for *Laminaria.* The potential production from this 7,200 m of seeded line is therefore 50.4 tonnes. Since 2 batches could be raised in this system per year, monthly deployments from November to February could yield a final harvest weight of 100 tonnes of product. For information purposes it is also envisaged that *Alaria* and *Saccharina latissima* could also be produced in this hatchery.

Figure 1 Schematic of 24xfibreglass tank layout in 12.19m long insulated container.

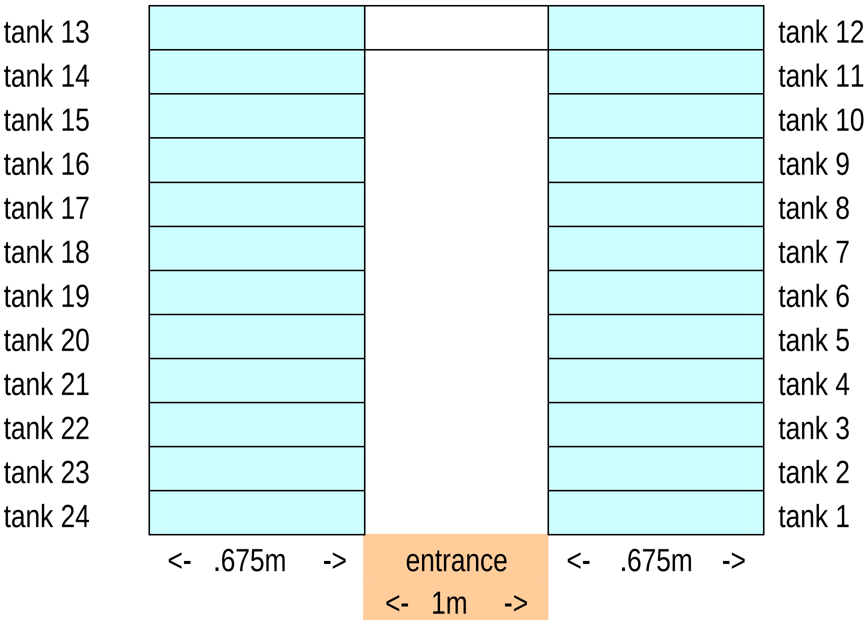

Table 1 Indicative Hatchery set-up and operational costs year 1

Hatchery Costs	€
1xinsulated room with AC and control panel	8,500
Autoclave	14,000.00
Microscope	1,500.00
Precision balance	1,500.00
Pipework	2,000.00
Tankage16.2m³	14,000.00
UV	1,000.00
Consumables	
Glassware	1,500.00
fluorescent tubes	500.00
Nutrients	750.00
Collectors 480 (240x2 €5/ea) *Laminaria*	2,400.00
Nets 48 (48x1 @€10/ea)	480.00
Total	48,130.00
Electricity per annum	30,000.00
Labour per annum	60,000.00
Total	138,130.00

Table 2

Example of calendar of hatchery work on seaweeds showing the possible dovetailing of work in line with the lifecycle of the different seaweed species.

<table>
<tr><th colspan="12">2011</th><th colspan="12">2012</th></tr>
<tr><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>June</th><th>Jul</th><th>Aug</th><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>June</th><th>Jul</th><th>Aug</th><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td colspan="4">Alaria sea grow-out/harvest</td><td colspan="5"></td><td colspan="3">Alaria in hatchery</td><td colspan="4">sea grow-out/harvest</td><td colspan="5"></td><td colspan="3">Alaria in hatchery</td></tr>
<tr><td colspan="4">Laminaria sea grow-out/harvest</td><td></td><td colspan="5">Laminaria in hatchery</td><td colspan="6">sea deployment/grow-out/harvest</td><td></td><td colspan="5">Laminaria in hatchery</td><td colspan="2">sea deploy.</td></tr>
<tr><td></td><td colspan="4">Palmaria in hatchery</td><td colspan="4">Palmaria holding hatchery</td><td colspan="9">Palmaria sea deployment/grow-out/harvest</td><td colspan="6"></td></tr>
<tr><td colspan="6">Palmaria sea deployment/grow-out/harvest</td><td colspan="7"></td><td colspan="4">Palmaria in hatchery</td><td colspan="4">Palmaria holding hatchery</td><td colspan="3">sea deploy</td></tr>
</table>

What can be seen here is that it may be possible to co-ordinate *Alaria* and *Laminaria* or possibly *Alaria* and *Palmaria* using the full complement of tanks for a single species. It is not possible to co-culture *Laminaria* and *Palmaria* in the same hatchery unless the tankage is divided because *Palmaria* and *Laminaria* overlap in that *Palmaria* must be maintained in the hatchery from June to October when it is deployed. *Laminaria* is ripe from June to October and will be manipulated in the hatchery during this time.

Table 3
Example of a scallop/seaweed hatchery demonstrating year on year complementary work programme

2011												2012											
Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
	scallop spawning in hatchery					nursery at sea			NWPT at sea				scallop spawning in hatchery					nursery at sea			NWPT at sea		
Alaria sea grow-out/harvest									Alaria in hatchery			sea grow-out/harvest									Alaria in hatchery		
Laminaria sea grow-out/harvest					Laminaria in hatchery					sea deployment/grow-out/harvest							Laminaria in hatchery					sea deploy.	

In this example it can be seen that it may be possible to combine seaweed and scallop hatchery work in the same unit.

Hatcheries of this size and with this amount of equipment exist in Ireland at the moment and these are mainly used for shellfish spat production (oysters, scallops and clams). The costs given above are an accurate reflection of the current situation. A hatchery of this size could be used for bivalves in association with seaweed work.

Production from Hatchery

As discussed, this hatchery could produce 48 nets for *Palmaria* grow-out in just one batch and for sea deployment in October, November, December and January, or it could produce 14,400 m of seeded *Laminaria* string in two batches for sea deployment from November to February. Alternatively, the tankage could be divided to allow shared production of the two species.

4.4 At-Sea Costs (longlines and continuous culture grid unit)

Table 4 Cost of seaweed longline

Cost of seaweed longline		
Nylon rope 110mx28mm	€	350.00
Anchor rope 90m	€	200.00
Chain 5m	€	100.00
Blocks 2x2tonne concrete	€	600.00
Buoys 20xA2 buoys with spliced ropes	€	400.00
Trawl floats 2	€	27.00
Shackles	€	40.00
Tying rope	€	100.00
Total	€	1,817.00
Cost of 10 longlines	€	18,170.00
4 Navigation buoys and anchors	€	11,340.00
Deployment	€	500.00
Total cost 10x100m longline unit	€	30,010.00

The total cost of one 100-m longline is put at €1,817. The cost of a 10x100 m stand alone longline unit is €30,010. An alternative to this standard unit is the continuous-rope culture unit (Figure 2). This prototype unit is 30x30 m (900 m^2) with a total of 450 m of seeded rope. The cost of construction of this unit is €2,629 (Table 5). This unit is not deemed to be usable with droppers or nets because of the risk of entanglement. It is therefore not suitable for *Palmaria*, but could be used for horizontal deployments of kelp species, such as *Laminaria, Alaria* and *Saccharina latissima*.

Figure 2 prototype continuous rope culture seaweed grow-out unit

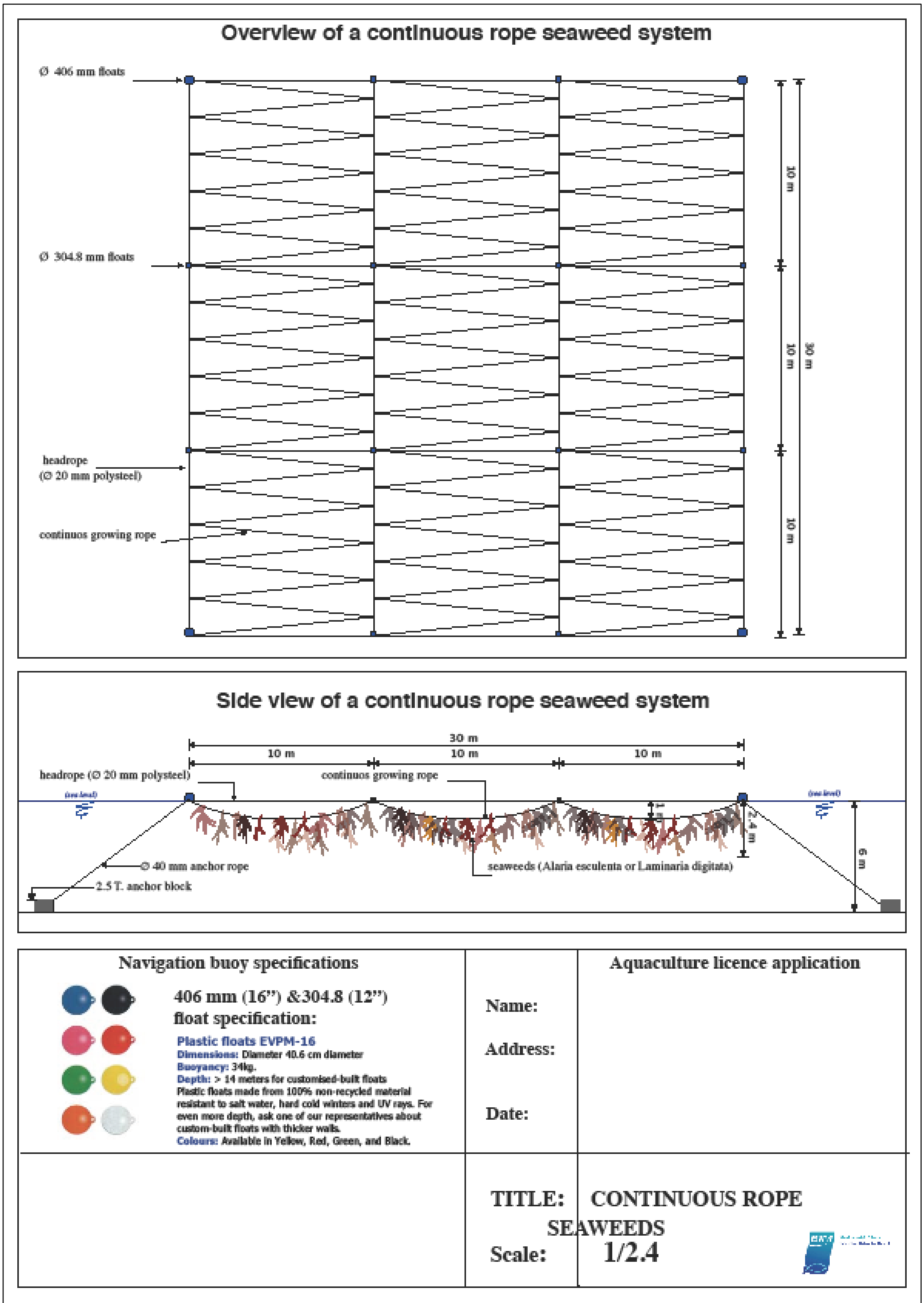

Table 5 Cost of continuous culture 30x30m grid system

Component	Cost (€)
A2/LD Buoys x 16 @ €29	464
Nylon Rope 18mm x 440m @ €280/220m	560
Nylon twisted twine 9mm (8.5kg spool) x 3	255
2.5T Concrete anchors x 4 @ €337.5	1,350
Total	€2,629

(Total including VAT, € 3,181.89)

4.5 *Palmaria* seaweed farm productivity and value

A 100-m longline with capacity of 70 nets x 26.4 kg each will produce 1.8 tonnes wet *Palmaria* using this technique. NB. the hatchery described only has capacity for 48 nets.
The dry yield from 70 nets is 20% of 1.8 tonnes which is 0.36 tonnes

Assumption. Value in the market place
Palmaria palmata

The price per wet kg is €2.50.
The price per bulk, dry and bagged kg is €16 – 19.
The sales value ex farm per 100-m longline with 1.8 tonnes @ €2,500 per tonne wet weight is €4,500
The sales value for dry weight product (0.36 tonnes) @ €16-19 per kg is €5,760-6,840

The potential value of sales of bulk, dried and bagged *Palmaria* from 48 nets is €4,055-4,815

4.6 *Laminaria digitata* seaweed farm productivity and value

The hatchery described and costed has the capacity to produce two batches of collectors with a total grow-out length of 14,400 m. At a yield of 7kg m^{-1}, the total potential harvest from this is 100 tonnes wet weight product. The wet : dry seaweed yield calculation is variable and dependent on a number of factors including quality of product. The value applied in this analysis is 15% in relation to *Laminaria.* A 100 tonne wet weight will therefore result in 15 tonnes of dry product.

Assumption. Value in the market place

Laminaria digitata

Price per kg wet €1.00/kg (product for high end marketing, for example, human consumption only)

Price per kg bulk, dry and bagged €10/kg - €16/kg

Sales value ex farm 100-m longline with 0.7tonnes @ €1,000/tonne wet weight is €700

Sales value dry weight product 0.105tonnes@ €10/kg-€16/kg is €1,050-€1,680

The potential value of sales of bulk, dried and bagged *Laminaria* from 14,400m is €150,000-€240,000. It is important to stress that this price can only be achieved for high quality product fit for high end markets.

At –sea costs

To deploy the full amount of *Laminaria* collectors will require for example 32 of the 900-m^2 continuous rope culture grow-out units, each with 450 m of line to deploy the collectors on. These units can be linked together as a flotilla with anchorage at strategic points. The cost of such a unit will be dependent on the cost of the basic structure itself (costed at €2,629) and then the required anchorage and buoyancy for a larger group comprising 32 units. It is postulated that the make-up and specific design of the structure will be site dependent. There are many variables that will impact on it, for example, the size and shape of the licensed site, exposure, currents, wave height and water depth. One 900-m^2 grid with 450-m of string grow-out capacity with a potential yield of 7kg/m can potentially yield 3.15 tonnes of *Laminaria*.

In contrast, a 100-m longline (costing €1,800) achieving the same yields will result in only 0.7 tonnes of *Laminaria* if a single header rope is used or 1.4 tonnes if a double head rope is used.

In this regard it makes sense to consider only the continuous rope culture grow-out unit. If 32 units are to be deployed, the capital cost is estimated to be €84,128.

4.7 Continuous culture units per hectare

A hectare is 10,000 sq m so theoretically 11 of the 900-m^2 units could fit in a 10-hectare licensed area. However with the space requirements for anchorage and access it would be more realistic to envisage 6 units per hectare.

4.8 Longlines per hectare

Given a one-hectare site of 200m x 50m, it would be feasible, for example, to fit in 5 x 100-m seaweed longlines per hectare (other sized units such as 10 x 100-m or 5 x 200-m could also be used).

5 Financial Appraisal of Seaweed Farming in Ireland

This section provides a full financial appraisal of the commercial viability of seaweed farming in Ireland, building firstly on the growth results of *Laminaria digitata* realised during the current project and secondly on data collated concerning the costs of setting up a hatchery unit and the costs of setting up a grow-out farm at sea. All the relevant data and assumptions are included.

5.1 Seaweed growth rate

For the purposes of the analysis seaweed growth rate is deemed to be straight-line in nature. The work carried out thus far on the project and previously by BIM and Cartron Point Shellfish Ltd on *Alaria esculenta* shows that *Laminaria digitata* when put to sea as tiny plantlets on collectors during the autumn months, will grow-out consistently to give a crop at a measured yield of 7kg/linear metre by the following spring. In this regard the lifecycle is of the order of 6 to 7 months. This is a straightforward growth cycle offering an annual return on investment to the farmer.

5.2 Cost Analysis

Hatchery Unit

The cost of setting up the hatchery unit is estimated to be €48,130 in year 1, and the running costs are estimated at €90,000 (Table 1). Labour is costed at one full time and one part time person costing in total €60,000 per annum.

Seaweed farm

Because the continuous culture unit offers the best value, the costing is based on this unit. The total capital cost requirement is €84,128. The farm will need to be constructed and deployed in year 1. Peak deficit funding occurs in year 1 with a total outlay of €206,035 (Table 12). This is met by bank borrowings and grant support on capital expenditure at 40%. Labour is costed at one part time person costing €25,000 per annum.

5.3 Financial Performance

To assess the financial performance of a 100-tonne seaweed grow-out farm and associated hatchery unit, two separate strands of financial data are analysed. As already described above, an insulated 'hatchery' as an add-on to an existing hatchery building is costed, as is the capital cost of setting up a new seaweed grow-out site comprising a set of 30 x 30-m grids. The adaptation of an existing hatchery unit is the most likely scenario for an Irish seaweed promoter. As mentioned previously, it is unlikely that a proprietary hatchery will be built. There are a number of existing marine pump-ashore hatcheries around the Irish coast. The addition of an insulated tanked container is the optimum way to provide the additional space that is needed without going into the significant expense of a new build.

The farm set up and associated cost analysis is considered as 'self-start' in isolation. In this regard it is assumed that bank borrowings are the main source of financial support coupled with grant aid on eligible capital items

Indicative financial analyses are presented for four case studies in which different scenarios are envisaged for setting up a farm to grow 100 tonnes of *Laminaria* per year. These scenarios are:-

Case Study 1. A new seaweed hatchery with a new grow-out site.
Case Study 2. A new seaweed hatchery and an existing mussel site partially used for seaweed grow-out.
Case Study 3. A new seaweed and scallop combined hatchery with a new seaweed grow-out site.
Case Study 4. A new seaweed and scallop hatchery with an existing mussel site partially used for seaweed grow-out.

In identifying the costs associated with these options, 'common costs' are isolated. These are costs that will be incurred regardless of the eventual seaweed production method chosen. The common costs for the profit and loss and cash flow statements are itemised in Tables 6 and 7. The common or fixed costs are associated with both the hatchery and the sea site set-up and operation. In addition, there are variable costs which depend on the type of farm option chosen. The variable costs are labour in the hatchery and at sea, vessel and skipper hire and also bank interest which itself is dependent on the capital required for the undertaking.

Table 6 Summary profit and loss statements for a 100-tonne *Laminaria digitata* farm and hatchery unit. Costs common to all scenarios:

3 Year projections	5 months to Dec-10	Year 2 Dec-11	Year 3 Dec-12	7 months to Jul-13
COGS				
Hatchery				
Nutrients	750	750	750	0
Collectors	2,400	2,400	2,400	0
Electricity	12,500	30,000	30,000	17,500
Total common hatchery costs	15,650	33,150	33,150	17,500
Sea site & General				
Regulation 6-ha seasite	340	309	309	309
Van Lease	1,625	3,900	3,900	2,275
Depreciation	10,719	25,726	25,726	15,007
Diving	1,600	3,200	3,200	1,600
Protective clothing	1,000	1,000	1,000	0
Repairs/maintenance	600	1,800	1,800	1,200
Audit and accounts	0	1,000	1,000	0
Insurance	2,000	2,000	2,000	0
Telephone/postage	750	1,800	1,800	1,050
Total common sea site costs	18,634	40,734	40,734	21,440

Table 7 Summary cash flow statement for a 100-tonne *Laminaria digitata* grow-out farm and hatchery unit including capital budgets and grants. Costs common to all scenarios:

3 Year Projections	5 mths to Dec-10	Year 2 Dec-11	Year 3 Dec-12	7 mths to Jul-13
Cash Out				
Hatchery				
Insulated room plus equipment	8,500	0	0	0
Autoclave	14,000	0	0	0
Microscope	1,500	0	0	0
Precision balance	1,500	0	0	0
Pipework	2,000	0	0	0
Tankage	14,000	0	0	0
UV steriliser	1,000	0	0	0
Glassware	1,500	0	0	0
Fluorescent tubes	2,000	0	0	0
Nutrients	750	750	750	0
Collectors	2,400	2,400	2,400	0
Electricity	12,500	30,000	30,000	17,500
Total common hatchery costs	61,650	33,150	33,150	17,500
Sea site & General				
Regulation 6ha seasite	340	309	309	309
Van Lease	1,625	3,900	3,900	2,275
Diving	1,600	3,200	3,200	1,600
Protective clothing	1,000	1,000	1,000	0
Repairs/maintenance	600	1,800	1,800	1,200
Audit and accounts	0	1,000	1,000	0
Insurance	2,000	2,000	2,000	0
Telephone/postage	750	1,800	1,800	1,050
Total common sea site costs	7,915	15,009	15,009	6,434

Labour costs in the hatchery are associated with work on seeding collectors, and represent the greatest monetary outlay for the hatchery, apart from the initial capital costs. One full-time and one part-time worker are allowed for. When scallop cultivation is added for Case Studies 3 and 4, two full-time workers are required for the hatchery. At sea, the major costs are associated with labour (one part-time worker) and with hiring a vessel and skipper for the initial establishment of the grow-out units, and the annual deployment of seeded collectors and subsequent harvest of material. These costs are reduced, however, when the seaweed is grown out using and sharing an existing mussel farm set-up. The necessary vessels for this work are available around the coast on mussel and salmon farms. It is more effective to hire this equipment than it is to purchase it. ‘Diving’ is required for the placement of the sea structures and ‘Repairs and maintenance’ refers to both the hatchery and the sea site.

In the analysis two potential sales prices for *Laminaria digitata* are used, €1/kg and €2/kg, and, in the scallop hatchery examples, a price of €0.05 per scallop spat is applied.

The capital items are grant supported at 40%. For illustrative purposes, the remaining funding is sourced from bank loan arrangements. In this regard a loan term loan over ten years in envisaged. The interest cost indicated is commercially available at the current time.

The financial analysis starts from August in Year 1 and runs until July of Year 4. This allows three full growth cycles of seaweed. All the required hatchery work takes place during the latter part of the year and, for all the scenarios studied, it is during the last 5 months of Year 1 that there will be the greatest monetary outlay and there will be no income.

Taking the scenarios in turn, the farm in Case Study 1 performs poorly. Table 8 sets out a summary profit and loss statement using the two potential sales prices for *Laminaria* (€1/kg and €2/kg) and Table 12 contains the summary cash flow statements. At a sales value of €1/kg, the venture is loss making for all three years analysed. At a sales value of €2/kg, the profit and loss statement shows a small positive balance in Year 3, and a healthy profit is demonstrated in the 7 months to July of Year 4. The cash flow (Table 12) shows the large cash outlay required in Year 1 to buy the 32 grow-out grids (€84,128). The cash flow is positive from Year 2 at €2/kg, but is only marginally positive by Year 4 at €1/kg.

Table 9 shows the profit and loss statements for Case Study 2, and Table 13 the corresponding cash flow statements. When the grow-out of seaweed is combined with a mussel farm there is a reduction in the total overheads because of reduced costs for labour and vessel/skipper hire, together with lowered bank interest charges. These savings result from the sharing of manpower and vessel time between the mussel farm and the seaweed farm. In addition, the very costly outlay on the 32 grids is avoided completely, which reduces bank borrowings. Nevertheless, the undertaking is still loss making until Year

4 at €1/kg, but it performs significantly better at a sales price of €2/kg. Mussel longlines are ideal for growing seaweed, and they are located in near- shore licensed areas that are suitable for both seaweed and mussel growth.

Tables 10 and 14 show indicative profit and loss and cash flow statements for Case Study 3. In this analysis, the potential profit in carrying out both scallop and seaweed cultivation in the same new hatchery is examined. Table 3 sets out a scheme for the combined seaweed / scallop hatchery work programme. Hatchery work for scallops takes place from February to June with a nursery phase from July onwards, whereas *Laminaria* is worked on in the hatchery from June to October and is deployed to sea in November. The hatchery production capacity is estimated to be 1.5 million juvenile spat per annum. At a nominal €0.05 each, this returns €75,000 to the hatchery each year. The annual cost of consumables to produce 1.5 million scallop is estimated at €3,000 to include algae, culture bags, netlon mesh, green and white bags. Extra labour is also allowed for, bringing the total hatchery labour to two full time persons (€80,000 in total). The indicative cash flows are much improved by the revenue from the scallop production. Profit is achieved in Year 2 at a sale price of €2/kg for the seaweed and €0.05 for scallop spat, but is delayed until Year 4 at only €1/kg for seaweed.

Case Study 4 is the most attractive and profitable option because it combines the advantages seen in Case Studies 2 and 3 (i.e. a combined scallop and seaweed hatchery with the seaweed grow-out at an existing mussel site). Table 11 presents indicative profit and loss statements and Table 15 contains the cash flow statements. Greater income is realised from the two products, and cost savings are achieved through reduced labour at sea and vessel and skipper hire. Since there is no large monetary outlay for grids, bank interest charges are reduced. These savings are partially offset, however, by the increased costs for labour and consumables in the hatchery. At a sale price of €2/kg for the seaweed, a substantial profit is achieved in Year 2 but, again, profit is delayed until Year 4 at only €1/kg.

Table 8 Summary profit and loss statements for Case Study 1.

3 Year projections	**5 months to Dec-10**	**Year 2 Dec-11**	**Year 3 Dec-12**	**7 months to Jul-13**
Sales				
Total sales at €1/kg	0	100,000	100,000	100,000
Total sales at €2/kg	*0*	*200,000*	*200,000*	*200,000*
COGS - Hatchery				
Common costs	15,650	33,150	33,150	17,500
Labour	25,000	60,000	60,000	35,000
COGS - At Sea				
Common costs	18,634	40,734	40,734	21,440
Labour	10,417	25,000	25,000	14,583
Vessel/skipper hire	8,000	20,000	16,000	8,000
Bank Interest	8,925	21,420	21,420	12,495
Total OH	86,626	200,304	196,304	109,018
Net Profit/loss @ €1/kg	-86,626	-100,304	-96,304	-9,018
Net Profit/loss @ €2/kg	*-86,626*	*-304*	*3,696*	*90,982*

Table 9 Summary profit and loss statements for Case Study 2.

3 Year projections	**5 months to Dec-10**	**Year 2 Dec-11**	**Year 3 Dec-12**	**7 months to Jul-13**
Sales				
Total sales at €1/kg	0	100,000	100,000	100,000
Total sales at €2/kg	*0*	*200,000*	*200,000*	*200,000*
COGS - Hatchery				
Common costs	15,650	33,150	33,150	17,500
Labour	25,000	60,000	60,000	35,000
COGS - At Sea				
Common costs	18,634	40,734	40,734	21,440
Labour	7,500	18,000	18,000	10,500
Vessel/skipper hire	4,000	9,600	7,680	5,600
Bank Interest	5,770	13,848	13,848	8,078
Total OH	76,554	175,332	173,412	98,118
Net Profit/loss @ €1/kg	-76,554	-75,332	-73,412	1,882
Net Profit/loss @ €2/kg	*-76,554*	*24,668*	*26,588*	*101,882*

Table 10 Summary profit and loss statements for Case Study 3.

3 Year projections	**5 months to Dec-10**	**Year 2 Dec-11**	**Year 3 Dec-12**	**7 months to Jul-13**
Sales				
Total sales at €1/kg	0	100,000	100,000	100,000
Scallop spat €0.05	0	200,000	200,000	200,000
Total				
Total sales at €2/kg	*15650*	*33,150*	*33,150*	*17,500*
Scallop spat at €0.05	*25000*	*60,000*	*60,000*	*35,000*
Total				
COGS - Hatchery				
Common costs	15,650	33,150	33,150	17,500
Algae/culture bags/netlon		3,000	3,000	3,000
Labour	33,333	80,000	80,000	46,662
COGS – At Sea				
Common costs	18,634	40,734	40,734	21,440
Labour	10,417	25,000	25,000	14,583
Vessel/skipper hire	8,000	20,000	16,000	8,000
Bank Interest	8,925	21,420	21,420	12,495
Total OH	94,959	223,304	219,304	123,680
Net Profit/loss @ €1/kg	-94,959	-48,304	-44,304	51,320
Net Profit/loss @ €2/kg	*-94,959*	*51,696*	*55,696*	*151,320*

Table 11 Summary profit and loss statements for Case Study 4.

3 Year projections	**5 months to Dec-10**	**Year 2 Dec-11**	**Year 3 Dec-12**	**7 months to Jul-13**
Sales				
Total sales at €1/kg	0	100,000	100,000	100,000
Scallop spat at €0.05		75,000	75,000	75,000
Total	0	175,000	175,000	175,000
Total sales at €2/kg	*0*	*200,000*	*200,000*	*200,000*
Scallop spat at 0.05	*0*	*75,000*	*75,000*	*75,000*
Total	*0*	*275,000*	*275,000*	*275,000*
COGS - Hatchery				
Common costs	15,650	33,150	33,150	17,500
Algae/culture bags/netlon		3,000	3,000	3,000
Labour	33,333	80,000	80,000	46,662
COGS – At Sea				
Common costs	18,634	40,734	40,734	21,440
Labour	7,500	18,000	18,000	10,500
Vessel/skipper hire	4,000	9,600	7,680	5,600
Bank Interest	5,770	13,848	13,848	8,078
Total OH	84,887	198,332	196,412	112,780
Net Profit/loss @ €1/kg	-84,887	-23,332	-21,412	62,220
Net Profit/loss @ €2/kg	*-84,887*	*76,668*	*78,588*	*162,220*

Table 12 Summary cash flow statements for Case Study 1

3 Year Projections	5 mths to Dec-10	Year 2 Dec-11	Year 3 Dec-12	7 mths to Jul-13
Cash In				
Total Cash In at €1/kg	0	100,000	100,000	100,000
Total Cash In @ €2/kg	*0*	*200,000*	*200,000*	*200,000*
Cash Out - Hatchery				
Common costs	61,650	33,150	33,150	17,500
Labour	25,000	60,000	60,000	35,000
Cash Out - At Sea				
Common costs	7,915	15,009	15,009	6,434
32 grow-out structures	84,128	0	0	0
Bank Interest	8,925	21,420	21,420	12,495
Labour	10,417	25,000	25,000	14,583
Vessel/skipper hire	8,000	20,000	16,000	8,000
Total Cash Out	206,035	174,579	170,579	94,012
Net Cash @ €1/kg	-206,035	-74,579	-70,579	5,988
Net Cash @ €2/kg	*-206,035*	*25,421*	*29,421*	*105,988*
Capital Income	0	0	0	0
Long term loan	154,584	0	0	0
Capital Grants	51,451	0	0	0
Opening Bank @ €1/kg	-206,035	0	-74,579	-145,157
Closing Bank @ €1/kg	0	-74,579	-145,157	-139,169
Opening Bank @ €2/kg	*-206,035*	*0*	*25,421*	*61,888*
Closing Bank @ €2/kg	*0*	*25,421*	*61,888*	*167,876*

Table 13 Summary cash flow statements for Case Study 2.

3 Year Projections	5 mths to Dec-10	Year 2 Dec-11	Year 3 Dec-12	7 mths to Jul-13
Cash In				
Total Cash In at €1/kg	0	100,000	100,000	100,000
Total Cash In @ €2/kg	*0*	*200,000*	*200,000*	*200,000*
Cash Out - Hatchery				
Common costs	61,650	33,150	33,150	17,500
Labour	25,000	60,000	60,000	35,000
Cash Out - At Sea				
Common costs	7,915	15,009	15,009	6,434
32 grow-out structures	0	0	0	0
Bank Interest	5,770	13,848	13,848	8,078
Labour	7,500	18,000	18,000	10,500
Vessel/skipper hire	4,000	9,600	7,680	5,600
Total Cash Out	111,835	149,607	147,687	83,112
Net Cash @ €1/kg	-111,835	-49,607	-47,687	16,888
Net Cash @ €2/kg	*-111,835*	*50,393*	*52,313*	*116,888*
Capital Income	0	0	0	0
Long term loan	92,835	0	0	0
Capital Grants	19,000	0	0	0
Opening Bank @ €1/kg	-111,835	0	-49,607	-97,294
Closing Bank @ €1/kg	0	-49,607	-97,294	-80,406
Opening Bank @ €2/kg	*-111,835*	*0*	*50,393*	*102,706*
Closing Bank @ €2/kg	*0*	*50,393*	*102,706*	*219,594*

Table 14 Summary cash flow statements for Case Study 3

3 Year Projections	5 mths to Dec-10	Year 2 Dec-11	Year 3 Dec-12	7 mths to Jul-13
Cash In				
Total Cash In at €1/kg	0	100,000	100,000	100,000
Scallop spat €0.05		75,000	75,000	75,000
Total	0	175,000	175,000	175,000
Total Cash In @ €2/kg	*0*	*200,000*	*200,000*	*200,000*
Scallop spat €0.05	*0*	*75,000*	*75,000*	*75,000*
Total	*0*	*275,000*	*275,000*	*275,000*
Cash Out - Hatchery				
Common costs	61,650	33,150	33,150	17,500
Algae/culture bags/netlon		3,000	3,000	3,000
Labour	33,333	80,000	80,000	46,662
Cash Out - At Sea				
Common costs	7,915	15,009	15,009	6,434
32 grow-out structures	84,128	0	0	0
Bank Interest	8,925	21,420	21,420	12,495
Labour	10,417	25,000	25,000	14,583
Vessel/skipper hire	8,000	20,000	16,000	8,000
Total Cash Out	214,368	197,579	193,579	108,674
Net Cash @ €1/kg	-214,368	-22,579	-18,579	66,326
Net Cash @ €2/kg	*-214,368*	*77,421*	*81,421*	*166,326*
Capital Income	0	0	0	0
Long term loan	162,917	0	0	0
Capital Grants	51,451	0	0	0
Opening Bank @ €1/kg	-214,368	0	-22,579	-41,158
Closing Bank @ €1/kg	0	-22,579	-41,158	25,168
Opening Bank @ €2/kg	*-214,368*	*0*	*77,421*	*158,842*
Closing Bank @ €2/kg	*0*	*77,421*	*158,842*	*325,168*

Table 15 Summary cash flow statements for Case Study 4

3 Year Projections	5 mths to Dec-10	Year 2 Dec-11	Year 3 Dec-12	7 mths to Jul-13
Cash In				
Total Cash In at €1/kg	0	100,000	100,000	100,000
Scallop spat €0.05		75,000	75,000	75,000
Total	0	175,000	175,000	175,000
Total Cash In @ €2/kg	*0*	*200,000*	*200,000*	*200,000*
Scallop spat €0.05	*0*	*75,000*	*75,000*	*75,000*
Total	*0*	*275,000*	*275,000*	*275,000*
Cash Out - Hatchery				
Common costs	61,650	33,150	33,150	17,500
Algae/culture bags/netlon		3,000	3,000	3,000
Labour	33,333	80,000	80,000	46,662
Cash Out - At Sea				
Common costs	7,915	15,009	15,009	6,434
32 grow-out structures	0	0	0	0
Bank Interest	5,770	13,848	13,848	8,078
Labour	7,500	18,000	18,000	10,500
Vessel/skipper hire	4,000	9,600	7,680	5,600
Total Cash Out	120,168	172,607	170,687	97,774
Net Cash @ €1/kg	-120,168	2,393	4,313	77,226
Net Cash @ €2/kg	*-120,168*	*102,393*	*104,313*	*177,226*
Capital Income	0	0	0	0
Long term loan	101,168	0	0	0
Capital Grants	19,000	0	0	0
Opening Bank @ €1/kg	-120,168	0	2,393	6,706
Closing Bank @ €1/kg	0	2,393	6,706	83,932
Opening Bank @ €2/kg	*-120,168*	*0*	*102,393*	*206,706*
Closing Bank @ €2/kg	*0*	*102,393*	*206,706*	*383,932*

Cost structure and Sensitivity Analysis

It is clear from these analyses and from Table 16 that the opportunity for profit lies in increasing the sales price above €1/kg and/or including an alternative income stream from sales of scallop spat (€0.05 each). The scenarios presented show substantially improved cash flows at €2/kg wet weight of product. Any economies of scale to be achieved by increasing the size and capacity of the farm are likely to be in the costs of labour both in the hatchery and at sea, and in the co-use of vessels, in particular where a combined mussel / seaweed farm type activity is carried out. It is unlikely that many other economies will be found as additional scale will result in a proportionate increase in costs for capital items, such as the bespoke grow-out seaweed grids and associated moorings. In the hatchery, increased capacity will require additional containerised hatchery units plus associated fit-out costs, together with extra costs for electricity and consumables.

Table 16 Sensitivity analysis: 3-year break-even point for *Laminaria digitata* (fresh weight) under Case Studies 1-4.

Case Study	Description	Break even price (€/kg)
1	Seaweed hatchery and grow out farm	€2.15
2	Seaweed hatchery and existing mussel site	€1.65
3	Seaweed and scallop hatchery and grow out farm	€1.63
4	Seaweed and scallop hatchery and existing mussel site	€1.12

5.4 Primary processing of Product

Drying *Laminaria digitata* costs about €150/tonne of dried seaweed product, if a contract type arrangement is entered into. For those wishing to invest in the technology required, a 12.19-m container including humidistat, fans and heaters is costed at €10,000-€12,000 plus VAT. Appropriate premises would also need to be acquired as well, where seaweed deliveries can be received and the product is handled.

A dehumidifier costs approximately €3,000 plus VAT, which may or may not be necessary for the dryer. The running costs for the unit are calculated at €10/hour for a three phase generator or €7.50/hour for three phase mains power.

As an example of capacity, 2 tonnes of product should dry to 10-15% moisture in 6-10 hours. Therefore the total running cost would be €60-€100 using a three phase generator, or €45-€75 using three phase mains power. Two tonnes of wet weight product will yield .2-.3 tonnes of dry product which will be worth €2,000-€3,000 assuming €10-16/kg.

In the 100-tonne farm model developed above, it is possible therefore to estimate that the running costs of drying 100 tonnes of *Laminaria* in a unit with a 2-tonne capacity will be €3,000-€5,000 using the generator or €2,250-€3,750 using mains power. This cost is realised over the period of product harvest which for *Laminaria* is the period March to April.

6 Economic assessment of tank cultivation of *Palmaria*

A preliminary assessment has also been conducted of the economics of the type of tank cultivation of *Palmaria* that was investigated in the last few months of the project. The approximate costs of the capital equipment required have been assembled, and the electricity demands estimated for farms with either 40 or 80 tanks of 1000 litres (Table 17).

Table 17 Estimates of costs of establishing and running a farm for cultivation of *Palmaria palmata* on land with either 40 or 80 tanks.

Capital costs €	Unit cost	40-tank total	80-tank total
Tanks, 1000 L, polyethylene	254	€10,164	€20,328
Ball valves, 2 cm	18	€720	€1,440
Aerators	6	€240	€480
Air blower: BBC	960	€960	
Air blower: Rieschle			€1,450
Submersible seawater pump	800	€800	€800
Pipework	300	€300	€600
Joints, glue, sundries	200	€200	€400
Switch gear (installed)	300	€300	€300
Shading net (50 m2)	120	€120	€240
Total capital cost		€13,804	€26,038
Depreciation (20%/year):		€2,761	€5,207
Electricity costs (€):	Rating (kW)	Cost/year	Cost/year
Seawater pump (40% of time)	1.50	€778	€778
Air blower: BBC	0.85	€1,102	
Air blower: Rieschle	1.50		€1,944
Total running costs		€1,879	€2,722
Running + depreciation costs (€/year):		€4,640	€7,929

The production to be expected from a 40-tank farm has been estimated from the data obtained in the project , and from the experiences of Klaus Lüning at Sylter Algenfarm in Denmark. The maximum growth rate observed was 2 kg fresh weight m^{-2} 14 $days^{-1}$, and this value is in close agreement with the general observation at Sylter Algenfarm that, at a stocking density of 4 kg m^{-2}, *Palmaria* doubles in weight every 4 weeks (i.e. the growth rate is 4 kg m^{-2} $month^{-1}$). If this rate can be maintained throughout the year, the annual production will be 48 kg m^{-2}, and the total production from 40 tanks will be 1,920 kg.

The current value of wet *Palmaria* in Ireland is €2.50 per kg (see Section 4.5), so that the total value of full production from a 40-tank farm would be €4,800. Although this return would be just enough to cover the electricity costs and the depreciation on the equipment (20% of value per year), there would be very little left over

(€160 per year) to pay anyone to do the work of harvesting the *Palmaria* and maintaining the tanks. Consequently, if it were to be economic, the farm would need to have more than 40 tanks, and the final column of Table 17 shows the capital and running costs for 80 tanks. A more powerful air blower would be needed, with a consequent increase in both capital and running costs. Although the total production would be 3,840 kg with a value of €9,600, giving an excess over running and depreciation costs of nearly €1,671, this is still not enough to cover a significant amount of labour. Further increases in the number of tanks would require a considerable area of land, so that the rent might add significantly to the costs.

An alternative approach, as with all seaweed species, is to try to obtain a higher value for the cultivated material. A small company in northern Spain (Cultivos Marinos del Cantábrico) started to sell *Palmaria* directly into restaurants in 2000 and was able to demand at least 5 times the price that was being paid in Ireland at that time. A similar strategy of obtaining a premium price by selling directly to restaurants is currently operated by Sylter Algenfarm. Such prices would clearly transform the prospects for tank cultivation of *Palmaria* (or any other similar seaweed) at the scale envisaged here.

7 Conclusion

The new seaweed farm (*Laminaria digitata*) must target its sales price at the higher end, for example €2+/kg wet weight product, in order for there to be profitability in the undertaking, otherwise it is necessary to consider a combination hatchery producing a comparatively valuable bivalve such as scallop. The model presented here shows a very simple but practical hatchery design and a grid structure for grow-out at sea. Using the techniques perfected in this project, the analysis shows the costs associated with setting up and running a 100-t *Laminaria* farm.

The question is what price the market can bear. The price for wet weight product (say €2/kg) is the same as the price for the equivalent dry weight of product at 15% yield, (say €10/kg-€16/kg). In order to seek cost recovery as early as possible, it is obvious that the farmer should attempt to sell his product at the raw material stage. Evidence shows that there is little point in investing in more infrastructure to dry the product when there is no inherent gain. That is of course also assuming that the buyer is willing to dry the product himself.

So a farmer with 100 t of *Laminaria* at €2/kg has an annual product worth €200,000 to sell. The market for product at this price is relatively small. Irish market research shows that there are specialist products in the areas of human specialist nutrition, medicine and functional foods where promoters have shown interest in high quality farmed seaweed at prices of €1+/kg of wet product. In such cases, the market is looking specifically for a clean, fast grown frond from a reliable source in a farmed environment. The market is prepared to pay a premium price because the product they are preparing is highly specialized and exceptionally valuable. Now that a methodology for seaweed culture for *Laminaria digitata* has been perfected, the market for this species can develop with some confidence. For *Palmaria palmata*, it seems that there is more work to do in terms of further perfecting hatchery techniques to allow a year-on-year consistent production result. Tank cultivation of *Palmaria*, at least on a modest scale, seems to offer a greater potential for an economic return.

8 References

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