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Prospective Analysis of the Aquaculture Sector in the EU

PART 2: Characterisation of emerging aquaculture systems

Helen Sturrock, Richard Newton, Susan Paffrath, John Bostock, James Muir, James Young, Anton Immink & Malcom Dickson

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PART 2: Characterisation of emerging aquaculture systems

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Executive Summary

This report is based on the outcome of the study on "Prospective analysis of the aquaculture sector in the EU", launched and coordinated by the JRC (IPTS) and carried out by the University of Stirling. The report consists of two parts:

1) "Prospective analysis of the aquaculture sector in the EU – Part 1: Synthesis report", and
2) "Prospective analysis of the aquaculture sector in the EU – Part 2: Characterisation of emerging aquaculture systems"

This second report is concerned with the identification and characterisation of emerging aquaculture systems. The overall aim of the study is to provide a detailed analysis of how the EU aquaculture sector may respond to the many challenges and pressures faced with respect to economic, social and environmental issues, technological changes etc. As has been the case in the past, these challenges may lead to the emergence of new approaches, products and in the widest sense, aquaculture systems. The degree and possible directions of development of these "emerging systems" will be influential for the future of the EU aquaculture sector. This report aims therefore to provide greater technical detail on emerging aquaculture systems, and has also fed to the development of the synthesis report (Part 2). It follows a format in which we:

- Provide detailed descriptions of the technologies, European overviews, detailed country perspectives, technical and financial feasibility, drivers and barriers, environmental impacts and prospects for each system.
- Give a brief overview of the drivers and barriers to emerging aquaculture systems including a discussion on economic viability/profitability, on technical/biophysical constraints and on market issues.
- Develop conclusions.

The study was conducted between January 2006 and November 2007, the data collection taking place in the early stages followed by the analysis in the later stages.

Policy context

The Common Fisheries Policy (CFP) covers the fishing and aquaculture sectors including the processing and marketing of fisheries products. Since the late '70s, Community intervention in aquaculture (mainly through research and investment aid measures) has stimulated production growth, but recently this was changed, as overproduction is perceived as a threat for some branches.

The Commission developed a strategy in 2002 based on a ten-year vision for the sustainable development of the aquaculture sector in recognition of its importance in the framework of the reform of the Common Fisheries Policy[1]. The strategy identified a number of actions to be taken at different levels (Community, Member States, economic operators). Actions identified at EU level mainly consist of creating

1 "Strategy for the Sustainable Development of European Aquaculture", COM (2002) 511 final.

a support framework to encourage the sustainable development of aquaculture (through fisheries structural funds), stimulating research and innovation (through Community Research Programmes), while establishing a regulatory context which ensures a high level of environmental consumer and animal protection.

The 2002 strategy set a target to increase annual production growth from 3.4% to 4% per year, mainly as a means to the creation of new jobs in the aquaculture sector (for the period 2003-2008). Therefore, an increase in aquaculture production was still envisaged, but Community financial support was to focus on new market outlets, species diversification and environmentally friendly production.

Structural assistance to the fisheries and aquaculture sectors in Europe has been mainly provided through the Fisheries Instrument for Fisheries Guidance (FIFG), recently replaced by the European Fisheries Fund (EFF)[2] covering the period 2007-2013. The central objective of this instrument is to ensure sustainable fisheries and diversify economic activities in fishing areas. One main focus is on aquaculture, processing, and marketing of fisheries/aquaculture products, aiming at guiding and facilitating restructuring, particularly at balancing supply and demand while securing long-term employment, environmental protection and product safety and quality.

To take stock of progress made so far and to explore the need for any potential follow-up actions, the Commission launched a debate in 2007 with all stakeholders on the further development of sustainable aquaculture in the European Community.[3]

Emerging systems and emerging practices

The difficulty with aquaculture (in comparison to other sectors, such as agriculture) is that, with its short and dynamic history, very few systems can be described as mainstream. Nevertheless, it is possible to discriminate between mainstream systems, those used by the majority of the industry for some time, and relatively new techniques or practices that have progressed beyond the research stage and are starting to be applied on a commercial scale. These emerging systems may be new species, new farming systems or different approaches towards marketing aquaculture products. Although the word 'system' implies a completely new set of practices, this is not necessarily the case - the novel approach may only affect one aspect of that system.

There are also a number of new trends that are finding increasing applications across a range of aquaculture sectors. Emerging practices such as the increasing use of vaccines for disease control would not qualify as 'systems' but may have a profound impact on the viability of an aquaculture system.

Another important feature of an emerging system should be that it holds considerable potential for further development – there is little point in committing resources to developing systems that will always be limited in scale or applicability. On the other hand it is important to include 'niche market' systems which will be important in the European context.

2 Council Regulation (EC) No 1198/2006
3 http://ec.europa.eu/fisheries/cfp/governance/consultations/consultation_100507_en.htm

Offshore systems

Much has been made of the potential for development of offshore aquaculture systems and these systems are already in use in Ireland and Norway for salmonids and in Spain, Portugal, Malta, Greece and Cyprus for sea bass, sea bream and tuna. Major growth of the sector is being seen in Cyprus and Italy whereas offshore production has been fairly static in other producing countries. There is a wide range of systems available and the technology can be used for the production of an increasing number of species.

The major drawback for offshore systems is high capital and operating costs compared to inshore sites. Cage and mooring system designs need to be more robust, larger service vessels are required, SCUBA divers are often involved in regular maintenance operations and the distance from shore base to the farming site adds extra transport costs. This means that offshore production systems cannot compete directly on price with fish produced at inshore sites. On the other hand, the relative difference in costs shrinks at larger sites and where all the available inshore sites have been allocated, offshore production provides a clear option for development.

Because the scale of development has a clear impact on feasibility, and it carries significant risks, offshore developments will probably only be carried out by companies that have already been involved in large-scale aquaculture production. It would be difficult to forsee openings for SME companies in future developments. Fish sale price will also have a major impact on the profitability of offshore systems. At the minimum sale price for salmon in recent years a new system would not have been viable, whereas more recent higher prices would suggest an enterprise of this type could be very profitable.

The main drivers for the establishment of offshore systems appear to be the shortage of available inshore sites and increasingly strict environmental legislation. In some cases this is because inshore sites have already been developed – in others there are official policies to separate aquaculture production from competitive uses for coastal zones such as tourism.

In summary, offshore aquaculture appears to have a bright future, if only because there are few other tried and tested options for substantially increasing aquaculture production. The key to its future development will be production scale, achieving competitive cost of production and product prices – if growth in demand outstrips supply from inshore systems, prices will tend to rise and offshore systems should be increasingly viable.

Recirculation systems

A wide range of recirculation systems have been developed for an equally wide range of species however commercial fish production using these systems has been fairly limited - only around 20,000 tons/annum in the EU25 + Norway compared to around 500,000 tons/annum from cage farming in Norway alone.

Experiences with recirculation systems have been mixed. They generally require a high degree of management expertise, have higher capital and operating costs compared to conventional farms and involve greater risks – a major system failure can very rapidly lead to the loss of the entire stock of fish. On the other hand, they make very efficient use of available water supplies and allow fish to be grown in optimal conditions in close proximity to potential markets. There have been minor booms in enthusiasm for recirculation systems over the years for relatively high value species such as salmon smolts, eels and turbot. Other farms have concentrated on species that perform exceptionally well in recirculated systems such as tilapia and catfish. Despite a relatively long history, proponents of recirculation technologies have found it difficult to sell the concept to large-scale fish producers. Environmental groups, particularly in the US and Canada, have frequently suggested that aquaculture production should be shifted from cage sites to land-based recirculation farms so that aquaculture pollution from be better managed. However, little research has been conducted into likely consumer responses to recirculated systems if they were to become more prevalent.

The financial feasibility model used in this study shows that a 120 ton/yr turbot farm should be viable, however this is at a fish sale price of €9.39/kg whereas salmon and trout prices are less than half this. For the main aquaculture species it is much harder for recirculation systems to compete with conventional production systems. However, recirculation systems offer a flexible way for niche producers to supply specialist, high value markets. There is also scope for further technical and cost optimisation as well as scale economies that could lower the barriers to adoption slightly.

Integrated systems

Although integrated systems offer the prospect of more efficient use of resources, the development of commercial systems is still at an early stage. The few commercial fish farms that have already embraced the concept of integrated production are still at a pilot-scale level and appear to value it more on ideological grounds than the purely financial point of view.

It remains to be seen whether integrated systems will develop into a significant sector in Europe. There appear to be legislative barriers to its adoption in some countries, potential risks concerning market image, and a reluctance on the part of some commercial fish farmers to accept that it may have a serious role to play in the future.

Certification systems

There has been tremendous growth in the range of labelling and certification systems used for aquaculture products in recent years. This mirrors trends in the overall food sector with consumers being offered greater choice and more information than ever on the source, attributes and quality of their purchases. In particular sectors, such as organically certified salmon, production has not been able to keep up with demand, however there is also evidence that the plethora of labelling and certification systems has left consumers confused. Producers need to weigh up the substantial actual costs and opportunity costs involved in producing specialist certified products against the potential increase in prices that they might obtain when they are fully certified. At present, very few large producers appear to be convinced that organic certification is worth pursuing. However a number of small, very committed producers clearly think it is worthwhile, and some larger producers have designated one or more organic production sties. More general certification systems are being applied to many other aquaculture products and this is likely to increase in the future.

Emerging species

European commercial aquaculture production is based on relatively few major species, although a wide range of species have been tested at experimental or pilot scales. The most significant developments in recent years have been the growth of marine finfish aquaculture in northern Europe and Norway to levels where cod and halibut farming could start to make a significant impact on markets, and the growth of tuna fattening in southern Europe. The sustainability of tuna fattening is questionable as it depends on severely depleted wild-caught stocks and wasteful feeding practices. The industry has grown due to the strength of the Japanese market which may not be sustained.

There are new possibilities for marine finfish farming in southern European waters through the development of farming systems for species such as meagre. The key requirement for new species development is a ready market for the product and this is a constantly changing factor. In some cases, markets are likely to improve as wild fisheries come under increasing pressure. In other cases, aquaculture production will have to fit in with seasonal fluctuations in fish prices.

The level of technical knowledge which is required for new species development should not be underestimated. Each new species presents a new suite of issues that must be investigated – not just feed and breeding requirements but more complex issues such as disease challenges and possible environmental impacts of large scale farming of that particular species.

The pressure to identify new species for aquaculture has also grown because regulatory authorities have become more worried about introducing new species or even new genetic strains of species from other geographical locations. These factors mean that research into new species development will continue, although market forces will determine which of these species can be developed into commercially viable industries.

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1 Introduction

This aim of this report is the identification and characterisation of emerging aquaculture systems. This report has fed to the development of the Part 1 report, but is also meant to serve as a technical reference on its own.

Emerging systems are defined as relatively new techniques or practices that significantly alter the production process and/or product that is marketed. They will also have progressed beyond the research stage and are being applied commercially, although not yet extensively. The main emerging systems identified are offshore cage systems, recirculation systems, integrated systems, certified production systems and individual emerging species. The study also considered culture based fisheries and ornamentals (briefly discussed in the Part 1 report), but there was insufficient evidence to suggest that these were 'emerging' in the EU at present. The report also considers the role that wider, cross-sectoral 'emerging practices' play in the development of the EU aquaculture industry.

1.1 Content of report

The report is organised under main system headings, sub-headed with descriptions of the technologies, European overviews, detailed country perspectives, technical and financial feasibility, drivers and barriers, environmental impacts and prospects for each system.

Section 2, offshore systems, looks in detail at current and future technologies for use in more exposed environments. Country by country information describes current production status in Europe, followed by analysis of technical feasibility. The financial feasibility of an offshore salmon farm is explored, including sensitivity analysis for key variables such as sale and feed prices. The drivers and barriers of this emerging system are considered by country, followed by a look at the environmental impacts of offshore production and its prospects for the future.

Section 3, recirculation systems, explores the emergence of aquaculture production using close to 100% recirculation techniques, and follows a similar pattern to section 2. The related financial analysis looks at both turbot and eel recirculation farms.

Section 4, integrated systems, focuses more on current research as there are limited examples of their commercial use so far in Europe. Country experiences, technical and financial feasibility, drivers and barriers, environmental impacts and prospects are discussed.

Section 5, certification systems, reveals the number and variety of schemes available for certifying seafood production. Organic, environmental, ethical, quality management and other schemes are described, with discussion of situations in European countries. The technical and financial feasibilities of these schemes are explored, with examples of the process and fees involved. Drivers and barriers, environmental impacts and prospects are then addressed.

Section 6, emerging species, explores recent introductions to aquaculture in Europe. Country perspectives are followed by detailed analysis of key species: meagre, common seabream, octopus, bluefin tuna, cod and arctic charr. For each, European status, technical and financial feasibilities, environmental impacts and prospects are discussed. For emerging species in general, drivers and barriers, environmental impacts and prospects are then addressed.

Section 7 addresses the emerging practices identified in Task 1. These are recent advances in aspects of aquaculture production that currently or may potentially have a significant impact on aquaculture in Europe.

Section 8 gives a brief overview of the drivers and barriers to emerging aquaculture systems. It includes a discussion on economic viability/profitability, on technical/biophysical constraints and on the market.

Conclusions of the report are brought together in Section 9.

1.2 Methodologies and approaches

The approach has been to collect information from official sources where available. However this has highlighted the lack of detailed information available at system level. Most countries and official trade bodies collect statistics based on species rather than systems. Hence most information has come from less formal sources; mainly through key contacts in the industry (listed in Section 12 and annotated through the document), and the trade press. The other main source of information has been scientific literature (footnotes).

The aim is to provide sufficient information to support assessments on the prospects of emerging aquaculture systems.

A key challenge in analysing and characterising 'emerging systems' is in defining the features of emergence. Emerging systems may develop incrementally rather than being radically new. For example, plastic circle cages can be used in both sheltered and offshore sites, simply with larger or more robust components. Similarly, the degree of recirculation, and the technology used can vary widely. We have tried to address this by noting key distinctions of emergence.

One of the main factors which might identify whether a system is an 'emerging system' is to compare its pattern of development to the way that other aquaculture sectors have developed in the past. The comparatively short history of aquaculture however does not always provide a suitable comparison and thus may demand that similarities are drawn from other land-based food production systems. Growth of most aquaculture sectors appears to follow an S-shaped curve starting with a period of relatively slow growth, followed by rapid expansion and levelling off when either resource limitations make further expansion difficult or market forces mean that profit margins are eroded making it less attractive to new investors. Emerging systems should be on the early part of the development curve. However as with any emergent system or innovation, estimating future benefits (and costs) and thus potential adoption rates is fraught with difficulty not least to the probability of change in alternative and competing choices.

While the aim was to be as comprehensive as possible, ensuring the inclusion of most relevant emerging systems, the coverage is not exclusive (especially on emerging species and practises); moreover it was not possible to obtain the same level of detail for all of the emerging systems because of the varying degree of available information.

2 Offshore systems

2.1 Overview

Aquaculture based on net pens suspended from floating collars (gravity cages) have become the predominant system for marine fish culture in Europe. Cages have become larger as the industry has developed, and designs and the materials used have also evolved. Early cages used wooden collars with polystyrene buoyancy. The next generation were predominantly steel, which was stronger and allowed larger cages to be constructed. As simplicity and cost became more important, circular cages based on plastic pipes were developed and have since become the most common. These are generally deployed in sheltered locations such as fjords (Norway), sea lochs (Scotland) and protected bays, where their presence has often been questioned, due to concerns for local environments or visual and leisure amenity values. It is argued that moving aquaculture offshore would reduce such problems and enable operators to increase scale and efficiency. It is widely proposed that any further expansion of marine aquaculture should only take place in offshore sites.

The primary approach to more remote sites has been to use larger and potentially more robust versions of inshore cages, primarily steel, plastic pipe, or using much more resilient rubber hose. Experience to date has been variable[4]; systems have been expensive, but not rigorously definable in performance. A fundamental design factor is simple to define expected operating conditions. Offshore systems can be classified with respect to a number of environmental and operational parameters, as illustrated in the following table.

Each of these are important factors, and set important design characteristics with respect to cage systems and ancillaries. In more recent literature (e.g. Ryan, 2004) there has been a particular emphasis on wave height as a key defining factor, particularly as it enables the simple classification of sites that are considered intermediate between fully inshore and fully offshore (Illustrated in Figure 2-1).

Classification systems based on 4 or 5 divisions have been proposed.

4 Offshore cage systems: A practical overview. Scott, D. & Muir, J. CIHEAM, 2000

Table 2.1 Comparative characteristics of inshore and offshore aquaculture sites

Characteristics	Coastal (inshore)	Offshore aquaculture
Location/hydrography	0.5 – 3 km; 10-50 m depth; within sight, usually at least semi-sheltered	2+ km; generally within continental shelf zones; possibly open ocean
Environment	Hs <= 3-4 m, usuall <= 1 m; short period winds; localized coastal currents, possibly strong tidal streams	Hs 5 m or more, regularly 2-3 m; oceanic swells, variable wind periods; possibly less localized current effect
Access	>= 95% accessible on at least once daily basis; landing usually possible	Usually >80% accessible; landing may be possible, periodic, e.g. every 3-10 days
Operation	Regular, manual involvement, feeding, monitoring etc.	Remote operations, automated feeding, distance monitoring, system function

Source: Muir & Basurco, 2000.

Figure 2.1 Classification of offshore aquaculture sites based on site exposure[5]

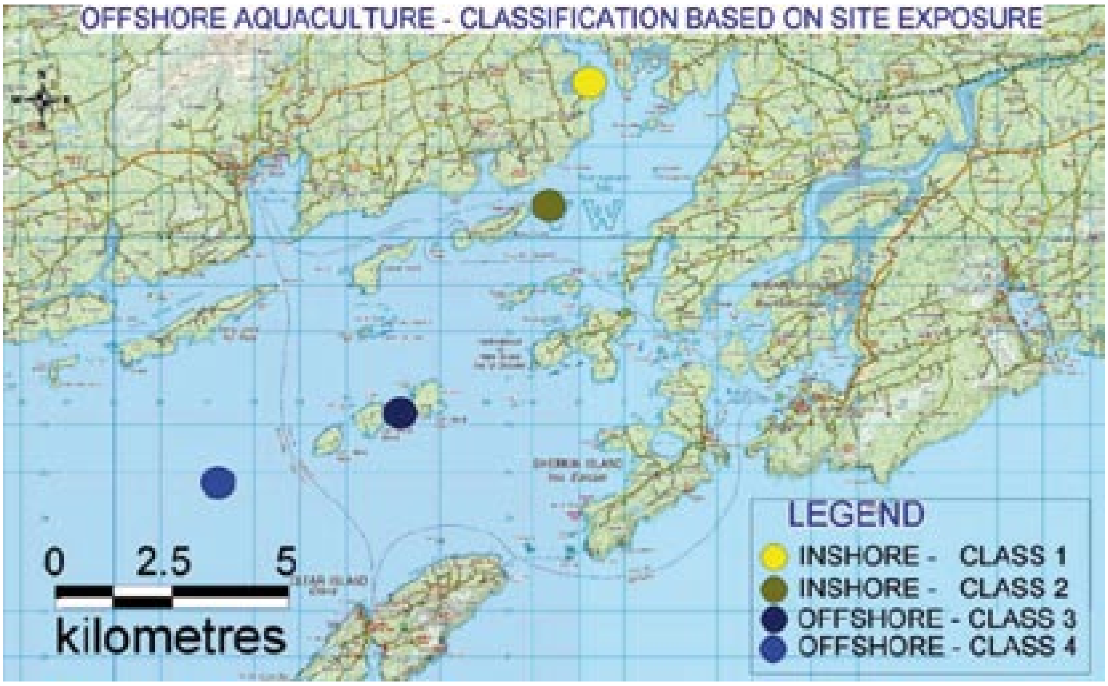


Table 2.2 Site classification by significant wave height

Site class	Significant wave height[6] (m)	Degree of exposure
1	<0.5	Small
2	0.5-1.0	Moderate
3	1.0-2.0	Medium
4	2.0-3.0	High
5	>3.0	Extreme

Source: Ryan, 2004 t

Increasing exposure tends to imply greater average wave heights and more severe sea conditions during storms and high winds. Currents may also be higher in exposed locations.. However, in some places, more open sea conditions may be less demanding in terms of wave height, and may have lower current velocities than near-shore environments, but will be more challenging with respect to depth or other variables.

The primary issue for offshore cage design is therefore to ensure robust structures and operating systems that can maintain integrity and function in high-energy environments and keep the stock safe and secure. The system should facilitate routine husbandry and maintenance operations under most sea conditions. More generally, offshore production requires to be designed as a complete system, covering all aquaculture functions effectively and reliably, to be feasible.

For the purposes of this report, current offshore systems are those that typically fall into exposure classes 3 or 4 (or 4 and 5) , but future systems may be more closely defined by strategic location and design choices. Hence there is no point in developing a highly robust and expensive system to meet localised conditions 1 km from a landing point, when those 1 km further, in more open water, are less demanding.

5 Farming the Deep Blue. Ryan, J. 2004. 82pp
6 The average height of the highest one third of waves recorded in a given monitoring period.

Table 2.3 Types of offshore cages

Type of Cage Structure		Example companies/products
Flexible Floating	- Rubber	Dunlop, Bridgestone
	- Plastic	Fusion Marine, Polar Circle, Corelsa, Aqualine etc.
	- Tension leg	Ocean Spar Net Pen
	- Rope/collarless	(None identified in Europe)
Rigid Floating		Pisbarca, Cruive, AquaSystem, Storm Havbruk AS[7]
Flexible Semi-submersible		Refa (and some modified plastic cages)
Rigid Semi-submersible		Farm Ocean, Ocean Spar Sea Station
Rigid Submersible		Sadco, Trident, Marine Industries, Sea Trek

2.2 Offshore technologies

A range of cage systems has been developed for more exposed locations over the last 20 years. This section reviews types of cages currently available and their advantages and disadvantages. These are categorised by structure and flotation features in Table 2.3

2.2.1 Flexible floating cages

Rubber and plastic collar cages

There are 4 main types, the most commonly used structures in offshore aquaculture. Historically, the first cages of this type utilized adapted rubber hoses designed to transfer oil between oil tankers and onshore terminals. The two main systems commercially available are manufactured by Dunlop and Bridgestone. Rubber cages, especially larger ones, can cope with maximum wave heights of 5-8 m and sometimes more.

Bridgestone cages are the most widely used, with over 300 units in operation. They come in a range of shapes; square, hexagonal and octagonal. The flexible rubber hoses are linked by steel corner joints, with upright bars (stanchions) clamped at regular intervals along their length. Owing to the surface dependency of these cages, strength and structural difficulties arise as a result of wave action and impact (Technical Report, Aquatic Resources Division, 1999). The collar's main use is to maintain the shape of the net. The most important feature of the structure is the interface between the net and the collar, where most of the stress is transferred. A float line attached to a trawl net which joins the main cage net below the waterline, carrying the weight of the net and acting as a shock absorber. The cages are in use in Ireland, Spain, Cyprus, Italy and the Faroe Islands. The largest in operation is used to farm Atlantic salmon in Ireland. With a depth of 20m and circumference of 160m, its capacity of 40,000 m^3 can hold some 600-800t of stock at conventional densities[8].

Dunlop cages are mainly in use in the Mediterranean for culture of sea bass and sea bream, and have a similar design to the Bridgestone system. However, they are usually square in shape, and commonly assembled in modules, thereby helping to reduce the hose length and mooring investment per installed volume. Some models have walkway systems mounted at corner joints, which allow hand feeding and observation of fish. Typical configurations are for 16 x 16m square cages with a volume of 2400 m^3 and a depth of 10 m[9]. As with Bridgestone cages, internal float lines are commonly used to support the net.

Circular plastic cages based on HDPE pipes have also been available for 20 years. Design and

7 http://www.tekmar.no/konf04/foredrag/Tore_Haakon_Riple-Marine_Construction.pdf#search=%22Storm%20Havbruk%20AS%20%22

8 Offshore cage systems – a practical overview. Scott, D.C.B. & Muir, J.F. 2000. CIHEAM Options Mediterranees.

9 Op. cit.

Figure 2.2 Rubber cage system flexing with waves at site in Sicily

manufacture have gradually improved and sizes have increased from around 12 m diameter to over 50 m, giving volumes of between 10,000 and 20,000 m³. Up to 3 concentric pipe rings may be used, with upright stanchions for handrail and net attachments. A system is illustrated in Figure 2-3. These systems also use internal float lines. HDPE cages are not quite as flexible as rubber pipe cages, but have proved sufficiently robust for use at sites with maximum wave heights of 4m and sometimes higher. Plastic collar cages therefore compete well with respect to capacity, and have the lowest installation cost per cubic meter. However, their limits with respect to wave height and current speeds are reached sooner than with other offshore designs.

An important consideration with all cage systems is the mooring system and requirements with respect to service vessels, feed systems and other ancillary equipment. Plastic and rubber collar cages do not provide a suitable all-weather work platform for personnel, so many operations must be carried out from service boats or smaller platform areas attached to the pipes. The cages may be moored singly or more usually in a grid arrangement, optimising anchor and float usage.

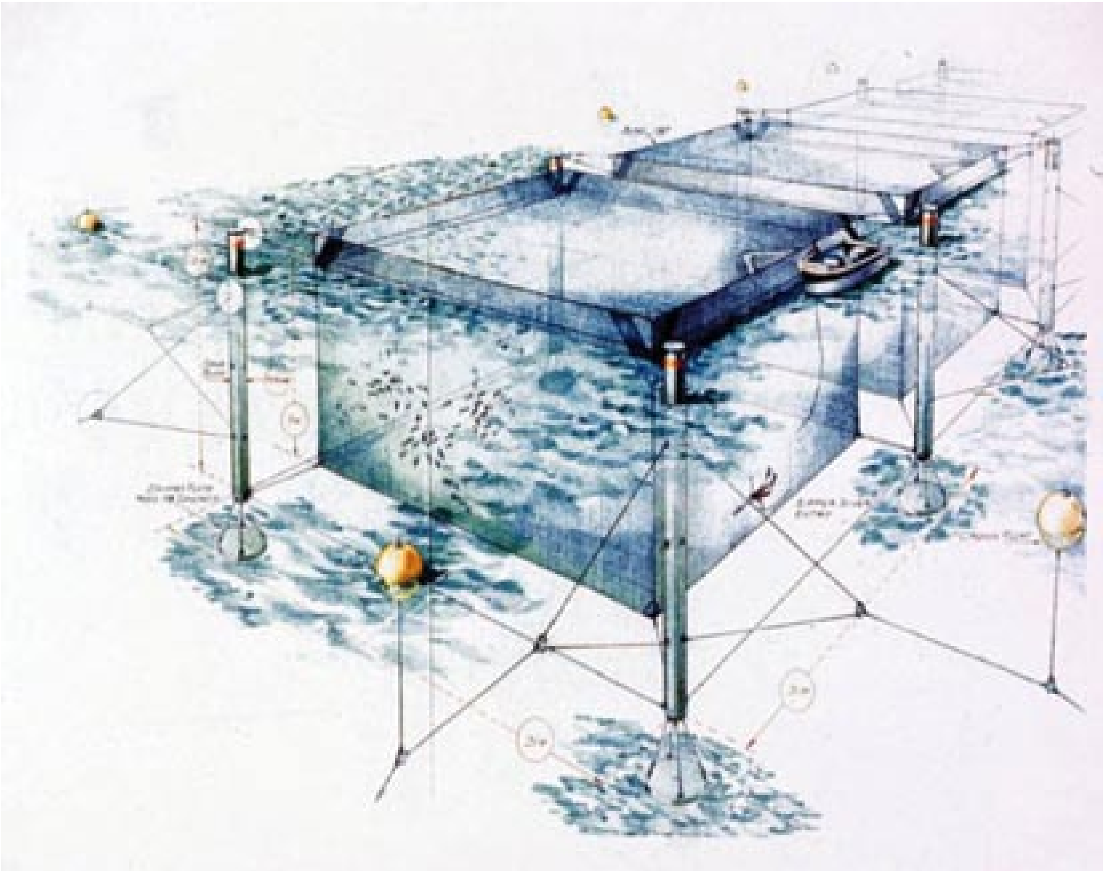
Figure 2.3 Specialised work boat operating a feed cannon on a plastic collar cage in Norway[10]

10 Farming the Deep Blue. Ryan, J. 2004. 82pp

Table 2.4 Advantages and disadvantages of flexible floating cage systems[11]

Advantages	Disadvantages
Highly resilient to wave action and impact Lasts more than 10 years	Stanchions can twist and bend due to wave action
Commercially, most widely used system	Limited walkway access Need large service vessels
Good net hanging system	Operational and worker safety issues Placement of top net and feeding systems difficult
Cheap at higher volume capacity	Expensive at lower volume capacity

Figure 2.4 Ocean Spar Net pen[12]



Tension leg cages

An alternative approach was taken by Ocean Spar with their Net Pen range, which comes in a variety of shapes from squares to polygons. The cage net is held in shape by vertical buoys at each corner, held apart by a tensioned mooring system. The design is simple and with large volume capacity relatively cost effective. In strong currents, the net can maintain 90% of its water volume. On the downside, the design and operation of the mooring system is complex, there is limited walkway access, feeders cannot

11 Adapted from: Offshore cage systems – A practical overview. Scott, D.C.B. & Muir, J.F. 2000; and Potential Offshore Finfish Aquaculture in the State of Washington. May 1999. Technical Report. Washington State Dept of Natural Resources.

12 Offshore Aquaculture. Ryan, J. Seville, Jan 2005.

Table 2.5 Advantages and disadvantages of Rigid Floating Cages

Advantages	Disadvantages
Stable platform for husbandry and management	Large heavy structures Need good port facilities
Integral feeding and harvesting systems	Structural failure in extreme conditions, net failure
Potential for improved operator safety and efficiency	Heavier mooring systems required
	High capital costs
	Limited knowledge of track record

be attached and few of these systems have been tested commercially.

Rope/collarless cages

A number of systems have been developed based on suspending the net pens more directly within the mooring grid, and eliminating collars entirely. Systems of floats and ropes maintain the top of the cage at the surface. The advantage is a significant further reduction in capital cost, and a reduction in solid surface area which reduces stresses on the mooring structures. These systems are used in China, but have not been developed beyond initial pilot units in Europe though early results were very positive[13].

2.2.2 Rigid floating cages

Rigid floating cages aim to be structurally robust to withstand wave action and impact. Large steel structures, they can incorporate a number of management facilities; fish feeders, harvest cranes, fuel stores and power generation facilities. They are the most expensive system, and after initial investments in pilot systems, are not much used at present.

Examples are the Pisbarca and Cripesa designs from Marina System Iberica (Spain) and Storm Havbruk AS (Norway) and Cruive system (Scotland). The Pisbarca and Cripesa cages are individual modules designed around a hexagonal plan with vertical cylindical flotation columns and a steel frame deck on which accommodation, feed store and handling equipment may be mounted. The Storm Havbruk cages are also hexagonal whilst the Cruive system is rectangular, again both with facilities for deck mounted ancillaries and accommodation. Capacity for the Cruive system was up to 40,000m^3 and cost per unit volume proposed to be relatively cheap. However, there were numerous operational difficulties and the system was not developed or commercialised.

2.2.3 Flexible semi-submersible cages

Semi-submersible cages are lighter and less complex systems, designed to have the capacity to be partially or fully submerged for periods when cage conditions are poor, and therefore endure less physical stress. This may also maintain stocks in better condition by reducing stress through exposure and motion. There are two structural types; flexible and rigid; as with floating cages, flexible systems, described below, are usually cheaper per enclosed volume.

Plastic circle

Several companies, including Polar Circle, have developed semi-submersible versions of their standard HDPE plastic cages. These have sections that can be flooded to sink the cages by several meters, or filled with compressed air to refloat. A top-net is fully attached to provide an escape-free holding volume. This approach is proving most popular in coastal areas prone to hurricanes and typhoons (e.g. the tropics) where the cages might otherwise be destroyed.

13 Stirling Aquaculture project experience

Tension leg

The Refa cage system is a tension leg system[14] held in place by vertical mooring ropes attached to concrete blocks on the sea floor. A circular positive buoyancy device is held below the pen. Above this is a conical section housing a small plastic collar which allows access to the cage. This area can be removed for harvesting or net changing. The main cage volume is always in the lower water column zone. When weather conditions change or currents become stronger, the net is pulled under water, thereby preventing any physical damage.

2.2.4 Rigid semi-submersible cages

These systems are rigid and are generally made of steel, with adjustable buoys to raise or lower the structure in the water column. The examples below have been used in Europe, but the principle is also in use in China where special semi-submersible cages have been designed for flatfish, providing multiple levels (or cage floors) for the fish to rest.

Example: Farmocean

The Farm Ocean system was developed in Sweden and operates in Northern Europe and the Mediterranean. The main structure comprises a hexagonal umbrella-like frame of six steel flotation tubes, above which is attached a circular platform incorporating the feeding system and storage capacity. The feeding system is computerised and allows several days feeding or can switch off if access to the cage is denied when weather conditions are bad. At the bottom of the flotation tubes a pontoon ring is attached. The net is secured to the framework and its shape is maintained by a submerged tube which is attached to the pontoon ring. Volume capacity was initially 3500m^3, but has been subsequently expanded to 4500 and then 6000 m^3. They can be expected to operate at sites with maximum wave heights in the range 5-7 m.

14 This configuration is sometimes used as a primary design factor, ie between gravity cages, with top flotation and shape structures attached to the seabed, and tension-leg systems, where the main structural element is closely attached to the seabed, with the upper elements then being simpler and more flexible.

Figure 2.5 Refa Tension Leg system

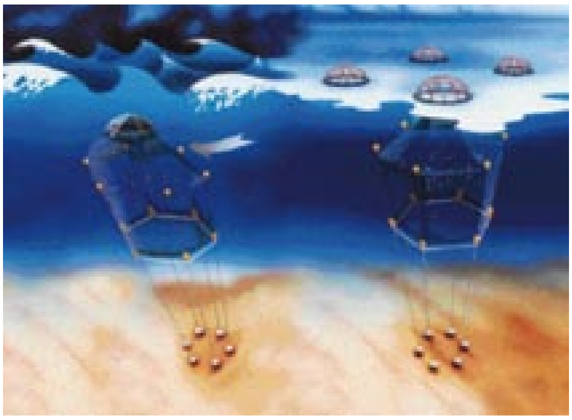


Figure 2.6 Semi-submersible offshore system from Farm Ocean

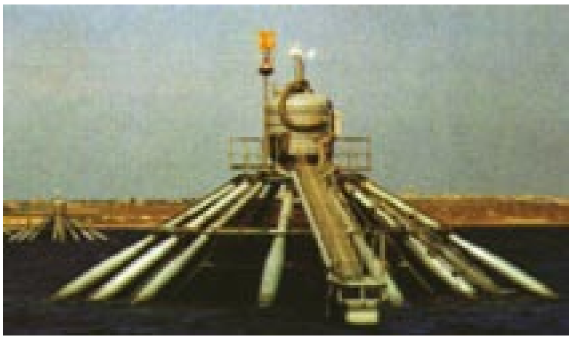


Table 2.6 Advantages and disadvantages of Rigid Semi-submersible Cages

Advantages	Disadvantages
Highly resilient, long service life > 10 years	Expensive set up and operation
Integrated feeding system	Difficult harvest conditions
Stable water volume	Difficult and expensive to maintain both nets and steel structure

Figure 2.7 Ocean Spar Sea Station cages[15]

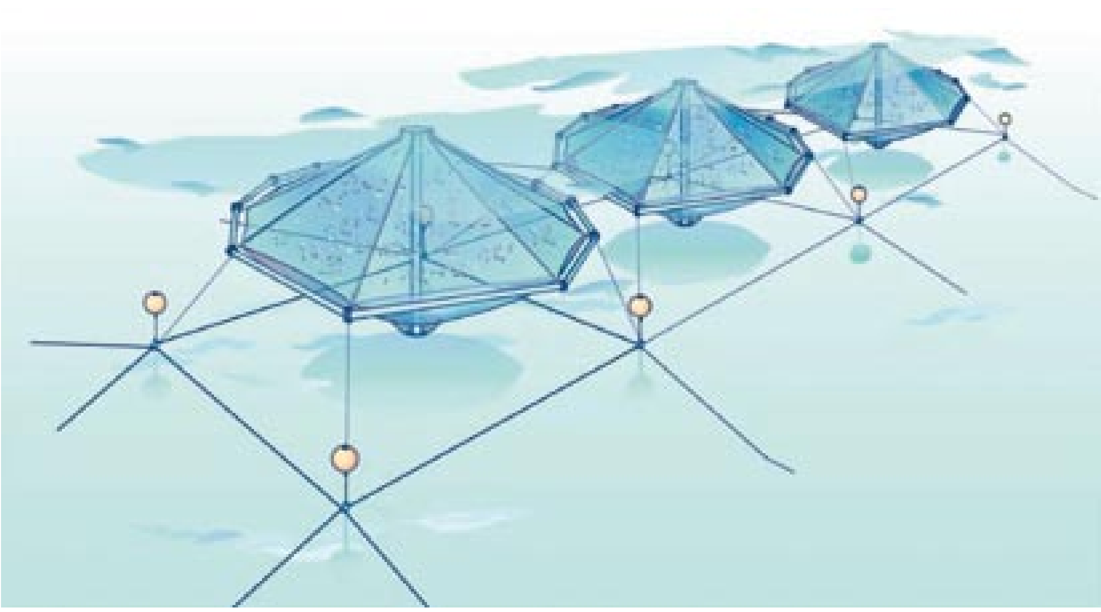


Table 2.7 Advantages and disadvantages of Ocean Spar Systems

Advantages	Disadvantages
Simple format and structure	High capital costs
Semi to fully submersible	Feeding and net changing difficult
Stable water volume	Not widely used, limited known track record
Simple moorings	

Example: Ocean Spar Sea Station

The Ocean Spar Sea Station resembles a double cone with a single central spar tube. This tube provides buoyancy to the net and a circular tubular rim provides attachment of radiating arms to the spar. An additional circular rim can be positioned below the first, adding greater depth and more tension to the net, allowing greater stability during severe weather conditions. With much less steelwork than systems like the Farmocean, it has the potential for lower costs per volume, though it lacks the integral feed delivery and other autonomous operational features of the FarmOcean.

2.2.5 Rigid submersible cages

For true offshore farming fully submersible cages may be required to avoid surface conditions, debris and ice. The structure can be raised for management purposes. There are various designs available and some pilot commercial systems in operation. The practical differences between these systems and semi-submersible designs are essentially that fully submerged systems are designed to be operational most of the time below the surface, raised only for specific maintenance or harvesting needs, while semi-submersible systems are normally accessible at the surface, dropped below only in poor weather conditions. At this stage the primary systems are rigid designs, though flexible systems could be feasible.

15 OceanSpar SeaStation. www.oceanspar.com

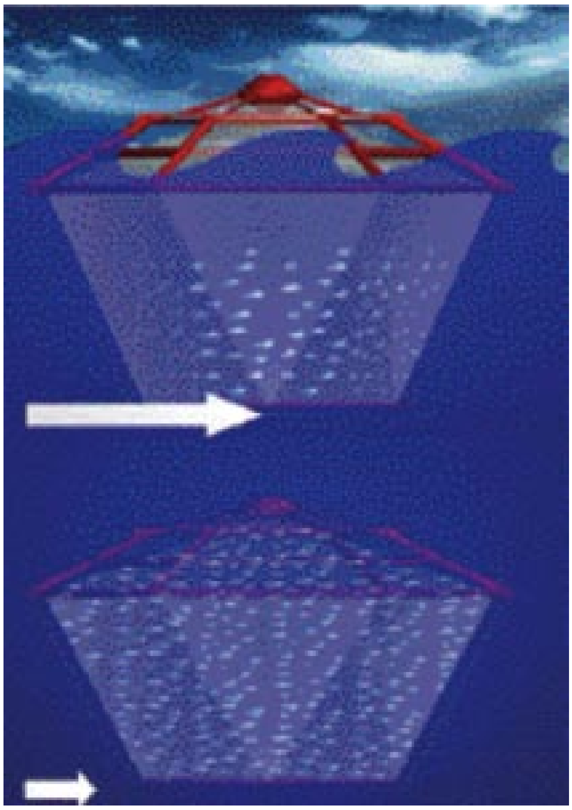
Table 2.8 Advantages and disadvantages of rigid submersible cages

Advantages	Disadvantages
Submersible designs avoid surface debris, ice, and storms	Lack of accessibility and visibility
Lower structural strength required	Complicated to operate
Minimal visual impact	Higher capital costs

Example: Sadco

The Sadco shelf is a Russian design. It has a heavy top framework with a suspended net and weight ring and an integrated automatic feeding system, and has proven resilient to extreme open ocean conditions. It has the capacity for a water volume of 4,000m^3, with the potential for greater volumes. Current models are based on a ballasted hexagonal steel structure which carries the net. Holding the net in place is a lower sinker tube. The cages have been installed in the Mediterranean, Caspian and Black seas, and one commercial unit is operating in the SW Italian Mainland.

Figure 2.8 Sadco Shelf System



2.2.6 Comparison of different cage types

The table below compares some of the different cages available. However, true cost comparisons are difficult to make since the limited information available on the costs of each system do not all include the total costs of each system (see notes under table). The main conclusions are that the semi-submersible cages are more expensive than the floating ones.

When the Farmocean and especially Bridgestone and Dunlop cages were first introduced, they represented a significant increase in volume over other designs that were in use. This potentially offered economies of scale, but required an approach to harvesting and marketing which was not always attractive to existing farmers. However, average capacities have gradually increased, matched by developments in harvesting, processing and distribution, such that capacity is no longer a distinguishing feature, although may be a factor that drives cage-based aquaculture offshore, if environmentally justified license restrictions constrain expansion at inshore sites.

2.3 European overview

Offshore systems have emerged as a solution to the shortage of suitable inshore sites in many countries e.g. Spain. The remoteness of sites allows increases in the size of operations, and hence realisation of economies of scale, without conflicting with other resource users.

Offshore aquaculture systems are already being used in Ireland, Norway, Spain, Italy Malta, Greece, Cyprus, Portugal (Madeira), Croatia and

Table 2.9 Water volume capacity and costs of each cage classification type

Cage structure	Volume (m³)	Capital cost (per m³)	Total cost
Flexible floating			
Bridgestone circular cage collar	25,000	€8-10	€210,000
Dunlop Tempest 2	2,300	€42	€95,000
Ocean Spar Net Pen	5,000		
Rigid floating			
Pisbarca (7 cages)	10,000	€250	€2.5M
Cruive (4 cages)	32,000	€27	€850,000
Flexible semi-submersible			
Refa	6,000	€17-23	€140,000
Rigid semi-submersible			
Farmocean	3,500	€83	€290,000
Ocean Spar Sea Station	3,000	€33	€100,000
Rigid submersible			
Sadco	2,000		

a 16m octagonal cage. Cost includes collar, nets and mooring materials. It does not include the cost of a vessel to support this type of cage structure

b Costs of smaller systems are relatively high due to limited volumes of water enclosed. Again, this does not include the cost of vessel to support this type of cage structure

c Basic steel structure without cranes and food stores but including net and moorings

d Includes cage and mooring materials, building and mooring supervision. Transport is not included but three 40' open top containers is needed per cage. The customer will provide local services such as anchors/concrete block and heavy chains, pipe fitters for building, cranes and barges as well as local transport, lodging and meal for our personnel.

Table 2.10 Offshore aquaculture: production statistics by country (2005 estimated)

Country	Production volume (tonnes)	Production value (€)	Percent exported	Change in production over last 5 years (%)	Employment	Species produced
Cyprus	3400 (2000 bass & bream; 1400 bluefin tuna	€31 million (18 million Cy pounds)	60 % (wt); 70% (val); all tuna exported	+20 %	150	Bass; bream; bluefin tuna
Denmark	7200	€18.6 million (US$24 million)			153	Rainbow trout & its roe 'caviar'
Greece	1000 t tuna			+		Bass; bream; tuna
Ireland	3-4000 tonnes (30% of total fish production)	>€20 million	90% by weight	No change	100	Salmon
Italy	>9000 tonnes	€54 million	10% (wt) 8% (val)	+70%	250	Bass; bream; other sea breams; bluefin tuna
Malta	4300 tonnes (3550 tuna; 550 bream; 200 bass)	€54.5 million	95%		150	Bass; bream; bluefin tuna
Norway	133,600	275 million*		+		Salmon
Portugal	500 tonnes		55%	No change	18	Bream; bass; oyster; mussels.
Spain	9000 t tuna			No change	~960 (~12 in each of 80 companies)	Tuna; bass; bream; turbot

** Estimated from 20% of total value of grow-out production in Norway*[16]

16 Aquaculture in Norway. 2005. Norwegian Seafood Federation (FHL). www.laksefakta.no/file_download.php?file_id=68

Libya producing an estimated 28,000 tonnes. The majority of offshore farming in the Mediterranean is of sea bass and sea bream. The rest is bluefin tuna. Salmon and trout are the main species cultured offshore in Northern European countries at present, although cod is a candidate for future systems. Class 4 offshore farms off Spain, Italy, Cyprus and Malta mostly use floating plastic or rubber cages. However, these technologies are not considered suitable for long-term survival in class 5 open ocean sites off Ireland, Scotland and North America[17].

2.4 Detailed country perspective

2.4.1 Countries with offshore systems

Cyprus

Cyprus has an important tourist industry and almost all sites are located to some degree offshore to minimise visual impact. In 2000, there were '8 privately owned commercial sea cage farms, licensed for an average annual production of 150 t (mainly seabream and sea bass). The farms were located 1-1.5 km offshore, spaced at 3 km intervals, in depths ranging from 20-35 m. Of the main manufacturers (PolarCirkel, Dunlop, Bridgestone, FarmOcean, etc.) the most commonly used cage was the circular 16 m diameter "PolarCirkel" type.' 'According to government policy, cage farms should not be anchored over *Posidonia* beds and should be at least 1 km offshore and in a minimum water depth of 20 m. The setting up of cage farms is not allowed in certain locations. These include site opposite residential zones, areas of natural beauty, nature reserves, marine parks, etc.[18]

There are currently 7 companies using offshore systems in Cyprus. Over the past five years there has been a 20% increase in the number of systems in use. Total production is around 3400 tonnes, with a value of 18 million Cy pounds (€30.8 million), of which 60% by weight and 70% by value is exported. Approximately 2000 tonnes of sea bass and seabream and approx 1400 tonnes of bluefin tuna (fattening) were produced in 2005. All of the tuna and 700t of bass and bream were exported. Around 150 people are employed in production. The government encourages offshore production, with schemes for co-financing investments in aquaculture which focus mainly on offshore systems and new technologies, including recirculation. The leading authorities on offshore systems in Cyprus are the Dept of Fisheries and Marine Research (DFMR), and private companies since they have a lot of experience as they have been pioneers in the use of offshore systems in the Mediterranean[19].

Denmark

All Danish offshore farms are located in the inner marine waters. These cover in total 1-2 square kilometres, about 0.02% of Danish marine territory. By 2003 Denmark had 24 offshore marine fish farms, the main product being large rainbow trout, 2–5 kg. An essential by-product is roe, salted and marketed as 'salmonid caviar', exported mainly to Japan and contributing substantially to revenues and profitability. Competition, however, is increasing and prices are decreasing. In 2003 there were 24 offshore farms with 186 cages, producing about 7,200 tonnes (down from 7,900 tonnes in 1993), worth €21.24 million. A total of 153 were employed in production in 2003, including full time, part time and seasonal workers[20].

Greece

Unlike most other Mediterranean countries which rely on more offshore sites. Greece has a heavily indented coastline permitting most farming to be carried out in sheltered waters. As tourism is a major industry and because of increasing opposition to aquaculture, it is likely

17 Ryan, Pers. Comm.
18 Stephanou IN: Muir & Basurco (2000).

19 Kyriacou, Per. Comm.
20 Denmark National Aquaculture Sector Overview. FAO FIGIS. www.fao.org/figis/servlet/static?dom=countrysector&xml=naso_denmark.xml

that most future development will have to be offshore.

Five companies currently operate offshore systems in Greece, with increasing numbers in use over the past five years. The main species produced are bass and bream, but a small amount of tuna is also produced. The government encourages the use of offshore systems, through provision of grants and information. The Aquaculture Dept of the National Centre for Marine Research, in Crete, is a key source of national expertise[21].

Ireland

According to Ryan (2004) limitations in Ireland's coastal topography resulted in offshore cages being used since the late 1980s when Bridgestone cages were first deployed off the west coast (e.g. Clare Island and Donegal Bay). However it had proven difficult to make an adequate return on investment from these sites, and a high proportion of the country's farmed finfish still comes from Class 1 and Class 2 sites. Nonetheless a number of operators developed particular experience with technological development/innovation and logistics mitigation, realising the unsuitability of inshore technologies, and were amongst the earliest to test cages specifically designed for use in exposed sites. In 1984, Emerald Fisheries at Ardmore, Connemara, installed the first Bridgestone cage. This was quickly followed by additional Bridgestone installations by Salmara in counties Donegal and Cork. Timar and Carrolls Seafoods continued the trend when they set up Bridgestone-only sites at Clare Island, Co. Mayo and Bertraghbuoy, Co. Galway in 1987 and 1988 respectively[22].

There are now 13 licensed offshore sites on the Irish coast (although not all are currently in use). 30% of total fish production in Ireland is in offshore systems[23]. Subsequent developments introduced Dunlop rubber collar systems, heavy plastic cage systems, the Farm Ocean semi-submersible and the Ocean Spar from Net Systems. Only the rubber collar and plastic collar systems are in widespread use. Ocean Spar Technologies has installed four anchor-tension cages in Ireland since 1998, three of which have a 20,000m^3 capacity and a fourth has a 15,000m^3 capacity.

Ryan (2004) noted that there were few, if any, Class 4 operations around the coast of Ireland, but estimates that there are at least 15 potential Class 3 sites. He predicted that if Class 3 sites became economically viable, Ireland could potentially increase aquaculture production to 150,000 tonnes, valued at €500 million per annum. To be viable at present, offshore farms need to obtain a price premium, which the farm at Clare Island is doing through organic certification.

However, production has not changed over the past five years. In 2004, 14,067 tonnes of salmon were produced from offshore sites, with a value of €51.3 million, and 85% was exported. Salmon is the only species currently produced in offshore systems in Ireland. There were 273 full time equivalents employed in 2004. The government encourages offshore production through promotion and funding of state of the art production techniques including technology transfer and training. The leading authorities on offshore production in Ireland are: State Development Agencies, BIM, Udaras na Gaeltachta, Marine Institute, and Taighde Mara Teo[24].

Italy

The sea bass and sea bream industry in Italy is increasingly developing Class 4 offshore farms using Polar-Circle and other gravity cages, or with REFA-Med tension leg cages. There are also some sites with Farmocean or rubber cages. Some 18 companies use offshore systems in Italy, mostly

21 Charalabakis, Pers Comm.
22 Ryan, 2004
23 Jackson, 2006.
24 Watson, Pers. Comm.

situated in the south of the country, of which 14 are currently in production, employing 250 people. Total production from offshore systems is greater than 9,000 tonnes, valued at €54 million, of which 10% by weight and 8% by value is exported. The species grown are sea bass, seabream (mostly gilthead but also some other species), and bluefin tuna. Some of the species produced in offshore systems can command a price premium.

Although government policies encourage offshore production, there is very little economic support. The leading authorities are the Ministry of Agriculture and Forestry politics, Dept of Fisheries and Aquaculture. However, a referendum is on the way and responsibility may devolve to the regional authorities[25].

25 Saroglia, Pers. Comm.

Malta

All aquaculture takes place in floating cages, approximately 1km offshore. In 2005, sea bass and seabream production was 772 tonnes from two farms. All fish farmed in Malta are reared in floating sea cages. Various cages are used for sea bass and seabream production, with Dunlop and Corelsa cages for offshore ongrowing sites and Floatex and Kames cages for inshore nursery sites. The cages used inshore for nursery sized fish are 5 m x 5 m x 5 m or 10 m depth whereas the offshore cages are 15 m x 15 m x 5 m or Ø 20 m x 10 m deep. At the turn of the century, Maltese companies showed interest in the capture based aquaculture of northern bluefin tuna *Thunnus thynnus*, using high technology, circular floating offshore cages, a large number of which are 50 m Ø and usually 30 m deep. A few 90 m Ø cages have also been used since

Table 2.11 Operational aquaculture sites around Malta

Company Name	Species Reared	Location	Coordinates	Sea Surface Area (m^2)	Licensed Capacity, (Tonnes)
Pisciculture Marine de Malte					1,100
Site A (nursery)	Sea bass & bream	Mistra Bay	35°57 14°23	9,000	
Site B (Fattening)		Off St. Paul's Islands Mellieha Bay	35°57 14°24	70,000	
Site C (Fattening)			35°58 14°22	40,000	
AJD Tuna Ltd.					
Site A (Fattening)	Blue Fin Tuna	Sikka l-bajda (St. Paul's Bay) Commino Channel	35°58 14°25	175,000	1,500
Site B (Fattening			36°00 14°20	25,000	800
Malta Fish Farming Ltd.	Sea bass & bream				150
Site A (Nursery & fattening)		Marsaxlokk Bay	35°49 14°32	10,000	
Site B (Fattening)		Off Munxar Reef, Marsascala	35°51 14°34	350,000	
Fish & Fish Ltd.	Sea bass and bream	Off il-Hofra z-zfhira, Marsaxlokk	35°49 14°34	7,200	300
Melita Tuna Ltd.	Blue fin tuna	Off Munxa Reef, Marsascala	35°51 14°34	350,000*	1,500
Malta Tuna Trading Ltd.	Blue fin tuna	Off il- Hofra z-zfhira, Marsaxlokk	35°49 14°34	80,000	1,200

Sea bass and sea bream culture within the same area

Table 2.12 Maltese aquaculture production, 2005

Species Produced 2005	Quantity Produced, mT	Quantity Exported, mT	Value
Sea bass *(Dicentarchus labrax)*	205	174	US$ 1.4 million (€ 1.2 million)
Sea bream *(Sparus aurata)*	567	529	US$ 3.9 million (€ 3.3 million)
Blue fin Tuna *(Thunnus thynnus)**	3,550	3,550	US$ 65.5 million (€50 million)

**Latest officially released value for Blue fin tuna is 2003 production.*

2003. The 50 m Ø cages are Spanish, Italian or British offshore cage moored in 50 – 60 m deep water about 1 to 2 km from the coastline. Due to a conflict between tourism and aquaculture, the Ministry is creating an aquaculture zone, 6km off the east coast of Malta, so that tuna farming operations will be moved further away from the shore. Seabream is usually sold locally at prices that vary between US$ 7.23 (€ 5.59) to US$ 8.29 (€ 6.41) throughout the year. Sea bass prices are slightly higher but a smaller quantity is purchased Locally.

There are currently four offshore farms with total production of approximately 4,300 tonnes, and 95% of this is produced for export. Species grown are sea bass, seabream and Bluefin tuna. Around 150 people are employed in offshore production. The Government neither encourages nor discourages offshore production[26].

Norway

Offshore systems are currently in use off Norway. The number in use has increased over the past five years since competition for inshore sites has increased. Around 20% of aquaculture production is in exposed locations (offshore sites). In 2000, 17% of marine cage farming licences are in sites of Class 3 or higher[27]. Only salmon are currently produced. Government policies indirectly encourage offshore production, since companies are more likely to gain a permit for an offshore site. Leading authorities include: SINTEF; Salmar – commercial producer with production costs of <£1/kg (approx €1.47/kg).

Total Norwegian aquaculture production in 2005 was 668,000 tonnes (588,000 Atlantic salmon and 80,000 Sea trout). Therefore, if estimated at 20% of total production, offshore farming would account for around 133,600 tonnes per year[28].

Portugal

Six companies currently use offshore systems in Portugal (mainly Madeira and Azores), employing a total of 18 people. The number of systems has not changed over the past five years. Approx 500 tonnes are produced in offshore systems in Portugal, with 55% of this being exported. The species grown are seabream (*Sparus aurata*), sea bass (*Dicentrarchus labrax*), oyster (*C. gigas* and *O. edulis*), and mussels (*M. edulis* and *M. galloprovincialis*). Seafood produced in offshore systems is not considered to command a price premium. Primarily because of a legal vacuum, the government currently discourages offshore production. This arises from the absence of aquaculture in provisions for licensing use of offshore areas, unlike installations such as oil platforms, or offshore refuelling stations, etc. Authorization to use offshore areas (up to 30m depth) was the responsibility of the Ministry of the Environment, until they recently (3 years ago) realized they had no expertise in aquaculture and then refused to give further permits. In the near future, these permits may be given by the Marine Authority, linked to the Ministry of Defence (Navy),

26 Vassallo-Agius, Pers. Comm.
27 Ryan, Pers. Comm.
28 Fredheim Pers. Comm.

Table 2.13 Countries without offshore systems

Country	Comment	Reference
Czech Republic	Land locked	
Estonia	There are no prospects for offshore systems in the Baltic Sea. The sea is cold and brackish and frozen for a long time. The Estonian coast is shallow, eutrophic, and polluted by algal blooms, which are common. There is intensive shipping and a high risk of oil spills, and a high crime rate makes it difficult to protect the cages situated far from ports.	Paaver
Finland	There are no 'real' offshore environments in the Baltic Sea Archipelago of Finland, so offshore aquaculture cannot be practiced.	Molsa
France	'The main limiting factor against further development remains access to farming sites as most coastal authorities prefer to support the development of the tourism sector or to maintain free access to offshore waters rather than establish marine farms. Regarding offshore farms, it might be a solution to the coastal management problems and competition, but is not developed at the moment. It probably won't be developed on the Atlantic coast due to strong wave conditions but might be the future of the Mediterranean aquaculture, especially if we consider the actual pressure on aquaculture in this area which is of high tourist interest.'	Blancheton
Germany	There is a lack of offshore sites off the coast of Germany.	Brämick
Hungary	Hungary has no coastline.	
Latvia	No mention of offshore production can be found in the literature. Its situation in the Baltic means it is likely that there are no offshore environments off its coast.	Woynarovich
Lithuania	There is no marine culture in Lithuania.	Woynarovich
Netherlands	There are currently no offshore systems in the Netherlands as the coastline is not suitable for this.	Van Dooren; Schneider
Poland	Recent documents on the situation in Poland suggest that there is no offshore farming being carried out off Poland.	Woynarovich; Lirski
Sweden	There are no offshore systems in Sweden. The vast majority of Swedish Farming at present takes place in Grade 1, 2 and perhaps a few grade 3 systems. More than 50% of total production (8000 tonnes) takes place in freshwater, and another 35% in the Brackish water of the Baltic. Marine farming is to a large extent blue mussel production (North Sea).	Eriksson
UK	There is currently no offshore production in the UK, and no research is being carried out either[31]. The growth of the offshore renewables sector in UK waters will be significant over the next twenty to thirty years, and these developments may be capable of accommodating aquaculture production[32]. There could be economies achieved by co-use of logistics and facilities. Conflicts with other marine users may also be reduced if navigation and fishing, for example, are excluded from these areas. Some structures may provide aquaculture operations with physical protection from excessive wind and wave action. Direct electrical power access could also reduce operating costs and open up opportunities for increased photoperiod production, together with increased levels of automation and remote operation. However, some wind farm operators are cautious about encouraging any activity which could potentially interfere with or damage the wind farm and its operation.	Smith

but this is still under discussion. In the meantime, until a decision is reached, the Ministry of Fisheries and Agriculture is trying to get the Ministry of the Environment to resume giving out permits. The leading authority on offshore systems in Portugal is Ostracultura[29].

Spain

Most sites in Spain could be classified Class 3 or even 4. Sea bass and seabream are farmed in 70-80 m Corelsa plastic circle cages. There are 80-90 companies using offshore systems in Spain, each with around 15 sites per company. Production has not really changed over the past five years. The species grown are tuna, sea bass, seabream, and turbot. Around 12 people are employed in offshore production per company. The government encourages offshore production, but provides no money towards it. The CSIC is a leading authority on offshore production in Spain[30].

2.4.2 Countries without offshore systems

Several countries have no offshore aquaculture development, mostly since they are land-locked, or have highly restricted coastlines.

29 Bernardino, Pers. Comm.

30 Quintas & Quintas, Pers. Comm.

31 Kate Smith, Fish Health Inspectorate at Fisheries Research Services (FRS), personal communication.

32 Appraisal of the opportunity for offshore aquaculture in UK waters. James, M.A. & Slaski, R. 2006. Report of Project FC0934, commissioned by Defra and Seafish from FRM Ltd., 119pp. www.defra.gov.uk/science/project_data/DocumentLibrary/FC0934/FC0934_3856_FRP.pdf

2.5 Technical feasibility

2.5.1 Husbandry

Offshore sites are seen as having a more beneficial husbandry environment than inshore sites due to:

- Greater water exchange leading to increased oxygen, reduced ammonia, improved dispersion;
- Lower impact on the benthos, owing to improved waste dispersal;
- Open sea environment has more stable temperature and salinity conditions;
- Reduced fouling of equipment;
- Fitter fish due to stronger currents.[33]

2.5.2 Safety and efficiency

Offshore systems must be able to withstand extreme weather conditions, so although the technology may be based on traditional cage farming, the materials and structure must be much stronger and also more flexible to cope with large waves and strong currents. To date there has been a reliance by some on SCUBA divers to carry out routine maintenance activities, which in the best conditions can be dangerous. There is a need to develop and implement greater mechanisation and automation of routine operations for maintenance and harvesting so to promote safety and efficiency.

2.5.3 Supporting hatchery capacity

In order to expand offshore operations, an increase in hatchery capacity will be required to provide adequate juveniles to stock offshore farms. This may be a constraint for some species for which the technology has not yet been fully developed (e.g. tuna)

33 Offshore Aquaculture. Ryan, J. Seville, Jan 2005.

2.5.4 Links with renewable energy projects

There have been suggestions that offshore aquaculture developments might be linked with offshore energy generation using current, wind or wave power. The suggestion is that there might be some synergies with respect to structures and servicing. In practice there may be several constraints, however, the need for power on offshore cages increases as additional mechanisation is introduced, so the use of renewable energy sources would in any case be attractive, especially if fossil fuel prices continue to rise.

2.6 Financial feasibility

The high fixed costs associated with offshore farming mean that it must generally be carried out on a large scale to be economically viable. Ryan[15] suggests that Atlantic salmon production on a Class 3 offshore site would require a minimum of 10,000 tonnes production per annum to be viable, based on the use of 14 x 40,000 m^3 anchor tension cages and 2 x 30 m support vessels. However, there are no offshore farms yet working at this scale, and this section therefore takes as a base case a farm of around 2000 t of the type currently in operation on Class 3 sites such as those in Ireland, and investigates the impact of changes in key input costs and sales values on financial feasibility.

2.6.1 Market considerations

Producers can expect to obtain the same prices for fish from offshore systems as those produced in inshore systems if they are selling into a commodity market. However, it may be possible to exploit the generally held belief that offshore production has a lower environmental impact due to increased dispersal of wastes, and that flesh quality may be superior since the fish must swim in stronger currents, through differentiating the product in the marketplace. This would enable a premium to be charged, but would most likely entail certification under an appropriate quality or environmental management scheme. (see section 5).

2.6.2 Base model – offshore salmon

The base case model is based on a production of 2000t pa Atlantic salmon over an 18 month cycle, with separate inshore smolt production site using 4 conventional plastic cages, and 4 Bridgestone gravity cages of 25,000 m^3 each offshore. A further 4 plastic preharvest holding cages with 10,000 m^3 capacity have been allowed at a separate inshore site. Feeding is assumed to be by cage mounted hoppers on the inshore site and by boat mounted feed blowers at the offshore site, as the serviceability of feed barges is yet to be confirmed. Servicing of the offshore site is assumed to be by two 12-15 m workboats given the heavy feeding duties required. Shorebased facilities are limited to equipment and feed storage, and office, with all processing done at a separate location.

Table 2.14 Financial model for offshore salmon farm

Key assumptions

Production rate (t/yr)	Fish value (€/t)	Feed (€/t)	F.C.R.
2000	2900	900	1.2

Financial model

10 year cash flow	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Production (t)	0	1,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
RECEIPTS										
Cash sales	0	1,160	4,640	4,640	4,640	4,640	4,640	4,640	4,640	4,640
From debtors	0	290	1,160	1,160	1,160	1,160	1,160	1,160	1,160	1,160
TOTAL RECEIPTS	0	1,450	5,800	5,800	5,800	5,800	5,800	5,800	5,800	5,800
PAYMENTS										
Working capital costs	2,321	4,022	4,427	4,427	4,427	4,427	4,427	4,427	4,427	4,427
Capital expenditure	2,255	0	0	0	0	0	0	0	0	0
TOTAL PAYMENTS	4,576	4,022	4,427	4,427	4,427	4,427	4,427	4,427	4,427	4,427
NET INFLOW/(OUTFLOW)	-4,576	-2,572	1,373	1,373	1,373	1,373	1,373	1,373	1,373	1,373
Bank balance brought forward	0	-4,576	-7,149	-5,776	-4,403	-3,030	-1,657	-285	1,088	2,461
Bank balance at end	-4,576	-7,149	-5,776	-4,403	-3,030	-1,657	-285	1,088	2,461	3,834
IRR	9%									

continue →

*Table 2.14 Financial model for offshore salmon farm (**continued**)*

Breakdown of operating costs	'000 EUR/ annum	% of total
Fish feed	2,160	46
Selling costs	810	17
Smolts	384	8
Wages/salaries	339	7
Misc. operating costs	258	6
Depreciation	226	5
Vet	120	3
Overhead costs	156	3
Stock Insurance	120	3
Power and fuel	80	2
Total operating costs	4,653	100
Cost/kg	2.33	
NB excludes finance costs		

Capital costs	No	Unit cost	Total ('000 EUR)
Smolt cages (m^3)	32,000	5.64	181
Bridgestone cages (m^3)	100,000	8.57	857
Harvest cages (m^3)	10,000	5.50	55
Shore infrastructure	1	142,857	143
Large workboats	2	257,143	514
Small boats	3	12,000	36
Vehicles	2	25,000	50
Misc. equipment	1	214,286	214
Total capital cost			2,050
Contingency (10%)			205
Capital costs inc. contingency			2,255
Annual depreciation (10 yr avg. life)			226

2.6.3 Sensitivity analysis

This section examines the impacts of changes in key variables, such as fish sale price and feed cost.

James & Slaski (2006)[34] reviewed the opportunities for offshore aquaculture in UK waters and concluded that it presented no overwhelming financial advantage over existing inshore pen aquaculture, unless inshore systems become more expensive due to new regulations. This could become the case if polluter pays mechanisms are brought in to address the nutrient effluent discharges from coastal cage farms. It is perhaps more useful to note that offshore systems did not appear to offer a significant cost disadvantage, though risk perspectives were not fully developed.

34 Appraisal of the opportunity for offshore aquaculture in UK waters. James, M.A. & Slaski, R. 2006. Report of Project FC0934, commissioned by Defra and Seafish from FRM Ltd., 119pp. www.defra.gov.uk/science/project_data/DocumentLibrary/FC0934/FC0934_3856_FRP.pdf

Table 2.15 Sensitivity analysis for offshore salmon farm

Assumption	IRR	Max funding (€)	Payback (yrs)
Base case	9.1%	7,148,557	7
Sale price EUR2.68/kg	0.5%	7,258,557	10
Sale price EUR4.14/kg	42.8%	6,528,557	3
+20% feed cost	-0.6%	7,753,357	
-20% feed cost	18.1%	6,543,757	5

2.7 Drivers and barriers

One of the main drivers of offshore aquaculture is the increasing global demand for seafood, which can only be met by significantly increasing aquaculture production. Since offshore farms have a large capacity, and there are potentially large numbers of sites suitable for offshore farming, this area of has considerable apparent potential. However, other expansion options need to be considered, and the comparative risks and returns, combined with consumer and regulatory conditions, will determine whether and how this will be realised.

At a meeting of offshore operators in Ireland in 2003[35], three principal challenges to successful daily operations were identified, namely: wear and tear, feeding and harvesting. This accords with operational experience developed in high-exposure Mediterranean sites (STAQ, 2000). Clearly these challenges are likely to be common to all offshore operators regardless of their global location

A key barrier is the scale that offshore systems must be operated on. This not only excludes many companies due to lack of investment funds, but also significantly hinders research and development approaches due to the large amounts of capital required and the high risks involved.

35 Farming the Deep Blue. Ryan, J. 2004. 82pp

2.8 Environmental impacts

To date little data is available specifically outlining the environmental impacts of offshore aquaculture. Critics of cage farming believe that to some extent the same risks associated with inshore fish farming will arise from offshore farming, including: escapees, sedimentation and benthic pollution, chemical contamination, and exotic disease introduction[36]. If higher-value carnivorous species are the primary focus, their culture on a larger scale will also increase the pressure on wild fish stocks to provide fish meal and oil for feed, unless adequate substitutes can be found. However, some believe that offshore farms will offer environmental benefits over inshore cages, including:

- Good dispersion means lower impact on seabed from wastes and uneaten food – little or no benthic impact has been recorded;
- Lower rate of net fouling due to good dispersion and distance from shore and reefs – reduction in net cleaning and antifouling chemicals necessary;
- Lower levels of ecto-parasitic infestation – planktonic juveniles tend to be swept away, so rarely have to medicate against lice;
- Visual impacts – reduced due to distance offshore, and for submersible cages it is almost completely eliminated. However,

36 Seas of Doubt – Upstart fish farms feed on theory, not fact. 2006. Food & Water Watch. 18pp. www.foodandwaterwatch.org

Table 2.16 Drivers and barriers for offshore systems

Country	Drivers	Barriers	Reference
Denmark	Profit, increased production, new species/product, water availability and cost, improved scale of production, market demand.	Potentially higher losses, difficulty in getting investment, higher production costs.	Jokumsen
Estonia		Baltic is too brackish and unsuitable for many species. Shallow coast. Eutrophication and algal blooms common. Intensive shipping means higher pollution. High crime rate.	Paaver
Finland	Larger units available in more remote areas.	Transport costs, security. Environmental restrictions limit aquaculture in many areas. Enough inshore and FW sites available.	Molsa
France		Heavy investments required, technology is not well established. Large scale needs to be in accordance with market.	Blancheton
Germany	Technology overlap with other industries, e.g. offshore borrows from oil and fishing industries.	Competition from cheaper imports outside of the EU.	Brämick
Greece		Well established inshore industry with highly developed technology. Still plenty of available inshore sites. Larger cages and economy of scale is not a pressing issue and requires different management protocols to inshore. High wave height and short wave length. May interfere with commercial shipping lanes.	Triantaphyllidis
Italy	"Interesting" production costs compared to land based systems. Limited availability of land sites. Administrative and bureaucratic restrictions not a problem. Strict land environmental policies.	Difficulty getting investment, expert knowledge. Competition from Greece, Turkey and some other Mediterranean countries. Offshore technology is not advanced enough.	Saroglia
Malta	Good climate offers excellent conditions. Competition from tourism and diving clubs pushing aquaculture away from coasts.	Strict environmental policies.	Vasallo-Agius
Netherlands		No suitable sites for off shore aquaculture. May change in the future combining with offshore wind energy.	Schneider
Portugal	Possibility to increase production and reduce costs. Need to become more competitive in EU.	Lack of sheltered offshore sites. Lack of experience of investors. Low water temperatures.	Bravo
Spain	Pressure for space along coast especially in the Mediterranean. Need to develop better technologies for new species such as tuna.	High level of investment. Most producers are SMEs. Difficult ocean environment outside of the Mediterranean.	Tort

offshore sites must have access to inshore sites for harvesting;

- Competition for space – reduced conflicts with other inshore users such as tourism/marine leisure operators, inshore fishermen and shellfish farming activities;
- Escapees – it is suggested that most escapees of offshore farms will fall to natural predation before they can reach

the breeding locations of migratory stocks because of the distances involved;

- Restoring or enhancing capture fisheries – offshore units could play a role in the re-stocking of certain high value marine species that may have been depleted.

2.9 Prospects

The attraction of offshore aquaculture is the potential to greatly increase production using cage aquaculture technologies, without the environmental and visual impact that is constraining the expansion of inshore sites. Nevertheless, despite over 20 years of commercial development their impact on total marine aquaculture production has been relatively marginal. Ryan (2004) summarised the current position with respect to class 5 offshore systems 'Whilst a number of very worthwhile and innovative initiatives are taking place around the world, there is also a relatively high rate of failure. It should also be observed that the nature of the developments have been disconnected and piecemeal. This model of development is essentially wasteful and by necessity inefficient. Valuable knowledge gained and fundamental concepts, which may have been validated, can easily be lost in the fallout following an unsuccessful trial of a new piece of equipment.

As highlighted previously, the challenges relate to the engineering of offshore containment systems capable of withstanding extreme climatic conditions and developing safe and effective operational systems that provide good care for the fish whilst also ensuring staff safety. Both of these objectives must be achieved in a way that achieves a cost of production that is similar to, or lower than is available from competing inshore systems. It is likely that this will only be possible by significantly increasing economies of scale, with sites expected to expand from a current 1,000 to 2,000 tonne maximum to perhaps 10,000 tonnes. Key factors therefore include:

Environment and engineering

- Extreme climate conditions are key considerations when assessing the risk of an offshore operation. Inevitably, structural components will be more stressed, will need more maintenance and will wear out a faster rate. Parameters that need to be taken into consideration include wave action and height, wavelength and period, wave forces and current characteristics, both outside and inside the cage.

- Cages and enclosures used in offshore systems need to be part of an integrated package of systems. Aspects of production including fish husbandry, farm operation and maintenance will need to be developed in tandem with containment facilities to ensure success and to reduce operation failure. To date a number of ancillary developments have lagged behind development of cage design innovation[37]. This is particularly relevant in relation to the development of automation systems so the facility can operate with lower labour inputs.

- Prospective developments of offshore sites will probably be under greater environmental scrutiny. Further research into environmental considerations to investigate the effects of offshore aquaculture will be necessary.

Financial viability and competitiveness

- In the EU, there is substantial potential for the development of offshore aquaculture. In order for the industry to expand to meet present and future

37 James, M.A. Slaski, R. (2006) appraisal of the Opportunity for Offshore Aquaculture in U.K. Waters Report of Project FC0934, commissioned by DEFRA and SEAFISH from FRM Ltd.

demand, a number of biological, technical and operational challenges need to be addressed. In the main, capital costs to initiate offshore aquaculture operations are high.

- Operations will need to be a minimum size to be competitive and cover production and investment costs. Ryan (2004) estimates a production capacity of at least 10,000 tonnes per annum for an offshore operation to be viable. Site specific conditions will dictate which kind of system will be functional, and certain production systems will require higher investment than others.

- Capital investment to commence operation using a semi-submerged cage system is 43% higher than for floating cage systems. These costs are compensated for by lower labour costs, lower feed costs, better survival and higher fish quality in semi-submersible systems compared to floating systems.

- Market prices will need to be assessed to establish what consumers will be willing to pay. Providing a product priced at £7-8 per kilo will be acceptable, but with higher prices it may enter the more luxury end of the market and will not be considered for everyday consumption.

Regulation

- There is no integrated EU policy to protect the marine environment. A Communication and Framework Directive is in operation to develop an EU Marine Policy

- In Scotland where the majority of marine cages are placed, planning permission can be given up to 12nm, but SEPA who regulate discharges from farms only have a remit of upwards to 3nm

- In the EU, in the limit beyond 3nm, there are some clear legal and regulatory issues that need to be addressed. Unlike regulation for inshore operations, a regulatory framework is lacking for offshore aquaculture

- There is a need for both national and international legislation to cover aquaculture activities up to the 200 nm EEZ

Insurance

- Insurance costs are 1 to 10% of value of insured stock, generally examples quote 3%

- Assessment of risk will be site dependent and will take into consideration
  - Site and environment
  - Farm design
  - Species and health management
  - Redundancy backup
  - Personnel
  - Financial security

Sunderland Marine Mutual is well known for insuring pioneering aquaculture activities, for example offshore tuna operation in Australia. Maris Ltd, design offshore cage systems and offer full risk assessment and insurance cover.

Renewables

- The growth of offshore renewable energy generation will be significant over the next twenty years. If aquaculture systems and renewables evolve together then both systems may be able to accommodate each other in one integrated system.

- Advantages include the improvement of financial feasibility. If logistics and facilities are shared overall capital and operational costs may be reduced. For example, if electrical costs are shared, an increase in photoperiod may improve production. Shared facilities may improve levels of automation, improving overall production.

- Conflict with other marine users may be reduced

- Offshore structures may protect aquaculture activities from extreme weather conditions

- Problems which could arise with interference by aquaculture activities with renewables infrastructure

- Combining aquaculture with wave power generation may allow some of the surface or near surface technology to act as a baffle reducing wave action. This may provide a protected environment for cage culture. More detailed assessment is required

- Rational well planned pilot scale projects need to be established in order to prove that aquaculture can work alongside offshore renewables.

The following figures show some prototype designs of new offshore farming systems.[38]

38 Offshore Aquaculture. Ryan, J. Seville, Jan 2005.

Figure 2.9 Submerged cage

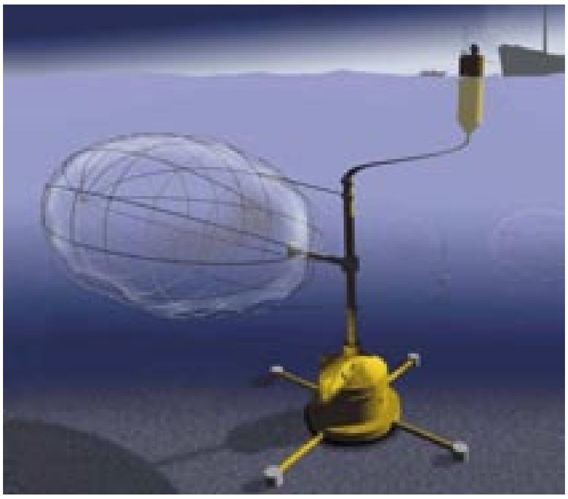


Figure 2.10 Oceanglobe submersible cage, Byks, Norway

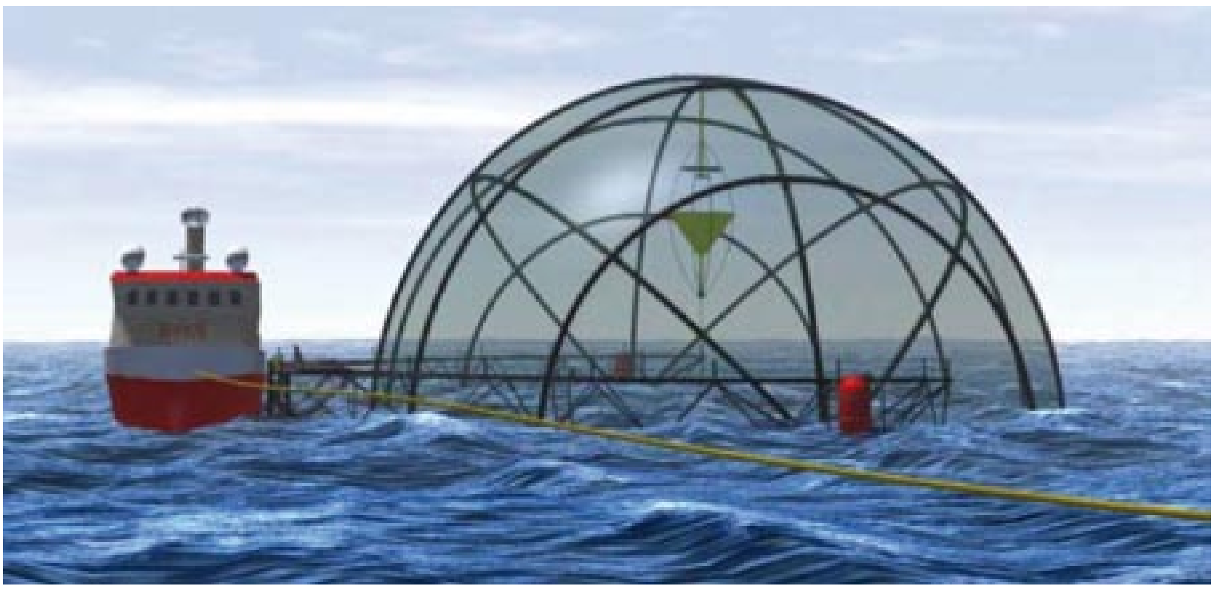


Figure 2.11 Semi-submersible platform, Izar Fene, Spain

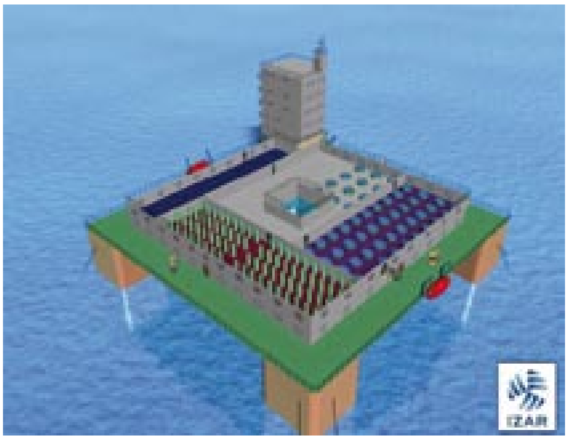
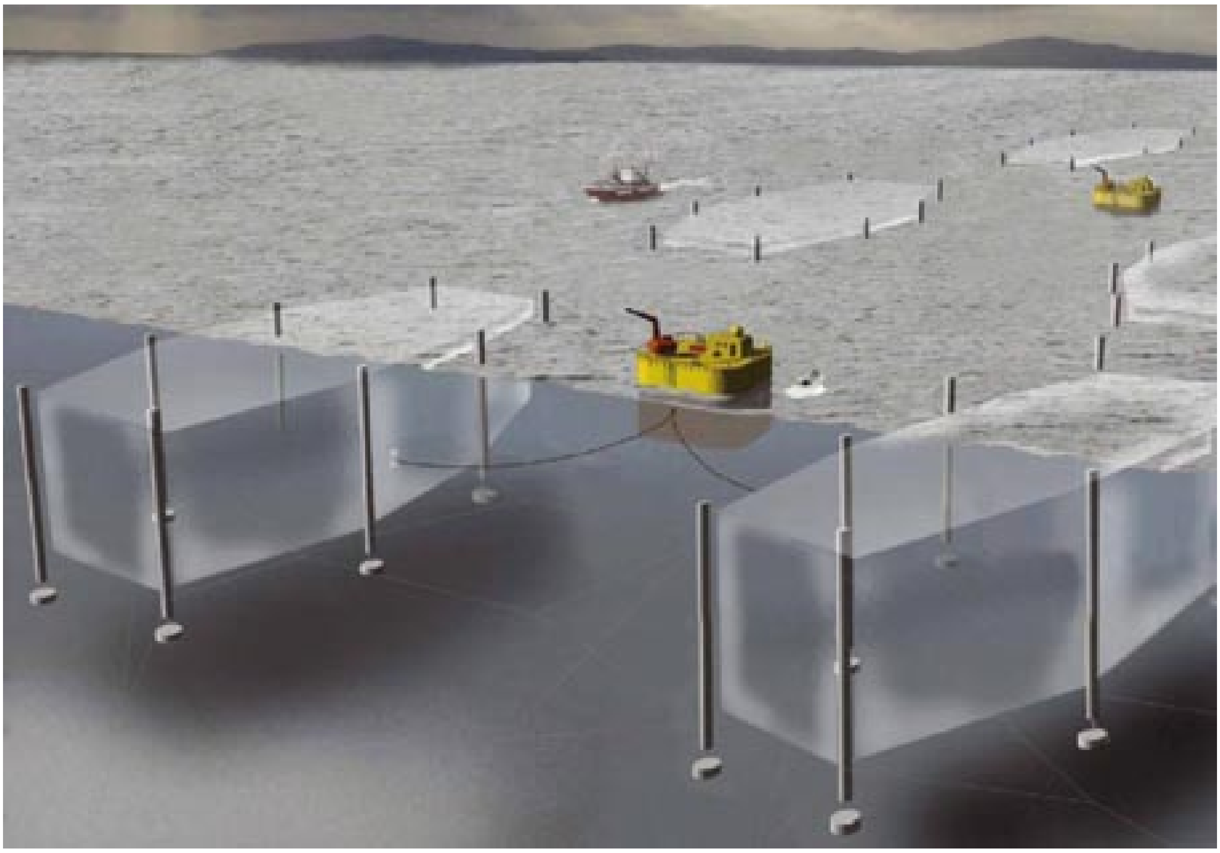


Figure 2.12 Offshore farm with anchor tension cages



3 Recirculation systems

3.1 Overview

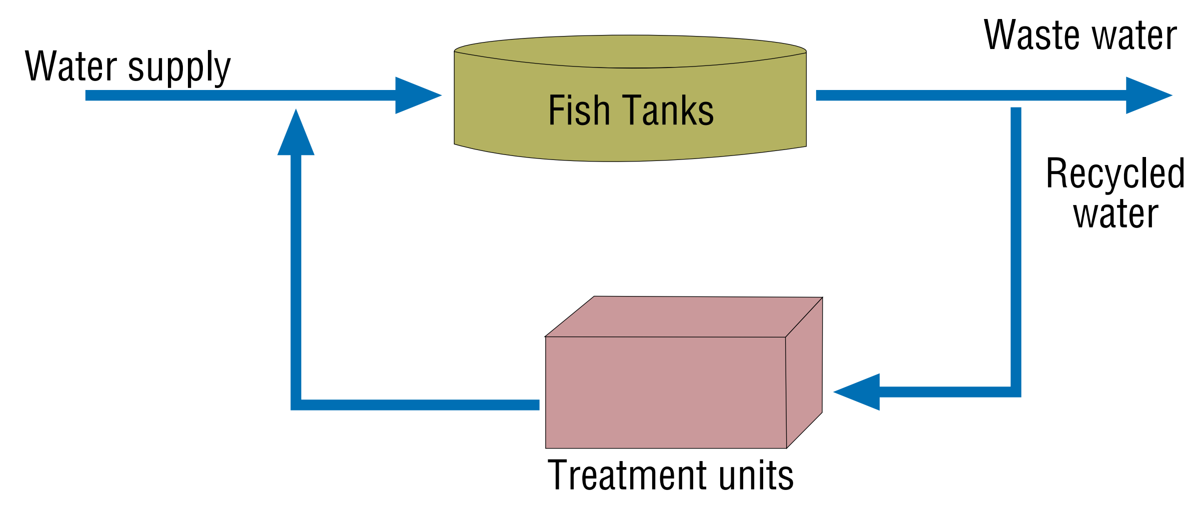
Recirculation aquaculture systems (RAS) are normally land based aquaculture facilities utilising containment systems such as tanks or raceways supplied with flowing water which serves to replenish oxygen and remove metabolic wastes, uneaten feed and faeces. Unlike other land-based aquaculture systems, some or all of the out-flow water is reused by treating it and returning it to the incoming supply stream. RAS systems may therefore be characterised firstly by the proportion of discharge water that is treated and reused on each pass. This varies from 50 to 99.9%, with increasingly sophisticated treatment systems required as the percentage increases. Most commercial RAS farms use between 95 and 99% recirculation rates. The degree of water re-use can also be expressed as the rate of water replacement per day (the percentage of the total system volume that is replaced by new non-recycled water each day). This can range from just 1-2% in highly recirculated systems, to several hundred percent in partially recirculated units.

The recirculation of water provides an opportunity not only to reduce water consumption, but also to provide a greater degree of control over water quality parameters such as temperature, salinity, pH, alkalinity, chemical composition and oxygen, providing these are continuously monitored and controlled. The water treatment system will normally include a means of adding oxygen (aeration, or more commonly, oxygenation), the removal of suspended solids (usually by settlement and/or via microscreen filters), and biofiltration to treat the waste ammonia (nitrification). For higher-rate recycle systems it may also be necessary to include disinfection (e.g. UV) or sterilization (e.g. ozone), temperature control, further gas balance control (e.g. to remove carbon dioxide), and pH control. For very high rate systems, denitrification filters may need to be added to remove nitrate that accumulates as an end product of nitrification. Marine systems normally include foam fractionators to help with the removal of other dissolved and finely particulate organic matter.

The waste outputs from recirculated aquaculture systems depend on the treatment systems employed. Most will produce a waste sludge from the solids removal system. This can be further processed through biological digestion processes, or utilised as an organic fertilizer (at least from freshwater systems). Sludge from marine systems has been used as a substrate for polychaete worm production. In lower-rate recycle systems, a waste water stream enriched with nitrate and phosphate is typically produced. In freshwater systems, this waste has been used for hydroponic plant culture, mainly herbs and vegetables, and in seawater systems, mollusc and seaweed production has been linked with wastewaters. In both cases, designed wetlands have been trialled for final 'polishing' – removal of remaining nutrients.

A slightly different approach to RAS is activated suspension technology (AST) which is being developed for species such as tilapia. This system attempts to address one of the main concerns of RAS that they are relatively complex and expensive to install and operate. Essentially a development of intensive stirred ponds, borrowing concepts from conventional activated sludge technology used for domestic and industrial waste water treatment, they use partial solids removal and aeration, together with high levels of suspended floc in the fish rearing volume to carry out metabolite processing. AST systems attempt to optimise biological processes,

Figure 3.1 Schematic diagram of a recirculation system



with some trade-offs with respect to ease of management and productivity per unit volume.

RAS systems may present many apparent advantages including reduced land and water use, strict water quality control, lower environmental impact, higher biosecurity and better control of waste production as compared to other production systems.

3.2 Recirculation technologies

The principles and design features of recirculation technologies have been widely described[39] and are not repeated here. There have also been many examples of laboratory and pilot scale systems, which have not ultimately been tested in commercial reality. Equally, commercial reality has proved to be the undoing of a number of marketed systems, and the overall experience of these technologies, outside of high biomass value sectors such as hatchery production, has been variable at least. Here, however, we highlight as case studies two of the systems which have gained relatively good commercial respectability, combining an effective mix of research background with practical application. A third case study explains the concept of the AST system.

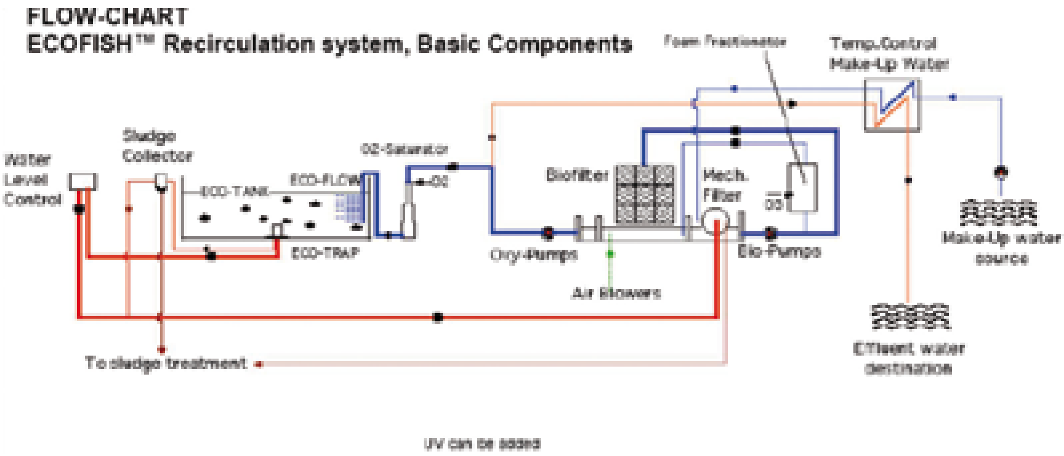
3.2.1 Case study 1: AquaOptima (Norway)

AquaOptima is a Norwegian based company which produces aquaculture facilities for both onshore hatcheries and grow-out facilities. The company has developed its own industrial components and technology for the intensive farming of fish and recirculation of water. Their system is based on several products which control the quality of water in the system by optimising essential parameters such as oxygen, energy and feed.

The shape of the tank (Eco Tank) and the design of the inflow (Eco Flow) and outflow (Eco Trap) channels allow a unique hydrodynamic flow allowing mixing of new water and oxygen with the total volume of water in the system, and self cleaning of the bottom and wall of the tank. Water passes from tank to tank by gravity and when it has passed through the outflow channel it is pumped through a 'bio-pump' and biofilter stage where ammonia and CO_2 are removed. The water is then pumped back to the tanks through low pressure oxygenators to compensate for any oxygen loss. Foam fractionation and ozone are used to further improve water quality by removing fine and dissolved solids. The outflow channel is equipped with a device (Eco Trap) which removes

39 E.g. Timmons et. al. 2002

Figure 3.2 Components of an AquaOptima recirculation system[40]



both particulate and feed waste for collection in a sludge collector outside the tank, with minimal use of water. Removal levels of 50% for suspended solids are well documented. The amount of waste collected as sludge gives a good indication of the appetite and potential of the fish providing the opportunity for maximum growth and feed economy. This reduces the amount of handling of the fish, reducing stress and promoting overall health and good growth rate.

The rapid and efficient removal of solids from the tank makes the effluent water suitable for recirculation via a simpler means of water treatment compared to other tank systems. Based on this, water treatment systems for recirculation have been designed which provide maximum efficiency in the form of good water quality and growth rates.

AquaOptima's newest systems include those for cod and halibut in Norway, Barramundi in the U.K. and tiger puffer fish in Japan. The two salt water Norwegian systems rearing cod fingerlings and halibut have been in operation since May 2005 and replace 10% of water on a daily basis. Both are maintained at 10°C. The barramundi operation commenced in Sept 2005, and is designed to produce 400 tonnes per annum, mainly for restaurant markets in London. In the first year fingerlings were imported but a hatchery

Figure 3.3 Example of a recirculation system[41]

and broodstock facility are planned. Temperatures to rear these sub tropical fish are maintained using heat exchangers and boilers.

Another project using AquaOptima technology rearing pollock in Spain has been in operation for the last two years. Pollock are thought to be an interesting aquaculture candidate due to their fast growth rate and low food conversion ratio, though market prices are as yet comparatively low. At present, pollock fry are not easily available, but hatchery and nursery production technology is established. The project uses a new design of larval rearing tank incorporated into the recirculation model in order to improve water quality and reduce handling.

40 AquaOptima Norway AS

41 Op. Cit.

3.2.2 *Case study 2: HESY (Netherlands)*

HESY specialize in the design and construction of re-circulated freshwater and saltwater fish farms. Worldwide, the company has more than 50 systems in operation, to farm barramundi, carp, catfish, eels, grunter, mullet, Murray cod, perch, salmon smolts, sea bass, sea bream, sturgeon, tilapia, trout, and turbot. Emerging European systems include the rearing of:

- Carp in England;
- Pike perch in Austria;
- Eels in Spain and the Netherlands; and
- Trout in Greece.

Figure 3.4 HESY sea water recirculation system

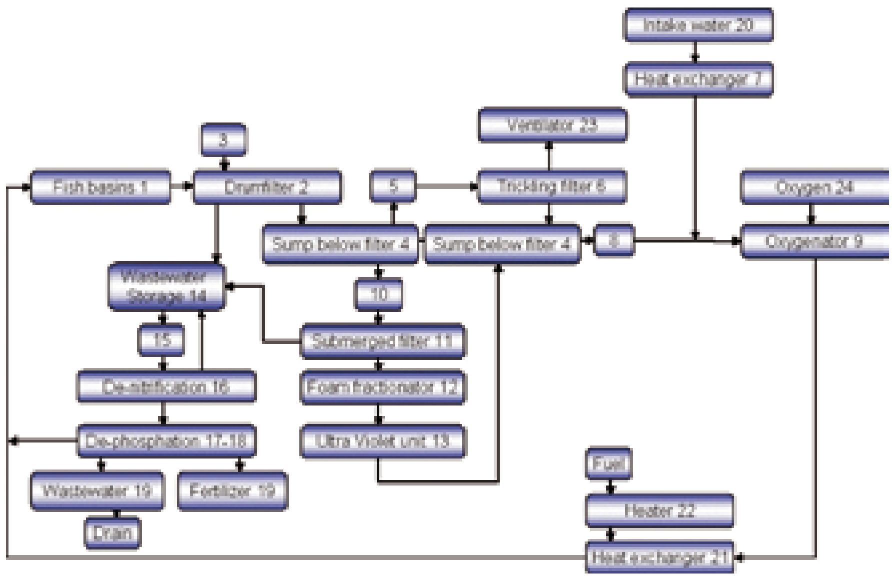
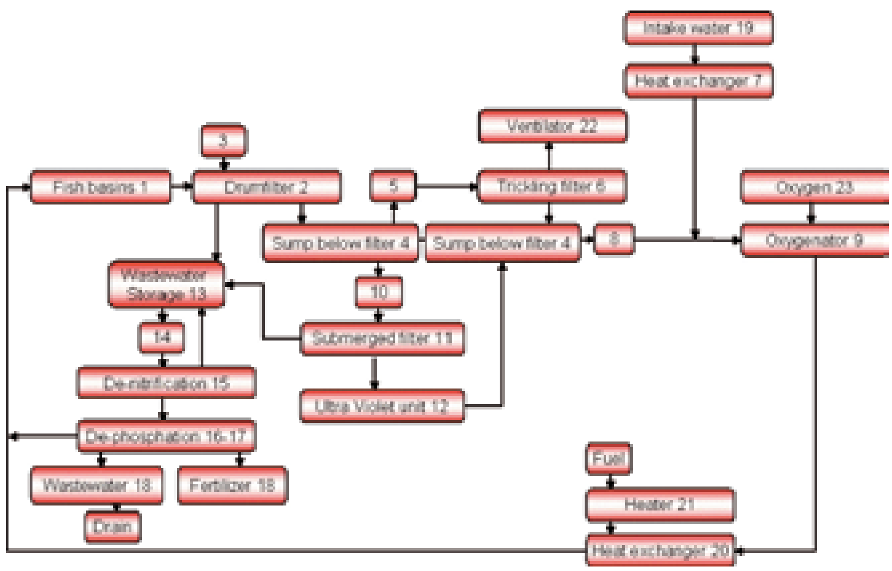


Figure 3.5 HESY freshwater recirculation system



Components of their systems include automatic feeders, brush machines on outlet devices, U.V. filters, drum, belt and disc-filters, bio-filter material, pumps, blowers, grading equipment, airlift systems for fish transportation, oxygen reactors, oxygen generators, submerged filters, trickling filters, fish tanks and stainless tank frames. HESY design and manufacture most of the components themselves. Typical process diagrams for salt and fresh water operation are shown in Figure 3.4 and 3.5.

All systems in operation are reported to have reached at least the predicted and calculated production capacity, and most farms are estimated to achieve 10-40% more than predicted capacity. There is no limitation to the size of the system.

The systems are proposed to be easy to run, with low maintenance requirements, and is claimed to be well-secured in its performance characteristics and management requirements, which would reduce risk in production. The company sell the system complete, offering full training and biological advice. This includes support during start-up, intake of fish, grading, and after-sales service.

3.2.3 Case study 3: Activated Suspension Technology

Conventional RAS are technically complex, have high investment and operating costs and potentially high financial and technical risk, Activated Suspension Technology (AST) is an alternative recirculation technology that is technically much simpler and has lower capital costs. AST systems allow bacteria or algae to grow intensively in the water, along with the fish in the same holding volume. The system converts fish metabolites, and provides a high quality natural food *in situ*, hence also reducing the crude protein requirement of the fish. This environment is suitable for fish species such as tilapia, which are herbivorous or omnivorous and adapted to living in water high in bacteria or algae. Water quality must still be maintained, particularly dissolved oxygen levels[42].

AST is in use in a few countries, usually where there are high levels of photosynthetic energy, but not yet applied to UK conditions. However preliminary studies have shown the AST system to be potentially more cost effective than conventional recirculated water systems[43 44]. The use of lower fish stocking densities than in highly intensive RASs ensures high welfare standards, reducing disease and stress. Moreover the fish could be produced using locally produced ingredients, and quite possibly organic. Energy costs are still involved in aeration and mixing, and in some cases, low-level pumping, but are usually well below those in conventional RAS units. AST has other potential environmental benefits since the species grown do not require fish meal, and there is minimal discharge as effluent is reused.

Potential constraints of AST include:

- Unproven performance in temperate climates;
- Low visibility in bacterial floc, so stock monitoring may be a problem;
- Medication may affect bacteria and other floc species;
- Consumer perception of fish grown in bacteria/waste;
- Possible off-flavours due to production method[45].

42 Warm water fish production as a niche market and diversification strategy. Little, D.C., Young, J.A., Watterson, A., Murray, F. and Grady, K. 2005. RELU conference presentation.

43 Carbon/nitrogen ratio as a control element in aquaculture systems. Avnimelech, Y. 1999. Aquaculture, 176:227-235.

44 Sedimentation and resuspension on earthen fish ponds. Avnimelech, Y.Hochva, M. and Hargreaves, J.A.. 1999. Journal of the World Aquaculture Society, 30(4) 401-409.

45 Warm water fish production as a niche market and diversification strategy. Little, D.C., Young, J.A., Watterson, A., Murray, F. and Grady, K. 2005. RELU conference presentation.

The requirement for maintaining warm water temperatures under commercial conditions is not expected to be a major constraint. Preliminary analysis suggests that with modern insulation technologies, energy costs remain below 5% of total production costs[46]. However, the other issues may be more critical, and for the last two in particular, may require a separate pre-harvest system. Temperate climate performance may also be enhanced by light manipulation, though this adds to technical complexity and energy costs, and so its most likely potential may be expected in higher photosynthetic regimes.

3.3 European overview

Currently, RAS technology in Europe produces a range of different species at one or more stages or development; fingerlings, grow-out and broodstock. At hatchery level approximately 390 million fingerlings were estimated to be produced in 2005, with the dominant species including sea bass, seabream and trout. The main centres of production were Italy, France, Greece, Turkey and Denmark (see table below).

Grow out facilities account for the most use of RAS by volume, producing approximately 20,000 t per annum in 2005 (see below). Eel, African catfish, and trout are by far the most significant, with Netherlands and Denmark, accounting for some 50% and 25% respectively of total European production.[48]

The main constraint to eel farming is its dependency on natural supplies of glass eels for stocking, and production outputs depend on fluctuations in the price of glass eels. RAS are ideally suited to maintaining eels as they can provide the optimal temperatures for growth (23-26°C), mortality rates between growth stages are low, and food conversion ratios are higher than in ponds. Most operations are in close proximity

Table 3.1 Hatchery production (million fingerlings) from RAS in Europe for 2005[47]

	Salmon	Sea bass	Seabream	Sturgeon	Turbot	Trout	Total
Denmark						100	100
Faroe Islands	4						4
France		26.5	30	0.3	3.4		60.2
Greece		44	60				104
Italy		45	45				90
Norway**	0.35						0.35
Portugal			5		5		10
Spain			3.75		1.25		5
Turkey		15					15
U.K.	3						3
Total	7.35	130.5	143.75	0.3	9.65	100	391.55

A Norwegian source believes that there is actually little production of salmon smolts in RAS systems, and that there is also some production of cod juveniles in RAS[48]

46 Op. Cit.
47 Adapted from: Recirculation Aquaculture in Europe. Schneider, O., Eding, E. H. and Verreth, J. A. J. (In preparation). CABI Aquaculture Compendium. As cited in Paper on existing knowledge. CONSENSUS. EU-funded Coordination Action FOOD-CT-2005- 513998. www.euraquaculture.info
48 Arne Fredheim, personal communication

Table 3.2 Fish grow-out production (metric tonnes) from RAS in Europe for 2005[49]

	African Catfish	Arctic Charr	Eel	European Catfish	Mixed	Sturgeon	Tilapia	Turbot	Pike perch	Trout	Total
Belgium			10								10
Estonia			30								30
Denmark			2000							5000	7000
Finland		130									130
Germany	5		320	165	377	20					887
Hungary					200	450					650
Portugal	180										180
Spain			300					280			580
Sweden	40		450								490
Netherlands	3900		4650				550	75	60		9235
Total*	4125	130	7760	165	577	470	550	325	60	5000	19,192

** 500-1,000 t can be estimated for the rest of Eastern Europe, including Bulgaria, Croatia, Poland Czech republic, Russia and the Ukraine.*

to markets and provide a consistent year round supply. These factors give eels raised in RAS a competitive advantage over those raised in ponds[50].

The African catfish is a resilient species which can be grown all year round. The Dutch are the main producers, accounting for approximately 40% of total European production. As the fish has some air-breathing capacity, it is very tolerant to low oxygen levels. This removes a major production expense and allows for higher stocking densities. Overall production and operational costs are low. Farmgate prices have varied between €0.90 and €1.10/per kg over the past couple of years, although data from the Federation of European Aquaculture Producers (FEAP) show prices as high as €1.72 in 2001[51].

3.4 Detailed country perspective

3.4.1 Countries with recirculation systems

Czech Republic

As there is plenty of water still available systems in use only recirculate a small percentage of the water. Of these, there are 5 companies using recirculation systems, and the number in use has not changed over the past five years. The total production is less than 20 tonnes, all consumed domestically. Species grown are European catfish, tilapia, African catfish, and eels which are grown for river restocking. Government policies encourage recirculation systems in the country, and EU funding is available for them. There is also a project supported by the Ministry of Agriculture[52].

Denmark

Aquaculture of rainbow trout has a long history in Denmark but production appears to be declining or stabilizing. However, due to new strategies using recirculation systems (i.e. model fish farms) production is expected to

49 Recirculation Aquaculture in Europe. Schneider, O., Eding, E. H. and Verreth, J. A. J. (In preparation). CABI Aquaculture Compendium. As cited in Paper on existing knowledge. CONSENSUS. EU-funded Coordination Action FOOD-CT-2005- 513998. www.euraquaculture.info

50 Paper on existing knowledge. CONSENSUS. EU-funded Coordination Action FOOD-CT-2005- 513998. www.euraquaculture.info

51 Op. Cit.

52 Adamek, Pers. Comm.

Table 3.3 Recirculation aquaculture current production statistics by country

Country	Production volume (tonnes)	Production value (€)	Percent exported	Change in production over last 5 years (%)	Employment	Species produced
Cyprus	0					
Czech Rep.	<20*		0	0		European catfish; African catfish; tilapia; eel.
Denmark	3300	~€16.3 m (US$21 m)	~80 of eels		64	Eel; turbot fry
Estonia	?					
Finland	300	€2.4 m	0	200	10	Arctic charr; sturgeon
France			50	50		Bass; bream; turbot; meagre; perch; trout; sturgeon; red drum.
Germany	830					Eel; catfish; sturgeon; striped bass hybrid.
Greece	?					Eel
Hungary	1000*		>90	+ small	<100	African catfish; sturgeon
Ireland	<50		75	+100	<20	Arctic charr; perch; live rotifers; codlings.
Italy	40 million fingerlings	€8 m	5	-100	30	Bass & bream fry
Latvia	0					
Lithuania	0					
Malta	0					
Netherlands	9220		58	-45% eels; -3% catfish; +25% turbot; +100% pike perch; 4 new tilapia farms	120	Eel; sole; African catfish; tilapia; turbot; pike perch; koi carp; barramundi
Norway	1 million smolts			+100	10	Cod, salmon
Poland	300			20 new farms		African catfish
Portugal	?			0		Bass, bream & turbot; and their fry; sole.
Spain	Just hatcheries					
Sweden	200	€1.6 million	80 (by weight)	-60	<10	Eel; perch.
UK	575+					Salmon smolts; tilapia; barramundi; turbot; dover sole

* *Partial recirculation only*

increase. Traditional farming in earthen ponds is developing into more technological farms using varying degree of water purification, reuse of water, oxygenation etc. An expert group on fresh water fish farming[53] recommended to initiate construction of three new types of model fish farms, all to be based on a common, overall layout, with a much reduced intake of fresh water and increased retention of nutrients. In these model farms basic principles and technologies from existing recirculation technology is implemented into traditional earthen pond trout farms in varying degrees (see next table).

53 See http://www.aquamedia.org/FileLibrary/10/Aquatreat_Modelfishfarms_Design.pdf for details

Table 3.4 The different types of Danish model fish farms

Types of model fish farms	Model I	Model I a	Model II and IIa	Model III and III a
Pond type	Earth or concrete	Earth or concrete	Earth or concrete	Concrete
Management				
Degree of recirculation (%), min.	70	85	85	95
Retention time in production plant (hr) – min.	8.9	11.9	12.3	18.5
Fish density (kg/m³) – max.	50	50	50	50
Water intake (l/sek) – max.	125	62.5	60	15
Daily feeding (kg) – max.	800	800	800	800
Cleaning devices				
Decentralized sedimentation zone	Yes	Yes	Yes	Yes
Equipment to remove solids	Yes	Yes	Yes	Yes
Biofilter	No	No	Yes	Yes
Plant lagoons	Yes	Yes	No	Yes

Water intake and maximum daily feeding is given based on a feed consumption of 100 tonnes of feed.

Figure 3.6 Danish eel farm (Photo: Danish Aquaculture Organisation)

Depending on the technological design (model type), the model fish farms, in principle, contain the following elements: fish tanks (raceways), sludge traps, biofilters (fixed film and moving bed filters), airlift pumps for recirculation, sludge drying beds, and finally constructed wetlands. Starting in 2005, 13 Danish trout farms have participated in the project using the models above.

In 2005, regulations were imposed in Denmark to reduce water usage from rivers. Model farms to produce at €1.6 /kg ex farm[54]. About 2500 tonnes of eels are produced in in-door recirculated freshwater plants in Denmark[55].

54 Bregnballe, Pers. Comm.
55 Jokumsen, Pers. Comm.

According to FAO[56] 3,301 tonnes are produced in recirculation tanks, with a value of US$21 million. In total, 64 people work in recirculation systems in Denmark, including full time, part time and seasonal workers.

Estonia

There is interest in recirculation systems but significant lack of capital. Thus no real increase of production has occurred yet. Also the regulations of water use do not stimulate recirculation yet. Currently there is only one full scale recirculation farm, which is producing eels, with 3-5 more farms at the design or building stage. There are 5-10 recently built farms that are based on partial reuse or recirculation of water and high densities. Over the past five years there has been a 100% increase in the use of recirculation systems. Total production is 30 tonnes per year, with a value of €200,000, and 100% is exported. Currently two people are employed in recirculation systems. The government could be said to be discouraging recirculation systems, and it is not easy to get any governmental support so it is mainly all private initiatives[57].

Finland

Two companies currently use recirculation systems in Finland, employing 10 people, and the number of recirculation systems in use has increased by 200% in the last five years. A total of 300t of Arctic charr and sturgeon are produced, with a value of €2.4 million. All of this is consumed domestically. Seafood produced in recirculation systems commands a price premium, though this is likely to be due to the species farmed rather than the system used. The government neither encourages nor discourages recirculation systems. No defined R&D policy exists; producers' and research institutes' approach is cautious due to 'risk' that the environment authorities could require adoption of recirculation systems in all production types. Recirculation technology has been applied in some first pilot trials of commercial scale for Arctic charr and sturgeon (flesh and roe)[58].

France

For freshwater aquaculture competition for sites is severe, with increasing environmental constraints in terms of the quality of water outflows. There have been technological breakthroughs in land-based systems relating to fully recirculated systems providing water quality control. There is no significant increase in the use of recirculation systems at the moment, simply because no new farms have been created. All the hatcheries and nurseries are already using recirculation systems. FMD and Vendée Aquaculture on the Atlantic coast, les Poissons du Soleil on Mediterranean are using recirculation systems for the pre-growing of sea bass, seabream and meagre. As far as on-growing is concerned, only a few farms are using it: France Turbot on the Atlantic coast and Aquanord on the North Sea with a partial recirculation. Approximately 20 companies use recirculation systems in France. Over the past five years the number of recirculation systems has increased by 50%. Sea bass, seabream, turbot, meagre, perch, trout, sturgeon and red drum are produced, and mainly as fingerlings. 50% is exported. The government encourages recirculation systems[59].

Germany

One system for eel production was newly established (capacity 80t), but it is now used as a fingerling and breeding station for striped bass. There have been some striped bass production trials, but marketing was difficult. The largest recirculation system in Europe for sturgeon and caviar production, capacity 11,000 kg Caviar and 130 t sturgeon meat, was built in 2005, and began production in September 2005. Previously, sturgeon production, coming mainly from

56 FAO FIGIS National Aquaculture Sector Overview – Denmark (http://www.fao.org/figis/servlet/static?dom=countrysector&xml=naso_denmark.xml)
57 Paaver, Pers. Comm.
58 Molsa, Pers. Comm.
59 Blancheton, Pers. Comm.

■ *Table 3.5 Production from recirculated fish farms in Germany 2001-04*

RECIRCULATED AQUACULTURE (t)	2001	2002	2003	2004
Eel (Anguilla anguilla)	347	381	372	328
Catfish (Silurus glanis)	81	95	106	145
Catfish (Clarias garipienus)	16	5		
Sturgeon (Acipenser ssp.)			15	37
Stripped bass hybrid (Morone ssp.)			2	25
Total	444	502	509	688
No. of Recirculation farms	24	28	31	31

Source: Schmidt-Puckhaber

ponds and some small recirculating systems, was approximately 200 t per year. There is small production of turbot in recirculation systems, and some ideas to increase this production exist[60].

Other candidates for recirculation farming are pike perch and koi[61].

Total production from recirculation systems in Germany is approximately 600 tonnes from freshwater systems, with a value of €4 million. Government policies neither encourage nor discourage recirculation systems in Germany[62].

Greece

There is currently little production of seafood in recirculation systems in Greece. This is because the main species produced are better grown in the sea. However, eels are farmed in small recirculation farms[63].

Hungary

Most of the intensive systems (using geothermal energy) are flow-through or partial recycling systems. Due to the increasingly stringent environmental regulations and high water prices, interest in recirculation is increasing. The principle of water recirculation is also applied in pond fish farms in order to save water and protect the environment.

The use of recirculation systems has increased slightly over the past five years. Around 10 companies currently use recirculation systems, with total production around 1000 tonnes, over 90% of which is consumed domestically. Fewer than 100 people are employed in recirculation systems. The species produced are African catfish and sturgeon. Government policies encourage recirculation systems that use geothermal energy for heating, since this is an available resource[64]. The Research Institute for Fisheries, Aquaculture and Irrigation (HAKI) is a leading authority on recirculation systems in Hungary.

Ireland

Two larger companies and some seven others are currently using recirculation systems in Ireland, although employing less than 20 people. The number of systems has increased by 100% over the past five years, and production has increased by 50%, although total production is less than 50 tonnes, of which 75% is exported. Species farmed are: perch, trout, salmon smolts, charr, seahorses, cod juveniles, abalone, and urchins. Seafood produced in recirculation systems commands a price premium. The government encourages recirculation through promotion and funding of state of the art production techniques including technology transfer and training. The leading authorities on recirculation production in Ireland are: State Development Agencies, BIM, Udaras

60 Weirowski, Pers. Comm.
61 Schmidt-Puckhaber, Pers. Comm.
62 Brämick, Pers. Comm.
63 Charalabakis, Pers. Comm.
64 Varadi, Pers. Comm.

na Gaeltachta, Marine Institute, Taighde Mara Teo and Research Institutions[65].

Italy

The record of recirculation systems in Italy has been rather mixed. Recirculation systems are not widely in use in Italy since there is plenty of water for flow-through systems[66]. However, there are currently two recirculated bass and bream farms and four hatcheries operating, employing 30 people. Total hatchery production is about 40 million fingerlings, valued at €8 million, with 5% produced for export. However, some recirculation farms (sea bass and seabream) were built with the wrong technologies and failed. Over the past five years, the number of recirculation systems has fallen by nearly 100%. A previously successful eel farm closed due to personal circumstances and a collapse in the eel market. There are a few recirculated farms operating at pilot scale, but none of real commercial interest. Government policies encourage recirculation systems. However, the projects that were financially encouraged all failed due to the wrong project and poor management. Encouragement may come from local environmental authorities. The leading authorities on recirculation systems in Italy are regional authorities, plus Ministry for Agriculture and Forestry politics/ Fisheries and Aquaculture Department[67].

Netherlands

The production of fish in the Netherlands differs from the rest of Europe as it is almost only produced in recirculation systems. Species cultured in recirculation systems are: European eel, African catfish, Tilapia, Turbot, Sole, Pike perch and Koi carp[68].

There are 80-100 companies using recirculation systems. Total production is in the range 9,400-13,000 metric tonnes, with a value of €45-52 million. 60-70% of this is produced for export[69]. Approximately 120 people are employed in recirculation systems (200 full time equivalents), and around 40% of farmers have something besides the fish farm, such as an agricultural business. Changes in production from recirculation systems during the past five years include:

- Many eel farms have closed, in total 30 small farms (-45% production). The last two years two 75 tonne eel farms started and some eel farms expanded,

65 Watson, Pers. Comm.
66 Fabris. Pers. Comm.
67 Saroglia, Pers. Comm.
68 Eding, Pers. Comm.
69 Schneider, Pers. Comm.

Table 3.6 Production from recirculated fish farms in the Netherlands

Species	No of farms	Production per farm (tonnes/yr)	Total production (tonnes/yr)	Percent produced for export (%)
Eel	31	5-900	4500	35
African catfish	27	30-600	3500	90
Turbot	3	30-90	120	
Tilapia	4	80-600	850	75
Pike perch	1	50	50	
Solea	1	50	50	
Sturgeon	1	100	100	
Barramundi	1	50	50	
Total	69	-	9220	

(Van Dooren)

so total production is more or less stable, but with larger units and greater concentration.

- 4 catfish farms closed and 3 took over their equipment, so production is stable. (-3%), also now with larger units and greater concentration
- 4 tilapia farms have started production in the last 4 years.
- A new turbot farm is being built (+25%).
- New pike perch farms are being built (+100%).
- A barramundi farm was built this year.

Catfish and eel are seeing little growth as the market is difficult for catfish, and eels have an unsure future due to the glass eel situation. The government encourages recirculation through subsidies, an innovation platform and research grants but sometimes due to local rules and regulation it can be difficult to set up a farm. Leading authorities on recirculation in the Netherlands include Hesy, Multivis, and Fleuren-Nooyen (catfish). Ministry of Agriculture, Nature and Food Quality (LNV), and the Dept of Fisheries[70].

Norway

Recirculation systems are being tested with differing success in production of cod (from larvae to juveniles) and are highly relevant for early stages/juveniles of salmon. Land-based technology is expected to develop from flow-through systems to more predictable and stable recirculation systems in significant larger units – probably more than 10 million smolts/year. Today the average is below 1 million[71].

Poland

The production of fish in recirculating systems is done at a dozen or more farms. These systems are used primarily for the production of stocking material for aquaculture and for stocking open waters. In recent years, over twenty private farms have been established that are outfitted with closed water systems for the production of African catfish. The largest farm produces 60 tonnes annually, and the average annual production is approximately 300 tonnes[72].

Portugal

Four companies use recirculation systems in Portugal, and approximately six systems are in use. Sea bass, seabream, turbot and sole are grown, mostly fry[73]. The number in use has not changed over the past five years. With regards to government policies, there is no distinction made when approving the installation of recirculation production units, but when it comes to grants, they are favoured because they operate in an intensive regime. This policy is likely to change in the near future. Leading authorities on recirculation systems in Portugal are Aquacria Piscicolas SA, Stolt Sea Farm SA, and A. Coelho & Castro, Lda[74].

Sweden

There are five companies using recirculation systems in Sweden. The number of recirculation systems has fallen by 60% over the past five years. Currently, approx 200t of seafood is produced in recirculation systems, with a value of €1.6million, and 80% (by weight) is exported. Production is mainly of eel, but perch is also produced. There are less than 10 people employed in recirculation systems. Aquaculture is neither encouraged nor discouraged by government policies, since they have no aquaculture policy. The leading authorities on aquaculture in Sweden are Chalmers University of Technology (Gothenburg), and KTH (Royal Institute of Technology) (Stockholm) (both at a low level)[75].

70 Van Dooren & Schneider, Pers. Comm.
71 Handa, Pers. Comm.

72 Woynarovich, Pers. Comm. (Confirmed by Lirski)
73 Bravo, Pers. Comm.
74 Bernardino, Pers. Comm.
75 Eriksson, Pers. Comm.

Table 3.7 Countries without RAS

Country		Reference
Cyprus	Currently there are no recirculation systems in use in Cyprus since freshwater aquaculture is very small (less than 100 tonnes), there is limited water use and recirculation at this point is too costly. However, the government encourages the development of new technologies, including recirculation, through co-finance investments.	Kyriacou
Latvia	A review of recent documents on the situation in Latvia revealed no evidence of the use of recirculation systems for aquaculture.	Woynarovich
Lithuania	There is no evidence of the use of recirculation systems in Lithuania.	Woynarovich
Malta	No recirculation - all full scale commercial activity is in sea cages. Recirculation is only used for research purposes. The government neither encourages nor discourages recirculation systems.	Vassallo-Agius
Spain	The use of recirculation systems has not developed at the moment as to be considered a trend in Spain, although this production system is becoming more popular and better known.	Tort

UK

In Wales, two companies use recirculation systems – Llyn Aquaculture Ltd and Bluewater Flatfish Farms Ltd. The number of systems has not changed over the past five years. Llyn has six systems currently in use, producing a total of 10 tonnes of turbot and Dover sole, and around 50% of this is exported. They employ 4 people. Bluewater Flatfish Farms (owned by the Greek company Selonda) are producing up to 100 tonnes of turbot and sea bass and have commenced building a larger facility that includes a hatchery and capacity for up to 1000 tonnes. Sister company to Bluewater is Intensive Aqua-Tech (IAT), which is a recirculation technology company that designs and installs recirculation systems for other clients.

The Welsh government encourages recirculation systems in Wales, by matching funding from FIFG. A key initiative "Aquaculture Wales[76]" is based at the University of Wales, Swansea, that includes a marine recirculated system for research and development (Centre for Sustainable Aquaculture Research). Expertise is also available from Bangor University.

76 http://www.aquaculturewales.com/

There is a turbot grow-out farm near Gainsborough in England that currently produces around 15 tonnes per year, but has capacity for 25 tonnes[77]. UK Tilapia use closed recirculation systems for their tilapia production. The three commercial tilapia farms in the UK produce a total of around 50-60 tonnes annually in recirculation systems[78].

Aquabella Group produces 400 tonnes of 'New Forest' barramundi at their closed recirculation system facility in Hampshire, England, which is one of the largest indoor farms in Europe.

There are three companies producing salmon smolts in recirculation systems in the UK. One company currently produces 0.5 million smolts of ~80g each (total 40 tonnes). Another, very large salmon producing company will not share its production details. The third company has plans to expand production to 65 tonnes of smolts. Therefore, it can be roughly estimated that a minimum of 100 tonnes and likely maximum of 240 tonnes of smolts (1.25 to 3 million) are produced in recirculation systems in the UK[79].

77 Arabi, Pers. Comm.
78 Grady, Pers. Comm.
79 Arabi, Pers. Comm.

3.5 Production feasibility

3.5.1 Technical performance

One of the main constraints to the development of RAS is their capital and operating cost. However, although the technology is expensive, claims of impressive outputs with year round production in locations close to markets, with little land and water use, have continued to attract interest in their use However, investors need to be aware of risks involved, as there are a number of constraints, particularly technical, which can limit operation, including: stocking density, waste and effluent management, and oxygen levels[80].

Primarily, the carrying capacity of the tank system must be high enough to facilitate sufficient rates of stock production to justify initial capital costs. As a result of limitations on biological filters, maintaining high stocking densities and good growth rates can only be achieved if the flow rates of recirculating water through the system are good. The flow rate is dictated by the water treatment system, as this controls the removal of solids, ammonia, the ammonia reduction rate and the appropriate concentration of ammonia-nitrogen providing suitable water for recirculation.

Additionally, carrying capacity is influenced by the levels of dissolved oxygen in the culture tank and filtration system. To provide adequate oxygen, this needs to be added to system at a rate equal to the consumption rate by fish and bacteria. This depends on a range of factors, including the length of time waste solids remain in the system. The importance of maintaining adequate dissolved oxygen (DO) levels and minimizing CO_2 concentrations cannot be underestimated, as if this aeration and oxygenation system fails, fish may be rapidly lost[81].

There are four types of solids generated in recirculation systems: settleable, suspended, floatable and dissolved. Tank design and the placement of drains and filtration systems, water exchange and foam fractionation all extract solids from the system[82].

3.5.2 Markets

To date, large scale production using recirculation systems has not been successful. So far it appears that small-to-medium scale efforts have had the greatest success and longevity. Most producers from recirculation systems supply fish live or on ice to local, high priced markets. Competing in the same markets as pond producers is not generally feasible so producers access niche markets such as gourmet foods, tropical and ornamental fish markets or those demanding year round supply of fresh products. For recirculation technology to survive, producers need to find niche markets, identify their size and meet commitments before the market expands. The U.K. operation which produces 400 tonnes per annum of barramundi for restaurants in London is a good example of such a market. Aside from demand, a strong influence in the sustainability of this operation will be access to or the generation of their own juveniles supply.

Markets will also be dictated by consumer opinion and a firm marketing strategy is necessary as farmed fish may be believed to be of inferior quality. Negative associations may be made regarding recirculation systems and biotechnology, with associated consumer concerns regarding animal welfare. RAS is almost always associated with intensification of production and higher stocking densities. Higher stocking densities have

80 Recirculating aquaculture systems (2nd edition). Timmons, M.B., Ebeling, J.M., Wheaton, F.W., Summerfelt, S.T. & Vinci, B.J. 2002. NRAC Publication No. 01-002.

81 Recirculating aquaculture tank production systems. Losordo, T.M., Masser, M.P., Rakocy, J. 1998. SRAC Publication No.451 http://aquanic.org/publicat/usda_rac/efs/srac/451fs.pdf

82 Op. Cit.

not always been shown to negatively impact upon fish and in some instances, for example, the African catfish showed increased performance and less aggressive behaviour when stocked at higher densities. Further research is required for species-specific stocking densities in order to determine optimal practices, and further research on consumer attitudes and how any negative perceptions might be addressed.

3.6 Financial feasibility

Capital investment in RAS is greater than other traditional systems and therefore profitability relies on economic productivity per unit volume of rearing space. Fish need to be stocked intensively in RAS, providing this agrees with the species in question. RAS need a range of support facilities to ensure against failure of any one of the operations within the system. This includes back-up generators. The cost of support systems needs to be compensated for by sufficient production in order to make overall production costs competitive.[83] This section looks at the setup and running costs of a recirculation system, and investigates the impacts of changes in the costs of key inputs and changes in the value of the fish.

3.6.1 Turbot model

The example of turbot is used as there are both recirculated and flow-though production units for this species in Europe.

83 Recirculating aquaculture systems (2nd edition). Timmons, M.B. et al. 2002. P6

Table 3.8 120t Turbot recirculation farm

Key assumptions

Production rate (t/yr)	Fish value (EUR/t)	Feed (EUR/t)	F.C.R.
120	11000	1100	1.0

Financial model
10 year cash flow (1000's of Euros)

Capacity	0%	50%	100%	100%	100%	100%	100%	100%	100%	100%
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Production (t)	0	60	120	120	120	120	120	120	120	120
RECEIPTS										
Sales,€	0	528	1,056	1,056	1,056	1,056	1,056	1,056	1,056	1,056
From debtors,€	0	132	264	264	264	264	264	264	264	264
TOTAL RECEIPTS,€	0	660	1,320	1,320	1,320	1,320	1,320	1,320	1,320	1,320
PAYMENTS										
Working capital costs,€	453	523	592	592	592	592	592	592	592	592
Capital expenditure,€	1,912	0	0	0	0	0	0	0	0	0
TOTAL PAYMENTS,€	2,366	523	592	592	592	592	592	592	592	592
NET INFLOW/(OUTFLOW),€	-2,366	137	728	728	728	728	728	728	728	728
Bank balance brought forward,€		-2,366	-2,228	-1,500	-772	-44	684	1,412	2,140	2,868
Bank balance at end,€	-2,366	-2,228	-1,500	-772	-44	684	1,412	2,140	2,868	3,595
IRR		20.87%								
NPV (10%), €		1173								

Operating costs

Operating costs	€	% of total
Food	138,600	15%
Fry	86,842	10%
Labour	66,000	7%
Medicines	16,500	2%
Stock insurance	1,931	0%
Power/fuel	99,000	11%
Rep and ren	33,000	4%
Gen insurance	16,500	2%
Admin	33,000	4%
Legal and prof	9,900	1%
Depreciation	315,506	35%
Consumables	8,250	1%
Other (10%)	82,503	9%
Total op costs	907,532	100%
Cost per kg	4.58	

Capital costs

Capital costs	no. units	cost unit, €	total, €	contingency +20%
Polytunnel per m^2	962	128.7	123809.4	148571.3
Office building/roads/parking/sewage	sum	198000.0	198000.0	237600.0
6m bio filter housings	4	3135.0	12540.0	15048.0
2.8m degaser housing	2	165.0	330.0	396.0
treatment pumps	4	3451.8	13807.2	16568.6
fish return pumps	2	3451.8	6903.6	8284.3
biofilter media	116.9	544.5	63639.0	76366.8
belt filter / drum filter	1	46200.0	46200.0	55440.0
Water storage tank 100 m^3	1	10725.0	10725.0	12870.0
ph MONITOR	2	1402.5	2805.0	3366.0
pH buffer	1	2475.0	2475.0	2970.0
pH pump	1	891.0	891.0	1069.2
blowers	4	2475.0	9900.0	11880.0
ozone monitor	2	1072.5	2145.0	2574.0
control panels	2	8250.0	16500.0	19800.0
oxygen monitoring system 8 channels	3	1072.5	3217.5	3861.0
probes	30	222.8	6682.5	8019.0
flow meter	1	1650.0	1650.0	1980.0
containers	2	2805.0	5610.0	6732.0
ozone generator	1	11550.0	11550.0	13860.0
contact column	1	2887.5	2887.5	3465.0
engineering	18	577.5	10395.0	12474.0
Transport of equipment to site	sum			8250.0

Capital costs	no. units	cost unit, €	total, €	contingency +20%
fitting out biofilters (fluidised)				
pipework	10	577.5	5775.0	6930.0
screens	8	363.0	2904.0	3484.8
labour	30	577.5	17325.0	20790.0
trickle and submerged filter				
pipework	2	825.0	1650.0	1980.0
screen and supports	2	1419.0	2838.0	3405.6
labour	20	577.5	11550.0	13860.0
Subtotal, €				721895.6
standby generator	1	21450.0	21450.0	25740.0
Feeders (small tanks)	7	412.5	2887.5	3465.0
ongrowing feeders	23	1320.0	30360.0	36432.0
Fish tank assembly labour	30	577.5	17325.0	20790.0
mechanical filter installation	6	577.5	3465.0	4158.0
Subtotal, €				812480.6
tanks in GRP and circular				
fry tank	7	1320.0	9240.0	11088.0
grow out tank	23	13200.0	303600.0	364320.0
screens stand pipes etc sum	60	33.0	1980.0	2376.0
Subtotal, €				377784.0
Total, €				1912160.3

Sensitivity analysis

System	IRR (%)	Max funding ('000 €)	Payback time (years)
Base model (see 3.5.1 above)	21	2,366	6
+20% sale price	31	2,366	5
-20% sale price	9	2,366	8
+20% feed cost	20	2,368	6
-20% feed cost	22	2,363	5
+20% energy cost	20	2,387	6
-20% energy cost	22	2,344	5
+100% energy cost	12	2,518	7

120t Turbot flow-through farm

Table 3.9 Model of turbot flow-through farm

10 year cash flow, 1000's of Euros

Capacity	0%	50%	100%	100%	100%	100%	100%	100%	100%	100%
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Production (t)	0	60	120	120	120	120	120	120	120	120
RECEIPTS										
Sales,€	0	528	1,056	1,056	1,056	1,056	1,056	1,056	1,056	1,056
From debtors,€	0	132	264	264	264	264	264	264	264	264
TOTAL RECEIPTS,€	0	660	1,320	1,320	1,320	1,320	1,320	1,320	1,320	1,320
PAYMENTS										
Working capital costs,€	393	462	532	532	532	532	532	532	532	532
Capital expenditure,€	1,557	0	0	0	0	0	0	0	0	0
TOTAL PAYMENTS,€	1,950	462	532	532	532	532	532	532	532	532
NET INFLOW/(OUTFLOW),€	-1,950	198	788	788	788	788	788	788	788	788
Bank balance brought forward,€		-1,950	-1,753	-964	-176	612	1,401	2,189	2,977	3,765
Bank balance at end,€	-1,950	-1,753	-964	-176	612	1,401	2,189	2,977	3,765	4,554
IRR		29.58%								
NPV (10%), €		1866								

Operating costs

Operating costs	€	% of total
Food	138,600	18%
Fry	86,842	11%
Labour	66,000	8%
Medicines	16,500	2%
Stock insurance	1,931	0%
Power/fuel	74,250	9%
Rep and ren	8,250	1%
Gen insurance	16,500	2%
Admin	33,000	4%
Legal and prof	9,900	1%
Depreciation	256,908	33%
Consumables	8,250	1%
Other (10%)	71,693	9%
Total op costs	788,623	100%
Cost per kg	3.98	

Capital costs

Capital costs	no. units	cost unit, €	total, €	contingency +20%
Polytunnel per m²	962	128.7	123809.4	148571.3
Office building/roads/parking/sewage	sum	198000.0	198000.0	237600.0
fish return pumps	4	3451.8	13807.2	16568.6
belt filter / drum filter	1	46200.0	46200.0	55440.0
Water storage tank 100m³	2	10725.0	21450.0	25740.0
ph MONITOR	2	1402.5	2805.0	3366.0
pH pump	1	891.0	891.0	1069.2
blowers	4	2475.0	9900.0	11880.0
control panels	2	8250.0	16500.0	19800.0
oxygen monitoring system 8 channels	3	1072.5	3217.5	3861.0
probes	30	222.8	6682.5	8019.0
flow meter	1	1650.0	1650.0	1980.0
containers	2	2805.0	5610.0	6732.0
engineering	12	577.5	6930.0	8316.0
Transport of equipment to site	sum			8250.0
Subtotal, €				557193.1
Feeders (small tanks)	7	412.5	2887.5	3465.0
ongrowing feeders	23	1320.0	30360.0	36432.0
Fish tank assembly labour	30	577.5	17325.0	20790.0
mechanical filter installation	6	577.5	3465.0	4158.0
Subtotal, €				622038.1
tanks in GRP and circular				
fry tank	7	1320.0	9240.0	11088.0
grow out tank	23	13200.0	303600.0	364320.0
screens/stand pipes	60	33.0	1980.0	2376.0
Subtotal, €				377784.0
Total, €				1557015.2

Sensitivity analysis

System	IRR (%)	Max funding ('000 €)	Payback time (years)
Base model (see 3.5.1 above)	30	1,950	5
+20% sale price	41	1,950	4
-20% sale price	17	1,950	6
+20% feed cost	28	1,953	5
-20% feed cost	31	1,947	5
+20% energy cost	30	1,964	5
-20% energy cost	32	1,931	5
+100% energy cost	26	2,029	5

The above is assuming that a recirculation farm would be located in temperate areas where heating is required to achieve adequate growth rates. In warmer climates such as the Portuguese coast, flow through systems are much more feasible because no heating is required. A flow through system in cooler regions would need large energy inputs to heat water adequately, which is then lost, making flow through highly expensive in temperate areas.

3.6.2 Eel model

Eel farming is a relatively new line of aquaculture, only about 25 years of age, but the recirculation technique is now well established and suitable for a number of other species as well. There is still room for development of feed that is better suited for the specific requirements of eels in culture. Not least, progress on eel reproduction in captivity has been difficult and slow, and is not yet economically viable. Nonetheless, some optimism as to the opportunities in this field is prevailing[84].

Glass eels are captured around the shores of France, Portugal, Spain and the United Kingdom and either used nationally or exported to eel farmers in other countries. Intensive culture in recirculation systems consists of square or circular tanks from 25-100 m², usually built of cement or fibreglass. The eels are stocked at a size of 50 g. Densities reach up to 100-150 kg/m². Extruded dry feed (1.5-3 mm) is fed automatically several times a day. Individual growth rates are very different, and grading every 6 weeks is necessary in order to reach a high overall growth performance. The cost of elvers varies significantly depending on annual catches and the interest from Asian eel producers, who buy European eels for farming in their home countries. Prices during 2004 varied between € 300 and 750/kg. General overall production costs in recirculation systems of about € 6/kg have been reported (2003) from Denmark.[85]

120t Eel recirculation farm[86]

Table 3.10 Model of recirculated eel farm

Key assumptions

Production rate (t/yr)	Fish value (EUR/t)	Feed (EUR/t)	F.C.R.
120	8500	1100	1.3

Financial model

10yr cash flow	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10
Production (t)	30	120	120	120	120	120	120	120	120	120
RECEIPTS (€ 1000)										
Cash sales	204	816	816	816	816	816	816	816	816	816
From debtors	0	51	204	204	204	204	204	204	204	204
TOTAL RECEIPTS	204	867	1020	1020	1020	1020	1020	1020	1020	1020
PAYMENTS (€ 1000)										
Working capital costs	396	471	471	471	471	471	471	471	471	471
Capital expenditure	1144	0	0	0	0	0	0	0	0	0
TOTAL PAYMENTS	1540	471	471	471	471	471	471	471	471	471
NET INFLOW/OUTFLOW	-1,336	396	549	549	549	549	549	549	549	549
Bank balance brought forward	0	-1,336	-939	-390	159	708	1,258	1,807	2,356	2,905
Bank balance at end	-1,336	-939	-390	159	708	1,258	1,807	2,356	2,905	3,455
IRR (%)	35.5									

84 FAO NASO Denmark

85 Cultured Aquatic Species Information Programme – *Anguilla anguilla*. FAO FIGIS.

86 HESY www.hesy.com

Breakdown of operating costs	Year 1 ('000 EUR/yr)	All other yrs ('000 EUR/yr)	% of total (yr2+)
Fish feed	127	172	29
Wages/salaries	40	50	9
Rent oxygen tank	2	2	0
Power	37	50	9
Fingerlings	168	168	29
Discharge costs	4	6	1
Administration costs	5	6	1
Stock Insurance	8	10	2
Unforeseen costs	6	6	1
Depreciation	114	114	20
Total operating costs	510	585	100
Cost/kg (EUR)		4.88	
NB excludes finance costs			

Capital costs	Total ('000 EUR)
Installation costs	800
Building and infrastructure costs	240
Total capital cost	1040
Contingency (10%)	104
Capital cost inc. contingency	1144
Annual depreciation (10 yr av. life)	114

Sensitivity analysis

System	IRR (%)	Max funding (€)	Payback time (years)
Base model (see 3.5.3 above)	35.5	1,335,522	4
+20% sale price	52.0	1,294,722	3
-20% sale price	18.1	1,376,322	6
+20% feed cost	32.7	1,335,522	4
-20% feed cost	38.1	1,335,522	4
+20% energy cost	34.4	1,342,964	4
-20% energy cost	36.5	1,328,080	4
+100% energy cost	30.4	1,372,734	5

3.7 Drivers and barriers

Czech Republic: Drivers: Profit; New products for restocking purposes. Barriers: Lack of practical experience; Shortage of quality feed mixtures; Competition from cheaper imports from outside the EU is a newly occurring and rapidly growing problem; Lack of demand for product since the flesh quality is poorer than from pond culture; High costs of production; High energy costs[87].

Denmark: The drivers are: Profit; New product - more attractive to market, including environmental attributes; Changing cost structures; Cost of production advantage; Planning of production (delivery at certain seasons of the

87 Zdenek, Pers. Comm.

year/best prices); Water availability and cost; Pollution controls; Market demand. The barriers are: Difficulty getting investment; High costs of production; Energy costs[88].

Finland: Drivers: Interest towards emerging species that often include lake-dwelling, fresh water species. Lake fish farming cannot be expanded in conventional cages or earth ponds due to environmental restrictions. Novel lake fish species are expensive enough to be farmed feasible in recirculation systems. Positive environmental effects (less pollution; water saving; fish health; positive image) are favourable. Barriers: Rainbow trout is still the main product in Finland with low margins and thus not feasible in recirculation systems. The producers are afraid of the 'risk' of the environment officials' requirement of recirculation technology in every environment. No tradition and intensive R&D in Finland[89].

France: Recirculation is already successfully used for early stages, but there are still some questions for ongrowing (growth inhibiting substances for turbot) and fears concerning the complex system and fish quality. Trout production is slowly increasing its use of recirculation technology. If it is successfully used in this sector (which is difficult from an economic point of view), development will probably be fast[90].

Germany: Drivers: Pollution controls and fees; profit (mainly for suppliers of equipment). Barriers: Energy costs; competition from cheaper imports from outside the EU[91].

Greece: For much the same reasons as above (capitalization of existing technology, availability of sites) there seems to be little scope of development of recirculation systems. In fact, some 'land systems' that existed in the early years of the sector's development proved to be much more expensive (land cost, energy cost, etc) than their cage counterparts and were soon abandoned. Such systems are only used in hatchery stations, for the early stages of fish growth, before being moved to the cages. In some cases, land-based systems are used for research and development, but not for extensive commercial culture[92].

Hungary: The main drivers of recirculation are: profit; water availability and cost; technology overlap (using technology developed for other industries); and availability of geothermal water resources. The main barriers are: difficulty getting investment; competition from cheaper imports from outside the EU; lack of demand for product; high costs of production; and energy costs[93].

Italy: Drivers: Profit; possibility to control the production; little amount of water request; pollution control; possibility for new species; niche production. Barriers: Lack of good training; the recent investments done in Italy were made with the wrong technologies and investors are now scared[94].

Malta: There is only one recirculation marine hatchery that is used solely for research trials. Recirculation systems could be advantageous however Malta is very limited for space and electricity costs are among the most expensive in Europe. This discourages investors to set up recirculating systems[95].

Netherlands: Driver: That there will not be enough fish to meet large demand in the future[96]. Drivers are: the intensification of warm water fish culture with the traditional reasons for recirculation: conservation of energy and water, decrease environmental pollution, increase of production density[97]. Barriers: Limited amount of

88 Jokumsen, Pers. Comm.
89 Molsa, Pers. Comm.
90 Blancheton, Pers. Comm.
91 Brämick, Pers. Comm.
92 Triantaphyllidis, Pers. Comm.
93 Varadi/Ronyai, Pers. Comm.
94 Saroglia, Pers. Comm.
95 Vassallo-Agius, Pers. Comm.
96 Van Dooren, Pers. Comm.
97 Schneider, Pers. Comm

species that can be farmed in recirculation systems (still much research to be done); competition from cheap fish imports[98]. Other barriers: Capital intensity; lack of chain management or industry organisation (societal-economic issue); lack of standardised and appropriate regularity frameworks (societal issue); resources – availability of high quality groundwater, feed (fishmeal) and juveniles[99].

Portugal: Key driver would be the possibility to produce under controlled conditions, that could reduce cost, improve production and sales planning, increase product safety and environmental performance; all these could in turn be used to achieve a better market price, by turning a product that is presently very affected by seasonal effects (availability of both quantity and sizes) into a commodity, available on a permanent basis in sizes and quantities as required by the market. Main barriers would be the difficulty to obtain funding and licensing, due to the lack of experience in the field, of both investors, technical staff, banks and licensing bodies[100].

Spain: Recirculation has not entered in the seawater fish farming as a main industrial option in Spain, except for hatcheries. The barrier is essentially the necessary high investment required and the little profit in the culture of sea bass and seabream. It can be an option for turbot where the profits are still higher. As the cage system is well developed there is small room for other more expensive technologies. A driver for recirculation can be the degree of innovation that these systems can afford. It has been shown that a substantially higher fish density may be cultured in recirculation systems. Whether these systems demonstrate higher profits they may be introduce in the seawater fish culture. In freshwater systems some developments have been introduced which can be a driver for the future. Thus, some freshwater farms have been built with integrated systems including power cogeneration (from oil to electricity) plus recirculation. These systems allow an increase in the water temperature (resulting in higher growth rates) and sell the surplus of electricity to the power companies[101].

98 Van Dooren, Pers. Comm.
99 Eding, Pers. Comm.
100 Bravo, Pers. Comm.

3.8 Environmental impacts

Recirculation systems can help reduce the impacts of fish farming activities, since they reuse water and reduce or eliminate waste outputs. Since they can be self-contained units, the farms can be sited nearer to markets, reducing transport costs and 'food miles'.

The present need for sustainable use of aquatic resources including water will lead to the increased use of recirculation facilities by recycling technology. Depending on site-specific conditions advantages of these systems include;

- Decreased use of land and water
- Reduced nutrient emissions to the environment
- Biosecurity
- Production closer to the local market
- The exclusion of external disturbances such as bird or mammal predation

RAS use tanks for culture so substantially less land is required for their operations. A fraction of the water requirements of ponds are needed in RAS to produce similar outputs. Less water per kg of fish produced in a recirculation system is used (see table below). In addition, the energy requirements for water heating are reduced and electricity needs are maintained constant throughout the year.

Nutrient emissions to the environment are considerably less than those of other production systems. Chemical oxygen demand (COD) may be reduced to less than 10%. The farm effluent can often be collected in a sludge collector and

101 Tort, Pers. Comm.

Table 3.11 Comparison of System Performance in Different Aquaculture Production Systems[102]

System performance	Pond	Flow-through	Recirculation
Water use per m^3/kg/fish	2	14.5-210	0.15-0.40
COD discharge ($g0_2$/kg fish produced)	286	780	150
N-Retention (%)	20-50	14.5-210	0.15-0.40
P-Retention (%)	5-10	15-25	21-35

later used as compost. The best environmental units utilise denitrification units, a flocculation unit, a belt filter and a sludge storage facility to meet the strictest environmental demands.

Biosecurity is good with the incidences of escapee fish virtually non-existent. The need to use chemicals to treat infections is less as the incidence of disease is lower. This is thought to be due to relative increases in ion concentrations in recirculation systems which can inhibit the growth of bacteria, and/or reduce pH, which can inhibit the growth of some parasites[103].

3.9 Prospects

The need for sustainable use of aquatic resources including water will lead to a reduction in traditional flow-through aquaculture and increased use of recirculation technology[104]. Recirculation systems are still expensive, however, and small scale farmers are unlikely to be able to afford such systems unless financial incentives or legislation give them comparative advantage.

3.9.1 Priorities for future research in RAS

An ideal RAS will be completely closed, with no water added and none discharged. Research is already investigating this ideal, and it is predicted that future research will continue this quest, both for environmental and financial reasons. Likely focuses will be on improved purification technologies, such as: dephosphatation, denitrification and/or flocculation units; and re-use of the fish or farm waste for bacteria, algae and plant production[105].

Overcoming the growth inhibition that occurs particularly in marine species is another important goal. Within current technologies, the only solution is to use short hydraulic retention times and renew the system's water frequently. However, this goes against the aim of completely closing the system and cutting out water renewal, therefore more research is needed to identify and overcome the cause(s) of growth inhibition.

Because of the high potential image damage, research on welfare in fish is particularly of interest to RAS farming. For example, the relationship between welfare and stocking density is not straightforward, with some species preferring lower and some higher stocking densities. More research is needed in this area.

Other areas of research include: off-flavours and textures; management of health and the use of medicines; optimisation of technologies, such as pumping systems and biofilm management; and feed composition changes to reduce waste[106].

102 Adapted from: Paper on existing knowledge. CONSENSUS. EU-funded Coordination Action FOOD-CT-2005- 513998. www.euraquaculture.info
103 Paper on existing knowledge. CONSENSUS. EU-funded Coordination Action FOOD-CT-2005- 513998. www.euraquaculture.info
104 Sustainability in Aquaculture. HESY. 2006.
105 Paper on existing knowledge. CONSENSUS. EU-funded Coordination Action FOOD-CT-2005- 513998. www.euraquaculture.info
106 Paper on existing knowledge. CONSENSUS. EU-funded Coordination Action FOOD-CT-2005- 513998. www.euraquaculture.info

4 Integrated systems

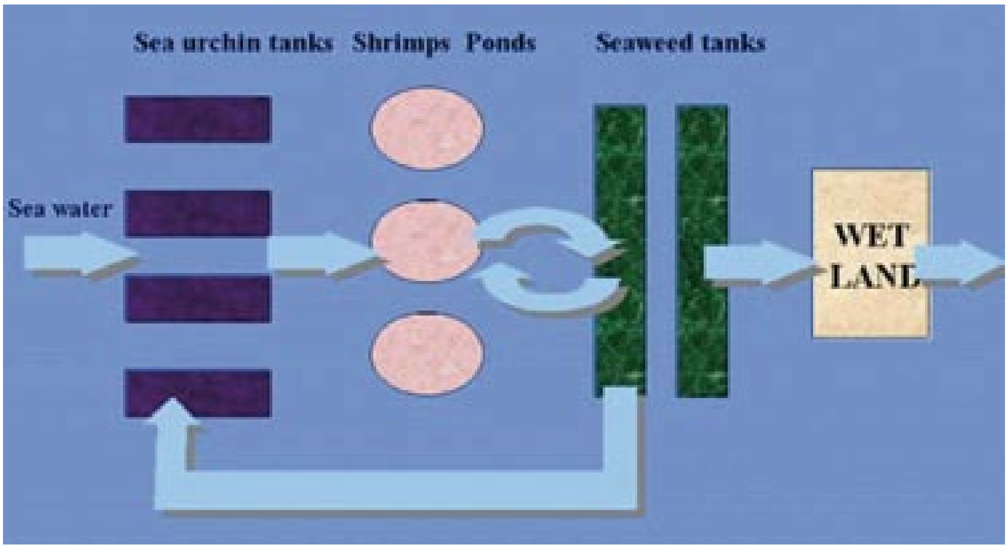
Emerging integrated systems refers to farms where a range of species are being farmed at the same site with the aim of producing more than would be produced if the species were farmed separately. Examples are seaweeds or sea-urchins grown near finfish cages absorbing some of the nutrients discharged from the cages or land-based integrated farms growing animals, vegetables and fish on the same site.

4.1 Integrated system components

It is sometimes referred to as Integrated Multi-Trophic Aquaculture (IMTA) to distinguish it from polyculture[107]. The differences lie in the trophic level of the species involved. For example, polyculture can describe a system farming three finfish species, which all have similar biological and chemical processes and produce unused waste, whereas IMTA refers to a system where fed organisms (finfish or shrimp) are combined with extractive organisms (seaweeds or shellfish), with their biological and chemical processes balancing each other and wastes from one species being used by another. When looking at emerging integrated systems, it is only IMTA that is an emerging system, not polyculture, which has been around for centuries.

The following two figures show the nutrient flows (blue arrows) through warmwater and temperate IMTAs.

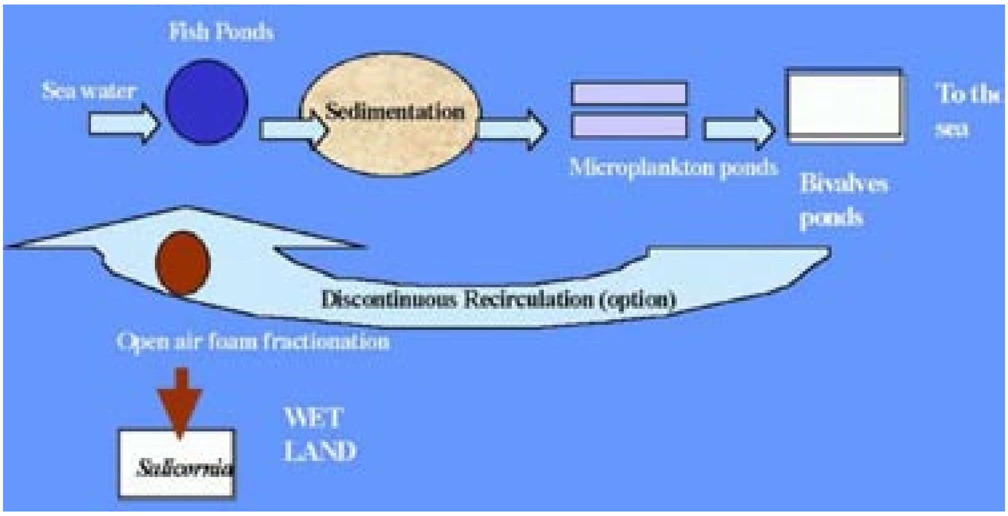
Figure 4.1 Example of a warm water integrated marine aquaculture system[108]



107 Integrated Multi-Trophic Aquaculture. Chopin, T. Northern Aquaculture, July/August 2006. Canada

108 GENESIS project

Figure 4.2 Example of a temperate water integrated marine aquaculture system[109]



A different type of integrated aquaculture can be seen in Hungary, where they are developing 'multifunctional pond fish farming'. This involves integrating fish production with nature reserves, renewable energy production, recreational angling, and eco-tourism facilities such as a health and leisure centre and excursions such as wildlife watching, all on one site. The Aranyponty Fish Farm is depicted below as an example of a multifunctional pond fish farm. The farms aim to integrate food production, environmental protection (renewable resources),

Figure 4.3 Aranyponty Fish Farm – multifunctional pond fish farm, Hungary[110]

109 GENESIS project

110 Multifunctional pond fish farming. Laszlo Varadi. 2006. Presentation at Aqua2006 conference, 11 May 2006, Florence.

nature conservation (biodiversity), and recreation (angling, tourism). The idea has grown up as a response to strict environmental regulations, limited and expensive water resources, and a need for recreational services. There are incentives and subsidies for setting up these farms.

Further examples of this multifunctional approach can be seen in Germany and France (e.g. Ecosite du Pays de Thau), where sewage treatment ponds are used to grow algae that act as sources of food for fish, either directly or indirectly[111]. Although these examples have been around for some time, recent interest has grown as pressure for more environmentally sensitive solution to waste control increases.

4.2 European overview

Some eastern European countries have traditionally used integrated systems in their freshwater aquaculture production e.g. carp polycultures, but these are not the IMTA that is considered as an emerging aquaculture system in Europe. IMTA is not in commercial use in most European countries at the moment, apart from a few mussel long-lines associated with bass and bream farms in Italy, and some seeding of bass and bream tanks with oysters and clams in Portugal (Section 4.3.1). There are several studies in Canada, Chile, Israel, Scotland, the U.S.A., South Africa, and Australia looking at the potential of IMTA systems for ameliorating the nutrient rich effluents of fish farms[112]. This section will describe the research and trials being carried out, since there is currently very little commercial production in Europe.

In Norway, SINTEF (The Foundation for Scientific and Industrial Research) and NTNU (Norwegian University of Science and Technology) are currently researching IMTA. The strategic project is called INTEGRATE – Integrated open seawater aquaculture, technology for sustainable culture of high productive areas[113]. The main objectives of the programme are:

- To develop technology for an integrated multi-trophic aquaculture in open seawater that contributes to a future economically feasible and environmentally sustainable aquaculture industry;
- To contribute to the next generation of knowledge based policy and management tools for localisation and management of aquaculture in coastal waters.

The project will run 2006-2009, with a total budget of 14million NOK (€1.7 million).

An IMTA system in operation in New Brunswick, Bay of Fundy (Canada) has three components including fish, shellfish and seaweeds. The seaweeds bio-filter inorganic nutrients and the shellfish filter particulate matter. This system is relatively simple and there is scope for several other components, for example the addition of sea cucumbers, polychaetes and sea urchins[114].

A Canadian Research project "Development of Integrated Aquaculture for Environmental and Economically-balanced Diversification and Social Acceptability has shown that kelp and mussel production increases by 46 to 50% when reared adjacent to salmon sites. Additional data has shown no transfer of therapeutants used by the salmon industry to kelp and mussel tissue, and all samples analysed have been below Canadian and the U.S.

111 Ecosite du Pays de Thau. www.ecosite-du-pays-de-thau.com

112 Rationale for Developing Integrated Multi-Trophic Aquaculture (IMTA): an example from Canada. Thierry Chopin & Shawn Robinson. Fish Farmer Magazine Jan/Feb 2006.

113 INTEGRATE – Integrated Open Seawater Aquaculture, Technology for Sustainable Culture of High Productive Areas. SINTEF www.sintef.no/content/page12____9016.aspx

114 Integrated Multi-Trophic Aquaculture. Chopin, T. Northern Aquaculture, July/August 2006. Canada.

Food and Drug Administration, and European Directive regulatory limits for heavy metals, arsenic, PCBs and pesticides. The researchers have shown the absence of faecal coliforms in kelp and mussel tissue, in addition to monitoring environmental parameters at production and reference sites. A survey of public opinion, including socio-economics is underway[115].

It has been calculated that if 80% of salmon farms in New Brunswick are suitable for IMTA, and two-thirds were in operation at any time, adding seaweeds and mussels could generate CDN$44.6 million (€30.9 million) in extra revenue, creating 207 jobs. At present the marine aquaculture sector in New Brunswick is value at CDN$188.2 million (€130.6 million)[116].

The above Canadian research validates the IMTA as the recreation of a simple ecosystem that is balanced with its environment and one which can provide responsible sustainable conditions for culture, and additional scope for economic diversification. The research reveals that an IMTA system contributes to:

- A more beneficial conversion of food and energy
- Environmental services through bioremediation and compliance with upcoming discharge and effluent regulations
- Improved insight into the bioeconomic costs of operations
- Better insight into the implications of integrated culture of marine organisms on issues of sustainability

As yet the appropriate and regulatory framework to promote the upscaling of IMTA operations from the pilot stage of development to commercial scale operations is still under negotiation and will greatly benefit once a flexible model of the IMTA including the above components has been generated[117].

There are a few projects based at the Scottish Association for Marine Science (SAMS) in Scotland, such as:

- REDWEED – Reducing the environmental impact of sea-cage fish farming through cultivation of seaweeds;
- MERMAIDS - Multi-trophic culture for Environmental Remediation – active Management of Aquaculture Initiatives for Diversification and Sustainability; and
- SPIINES 2 - Sea urchin Production In Integrated systems, their Nutrition and roe Enhancement[118].

One of these studies is assessing the dynamics of the IMTA system on Loch Duart in Scotland, investigating the nutrient distribution around marine fish cages and the growth of seaweeds *Palmaria palmata*, dulse or red algae, and *Laminaria saccharina*[119]. Nitrogen is the main limiting nutrient for many algae, particularly in the summertime. Owing to fish feed and excretion, the levels of ammonia around fish farms are high. Seaweeds can utilize ammonia as a source of nitrogen when levels of other forms are low. Therefore, the growth of algae and the cycle could be enhanced by growing them in the vicinity of fish cages. The study revealed that ammonia levels in the photic zone around cages increased 3 hours post feeding and remained high for 4 hours afterwards. This would indicate good conditions (depth and nutrients) for the growth of seaweed.

115 Integrated Multi-Trophic Aquaculture. Chopin, T. Northern Aquaculture, July/August 2006. Canada.
116 Integrated Multi-Trophic Aquaculture. Chopin, T. Northern Aquaculture, July/August 2006. Canada
117 Fish farms clean up their act. Helen Dell. 2003. AquaNet in the News. Canadian Network of Centres of Excellence for Aquaculture www.unbsj.ca/sase/biology/chopinlab/articles/tchopin_biomednet.pdf
118 Scottish Association of Marine Science (SAMS) www.sams.ac.uk
119 Reducing the environmental impact of sea-cage farming through cultivation of seaweeds. Sanderson, J.C., Kelly, M.S. & Dring, M.J. 2006. SAMS and Queens University of Belfast.

In the study, the culture of *L. saccharina* and *Palmaria palmata* were trialled adjacent (10-20m) to fish farm cages. Seasonal yields of *P. palmata* and *L. saccharina* increased by 50% and 63% respectively. Extrapolation of the data showed that, on one of the *P. palmata* sites, 1 ha of algae could potentially absorb up to 30% of excess nutrients through feed and faeces for a 500 tonne salmon production unit[120]. As the origin of nitrogen derived from fish farms may be present in the environment up to one kilometre away, cultured macroalgae could be sited in areas more suitable to algal growth while still maintaining the extractive effect of nutrients.

In 2004, a research award was given to develop dynamic ecosystem carrying capacity modelling for five sea loch systems in Northern Ireland. The aim of this project is to collect data to devise functional models of each loch collecting environmental variables and data, aquaculture activities and interactions. To evaluate the carrying capacity of different loch systems considering interactions of different cultured species for normal and alternative aquaculture methods. A full report of this work should be made available this year[121].

4.3 Detailed country perspective

4.3.1 Countries with integrated systems

Czech Republic

Integrated systems are a traditional method of aquaculture production in the Czech Republic, with polycultures of freshwater fish the most common type. Species grown together include: common carp (90%), herbivorous carp (5%), tench (1%), predatory fish (1%) and others[122].

Hungary

Most of the production in Hungary is integrated production – carp, pike and catfish polycultures are traditional aquaculture practices. There are some experimental integrated systems, with rice and fish, and effluent use, but nothing commercial at this stage. Government policies encourage new integrated farming systems, through matching funding from FIFG[123]. The Research Institute for Fisheries, Aquaculture and Irrigation (HAKI) is leading research on integrated systems in Hungary.

Italy

Integrated systems are being used in lagoons and basins in Italy. Carp, tench and pike, and mullet, seabream, sea bass and eel are cultured in these systems. Seaweed is not currently cultured as part of an integrated system. The government encourages integrated systems, but they have restrictions. Institutes near lagoons do research on integrated systems, e.g. the National Centre for Research, Venice[124].

There are integrated systems in Italy, mainly in extensive coastal lakes and lagoons. Also, some sea bass and seabream cages have mussel long-lines associated with them. There may be over 100 companies involved in integrated production, with 200-300 employees. Over the past five years the number of systems has increased by 10%. Total production is over 1500 tonnes, with a value of €7 million. Species grown together are: 1) mussel and sea bass/seabream; 2) sea bass, seabream, eel, mullets, other species. Government policies neither encourage nor discourage integrated systems[125]. The Ministry for Agriculture Politics and Regional governments for respective competencies are the leading authorities in Italy.

120 Op. Cit.
121 Sustainable Mariculture in Northern Irish Lough Ecosystems (SMILE) project. 2005. DARD; IMAR; Plymouth Marine Laboratory; CSIR; and Queen's University Belfast www.ecowin.org/smile/
122 Adamek, Pers. Comm.

123 Varadi, Pers. Comm.
124 Fabris, Pers. Comm.
125 Saroglia, Pers. Comm.

Poland

Carp, *Cyprinus carpio*, is produced in polyculture with herbivorous fish such as grass carp, *Ctenopharyngodon idella*; bighead carp, *Aristichthys nobilis*; European catfish, *Silurus glanis*, tench, *Tinca tinca*; Prussian carp, *Carassius auratus gibelio*[126].

126 Woynarovich & Lirski, Pers. Comm.

Portugal

It is known that some farmers are seeding tanks and other waterways (admission tanks and effluent channels) in their farms with oyster and clam, but no precise figures are available. The species grown together are seabream and/or sea bass with oyster (*C. gigas*) or clam (*Ruditapes decussatus*). There are no specific measures to encourage integrated systems, but the government

Table 4.1 Countries Without integrated systems

Cyprus	There are currently no polyculture systems in Cyprus since the demand for sea bass and seabream has not yet been satisfied.	Kyriacou
Denmark	There are currently no integrated systems in production in Denmark, but there are discussions about farming blue mussels with rainbow trout sea farms. The government encourage sustainable aquaculture with special attention to environmental impact - but there are currently no grants and/or regulations regarding integrated systems. The leading aquaculture research activities in Denmark are centred at The Danish Institute for Fisheries Research (DIFRES) in cooperation with governmental research bodies, and with close contact and cooperation with aquaculture industry players.	Jokumsen
Estonia	There are currently no IMTA systems in commercial use in Estonia. Polyculture of carps and juveniles of other species, such as pike-perch and coregonids, is practiced at some farms.	Paaver
Finland	No integrated systems exist in Finland due to ecological limitations.	Molsa
France	There are no integrated systems in production in France due to the economics of production.	Blancheton
Germany	There are no integrated systems in use in Germany.	Brämick
Greece	No integrated systems are currently in use in Greece.	Charalabakis; Triantaphyllidis
Ireland	There are currently no integrated systems in production in Ireland. However, some research is being carried out.	Watson
	There is a lack of knowledge and interest in integrated systems, and a problem with licensing laws. There are possibly some mussels on salmon farm anchor lines.	McElwee
Latvia	No information could be found indicating that integrated systems are in use in Latvia.	Woynarovich
Lithuania	It is possible that carp polyculture is practiced in Lithuania, but it appears that no other types of integrated aquaculture systems are in use.	Woynarovich
Malta	With regards to integrated species, farms only produce species separately and there are no plans for integrated culture. It is unlikely that integrated systems will be employed in Malta, since the vast majority of production is from offshore farms, which would not be suitable for integrated production.	Vassallo-Agius
Netherlands	There is some discussion on the use of integrated systems (greenhouses-fishfarms), but it is still under development and there is no commercial production.	Van Dooren
Norway	Production in Norway is all monocultures; there are currently no commercial examples of integrated aquaculture. However, SINTEF has a current research project investigating integrated aquaculture named INTEGRATE – 'Integrated open seawater aquaculture, technology for sustainable culture of high productive areas' (see Section 4.2 above).	Handa
Spain	It is assumed that there are no integrated systems in production in Spain, as no references can be found to them in the literature	
Sweden	Bivalves are seen as playing an important role in mitigating eutrophication and removal of nutrients in the coastal zone. Discussions about 'nutrient quotas' are underway, and paying for production of mussels may be a future alternative to traditional treatment.	Troell
	Integrated systems have not been encouraged, in spite of some plans. There are few apparent possibilities in the brackish water of the Baltic (so far).	Eriksson
UK	There is currently no commercial production from integrated systems, but there are research trials being carried out by the Scottish Association for Marine Science (SAMS) with commercial partners Loch Duart Ltd and West Minch Salmon in Scotland.	Kelly

encourages the use of bivalve molluscs with fish farming due to their filtering abilities, reducing the amount of organic material released in the effluent and maximising the economic return from the fish farm[127].

4.4 Technical feasibility

Research is still very much at the initial stages, and more information on this aspect of production will emerge as these studies progress. Work carried out in the Bay of Fundy, Canada, has shown that IMTA is technically feasible, with kelp and mussel productions increasing by 46% and 50% respectively when cultivated in proximity to salmon sites[128]. The culture of *L. saccharina* and *P. palmata* trialled adjacent (10-20m) to fish farm cages in Scotland showed that seasonal yields increased by 63% and 50% respectively. Extrapolation of the data showed that, on one of the *P. palmata* sites, 1 ha of algae could potentially absorb up to 30% of excess nutrients through feed and faeces for a 500 tonne salmon production unit.

There has been some mention of possible disease transfer issues related to growing different species together. Currently many farms leave sites fallow for a year on rotation, but diseases may persist if the additional species grown are not also removed for this year. However, research seems to indicate no increased risk[129].

Commercial companies may be reluctant to move into integrated production because it involves two or more species with very different requirements. Since most companies are likely to be specialists in the production of one species only, they will need to greatly expand their knowledge and technical expertise to deal with the additional species.

4.5 Financial feasibility

Although the use of seaweeds, urchins or shellfish to assimilate nutrient wastes may have environmental benefits, unless there is sufficient profit in the production of these additional species, commercial companies are unlikely to incorporate it into their systems. The addition of a second (and even third) crop adds complications with harvesting, disease harbouring, and all the technical aspects of a completely different aquaculture practice. Higher value species such as urchins are more likely to be accepted than low value crops such as seaweed, the sale of which is unlikely to cover its costs of production. However, some species of seaweed may be financially viable. In Ireland, currently the demand for *Palmaria palmata* cannot be met, and it sells for £2400/tonne. It has a high growth rate, doubling in size every week, and methods for seeding culture ropes have already been successfully demonstrated[130].

4.6 Drivers and barriers

One of the main barriers is a lack of knowledge and awareness about the possibilities of integrated systems. Western aquaculture on a commercial scale has tended to involve large monoculture farms, and so the concept of introducing other species to grow alongside the main crop is a totally new idea for many companies.

Czech Republic: Barrier: Not a topical issue[131].

Denmark: The drivers are: Profit; New product - more attractive to market, including environmental attributes; Changing cost structures; Cost of production advantage; Water availability and cost; Pollution controls and fees;

127 Bernardino, Pers. Comm.
128 Integrated Multi-Trophic Aquaculture. Chopin, T. Northern Aquaculture, July/August 2006. Canada
129 Maeve Kelly (SAMS) personal communication.

130 REDWEED project – Reducing the environmental impact of sea-cage fish farming through cultivation of seaweeds. Scottish Association for Marine Science (SAMS)
131 Adamek, Pers. Comm.

Scale of production; Market demand; Technology overlap - technology developed for other industries. The barriers are: Difficulty getting investment; Technological know-how[132].

Finland: Drivers: Some environmental advantages. Barriers: No tradition of multi-species farming. No herbivores or omnivores in farming[133].

France: Currently, the problem is the economy of the system: unsuccessful for the moment because it is a complex system and too difficult to combine the economic optima of the different products. Probably an approach will develop which uses integrated systems for better use of nutrients and energy, which means more or less treating the wastes of a profitable production system (towards better environmental sustainability)[134].

Germany: Drivers: Changing cost structures. Barriers: Environmental protection[135].

Greece: There is a general lack of interest towards more innovative methods of culture. The greatest majority of the producers use the existing technology for the existing marketed species. Very few producers experiment with fish species that would really diversify their product gamut, but none has officially introduced seaweeds, urchins, mussels, oysters etc as part of an integrated polyculture system. This is largely attributed to the lack of know-how, and the investment costs associated with the uncertainty of the outcome[136].

Unfortunately, government officials dealt some late efforts for the introduction of urchins and oysters, along an existing culture site, with extreme caution (based largely on ignorance). It is however believed that in the near future such integrated systems will make their appearance in the Greek industry all the more often, especially if the results of the few persisting pioneers prove promising[137].

Hungary (carp polyculture): The main drivers are: profit; cost of production advantage; and water availability and cost. The main barriers are: competition from cheaper imports from outside the EU; and difficulty getting investment[138].

Italy: Drivers: Profit; cost of production advantage; long traditions in the country; pioneer discovering a new way to do integrated. Barriers: Limited area adapted for this approach: new generations toward intensive mono-species; modern training needed[139].

Netherlands: Attempts towards integrated culture are driven by an increased environmental awareness. The Dutch culture industry is based on high tech recirculation, which makes water purification costly. It is therefore a logical thought to try to reuse nutrients otherwise wasted. Different commercial and research activities are currently exploring this option. To obtain furthermore additional feed or crops by integration is an additional idea that is being investigated[140].

Portugal: No drivers identified. Cultural and food safety barriers would be key barriers[141].

Spain: These systems have not been introduced in Spain to a significant extent. The drivers for these integrated systems would be the demonstration of profits and the viability of this polyculture. If some pioneer farmers could start these systems and demonstrate its viability this could encourage other farmers. The barriers can be the lack of the sense of risk, the lack of market

132 Jokumsen, Pers. Comm.
133 Molsa, Pers. Comm.
134 Blancheton, Pers. Comm.
135 Brämick, Pers. Comm.
136 Triantaphyllidis, Pers. Comm.
137 Op. Cit.
138 Varadi/Ronyai, Pers. Comm.
139 Saroglia, Pers. Comm.
140 Schneider, Pers. Comm.
141 Bravo, Pers. Comm.

for the second and third products and the lack of know-how for these systems[142].

UK: The main drivers of IMTA development include: shortage of suitable sites encouraging better use of space devoted to aquaculture; incentives of decreased times to market size, enhanced growth rates for shellfish for example (as suggested by work on mussels in Bay of Fundy); being seen to be green - if it can at least pay for itself, fish growers can prove they are redressing part of their nitrogen output; it might allow alteration to biomass consent in otherwise marginal areas, though there is still much research to be done[143].

The main barriers are: Current recommendations, in the UK, are that shellfish and fish farm sites are separated by several kilometers due to concerns about disease transfer and pollution, (although this is under review and the primary emphasis is now on carrying capacity). From a UK perspective (i.e. the seaweeds that can be cultured there), the market is not well developed for selling seaweeds for human consumption, or for other high value uses (cosmetic, nutraceutical, pharmaceutical). Cultured seaweeds might be too expensive for use as a general fertiliser (except perhaps for the organic market). In global terms vast quantities of seaweeds are cultured for human food and for alginate production. Shellfish farmers might not want to risk locating near salmon farms and attracting any of the negative publicity in the popular press associated with salmon farming[144].

4.7 Environmental impacts

Integrated production systems are seen as having potentially significant environmental benefits. If they can be used to reduce the impacts of, for example, inshore cage systems on benthic habitats, then they may prevent farms from having to reduce fish density or move to offshore sites, particularly if environmental regulations are tightened in the future.

Although the most visible effect of fish cage aquaculture is the output of particulate organic waste, which leaves a 'footprint' of organic enrichment on the seafloor in the vicinity of the cages, there is now a consensus of opinion that 80% of the total nutrient losses from fish farming are dissolved and in the form of plant-available and potentially eutrophicating substances[145]. A project currently running at the Scottish Association for Marine Science (SAMS) intends to address the impact of both the dissolved nutrients and the particulate wastes. The MERMAIDS project (Multi-trophic culture for Environmental Remediation – active Management of Aquaculture Initiatives for Diversification and Sustainability) will run until Sept 2007.

4.8 Prospects

Integrated production is receiving notable research attention at the moment, primarily focused on the reduction of impacts of wastes from salmon cage farming. The commercial and legislative drivers for adoption of this technology are yet to be developed, although reasonable market prices for species such as oysters should offer encouragement to the industry. Traditional shellfish producers are understandably cautious about associating their product with salmon production that generally receives a bad press, and all sectors are concerned about disease control issues with so many species in close proximity. Western perceptions of agriculture are typically of monocultures further restricting acceptance amongst producers.

142 Tort, Pers. Comm.
143 Kelly, Pers. Comm.
144 Op. Cit.

145 Scottish Association for Marine Science (SAMS)

If, in future, the polluter pays principle is applied to aquaculture production, with financial penalties for the discharge of nutrient wastes, then it is likely that IMTA would become more financially appealing as it could potentially significantly reduce wastes from farms whilst also producing a second (and third) commercial product.

Beyond increasing environmental legislation, the growing consumer demand for environmentally sensitive food may be enough to encourage some producers into niche markets. Scepticism about the financial and even technical feasibility of these systems will limit adoption in the short to medium term. In the long term producers will need to view all elements of these systems as central to production rather than shellfish and seaweed viewed as 'add-ons' to salmon production.

5 Certification systems

5.1 Overview

Certification and ecolabelling of food products is becoming more common in western countries and there is an increasing demand for certified products that address environmental, welfare, or safety concerns, or a combination of these. The issue of sustainable seafood began its rise to more widespread prominence from the mid-1990s but it was not until around a decade later, at the end of 2005, that the concept started to be more widely adopted. Protests and 'name and shame' campaigns have achieved some success in forcing UK retailers to change the fish they sell, and the claims they make for their produce, and raising public awareness of the environmental issues involved in seafood production.

Whilst price is generally the most important single variable affecting demand, other product attribute are important, especially at the premium end of the market, where product differentiation is important. A premium is generally paid for freshness, and for value added through processing and presentation. Other quality attributes such as origin and production methods may not provide a detectable difference in the product itself, and must therefore be demonstrated through labelling. For the label to have credibility, particularly if it is used to justify a higher price, the claims made must be independently verified by an appropriate certification body. Quality certification systems are being increasingly used to reassure consumers and guarantee that products are of a high quality. Whilst starting out as a means of product differentiation, certification is arguably moving towards becoming a necessity for market access. This is driven also in part by concerns over food safety and requirements for auditable traceability.

Whilst certification can be attractive to niche producers requiring indicators for differentiation, it can be a significant and unwelcome additional costs for commodity producers, especially smaller companies that do not have the economies of scale of larger competitors.

Consumers in the west, particularly Europe, are also demanding more fresh, top quality seafood products as they prize its superior taste and recognise it as a healthy, natural, pollution and additive free food. Imported fish account for over 60 percent of European fish consumption, and are often of better quality and of equal or lower price than local products[146].

5.2 Certification schemes

There is a whole range of mandatory standards and voluntary certification schemes which aim to ensure products meet minimum levels of stipulated criteria. Voluntary certification schemes include organic, environmental, ethical, quality management and other schemes addressing several issues. Mandatory standards tend to be those concerned with health and safety, such as prohibiting use of banned chemicals and setting maximum levels of contaminants and bacteria in food. Food safety requirements (e.g. Hazard Analysis and Critical Control Points – HACCP), and traceability labelling are two of the main mandatory standards currently in use.

The following five tables give details of some of the certification schemes that are available for certifying seafood production (Tables 5.1-5.5). The list is not comprehensive, but gives a good idea of the schemes that exist.

146 Electronic auctions and the fish trade: strategies for securing and maintaining comparative advantage in the seafood trade. Carleton, C. 2000. Nautilus Consultants Ltd, Scotland.

Table 5.1 Organic schemes[147]

Country	Scheme name	Details
UK	Soil Association	The largest organic certification agency in the UK. Aquaculture standards are still under development. Salmon has interim organic status. Draft standards for shrimp and bivalve shellfish. Other fish being considered include cod, haddock, turbot, tilapia.www.soilassociation.org
UK	Organic Food Federation (OFF)	The second UK agency. Standards for salmon. Cod standards recently approved. www.orgfoodfed.com
Germany	Naturland	One of Germany's largest organic certification agencies. Has standards for salmon, mussels, shrimp and other cold-water fish. www.naturland.de
France	Label AB	Qualité France, Ulase, Agrocert, Certipaq & Aclave are the six inspection bodies allowed to certify products for the Agriculture Biologique (AB) Label, which is administered by the French Ministry for Agriculture and Fisheries. www.agriculture.gouv.fr/spip/IMG/pdf/qualite_gb-1.pdf
Sweden	Krav	One of two national certification bodies in Sweden. Their aquaculture standards were developed with Debio (see below), so products approved by one agency are automatically approved by the other. www.krav.se/english.asp
Sweden	Svenska Demeterförbundet	The second national certification body in Sweden. www.demeter.nu
Norway	Debio	The Norwegian inspection and certification body for organic agricultural production. Debio is a private, democratic members' organisation. www.debio.no

5.2.1 Organic schemes

Organic certification schemes were originally developed for terrestrial food production, and many are currently being extended to include seafood. Research has found that consumers recognise organic labels as brands they can trust, particularly with regards to health and safety, and they are willing to pay a premium of around 10%[148]. There are many different organic schemes in Europe, and these are discussed in Table 5.1.

147 The role of certification and ecolabelling. Sturrock, H.T. & Young, J.A. 2006. DFID-funded AFGRP project 'Understanding markets: options to combat impoverishment through aquaculture.'

148 Background paper on the International Seafood Trade and Poverty. Macfadyen, G., Banks, R., Phillips, M., Haylor, G., Mazaudier, L. and Salz, P. 2003. DFID-funded EC-PREP project 'International Seafood Trade: Supporting Sustainable Livelihoods Among Poor Aquatic Resource Users in Asia'. Poseidon Aquatic Resource Management Ltd (UK), NACA and STREAM Initiative. Available at: http://library.enaca.org/ecprep/publications/EC-PREP_Output_1_Report_final_draft.pdf

5.2.2 Environmental schemes

Environmental schemes are those that are concerned with the environmental impacts related to the production of goods, in some cases specifically seafood. With relation to seafood, these schemes tend to be mostly concerned with capture fisheries rather than aquaculture, and are often known as 'eco-labels'. The Marine Stewardship Council scheme is perhaps the most well known, and there is discussion of opening this scheme up to farmed products also. Other non-specific schemes are more concerned with the general environmental performance of the organisation to be certified, e.g. ISO standards. The main European environmental schemes are described below (Table 5.2).

Table 5.2 Environmental schemes[149]

Scheme name	Details
Marine Stewardship Council (MSC)	The MSC is an independent, global, non-profit organisation who currently recognise, via a certification programme, well-managed wild-only fisheries. However, they are considering extending certification to aquaculture products. In order to use the MSC logo on seafood products it is necessary to be certified for chain of custody, where an independent certification body assesses the applicant's traceability systems and ensures products are sourced from certified suppliers. MSC labelled seafood products accounting for nearly 4% of world wild fish catch. www.msc.org
Friend of the Sea	Acknowledging the implicit potential of market incentives to improve sea resources management, Friend of the Sea project aims at promoting ecologically and socially sustainable fishing practices. Friend of the Sea is part of the Earth Island Project Network and is distinct from the MSC in covering both farmed and wild caught fish and shellfish products. The FoS label has been used by Carrefour in its Italian hypermarket chain, and by the country's largest retail chain, Coop Italia. www.friendofthesea.org
KRAV Sustainable Fisheries	Since 2001, KRAV has been engaged in a project to develop standards, inspection and certification for sustainable fisheries in Scandinavian waters since the MSC scheme is unlikely to gain acceptance in Scandinavia. Initially, standards will be applicable to fishing in Scandinavia. In the long-term, the system should be acceptable and possibly applied to other areas. www.krav.se
ISO 14001	A voluntary set of standards intended to encourage organisations to systematically address the environmental impacts of their activities. The International Organisation for Standards was founded in 1946 in Geneva with its key mission to promote trade by developing international voluntary consensus standards. www.iso.org
European Eco-management and Audit Scheme (EMAS)	A management tool for companies and other organisations to evaluate, report and improve their environmental performance. Participation is voluntary for public or private organisations operating in the EU and the European Economic Area (EEA). http://europa.eu.int/comm/environment/emas/index_en.htm
Svane (swan)	The Swan is the official Nordic ecolabel. The logo demonstrates that a product is a good environmental choice. It is available for around 60 product groups, everything from washing-up liquid to furniture and hotels. The Swan checks that products fulfil certain criteria using methods such as lab tests, certificates and control visits. www.svanen.nu/Eng/default.asp
Blaue Engel (Blue Angel)	The Blue Angel scheme is awarded to products and services which are particularly beneficial for the environment in an all-round consideration and which also fulfil high standards of occupational health and safety and fitness for use. Around 3,800 products worldwide are entitled to bear the Blue Angel. www.blauer-engel.de
European Eco-label	A voluntary scheme designed to encourage businesses to market products and services that are kinder to the environment and for European consumers to easily identify them. The aim of the eco-label is to initiate a Europe-wide programme with a cross-border European commitment to action that will provide a simple and effective tool for producers, retailers and consumers. http://ec.europa.eu/environment/ecolabel/index_en.htm

149 The role of certification and ecolabelling. Sturrock, H.T. & Young, J.A. 2006. DFID-funded AFGRP project 'Understanding markets: options to combat impoverishment through aquaculture.'

5.2.3 *Ethical schemes*[150]

The ethics of production are the central theme of these schemes, and include issues such as working conditions, fair trade and fair wages, and health and safety (Table 5.3). The vast majority of these schemes have little or no specific seafood provisions.

5.2.4 *Quality management schemes*[152]

These schemes require participants to meet minimum levels of quality and health and safety of product (Table 5.4). Quality management schemes are becoming more important, as international markets and suppliers demand tighter food health and safety standards and the World Health Organisation reports rising cases of food-borne illnesses in developed countries[153].

Table 5.3 Ethical schemes

Scheme name	Details
Fairtrade Labelling Organisations (FLO)	The worldwide Fairtrade Standard setting and Certification organisation. It permits more than 800,000 producers, workers and their dependants in 50 countries to benefit from labelled Fairtrade. FLO guarantees that products sold anywhere in the world with a Fairtrade label marketed by a National Initiative conforms to Fairtrade Standards and contributes to the development of disadvantaged producers and workers. Currently no seafood products are certified. www.fairtrade.net/
Ethical Trading Initiative (ETI)	A multi-stakeholder alliance in the United Kingdom which includes NGOs, unions and the private sector. The ETI focuses on ethical sourcing by companies, such as business ethics and corporate responsibility, promotion of worker rights and general human rights, working towards the ending of child labour, forced labour, and sweatshops. Fish-related firms can adopt the ETI Base code[151]. www.ethicaltrade.org/
The International Federation for Alternative Trade (IFAT)	The FTO Mark (see left) is a quality mark that means standards are being met regarding working conditions, wages, child labour and the environment. These standards are verified by self-assessment, mutual reviews and external verification. It demonstrates that an organization's trading activity is sustainable and committed to continual improvement. The FTO Mark is not a product label. It is a mark to identify Fair Trade Organizations. The FTO Mark is available to all IFAT members who meet the requirements of the IFAT Standards and Monitoring System. http://www.ifat.org/theftomark.shtml
Social Accountability International (SAI)	SAI works to improve workplaces and combat sweatshops through the expansion and further development of the international workplace standard, Social Accountability 8000 (SA8000), and the associated S8000 verification/certification system. www.sa-intl.org
RSPCA Freedom Food	Freedom Food is the only UK farm assurance scheme dedicated to improving farm animal welfare. A non-profit making charity set up by the RSPCA in 1994, they are completely independent from the food industry. All farm animals under the Freedom Food scheme must be reared according to strict RSPCA welfare standards. Species-specific standards cover each stage of an animal's life, including handling and transportation. The welfare standards can be implemented on both large- and small-scale farms, and cover indoor and outdoor systems. www.rspca.org.uk

150 The role of certification and ecolabelling. Sturrock, H.T. & Young, J.A. 2006. DFID-funded AFGRP project 'Understanding markets: options to combat impoverishment through aquaculture.'

151 Trade Issues Background Paper: Ethical/Social/Eco Certification, Labelling and Guidelines. Graeme MacFadyen. 2004. FAO Policy Research – Implications of Liberalization of Fish Trade for Developing Countries.

152 The role of certification and ecolabelling. Sturrock, H.T. & Young, J.A. 2006. DFID-funded AFGRP project 'Understanding markets: options to combat impoverishment through aquaculture.'

153 Vo, T.T.L. (2003) Quality management in shrimp supply chain in the Mekong Delta, Vietnam: problems and measures. Centre for ASEAN Studies (CAS) & Centre for International Management and Development Antwerp (CIMDA). CAS Discussion Paper No.43. Available at: http://143.129.203.3/cas/PDF/CAS43.pdf

Table 5.4 Quality management schemes

Scheme name	Details
ISO 9001:2000	An international standard that gives requirements for an organization's Quality Management System ('QMS'). ISO 9001 is a useful basis for organizations to be able to demonstrate that they are managing their business so as to achieve consistent good quality goods and services. www.iso.org
ISO 22000:2005	New International Standard ISO 22000 for safe food supply chains. Designed to ensure safe food supply chains worldwide, it provides a framework of internationally harmonized requirements which will make it easier for organizations worldwide to implement the Codex HACCP.
Tartan Quality Mark (TQM)	This scheme is a voluntary industry certification scheme. The mark is a recognised symbol assuring retailers and consumers that the salmon is Scottish and that the production processes have been rigorously and independently inspected at every stage. Every salmon carrying the Tartan Quality Mark can be traced back to source through a unique number printed on the gill tag on whole salmon or labels on pre-packed fresh salmon portions. Membership now represents around 65% of the tonnage produced by the Scottish salmon farming industry. www.scottishsalmon.co.uk/aboutus/tqm/
Safe Quality Food (SQF) 1000 Code & 2000 Code	A food safety and quality management certification program with product trace, regulatory, food safety and commercial quality criteria. The SQF Program is based on the principles of HACCP, Codex, ISO and Quality Management Systems. The 1000 Code is just for primary producers. The 2000 Code is for the whole food sector – primary producers, food manufacturers, retailers, agents and exporters. www.sqfi.com
Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI)	The European Union identifies two types of food quality names based on their geographical origin: PGI and PDO. Once these names are registered, they are protected against the sale of any other competing imitation product seeking to use the reputation of the name of origin. The legislation came into force in 1992. A PDO or PGI covers the term used to describe foodstuffs which are produced, processed and prepared in a given geographical area using recognised know-how. In the UK, there are currently three seafood products with PGI status: Arbroath Smokies, Scottish Farmed Salmon and Whitstable oysters. http://europa.eu.int/scadplus/leg/en/lvb/l21097.htm
Irish Quality Salmon, Trout and Mussels	Presence of the mark assures that the product has been hatched, raised, harvested and packed under the strictest levels of food hygiene. The mark ensures that the product can be fully traced from hatchery to packing. Participation in the Salmon Quality Assurance Scheme is voluntary and the Scheme currently has over 90% industry participation. www.irishqualityfish.com/salmon/index.asp

5.2.5 Other certification schemes

These are some of the schemes that encompass a range of issues involved in seafood production, including environmental, welfare, quality and other issues (Table 5.5).

5.3 European overview

The diversity and abundance of certification schemes, and the potential for confusion, misuse and inequity, has drawn the attention of the European Union and international organisations such as the Food and Agriculture Organisation of the UN (FAO). There are now plans to develop procedures for the harmonisation of standards and certification processes to ensure consistency. This will ensure a minimum standard is met and is supposed to ensure producers work to common criteria, facilitate trade and reassure the consumer that any certification meets basic standards. Critics of this intervention suggest that the market will regulate itself. One example of this harmonisation is the International Task Force on Harmonisation and Equivalence in Organic Agriculture, convened by FAO, IFOAM (International Federation of Organic Agriculture

Table 5.5 Other certification schemes[154]

Scheme name	Details
GAA Best Aquaculture Practices (BAP) Standards	The Global Aquaculture Alliance (GAA) standards for responsible shrimp farming address social and environmental issues, as well as food safety and traceability. The standards specifically deal with property rights and regulatory compliance, community and employee relations, mangrove conservation, effluent and sediment management, soil and water conservation, post-larvae sources, drug and chemical management, microbial sanitation, and harvest and transport. The Aquaculture Certification Council, Inc. (ACC) is a non-governmental body established as exclusive certifying agency for the GAA BAP standards. They combine site inspections and effluent sampling with testing and verification, sanitary controls, therapeutic controls and traceability. www.gaalliance.org/bap.html
EurepGAP Integrated Aquaculture Assurance Standard EUREPGAP®	A global scheme and reference for good aquacultural practice, based on food safety, environmental protection, animal welfare, and occupational health, safety and welfare. The Scheme covers the whole aquaculture production process of the certified product, from egg stage (identification and traceability of stock) to non-processed end product (no manufacturing, slaughtering or processing is covered). EurepGap is driven by 22 large-scale retail chains that form the core members of the Euro-Retailer Produce Association (EUREP). www.eurep.org/fish/Languages/English/index_html

Movements) and UNCTAD (UN Conference on Trade and Development)[155]. However, harmonisation is not limited to organic certification.

The potential for certification is still significant. Taking the example of organic seafood once more, demand is outstripping supply, pushing up prices. Supply is limited both for new species and for volume in certain existing organic species. One certifier has predicted that European organic seafood sales will reach €300 million by 2009; Naturland, the largest organic seafood certifier, already offer organic *Pangasius*, carp, shrimp, salmon, trout and mussels[156].

However, certification has its costs. Most EU governments would like to encourage greater adoption of certification by national companies, using FIFG funds where appropriate to facilitate the transition. However, many producers remain nervous about the financial benefits, especially as margins are reduced as more companies join niche certification schemes, with the benefits of wider trading opportunities seeming a long time and a lot of investment away.

Caution is not limited to farmers. Some established organic certifiers have shown caution with regards to certifying carnivorous species because it is felt that intensive production reliant on fishmeal feeding, producing a species that is still essentially wild within the confines of cages is against the founding principals of the organic movement.

Overall, the future looks positive for a co-ordinated approach to certification within the Europe. The social and environmental benefits from the improved management approaches demanded by most certification schemes meets EU expectations for a sustainable food production sector. Better quality food for a healthier population, increased traceability and informed consumer choice are also appreciable benefits.

5.4 Detailed country perspective

5.4.1 Countries with certification systems

Denmark

Organic farming of rainbow trout has started recently by certifying 4 farms producing 100-200 tonnes of trout. There is increasing interest in converting to organic farming. A serious hurdle

154 The role of certification and ecolabelling. Sturrock, H.T. & Young, J.A. 2006. DFID-funded AFGRP project 'Understanding markets: options to combat impoverishment through aquaculture.'
155 www.unctad.org/trade_env/ITF-organic/welcome1.asp
156 Sneak preview: Tomorrow's organic seafood. Intrafish. 15 Sept 2005.

is that the Danish legislation for obtaining the organic certificate is much more difficult than in other countries[157] (i.e. UK).

In 2004, a new Regulation on Organic Aquaculture came into force for a voluntary red Danish "Organic" label. Farmed fish for labelling may be treated with antibiotics only once, and no genetically modified or biologically treated fish are allowed in the farm. The "organic" label can only be used for fish from the family *Salmonidae* (salmon fish) and European eel. The label has attracted some attention, but the labelled production still is very small[158].

France

Potential for development still exists in niche markets for high quality and labelled products. A high degree of control of the whole production process from the farm to the consumer allows producers to guarantee the traceability of product throughout the production chain and quality product can attract high prices. The future of French aquaculture is highly linked to the development of labelled products as a solution to differentiate them from imported basic products. It is also a way to justify higher production costs compared with foreign countries such as Greece, Turkey etc. Finally, high quality products are responding to the customer's demand about traceability, food safety, respect of environment. There are a lot of labelled fish and shellfish products: Label Rouge for Turbot and Sea bass, AOC (controlled origin denomination), organic (for Sea bass). Private labels include Label Rouge and Label Bio. There are five or six farms certified under these schemes. Certified products, under the Label Rouge scheme, are imported into France. The French government encourages certification systems. The leading authorities on certification systems in France are Ecocert and Aqualabel[159].

157 Jokumsen, Pers. Comm.
158 FAO NASO Denmark
159 Blancheton, Pers. Comm.

France's organic label is 'Label AB' (Agriculture Biologique), which is administered by the French Ministry for Agriculture and Fisheries[160]. Qualité France, Ulase, Agrocert, Certipaq & Aclave are the six inspection bodies allowed to certify products under the Label AB scheme.

The Appellation d'Origine Contrôlée (AOC) is similar to the EU Protected Designation of Origin (PDO). It is granted to certain French products which are produced in a traditional manner in a designated geographical area. French mussels from Mont St Michel Bay have just been awarded this coveted quality mark, the first seafood to obtain this label[161].

Germany

There have been some activities to produce guidelines for organic trout production (Institut for Fishery Starnberg), and activities from big wholesalers (Deutsche See) to create organic production. Small trout farmers can potentially gain better prices, but there are problems with costs for certification and organic fish feed[162].

The main organic certification agency in Germany is Naturland, which has standards for salmon, mussels, shrimp, pangasius and other cold-water fish[163]. They recently included social conditions in their organic standards.

Greece

Private certification schemes: Agrocert Quality Certification Scheme (for farmed fish) – it is a recent scheme and only 2 or 3 farms are certified under it. A small amount of certified products are imported into Greece, under the French scheme 'Label Rouge'. Government policies encourage certification schemes through funding. The National Organisation for

160 Guaranteeing origin and quality. Ministry of Agriculture and Fisheries, France. 2002. 2pp.
161 French mussels gain coveted quality mark. Intrafish. 17 July 2006.
162 Weirowski, Pers. Comm.
163 www.naturland.de

Certification Schemes is a leading authority in the country[164].

Governmental certification scheme: The Organisation for Certification and Inspection of Agricultural Products of the Hellenic Ministry of Agriculture (AGROCERT). NGO/private schemes: HACCP; ISO 9000, 14001, 22000; OHSAS 18001. Aquaculture fish are almost exclusively sold plain, displayed on ice, without any quality or brand markings. Certification under the aforementioned schemes is aimed at the wholesaler and retailer rather than the final customer/consumer. Certified products are not imported into Greece. Product certification and labelling is encouraged through the financing of such actions under the Operational Programme Fisheries 2000-2006. However, there were no applications for financing under this scheme either due to the bureaucratic procedures or due to the fact that they had based that financing scheme mainly on the 'governmental' label of AGROCERT. The leading authorities on certification in Greece are TUV AUSTRIA, and ISO (ELOT)[165].

Hungary

Organic fish farming is being encouraged under the Environmental Management Program. Biocontrol Hungaria is a private organic certification scheme that exists in Hungary. Fewer than 10 farms of the total 200 are certified under this scheme. One farm wants to be certified under a foreign scheme. Total certified production is negligible, since it has only just emerged in Hungary. Certified products are not imported into Hungary as there is no market. The government encourages certification schemes, and currently has a major project on the development of organic fish[166].

Ireland

The government has three certification schemes: Irish Quality Salmon (IQS), Irish Quality Trout (IQT) and Irish Quality Mussel (IQM) schemes (see table 5.4 for more details). There are 11 companies certified under IQS (out of 14), 2 certified under IQT (out of 5), and 14 certified under IQM. The government encourages certification, and promotes all IQ schemes[167]. The leading authorities are BIM and IFQC.

Clare Island salmon farm, owned by Marine Harvest, produces organic salmon which is certified by Naturland (Germany), Bio Suisse (Switzerland), Qualite France, and The Irish Organic Farmers and Growers Association (IOFGA)[168].

Italy

The certification schemes used in Italy to certify seafood production are EMAS and ISO 14001. There are 400 fish farms certified. EMAS has 5% of total market share and ISO 14001 has 35%. Certified products are not imported into the country. The government encourages certification systems through the FIFG (SFOP in Italian). Leading authorities include the National Agency for Environment (ANPA) affiliated to Ministry of Environment; Ministry for the Agriculture Politics; Regional Authorities for SFOP, ISO 14001[169].

Netherlands

Four tilapia farms are currently certified under the European Eco-label (see Table 5.2 above). A behaviour code has been developed by a private company, NEVEVI. The code includes a handbook for drug use, welfare and a log book of farm activities. Market share for the eco-label is 6% of tonnage, and 80-90% of tonnage for the behaviour code. The government encourages certification through subsidies and grants. The Ministry of Agriculture, Nature and Food Quality (LNV) is the leading authority on certification in the Netherlands[170].

164 Charalabakis, Pers. Comm.
165 Triantaphyllidis, Pers. Comm.
166 Varadi, Pers. Comm.
167 Watson, Pers. Comm.
168 Marine Harvest. www.marineharvest.com
169 Saroglia, Pers. Comm.
170 Schneider, Pers. Comm.

Norway

Debio is the Norwegian inspection and certification body for organic agricultural production (www.debio.no). Their aquaculture standards were developed with Krav (Sweden), so products approved by one agency are automatically approved by the other.

The Norwegian government has technical standards (NS9415) which specify requirements for floating fish farms. Since 1 Jan 2006, all farms must be certified under these standards, and the last farms are currently completing their certification[171].

Portugal

There are several government and several private/NGO certification schemes in use in Portugal. Two farms are certified with private schemes, and this is less than 3% of the total number of fish farms. Overall, government policies encourage certification schemes – there is funding available for implementing certification[172].

Sweden

There are two organic certification bodies in Sweden: Krav (www.krav.se/english.asp), and Svenska Demeterförbundet (www.demeter.nu). The Krav aquaculture standards were developed with Debio (Norway), so products approved by one agency are automatically approved by the other.

Since 2001, KRAV has been engaged in a project to develop standards, inspection and certification for sustainable fisheries in Scandinavian waters. Initially, standards will be applicable to fishing in Scandinavia. In the long-term, the system should be acceptable and possibly applied to other areas.

Only 1 or 2 fish farms are certified organic, and around 15 are certified (or under development) with a quality scheme. The certification schemes available have less than a few percent market share. The government does not encourage nor discourage certification systems. The leading authority on certification systems is KRAV[173].

UK

The two main organic certifiers in the UK are the Soil Association (www.soilassociation.org) and Organic Food Federation (www.orgfoodfed.com). RSPCA Freedom Food scheme covers animal welfare issues (www.rspca.org.uk). Quality schemes include the Tartan Quality Mark (TQM), which is the label for Scottish Quality Salmon (SQS) (www.scottishsalmon.co.uk/aboutus/tqm/).

Organic salmon demand in the UK is outstripping supply, but the industry is slow to grow with major producers reluctant to embrace it. Major retailers are finding it difficult to get a 52-week supply of organic salmon and trout[174]. Scottish organic salmon production in 2004-2005 fell to approximately 2,500 metric tonnes, compared to 3,117 metric tonnes in 2003-2004, with a farm gate value in 2004-2005 of £6.8 million (€9.9 million). With the fall in production the average price of salmon per kilogram increased from around £2.40 to around £3. It has been suggested that the small fall in supply was due to wariness of market trends and changes in husbandry practices[175].

The first certified organic Scottish trout farm began production in 2005. It is currently producing approximately 60 tonnes per year in its start up phase, but plans to double production in 2006. Of the organic salmon produced in Scotland, 12 per cent was exported. Currently all

171 Handa, Pers. Comm.
172 Bravo, Pers. Comm.

173 Eriksson, Pers. Comm.
174 Demand for organic salmon keeps growing. Intrafish. 29 March 2006.
175 Market Research Study into the Market Penetration of Scottish Organic Produce. Barclay, K. & Cleeton, J. 2005. Soil Association.

of the organic trout produced in Scotland is sold through domestic retailers[176].

The first organic cod standards, for the Organic Food Federation (OFF), were approved by the UK Government in mid 2005, opening the door for UK producers to rear and sell farmed cod as certified organic. Johnson Seafarms began raising organic cod under OFF's interim standards in 2002, with the first harvest in early 2004. See Section 6.2.1 for more details on organic cod production in the UK.

5.4.2 Countries Without certification systems

5.5 Technical feasibility

Gaining certification of some schemes may involve significant change in the production methods of a fish producer, and hence certification is likely to be expensive. For example, organic production criteria will require lower stocking densities, change in allowable feeds and medical treatments, husbandry and welfare requirements, and traceability and labelling controls. Possible future issues may also include increased demand and higher prices for seed and feed which meets certification standards. As noted below, feed in particular will have an important impact on production costs and hence competitiveness. The other practical issue is simply that reliance on specialised markets with expected price premiums will become less feasible as more producers enter markets and as multiple retailers in particular demand specific standards for all products.

Table 5.6 Countries Without certification systems

Cyprus	Government certification schemes do exist, but none specifically for aquaculture yet. Certified products are not imported into Cyprus. The government encourages certification systems. There are currently no leading authorities on certification systems in Cyprus.	Kyriacou
Czech Republic	There are no certification schemes being used to certify aquaculture production in the Czech Republic, other than HACCP.	Adamek
Estonia	Organic production is not yet popular on domestic and neighbouring markets. Only low prices count at the moment. No certified products are imported into Estonia. There is no interest in certification because of the small market and low production in the country. A few companies voluntarily label their products. The quality labelling schemes for agricultural products could be applied to aquaculture production, but this has not yet been done.	Paaver
Finland	ISO quality standards applied until 2005 but not since then. There are no private/ NGO certification schemes. Government policies neither encourage nor discourage certification.	Molsa
Latvia	No information could be found on certification systems in Latvia, so it is assumed that none exist or are in use.	Woynarovich
Lithuania	Literature reviews showed that no certification systems are currently being used in Lithuania.	Woynarovich
Malta	All on-growing sea bass and seabream farms are EU approved and hold HACCP certification.	Vassallo-Agius
Poland	Review of recent reports shows that there are currently no certification systems being used in Poland.	Woynarovich (Confirmed by Lirski)
Spain	It may be the case that in the future, some production will take the strategy of organic food in order to survive in the competition with third countries.	Tort

176 Market Research Study into the Market Penetration of Scottish Organic Produce. Barclay, K. & Cleeton, J. 2005. Soil Association.

5.6 Financial feasibility

5.6.1 *Organics*

Although certification of aquaculture products as organic raises production costs significantly, organic products command much higher prices than the standard equivalent due to demand currently outstripping supply in Europe.

Farm production costs

The following example gives the costs of production for an organic salmon farm in Scotland, UK. Feed is by far the largest cost of production.

Table 5.7 Example production costs for a Scottish organic salmon farm

Item	€/kg*	% of total
Feed	1.89	45.6
Smolt	0.56	13.5
Labour	0.41	10.0
Overhead	0.38	9.3
Total month depreciation	0.30	7.1
Packing	0.30	7.1
Harvest expenses	0.19	4.6
Transport	0.10	2.5
Other variable	0.01	0.4
Total	4.15	

**These costs per kilo are for a 20 month cycle.*

Farm gate prices

It is difficult to get a figure from producers for the farm gate price of organic salmon for two main reasons:

- The price varies depending on the duration of contract, volume, specification, country of sale etc.; and
- The market is still small, and producers are unwilling to share sensitive information on prices.

A large UK processor currently pays farm gate prices of £4.50/kg (€6.67/kg) for gutted organic salmon and £7.50/kg (€11.12/kg) for filleted organic salmon[177].

Certification costs

The different certifiers have differing methods of charging for certification.

The Organic Food Federation (OFF), UK, does not have set licence fees; they send a quotation with application. Their system includes inspection, preparation of a report, assessment of that report, and certification, provided that all standards are met. Annual inspection is a mandatory requirement. They do not charge on turnover.

The Soil Association (UK), Naturland (Germany), and EurepGAP schemes all have set fees, which are explained in the following three tables.

177 Personal correspondence

Table 5.8 Soil Association (UK) organic aquaculture licence fees 2006-07

Item	Includes	Cost
Application fee	Initial inspection, 6 months organic certification/service & Producer Services membership	£199 + VAT
Annual licence fee	Due at end of initial 6 month period, and covers one inspection day, certification service, admin costs and ongoing Producer Services membership	£425 + VAT
Additional inspection costs	Small scale on farm processing or packing	0.3% of organic sales
	Farm inspections taking more than one full day. Price per additional half day	£170 + VAT
	Extension or follow-up inspection	£350 + VAT

Table 5.9 Naturland (Germany) organic aquaculture licence fees

Item	Includes	Cost
Annual membership fee	Admin costs, issuing of certificates, annual renewal of certificates and certification letters. It refers to single companies. Special rates for producer communities and small-farmers groups are possible.	€500
Farm inspections	Done annually. Tariff of inspection body, includes travel costs, lump sum for office work and report writing, and costs of inspection on-site.	Estimate up to €500 per day
Licence fee	Use of Naturland sign on products and advertising material. Same fee for producers and processors. Billing on annual basis, twice yearly if required.	1% of net sales
Pre-conversion consultation	Visit by Naturland experts to farm, pre-conversion. Special rates for developing countries. Travel and accommodation costs are extra.	€500

Table 5.10 EurepGAP fee table

FEE	Applies to	AMOUNT annual
Farmer Fees		
Certification license fee	per completed inspection	20 EUR per inspection based on the minimum frequencies established in Option 1 and 2 (charged through CB)
Farmer registration fee per product scope*/checklist	per registered farmer and scope	3-100 EUR depending on production in tonnes (incl. online management of master data and online self-assessment – can be set against the annual membership fee for Option 2 (charged through CB))
Certification Body fees		
Evaluation fee for applicant CBs	CB's that apply for EUREPGAP recognition	300 EUR (first applications only); second and further applications are free of charge – single payment (not annual)
CB base license fee	CB's only	1st application 3,000** EUR (500** EUR member discount); extension to additional product scope (e.g. Flowers, IFA, IAA, CF etc) 500** EUR each.
Online Exam fee	per scope and staff member	100 EUR (for EurepGAP Auditors and Inspectors)
Equivalent Certification System Owner fees***		
ECSO base administration fee (for private sector schemes with ECSO agreement)	per scope	2,550 EUR (can be set against the annual membership fee)
ECSO farmer registration fee per scope/checklist (for private sector schemes with ECSO agreement)	per scheme member	12-month fees same as farmer registration fees above (3 to 100 EUR per farm); max. 4,450 EUR per ECSO scheme and product (capping)
ECSO Farmer database fee above capping of 7,000 EUR (for private sector schemes with ECSO agreement)	per scheme member	1 EUR per each additional farm (using regular Excel sheets upload for database)
Compound Feed Manufacture (CFM)		
Individual CFM operator: online management of master data and online self-assessment in database	per operator	100 EUR
Evaluation cost for provision-al approval by FoodPLUS of CFM schemes: Initial Review	per scheme	500 EUR (single payment)
CFM scheme base administration fee (for applicant private sector CFM schemes with equivalent agreement)	per scheme	1,550 EUR (can be set against the annual membership fee)

FEE	Applies to	AMOUNT annual
Member fees		
Retail Membership	Retailers only	3,600 EUR
Supplier Membership	Farmer Group or Grower Organisation, or Scheme (incl. 1 sector/scope)	2,550**** EUR (maximum 3,600 EUR for Farmer Groups covering all scopes)
Supplier Membership	Individual Farmer, or Exporter/ Importer without production (incl. 1 sector/scope)	1,550 EUR (maximum 2,600 EUR for Individual Farmers covering all scopes)
Supplier Membership	for each additional scope (flower and ornamentals, Integrated Farm Assurance (IFA), Integrated Aquaculture Assurance, Green Coffee)	520 EUR
Associate Membership	Certification Body (CB), Consulting, plant-protection or fertilizer industry, etc. (covering all scopes)	1,550 EUR – 3,600 EUR
EUREPGAP Workshop Fees		
EUREPGAP Train-the-Trainer Workshop Participation	for participants and applicant trainers	750 EUR for non-members; 500 EUR for members
EUREPGAP Train-the-Public Examination fee	for applicant trainers	100 EUR (Membership is a prerequisite to take the exam to become an official EUREPGAP Train-the-Public Trainer)

** product scopes: Fruit&Vegetables, Flower&Ornamentals, Integrated Farm Assurance, Integrated Aquaculture, Coffee, Tea, Feed*
*** contains a free participation for one person per year to a CB workshop on the respective scope*
**** see also fee tables of EurepGAP external assessor organisations like JAS-ANZ and DAP for Benchmarking Process fees*
***** covers the number of farmer registration fees*

5.6.2 Quality schemes

Protected Designation of Origin (PDO)/ Protected Geographical Indication (PGI)

There are no fees for application to register a product under the PDO or PGI schemes. However, once a product is registered, an inspection body must be contracted, costing around £450 per day.

5.6.3 Animal welfare

RSPCA Freedom Foods

There are only two costs involved in the Freedom Food scheme, the annual inspection cost and the licence fee (details below).

5.7 Drivers and barriers

There are several reasons for establishing certification schemes, including: to achieve accountability; to reduce 'problems' within an industry, such as quality and environmental issues; to respond to consumer trends; to develop niche products; to mimic others' initiatives; to enable competition with imported products and to allow an industry to develop[178]. Importantly

178 Quality assurance schemes for seafood – structure and implementation. Norberg, H.M. 1998 *Proceedings of the 9th International Conference of the International Institute of Fisheries Economics & Trade*, 8-11 July 1998, Tromso, Norway

Table 5.11 RSPCA Freedom Foods certification fees

Item	Includes	Cost
Annual inspection	12 months membership, the audit and issuing of certificate	£400/day (try to include as many assessments as possible in one day)
Licence Fee	Fresh, processed and by-products. Payable by retailers and caterers.	0.3% of wholesale value

certification may also be seen as a mechanism to extend existing brand attributes and enhance consumers' product perceptions.

One of the main barriers is the lack of public knowledge about certification schemes. Some are not aware of the issues addressed by such schemes. Others may be aware but not willing to pay the price premium attached to certified products. In some markets, there are large numbers of certification schemes being adopted for certain products, potentially causing confusion for consumers who are faced with a variety of certified products and do not have the information to decide which scheme to support.

A recent European poll, conducted in the UK, Germany and Spain, found that most of the consumers surveyed regarded environmental impact as an important factor in purchasing choices, with the vast majority, 86%, stating that they would prefer to buy seafood labelled as environmentally friendly[179]. Forty percent of those surveyed said they would pay 5-10 percent more for ecolabelled seafood.

Czech Republic: Barrier: Not a topical issue, therefore no market demand[180].

Denmark: The drivers are: Profit; New product; Changing cost structures; Cost of production advantage, Food safety; Market demand. The barriers are: Difficulty getting investment; Energy costs[181].

Finland: Drivers: Consumers' preferences. Barriers: No real advantages to producers[182].

France: Certification is fast developing in France because there is a market for high quality certified products. Many producers are not convinced that the extra work and time is worth it[183].

Germany: Drivers: Food safety; increasing market potential. Barriers: Increasing costs of production[184].

Greece: The major industry players have long realized that product certification is pressing issue for maintaining the competitiveness of their product (and company) in the contemporary business and market environments. In a way, product certification is seen as a first step towards product diversification that the industry is so much in need of. The main barrier is the cost associated with the certification under a given protocol and the cost of labelling, especially the labelling of the individual fish (gill-tags, tail-tags). Progress has been made towards the development of sophisticated equipment for fast and efficient (on the gills, without damaging the head or the body of the fish) tagging of sea bass and seabream, but its application in mass commercial scale has not yet been achieved. Again, if one company starts using it, and the net outcome of its use proves positive, then it will very quickly expand to the other companies too[185].

Hungary: The main drivers are: profit; food safety; pollution controls and fees; and market demand. The main barriers are: difficulty getting investment; competition from cheaper imports from outside the EU; and lack of demand for the product[186].

Italy: Drivers: Possibility to get more money; better relationships with regulatory authorities; improved public perception of the industry. Barriers: High costs of certification; time requested; lack of knowledge about certification;

179 Constant cravings: The European Consumer and Sustainable Seafood Choices. Seafood Choices Alliance. 2005.
180 Adamek, Pers. Comm.
181 Jokumsen, Pers. Comm.
182 Molsa, Pers. Comm.
183 Blancheton, Pers. Comm.
184 Brämick, Pers. Comm.
185 Triantaphyllidis, Pers. Comm.
186 Varadi/Ronyai, Pers. Comm.

doubts about an actual possibility to increase the revenues[187].

Netherlands: Certification is seen as a guarantee of good quality and has additional value in ecologically sound production. It is therefore interesting for farmers. However, due to the technical constraints (density, fish feed etc.) it is difficult to obtain[188].

Portugal: Better price would be the key driver. Key barriers: lack of information, extension, training and support services, coupled with generally low education levels of investors/ owners and very limited presence of technical staff in most companies. Very strong cultural resistance to mostly any form of collaborative work (sector associations, producers' organizations) is also an important barrier[189].

Spain: Certification systems are of high interest in Spain. The industrial sector looks at the certifications as one main driver to maintain the differentiation of their own products with respect to competitors. As other sectors in the country are good examples of profitable food business, it is seen as a suitable strategy. The barriers may be that the certification process could be complicated or too slow regarding the administrative process, and the lack of promotion and publicity of the certified products[190].

187 Saroglia, Pers. Comm.
188 Schneider, Pers. Comm.
189 Bravo, Pers. Comm.
190 Tort, Pers. Comm.

5.8 Environmental impact

Certification schemes have the potential to improve environmental, social, welfare or quality conditions but only if their products are recognised and purchased by consumers. If ecolabelling programmes are to have an effect, they must elicit public awareness and market response[191]. Green products must be competitive on performance, quality and value to be successful, and cannot just rely on their environmental credentials.

5.9 Prospects

Certification schemes are becoming more widespread as western consumers gain greater knowledge of the issues surrounding sustainable seafood and demand a change in world seafood production and trade. Some schemes are increasingly becoming a prerequisite for market entry, such as the HACCP health and safety standards. Other schemes occupy niche markets, but current trends show that sustainable seafood will become more important as retailers are starting to promise to source 100% of their seafood from sustainable sources.

191 Eco-labelling: actual effects of selected programmes. OECD. 1997. Paris

6 Emerging species

6.1 Introduction

This section describes the seafood species that have entered commercial aquaculture production in Europe in the past five years or so. Some species may have more potential than others, but all are included. The accounts also include species which may be relatively common in other countries but are new to specific locations. Further detail, including technical and financial feasibility, is provided for those species which appear to have the most potential, including meagre, dentex, octopus, tuna, cod and arctic charr.

6.2 European overview

There are over 40 emerging species currently being commercially produced in Europe (Table 6.1), at varying scales of production from a few tonnes to several thousand tonnes, and the majority are marine species. Some of the most successful species include: bluefin tuna, cod, and various seabreams. The development of emerging species is encouraged by governments in the vast majority of European countries.

After an overview of developments by country, a subset of emerging species are examined in more detail. These have been selected primarily as examples of different sub-groups. For instance to include species that are relevant to different regions within Europe, or are likely to develop in tandem with different types of rearing system. Their commercial potential is considered, but not used as a primary means of selection as this can change depending on both production and market factors. The selection mainly involves species that have been in development for more than 10 years, and are in commercial production at modest levels. However, some species are included even though substantial further research input is required due to their potential significance for the future (e.g. tuna and octopus).

Table 6.1 Summary of the emerging species by country and species, sorted by family and order.

Key: C – commercial production; Ex – experimental stage

Species	Common name	Cyprus	Czech Rep	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Malta	Netherlands	Norway	Poland	Portugal	Spain	Sweden	UK
Breams		C																				
Puntazzo puntazzo	Sharpsnout bream								C			C							C			
Dentex dentex	Common dentex								Ex			C										
Pagrus pagrus	Common seabream								Ex			Ex								Ex		
Diplodus sargus	White seabream								Ex			C							C			
Pagellus erythrinus	Common pandora								Ex											C		
Lithognathus mormyrus	Striped seabream								Ex													
Diplodus cervinus	Zebra seabream																		C			
Drums and croakers																						
Argyrosomus regius	Meagre						C					C							C	C		
Sciaenops oscellatus	Red drum						C															
Rabbitfishes																						
Siganus rivulatus	Marbled rabbitfish	C																				
Basses																						
Lates calcarifer	Barramundi															C						C
Various	Grouper																		C	Ex		
Cobia																						
Rachycentron canadum	Cobia						C															
Tunas																						
Thunnus thynnus	Bluefin tuna	C							C			C			C							
Mullets																						
Mugil cephalus	Grey mullet											C										
Perches																						
Sander lucioperca	Pike-perch			Ex		C				C						C					C	
Perca fluviatilis	Perch			Ex		C					C										C	
Morone saxatilis hybrid	Striped bass hybrid							C														
Cichlids																						
Oreochromis niloticus	Nile tilapia									C						C						C
Wolffish																						
Anarhichas minor	Spotted wolffish																C					
Jacks and pompanos																						
Seriola dumerilii	Greater amberjack											Ex			Ex					Ex		
Eels																						
Anguilla Anguilla	European eel		C		C																	
Salmonids																						
Salvelinus alpinus alpinus	Arctic charr					C					C										C	C
Salvelinus fontinalis	Brook trout					C																
Coregonus sp.	Whitefish					C															C	
Thymallus thymallus	Grayling		C																			
Oncorhynchus aguabonita	Golden trout					C																
	Brown trout		C																			
Salmo trutta fario																						
Sturgeons																						
Acipenser baerii baerii	Siberian sturgeon				C		C															
Acipenser transmontanus	Sturgeon					C	C	C		C		C				C		C		C		
Pikes																						
Esox lucius	Pike										C											
Flatfishes											C											
Solea solea	Common sole			Ex					C							C			C			Ex
Solea senegalensis	Senegalese sole											C								C		
Hippoglossus hippoglossus	Halibut																C					C
Scophthalmus maximus	Turbot			Ex												C	C			C		C
Catfish																	C?					
Clarias gariepinus	African catfish									C								C				
Silurus glanis	European catfish																	C				

Species \ Country	Common name	Cyprus	Czech Rep	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Malta	Netherlands	Norway	Poland	Portugal	Spain	Sweden	UK
Cods																						
Gadus morhua	Cod			Ex							C						C				C?	C
Pollachius virens	Saithe/pollock																C					Ex
Melanogrammus aeglefinus	Haddock																					Ex
Merluccius sp.	Hake																					Ex
Seahorses																						
Hippocampus spp.	Seahorse										C											
Barbel																						
Barbus spp.	Barbel		C																			
Octopus																						
Octopus vulgaris	Common octopus											Ex								Ex		
Crayfish													C									
Astacus astacus	Noble crayfish				C	C																
Pacifastacus leniusculus	Signal crayfish					C																
Shrimps																						
Varioius	Shrimp															C						
Shellfish																						
Haliotis sp.?	Abalone										C											
various	Freshwater clam										C											
various	Scallop										C											
Mytilus edulis	Blue mussel			Ex																		
Ostrea edulis	Oyster			Ex																		
Sea urchins																						
various	Sea urchin										C									Ex		
Seaweeds																						
varioius	Seaweed										C											

6.3 Detailed country perspective

6.3.1 *Countries with emerging species*

Cyprus

Emerging species in Cyprus include bluefin tuna ranching, and *Siganus rivulatus* (Marbled spinefoot/rabbitfish). The number of emerging species has not changed over the past five years. Bluefin tuna has been produced commercially since 2003. There is currently one farm producing tuna, and in 2005 they produced 1400 tonnes, all exported. Production of *Siganus rivulatus* began commercially in 2005, with 2 farms producing less than 10 tonnes for the domestic market, at a price of 6 Cyprus pounds per kg (€10.39/kg). The government encourages emerging species, and Dept of Fisheries and Marine Research (DFMR) is the leading authority in Cyprus[192].

Czech Republic

There has been an increase in the culture of riverine species for restocking and angling. These include barb (*Barbus barbus*), eel (*Anguilla anguilla*), grayling (*Thymallus thymallus*), and brown trout (*Salmo trutta fario*). However, these only makes up about 0.1% of total aquaculture production in the country. The government encourages these emerging species through funding. It is prohibited to introduce exotic species into the country. The leading authorities are: Zdenek Adamek, and Anglers' unions[193].

192 Kyriacou, Pers. Comm.
193 Adamek, Pers. Comm.

Denmark

There has been significant research activity in the past five years to find alternative species for aquaculture. There are currently no emerging species that are in commercial production in Denmark. However, there are many at the experimental or pilot stage:

- Sole (*Solea Solea*): are tested at The Danish Institute for Fisheries Research (DIFRES) in recirculating systems with success. Waiting for commercial partners.
- Perch (*Perca fluviatilis*): are tested at DIFRES with success in cooperation with partners. Implementation in the producing sector on-going.
- Cod (*Gadus morhua*): are at the experimental stage at DIFRES and partners.
- Pikeperch (*Sander lucioperca*): are at the experimental stage.
- Blue mussels (*Mytilus edulis*) and Oyster (*Ostrea edulis*): are at the experimental stage at DIFRES (in cooperation with partners).
- Turbot (*Scophtalmus maximus*): fingerling production in recirculation system is taking place. Production of 600-800,000 fingerlings (3-10cm) per year, mainly exported to Spain for ongrowing. 1-3 Euro each.

The government encourage sustainable aquaculture with special attention to environmental impact - but there are currently no grants and/or regulations regarding emerging species. The leading aquaculture research activities in Denmark are centred at The Danish Institute for Fisheries Research (DIFRES) in cooperation with governmental research bodies and with close contact and cooperation with commercial aquaculture companies[194].

194 Jokumsen, Pers. Comm.

Estonia

The European eel and Noble crayfish are the two main emerging species in Estonia. Intensive eel rearing in recirculation systems is five years old, and production is small but rising. There is currently one farm producing 30 tonnes for export, and they receive €7.50/kg at the farm gate. Noble crayfish farming has become popular, with several extensive pond farms being established during the past five years. Production is very small but rising. Currently five farms produce a total of 2 tonnes for export, receiving €3 per crayfish (equivalent to €60-70/kg) at the farm gate.

The rearing of Siberian sturgeon in industrial thermal water is also underway. Small scale production existed before 1996, but it has now been restarted, although there are no sales yet. Aquaculture is a very small part of the Estonian economy, and as such it does not attract the attention of political organisations or the government compared to the fishing industry. However, there are some examples of financing of research and education projects to support the development of crayfish farming. Discussions with fish farmers concerning other potential species for aquaculture in Estonia suggest potential for arctic char, pike-perch, ornamental fish, halibut and striped bass, but no substantial attempts have been made yet[195].

Finland

Pike-perch (*Sander lucioperca*) is a new species with emerging markets and good production potential in Finland. Pilot experiments of pike perch culture have been completed taking benefits from R&D of farming in natural and increased temperatures, larvae feeding, and environmental technologies. Cage culture of perch in inland waters is also being started, as well as cage culture of whitefish. A first batch of golden rainbow trout is also under way at a private farm. Production of noble crayfish and signal crayfish

195 Paaver, Pers. Comm.

Table 6.2 Emerging species in Finland

Species	Date produced commercially	No of farms producing	Total production (weight & value)	Market – domestic or export	Farm gate and retail prices (where available)
Whitefish (Coregonis)	Since 2000	20	1000t?	Dom	6 €/kg
Arctic charr	Since 2004	1	300t	Dom	
Brook trout	Since 2000	1	100t	Dom	
Sturgeon	Since 2005	1	nil	Dom	
Perch	Since 1995	~15	N.A.	Dom	

(Molsa, Pers. Comm.)

is done on a minor scale in Finland[196] and Arctic charr is being cultured in recirculating systems. The Government encourages emerging species by providing R&D support. The Finnish Game and Fisheries Research Institute and the Ministry for Agriculture and Forestry are leading authorities on emerging species in Finland.[197].

France

Emerging species in France are: meagre, red drum and cobia; the fingerlings are produced in recirculation systems, and ongrowing occurs in cages. Over the past five years 1 or 2 more emerging species have appeared. Around five farms are producing red drum[198].

Germany

Plans for cod fingerling production for restocking to Baltic Sea are in discussion, but will not be realised before 2008/2009[199]. Striped bass hybrids are an emerging species in Germany. Commercial production began in 2005, and four farms are producing 25 tonnes for domestic consumption. Sturgeon is also an emerging species that has been produced since around 1990. Currently five farms produce a few hundred tonnes for domestic consumption. Government policies neither encourage nor discourage emerging species[200].

Greece

The government encourages emerging species by providing funding. The Hellenic Centre for Marine Research (HCMR) and the Fishery Research Institute (INALE) are two leading authorities on emerging species in Greece[201]. Commercial companies are also involved including Nireus Chios Aquaculture SA; Selonda; and Hellenic Fish Farm[202]. For instance tuna is an emerging species in Greece, through a joint venture between several companies.

Other emerging species include *Puntazzo puntazzo, Dentex dentex, Pagrus pagrus, Diplodus sargus, Pagellus erythrinus, Lithognathus mormyrus, Solea solea*. These are all produced under the 'traditional' extensive cage culture system, with the exception of sole that is cultivated in land-based tanks. The number of species has not changed over the past five years. The government strongly encourages emerging species, as licences for new sites are only granted for the production of new species (any species but bass and bream). The former Institute of Marine Biology in Crete (currently HCMR) have tried the following species: Seabream-like species *Boops boops, Pagellus acarne, Diplodus vulgaris, Diplodus sargus, Pagellus erythrinus, Lithognathus mormyrus, Oblada melanura;* Average growth species *Pagellus bogaraveo, Pagrus pagrus, Puntazzo puntazzo, Pagellus erythrinus, Umbrina cirrosa, Sciaena umbra;*

196 Molsa/Koskinen, Pers. Comm.
197 Molsa, Pers. Comm.
198 Blancheton, Pers. Comm.
199 Weirowski, Pers. Comm.
200 Brämick, Pers. Comm.
201 Charalabakis, Pers. Comm.
202 Triantaphyllidis, Pers. Comm.

Promising species *Dentex dentex, Epinephelus marginatus, Argyrosomus regius, Epinephelus aeneus;* Fast growing species *Seriola dumerilii, Polyprion americanus, Schedophilus ovalis, Coryphaena hippurus, Thunnus thynnus, Octopus vulgaris, Rachycentron canadum;* Species with problems *Solea solea, Solea senegalensis, Mullus surmuletus;* Hybrids *Pagrus x Aurata, Pagrus x Dentex, Sargus x Dentex, Puntazzo x D. vulgaris* - all combinations gave worse results compared to the initial species.

Hungary

African catfish is a successful emerging species in Hungary. It was first grown commercially 10-15 years ago, and production is still growing. Currently, 7 or 8 farms produce a total of 2000 tonnes per year. The fish is mainly consumed domestically. Other emerging species include sturgeon (for caviar), tilapia and pike-perch. The number of emerging species has increased very recently. Government policies encourage the development of emerging species in Hungary[203].

Ireland

Emerging species in Ireland include perch (0.5t at €3,500, 2004), charr (6t in 2005, worth approx €34,000), seahorses, non-native freshwater clams (180t at €711,000, 2004), abalone (150 indiv + spat for ongrowing, total value €37,500, 2004), urchins (3.5t + spat, total value €190,000, 2004), scallops (103t at €440,000, 2004) and seaweed. The government encourages emerging species through promotion and funding of state of the art production techniques including technology transfer and training. The leading authorities on recirculation production in Ireland are: State Development Agencies, BIM, Udaras na Gaeltachta, Marine Institute, Taighde Mara Teo and Research Institutions[204].

Italy

Bluefin tuna fattening is developing in Italy. Sturgeon production for caviar is developing (slowly because of the required time). Mullet farming or "Bottarga" production is growing in coastal lakes and lagoons[205]. Meagre is also an emerging species in Italy, with around 400 tonnes currently produced per year. Around 200 tonnes of *Puntazzo puntazzo* (Sharpsnout bream) and *Diplodus Sargus* (White seabream) together are also being produced. The number of emerging species has increased over the past 5 years[206]. Other emerging species still under development include red porgy, amberjack and octopus (See table below). The government (Ministry of Agriculture Politics) and some regional agencies encourages new species, and provides funding for research The leading authorities are the Ministry of Agriculture Politics, plus regional administrations for their competencies.[207].

203 Varadi, Pers. Comm.

204 Watson, Pers. Comm.
205 Saroglia, Pers. Comm.
206 Fabris, Pers. Comm.
207 Saroglia, Pers. Comm.

Table 6.3 Emerging species in Italy

Species	Date produced commercially	No of farms producing	Total production (weight & value)	Market – domestic or export
Bluefin tuna	2002	5		Export + dom.
Meagre	2001	2	200 tonnes, €0.8 million	Dom.
Solea senegalensis	2003	2	80 tonnes	Dom.
Dentex	2000	1	50	Dom.
D.sargus & P.puntazzo	1995	8	100	Dom.

(Saroglia, Pers. Comm.)

Latvia

In 1998 in Latvia, crayfish juvenile breeding was started[208]. It is concentrated in three centres, and every year a total of 2-3 tonnes of crayfish are reared. The crayfish breeding centres cooperate with private crayfish breeders. There are plans to start exporting the crayfish to Finland. Financing from the EU funds aquaculture enterprises, and will attract financial means for modernisation of fish and crayfish breeding equipment and technologies. Most aquaculture in Latvia is based on carp or trout, although there is also some growth in ornamental fish production, and some production of other freshwater fish including tench, pike, zander and sturgeon. The main centre of expertise is the Latvian Fish Resources Agency

Malta

Before 2000, aquaculture was focused exclusively on production of seabream and sea bass for EU markets (approximately 95% of total production), particularly Italy. Since the year 2000, the aquaculture industry redirected its interests mainly on the fattening of Bluefin tuna, the main export of which is to Asian markets with Japan being the prime consumer. The tuna fattening technology used in Malta is similar to that used in other Mediterranean countries such as Spain, Croatia, Turkey and Italy. Generally, fish are caught in international waters by purse-seine fishing during the months of June and July. They are then transferred to the cages where they are fed on raw fish and squid, depending on farm management and requirements. The fish are kept in the cages until they are harvested and exported as fresh or frozen products between October and January. The size of exported fish is dependent on the size of fish caught from the wild and generally ranges between 80 and 620 kg. In 2003 Malta produced 3,550 tonnes of Bluefin tuna with three farms operating in this business. Production is expected to increase off Maltese waters with the development of an Aquaculture Zone for tuna farming, 6 km off the coast of Malta[209].

Another major candidate for aquaculture in Malta is the amberjack (*Seriola dumerilii)*. Research is currently being carried out on its spawning and larval rearing, however there is no production on a commercial scale. There is also some interest among farmers for other species such as the common octopus, red porgy, grouper and dentex[210].

Netherlands

Emerging species in the Netherlands are all produced in recirculation systems, including: barramundi, sole, pike-perch, tilapia, and turbot. These species have been developed in the past five years. At the moment most growth is in tilapia. For the other new species there are only one or two farms[211]. The government encourages emerging species and diversification of the sector. The Ministry of Agriculture, Nature and Food Quality (LNV) is the leading authority on emerging species in the country[212].

Norway

Cod is one of the main emerging species in Norway. Farmed cod is the third most important fish-farm species measured by quantity. In 2003, 2,185 tonnes of cod were sold, valued at NOK 51 million. This is nearly twice as much as in 2002[213]. 3,168 tonnes of farmed cod were sold in 2004, an increase of 45 % from the previous year. For the first time, cod from hatcheries dominated. Other fish species sold as farmed fish in 2004 were halibut, char, turbot, mackerel, saithe, eel and catfish[214].

208 Food supply chain dynamics and quality certification. Aragrande et al. 2005. Review report. JRC/IPTS project. http://foodqualityschemes.jrc.es/en/documents/ReviewReport_000.pdf

209 Vassallo-Agius, Pers. Comm.
210 Op. Cit.
211 Van Dooren, Pers. Comm.
212 Schneider, Pers. Comm
213 Fish Farming 2003. Statistics Norway. 2005. 79pp.
214 Fish Farming 2004 Preliminary figures. Statistics Norway. 2005.

There are aims to produce 100,000 metric tonnes of cod per year by 2010 in Norway[215] whilst Nutreco, the Dutch food group, predicts annual cod output will rise to around 700,000 tonnes by 2015. There are 170 marine licenses for a total of 815,000 m^3 with a capacity of producing 40,000 – 100,000 tonnes of cod. France is currently the largest (60 %) market for Norwegian farmed cod.

Several Norwegian cod hatcheries have overcome the difficult start-up phase –several million fish were produced in 2005. Improvements are seen both in terms of lower mortality and less visible deformities. Many hatcheries have now turned to rotifers as the only live feed, but some still rely on *Artemia* nauplii as a second live feed prior to weaning. These hatcheries often have a lower deformity rate than those using only rotifers, which raises the question of the cost and benefits of the 'rotifer only' protocols. The hatchery operators rank feeding and nutrition highest on their recommendations for further research, with health and water quality following. Within nutrition, they'd like a closer look at broodstock nutrition, i.e. requirements for better egg quality. Improving knowledge of larvae nutritional requirements for better quality of live feed and weaning diets is also highly prioritised together with optimisation of feeding regimes. Within health, the possibility of vaccinating smaller fish and further reduction in the deformity rate are prioritised areas of research. There is also a need for standardised methods for evaluation of deformities. In grow-out production there are large variations in feeding regimes, suggesting lack of good protocols or knowledge in cod production in cages. Cod escaping from the cages is a challenge, due to both the losses to the farmers and any potential impacts on wild stocks. These challenges, along with disease treatments and better vaccines, are areas where grow-out producers would like more R&D. A positive development is that grow-out farmers have found that juveniles that are stocked in sea cages at a larger size have less mortality caused by vibriosis and cannibalism than smaller ones. Feed producers considered the most important challenges as finding substitutes to fish meal and marine lipids in the cod diets. Other major technical obstacles for establishing a successful commercial cod farming industry are poor flesh quality after storage. Due to the low water binding capacity the frozen or refrigerated flesh becomes dry and tough[216].

Atlantic halibut: There are 162 concessions licensed for halibut farming in Norway and currently 13 major producers, the majority of which are in Nordland County. The total production of commercial-sized fish (4-5 kg) has doubled each year since 2002 and was 1200 metric tonnes in 2004, corresponding to half of the world production of farmed halibut. It is estimated that Norwegian production of farmed halibut will reach 10,000 t by 2010, worth more than 750 million NOK per annum at today's prices[217].

Arctic charr has been produced commercially in small quantities for a number of years, but has not expanded along the lines of salmon and trout. Turbot for the table is produced commercially in only one site, based on using industry cooling water for increasing water temperature. Fingerlings are imported from Spain/Portugal. Saithe is not produced commercially from fingerlings and there is little R&D going on for this (the price of saithe is too low). However, approximately 2,000 tonnes were produced by one company in 2005 based on feeding wild caught saithe. There were a couple of farms producing eel, but they had problems with elver supply, so they are no longer produced commercially in Norway. There is one farm producing fingerlings and table-size spotted

215 Review predicts future of cod farming. Akvaforsk. FishUpdate July 2006.

216 Fish Muscle Research Group 2006 www.st-andrews.ac.uk/~fmrg/fellowship1.html

217 Fish Muscle Research Group 2006 www.st-andrews.ac.uk/~fmrg/fellowship1.html

wolffish (*Anarhichas minor*). The activity is low and is not expected to increase[218].

Poland

There is growing interest in Poland in the African catfish, *Clarias gariepinus*. This species is produced in facilities with recirculating systems. The intense production of European catfish (*Siluris glanis*) is developing dynamically as methods are mastered for the artificial spawning and intense fattening of this species in recirculating systems. The development of Acipenseridae (sturgeon) production is also promising (using recirculating systems). The major aquaculture species however, are trout (especially in the North) and carp (especially in the South)[219].

Several farms produce carp, sturgeon, and European catfish in cages (around 600 cages from 3 to 30 m^3) located in electric power plant discharge canals. One of the priorities in the National Strategy for the Development of Fisheries in 2007-2013 is to develop scientific understanding and new technologies[220].

Portugal

Emerging species in Portugal are: sole (*Solea vulgaris*) in recirculating and open systems; white seabream (*Diplodus sargus sargus*) in open systems; sharpsnout seabream (*Diplodus puntazzo*) in open systems; zebra seabream (*Diplodus cervinus cervinus*) in open systems; meagre (*Argyrosomus regius*) in open systems and grouper in ponds[221]. These are all produced for the domestic market. The government encourages emerging species by giving larger grants to companies producing or attempting to produce new species. The leading authorities on emerging species in Portugal are: A. Coelho & Castro, and IPIMAR CRIP Sul[222].

218 Handa, Pers. Comm.
219 Woynarovich & Lirski, Pers. Comm.
220 Op. Cit.
221 Bravo, Pers. Comm.
222 Bernardino, Pers. Comm.

Spain

There is a trend of slowly but consistently introducing a number of new species. This was the case for turbot over the last 8-10 years. Species that are currently studied as potential commercial species include octopus, sea urchin, amberjack, meagre, *Pagellus*, sole, red porgy, sturgeon and grouper, The meagre (*Argyrosomus regius*) and the sole (*Solea senegalensis*) which are already successfully produced in some fish farms, and the octopus has a high potential because of its acceptance and consumption in the country and the advances in culture technology. Sturgeon farming could also further develop in the future (two farms are already successfully producing them)[223].

Sweden

Emerging species in Sweden include: Arctic charr, perch, pike-perch, and whitefish (*Coregonus*), with the latter three emerging within the past five years. Currently, more than 10 farms produce Arctic charr, and total production is around 500t, consumed domestically. The government has encouraged strain improvement and research on Arctic charr. The leading authority on emerging species in Sweden is SLU (Swedish University of Agricultural Sciences).[224]

UK

The first UK farmed cod went on sale in January 2000[225]. Currently, 14 companies farm cod at 20 sites, and production in 2005 was an estimated 355.5 tonnes[226]. The market for cod in the UK alone is around 240,000 tonnes per year, only 7 per cent of which now derives from the North and Irish Seas[227].

Commercial production of organic cod started in early 2002, with the first harvest of

223 Tort, Pers. Comm.
224 Eriksson, Pers. Comm.
225 New species mariculture. British Marine Finfish Association. www.bmfa.uk.com/species.htm
226 Scottish Fish Farms Annual Production Survey 2004, Fisheries Research Services Marine Laboratory, SEERAD.
227 Fish Muscle Research Group 2006 www.st-andrews.ac.uk/~fmrg/fellowship1.html

organic cod in Shetland, Scotland, in early 2004[228]. Hatcheries are also located in Scotland, with two on Shetland and one on the mainland. Farmed cod is sold both in the UK and abroad. One company, Johnson Seafarms (subsequently names "No Catch"), is aiming to produce 3,000 tonnes of organic cod by 2007[229], and 15,000 tonnes by 2010[230]. Johnsons are working closely with three UK organic and welfare certification organisations, the Organic Food Federation (OFF), the Soil Association and the RSPCA.

Production of the warmwater Australasian fish barramundi (*Lates calcarifer*) began recently in England. The New Forest Barramundi, named after its location in the New Forest, became available to UK consumers in early 2006[231]. Initially, the barramundi producing company is on-growing imported juveniles, but there are plans to implement an in-house hatchery within a year. Around 400 tonnes of fish are produced annually, with plans for expansion. The fish is produced in advanced indoor recirculation systems, keeping the water temperature at 28°C. The fish is expected to retail at £15 (€22) per kg.

The first harvest of farmed UK halibut, of around 0.5 tonnes, took place in 1997[232]. In 2000, Weddell Fish Farm became the first Orkney Islands farm to move into halibut production[233]. The halibut are farmed in salmon cages that have been adapted so that they have a 'floor' for the bottom-dwelling fish. In 2005, an estimated 227 tonnes of halibut were produced, and there are currently 9 companies farming halibut from 17 sites[234]. It is envisaged that around 10,000 tonnes of halibut will be harvested annually by 2012[235].

Commercial production of turbot in Scotland dates back to the 1980s but has been very limited. The first turbot farm in England was set up in mid 2005 near Gainsborough. It uses a recirculation system in a temperature controlled building. The farm plans to produce up to 25,000 fish per annum of 500-1000g size[236]. A larger production facility was also built in North Wales around the same time aiming to produce around 100 tonnes per annum using recirculation technology.

Tilapia is being produced commercially in the UK. There are currently three commercial tilapia farms in England, and there may be others in the start-up phase. In total, an estimated 50-60 tonnes of tilapia are currently being produced annually[237].

Arctic charr is another emerging species, with five farms producing from eight sites. Production in 2004 was 3.25 tonnes, and estimated production for 2005 was 10.5 tonnes[238], including both table fish and fish for angling restocking.

Species that are still in the experimental/early pilot stage in the UK include: pollock, haddock, hake, and common sole.

6.3.2 Countries without emerging species

Lithuania

There have been no introductions, transferred species, or genetically improved species in the aquaculture industry in the last 10 years[239].

228 Johnson cod. Johnson Seafarms. www.johnsonseafarms.com
229 Johnson Seafarms brings cod to the table. Fish Farming Today, September 2005.
230 Cod producer buys hatchery. Fish Farming International, August 2005.
231 New Forest Barramundi. Aquabella Group. www.aquab.com
232 Halibut culture. Fisheries Research Services. www.frs-scotland.gov.uk
233 Commercial 'first' for Orkney fish farm. Highlands & Islands Enterprise. www.hie.co.uk
234 Scottish Fish Farms Annual Production Survey 2004, Fisheries Research Services Marine Laboratory, SEERAD.
235 New species mariculture. British Marine Finfish Association. www.bmfa.uk.com/species.htm
236 New turbot farm. Fish Farmer, Nov/Dec 2005.
237 Grady, Pers. Comm.
238 Scottish Fish Farms Annual Production Survey 2004, Fisheries Research Services Marine Laboratory, SEERAD.
239 Woynarovich, Pers. Comm.

6.4 Meagre

6.4.1 Introduction and European overview

The meagre (*Argyrosomus regius*, also known as *Sciaena aquila*) is found in the wild along the Eastern Atlantic from Norway south to Gibraltar and Congo, including the Mediterranean and Black Sea[240]. Farmed meagre come from intensive production, conducted both in land-based tanks and cages. The first commercial production was recorded in France in 1997. Since then production has expanded slowly in nearby regions, especially on the Tyrrhenian side of the Italian coast, and in Corsica.

The adult meagre market is now slowly expanding, especially in Italy; this could promote fry production in the future, as well as research on fry and juvenile production. Commercial production in Italy was first reported to FAO only in 2002. Production of farmed meagre is very limited so far and is confined to the Mediterranean Basin (southern France, Corsica and Italy). Reported production in 2002 was 231 tonnes (50 percent from Italian cages; 7 percent from Italian tanks; 40 percent from French cages; 3 percent from French tanks) with a value of US$1.55 million (€1.21 million)[241].

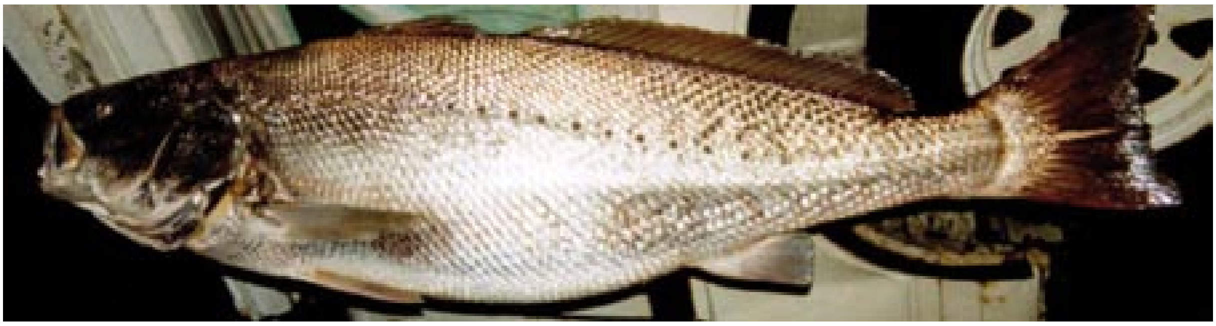
6.4.2 Technical feasibility

Ongrowing techniques are similar to those used for European sea bass and Gilthead seabream. In land-based farms production is mainly achieved in circular or rectangular tanks with a water depth of 1 m and a volume of 500 m^3; the tanks are usually covered with PVC cloth to avoid skin abrasions, especially where they are concrete. The tanks may be circular or rectangular and are stocked with 100 g fish at about 50/m^3. At normal stocking density (50/m^3) meagre reach 800-1200 g in less than 24 months. Very often they are fed until they reach 2000-3000 g, a size that is more suitable for fillets or slices. Nowadays meagre is mainly farmed in the sea, using circular or square surface cages of 500-1000 m^3. More recently, submerged cages have also successfully been used; these 2000 m^3 cages are submerged at 10-20 m, and a low stocking density (10-15/m^3) is used. Good results have been obtained in terms of growth rate and FCR - an FCR of about 1.7:1 has been achieved; in some cases (in large sea cages with a stocking density below 50 m^3), trials are showing even better FCRs[243].

6.4.3 Financial feasibility

Since the number of production units is low, cost comparisons are difficult to make. In land-based systems costs depend mainly upon the size

Figure 6.1 Meagre (Argyrosomus regius)[242]



240 Fishbase.org
241 Cultured aquatic species information programme – Argyrosomus regius. 2006. FAO FIGIS
242 Fishbase.org
243 Cultured aquatic species information programme – Argyrosomus regius. 2006. FAO FIGIS

of the farm. However, in cage culture the major expense is the cost of juveniles; currently these must be bought in the South of France. Generally, feed represents the other major cost during grow-out but it is lower than other marine fish species, since the FCR for meagre is generally better.

6.4.4 Markets

Meagre has a number of attractive features. It is a particularly lean fish, even when grown intensively and receiving the high fat diets that produce high quality marketable products. It has a high dress out percentage, low adiposity, healthy muscular lipid content, and long shelf life. It reaches relatively large commercial sizes quite rapidly, showing promise for the processing industry; this could create a different market niche for meagre, compared to sea bass and seabream.

6.4.5 Environmental impacts

There are no particular concerns relating to culture of meagre, so it is assumed that the environmental impacts will be similar to any other cage farming in the Mediterranean. Fish escapes from cages are not considered a major problem because meagre is endemic in the Mediterranean basin[244].

6.4.6 Prospects

A small but steady increase in the production of farmed meagre is expected in the next few years, especially in central Italy (southern Tuscany area). Two major factors need to be addressed if meagre farming is to expand significantly:

- Juvenile quality cannot yet be controlled, since there is currently only one source;
- Demand is low, because meagre products are not yet sufficiently well-known to the public. Meagre is generally sold by farms that also produce sea bass and seabream, which (so far) are generally more appreciated[245].

6.5 Breams

6.5.1 Introduction and European overview

Greece, Italy, Portugal and Spain have led the way in developing new species of breams, driven partially by the bass and bream price crises in the mid 1990s. However, the new breams have similar culture requirements to bass and bream, and the product is very similar, so the industry has not really progressed and developed an effective species diversification strategy.

New species include: *Puntazzo puntazzo* (Sharpsnout seabream) (Fig 6-2), *Dentex dentex* (Common dentex) (Fig 6-3), *Diplodus sargus* (White seabream), *Pagellus erythrinus* (Common pandora), *Oblada melanura* (Saddled seabream), *Diplodus cervinus* (Zebra seabream), *Lithognathus mormyrus* (Striped seabream) and *Pagrus pagrus* (Common seabream). All except the last two are in commercial production in one or more European countries.

6.5.2 Financial Feasibility

Since most of the new bream species have only entered the commercial production stage very recently, data concerning their costs of production could not be obtained. However, since the new bream have been developed with the existing methods of bass and bream culture, production costs are likely to be in direct relation to the costs of these two species. The key determinants of the production-cost are fry (fingerlings), the feed and the labour costs although account will need to be taken of the lower survival, and the much smaller scale of production, plus increased management and administration costs incurred by R&D. Seabream

244 Cultured aquatic species information programme – Argyrosomus regius. 2006. FAO FIGIS

245 Cultured aquatic species information programme – Argyrosomus regius. 2006. FAO FIGIS

Figure 6.2 Sharpsnout seabream (Puntazzo puntazzo)[246]

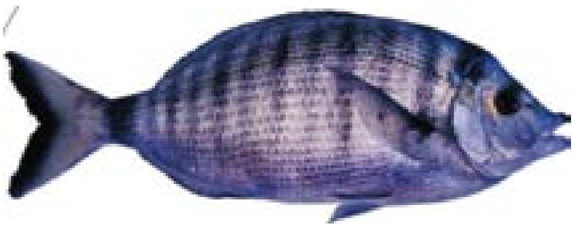


Figure 6.3 Common seabream (Pagrus pagrus)[247]

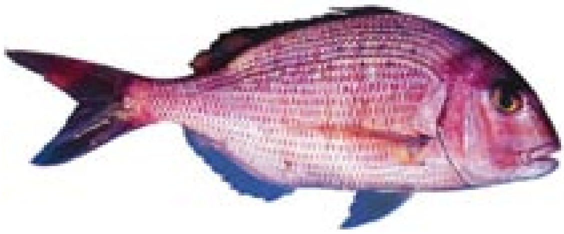


Figure 6.4 Gilthead sea bream, global production trends

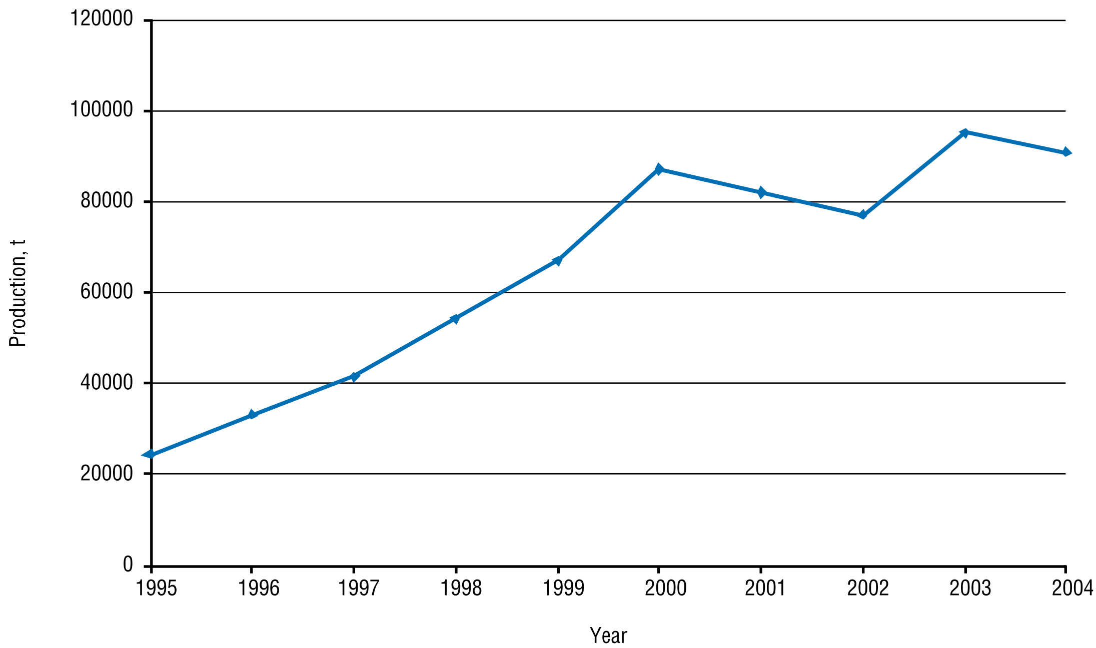
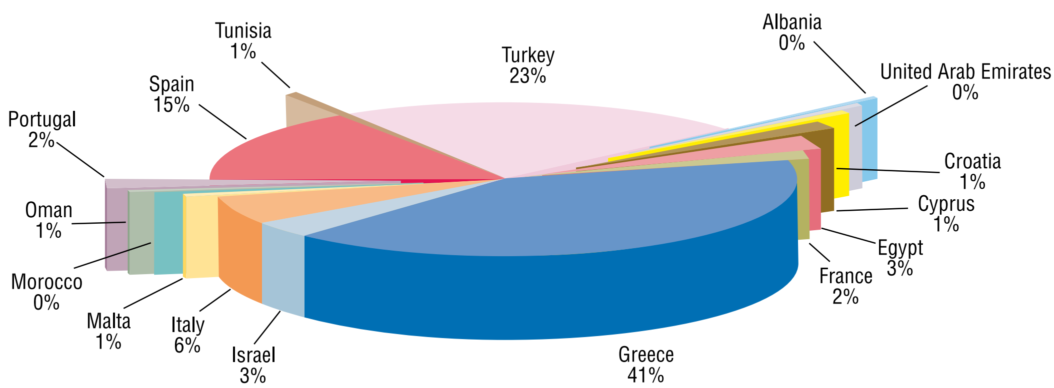


Figure 6.5 Gilthead sea bream, global production by country, 2004



246 New Mediterranean fish. 2006 Akuvatur Mediterranean Sea Foods. www.akuvatur.com

247 New Mediterranean fish. 2006 Akuvatur Mediterranean Sea Foods. www.akuvatur.com

produced by companies with a hatchery costs from €3.48 to €4.07/kg, whilst for companies who buy in fry the cost rises to €3.70-4.30/kg. Similarly, sea bass costs from €3.53 to €4.30/kg to the companies owning a hatchery, and about €3.75 to €4.36/kg to those without hatcheries. Greece is generally able to reduce production costs for sea bass and sea bream compared to most countries as it has a vertically integrated industry. It also has many more suitable inshore on-growing sites than other countries, which is also the case to some extent for Turkey. In general, the costs of fry, feed, labour, depreciation, packaging, and management, account for over 90% of the total production cost.

It is important to consider the history of the existing sea bass and sea bream culture as currently the farm gate price for both species is similar to the production costs. This is largely due to the price crash during 2001 to 2002 triggered by over-capacity induced through readily available development grants. Between 1998 and 2002 prices fell from €6.32 to €4.39 for sea bass and from €5.79 to €4.07 for sea bream. It has also been estimated that the total production has been miscalculated at around 60% of actual total production, which would also have affected farm gate prices. Historically the seasonal nature of sea bass and sea bream production has contributed to lower prices, however there has been an effort to remedy this with more consistent all year production. (Stirling Aquaculture, 2004). The following table presents an approximation of the production costs for some of the new species produced.

Table 6.4 Production costs for new bream species

Species name	Production cost (€/kg)*
Sparus aurata	3,4 – 4,3
Dicentrarchus labrax	3,5 – 4,4
Puntazzo puntazzo	4,3 – 4,9
Pagrus pagrus	3,8 – 4,1
Dentex dentex	5,3 – 6,5
Diplodus sargus	4,4 – 5,0
Pagellus erythrinus	4,0 – 4,5
Oblada melanura	4,0 – 4,7
Lithognathus mormyrus	4,2 – 5,0

* *Range shows difference between producers with and without hatcheries.*

Table 6.5 Cost structure for seabream production in Greece

	Cost when fry produced (% of total)	Cost when fry purchased (% of total)
Feed	44.4	41.9
Fry	14.7	19.5
Labour	14.6	13.8
Depreciation	7.0	6.6
Packaging	6.6	6.2
Management	5.7	5.4
Insurance	3.5	3.3
Medicines/vaccines	0.7	0.7
Repairs/maintenance	1.4	1.3
Fuel/energy	1.1	1.0
Consumables	0.2	0.2
Other	0.2	0.2
Mean total cost of production (€/kg)	3.78	4.00

*Table 6.6 Financial model for common seabream (**Pagarus pagrus**) production in Greece*

Key assumptions

Production rate (t/yr)	Fish value (€/t)*	Feed (€/t)	F.C.R.
310	5500	800	2.2

Financial model

10 year cash flow	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10
Production (t)	0	310	310	310	310	310	310	310	310	310
RECEIPTS										
Cash sales	0	1,364	1,364	1,364	1,364	1,364	1,364	1,364	1,364	1,364
From debtors	0	0	341	341	341	341	341	341	341	341
TOTAL RECEIPTS	0	1,364	1,705	1,705	1,705	1,705	1,705	1,705	1,705	1,705
PAYMENTS										
Working capital costs	1,089	1,084	1,084	1,084	1,084	1,084	1,084	1,084	1,084	1,084
Capital expenditure	1,495	0	0	0	0	0	0	0	0	0
TOTAL PAYMENTS	2,584	1,084	1,084	1,084	1,084	1,084	1,084	1,084	1,084	1,084
NET INFLOW/(OUTFLOW)	-2,584	280	621	621	621	621	621	621	621	621
Bank balance brought forward	0	-2,584	-2,303	-1,682	-1,061	-439	182	803	1,425	2,046
Bank balance at end	-2,584	-2,303	-1,682	-1,061	-439	182	803	1,425	2,046	2,667
IRR	16%									

Breakdown of operating costs	'000 EUR/ annum	% of total
Fish feed	682	54
Fingerlings	252	20
Depreciation*	164	13
Labour	113	9
Fuel	20	2
Stock insurance	15	1
Lease of sea area	5	0
Electricity	2	0
Total operating costs	1,253	
Cost/kg	4.04	
NB excludes finance costs		

**depreciation is not included in cash flow model*

Capital costs	Total ('000 EUR)
Cages	437
Nets	424
Anchoring/Buoying	331
Gear	94
Diving equipment	2
Transportation equipment	162
Other equipment	14
Environmental monitoring system	31
Total capital cost	1,495
Contingency (10%)	149
Capital costs inc. contingency	1,644
Annual depreciation (10 yr avg. life)	164

Sensitivity analysis

Assumption	IRR	Max funding (EUR)	Payback (yrs)
Base case	15.8	2,583,538	6
+20% sale price	30.1	2,583,538	5
-20% sale price	-2.5	2,583,538	>10
+20% feed cost	7.95	2,719,938	8
-20% feed cost	23.7	2,447,138	5

6.6 Octopus

6.6.1 Introduction

The common octopus (*Octopus vulgaris*) can be found worldwide in both temperate and tropical waters greater than 7°C in temperature (see Figure 6-6). It lives in depths up to 200m, in a variety of habitats including coral reefs, rocks and grass beds. In the western Mediterranean, larger and smaller individuals migrate inshore in early and late spring respectively, then retreat into deeper waters by September and December. Octopuses grow from 3 to about 20 cm in 17 months in the western Mediterranean. They feed on bivalves and crustaceans. Octopuses grow to a maximum weight of 10kg, but are commonly 3 kg. The species is highly desirable and commands high prices throughout its distributional range and supports artisanal as well as industrial fisheries[248].

Figure 6.6 Octopus (Octopus vulgaris)[249]

248 Species Fact Sheet – *Octopus vulgaris*. FAO FIGIS www.fao.org/figis/servlet/species?fid=3571

249 Octopus market report – Jan 2006. Globefish. www.globefish.org/index.php?id=2684

Figure 6.7 Distribution range of the common octopus (Octopus vulgaris)[250]

6.6.2 European overview

Italy and Spain are the main octopus consuming countries in the EU. Spanish catches have fallen from 100,000 to 17,000 tonnes in the past few years, and Italian vessels only catch around 10,000 tonnes per year, and this figure is falling. Spain imports around 34,000 tonnes per year of wild caught octopus, with almost 50% of this coming from Morocco. Italy imports 48,000 tonnes per year, with Spain and Morocco being the main sources[251].

There are problems with the marketing of undersized octopus contributing to over-fishing of the eastern-central Atlantic, so the EU have adopted a regulation forbidding landing and sale of octopus under the minimum size of 450g (gutted)[252]. This will impact on the supply of wild-caught octopus, raising prices, and potentially providing a gap in the market which could be filled by cultured octopus.

Commercial ongrowing of the common octopus (*Octopus vulgaris*) began in Galicia in 1996, following the results of research at the Coastal Centre of Vigo (Instituto Espanol de Oceanografia) and the University of Santiago. Since then, four companies have been set up and produced varying results, but have demonstrated the potential for octopus culture. In 2004, €350,000 was invested in research into the culture of octopuses in Galicia.[253].

Farmed octopus production in Spain fell from 32 tonnes in the late 1990s to only 10 tonnes in 2003.[254]

6.6.3 Technical feasibility

Octopuses are farmed in floating galvanised steel cages which are rectangular in shape and contain PVC columns for use as refuges. Cages can have a capacity of 150 octopuses. Ongrowing cycles last 3-4 months, starting with juveniles weighing 800g, and reaching 2.5-3kg by the end of the cycle. A company with 25 cages may fatten

250 Species Fact Sheet – Octopus vulgaris. FAO FIGIS www.fao.org/figis/servlet/species?fid=3571
251 Octopus market report – Jan 2006. Globefish. www.globefish.org/index.php?id=2684
252 Op. Cit.
253 Cost analysis of octopus ongrowing installation in Galicia. J. Garcia Garcia, L.M. Rodriguez Gonzalez and B. Garcia Garcia. 2004. Spanish Journal of Agricultural Research 2(4):531-537.
254 Octopus Market Report – April 2005. Globefish.

about 11,000 octopuses a year.[255] They are fed mainly on by-catch from trawlers – crab, horse mackerel, blue whiting etc. Due to differences in behaviour and biological characteristics, octopus cannot be fed on commercial fish feed. Research is in progress into feed and nutrition for octopus, but much work remains to be done. In 2004, the main constraints to large scale commercial production of octopus were:

- The complete reproduction cycle had not been mastered so juveniles must be captured from the wild;
- No specialist feed was commercially available, so their feed consisted of fish and crustaceans from trawling by-catch.[256]

Since octopuses are solitary animals, there can be problems with cannibalism if they are reared in cages together.[257]

6.6.4 Financial feasibility

Prices of octopus in Spain have doubled since 2000. Large octopus (2-3kg) exceed US$10/kg (€7.83/kg), and small octopus (300-500g) cost more than US$7/kg (€5.48/kg)[258]. In contrast, in Italy, smaller octopus are preferred.

While 2005 was a good year for the octopus trade, the new EU trade rules for undersized octopus will impact on both production and exports in 2006, hopefully helping the recovery of an over-fished resource. Prices are likely to rise significantly as the supply is curbed[259]. Morocco is moving towards a catch ban period, further reducing supply. Cold storage holdings of octopus in Japan, the largest global market for octopus, are currently at very low levels, indicating that prices could rise further[260]. This situation is beneficial for aquaculture producers, as higher prices would make production more profitable and encourage greater research and development.

Garcia Garcia *et al* (2004) performed a cost analysis of octopus ongrowing in Galicia, Spain. They concluded that, under present circumstances, octopus culture is a high-risk, low-profit business, not only because the variable costs are high, but also because the margins of the factors involved (e.g. current feed and selling prices) are very narrow. To lessen the risk and bring costs down, a dependable source of juveniles at a stable price is required, and this can only be done through production in captivity.

255 Culture of octopus (*Octopus vulgaris*, Cuvier): Present knowledge, problems and perspectives. Iglesias et al. 2000. CIHEAM Options Mediterraneennes.
256 Cost analysis of octopus ongrowing installation in Galicia. J. Garcia Garcia, L.M. Rodriguez Gonzalez and B. Garcia Garcia. 2004. Spanish Journal of Agricultural Research 2(4):531-537.
257 Preliminary observations on the productive responses of the common octopus (*Octopus vulgaris* C.) reared free or in individual nets. Cagnetta, P. 2000. CIHEAM Options Mediterraneennes.
258 Octopus Market Report – April 2005. Globefish.
259 Octopus market report – Jan 2006. Globefish. www.globefish.org
260 Octopus Market Report – April 2005. Globefish.

Table 6.7 Financial model for octopus ongrowing

Octopus ongrowing 10 year cash flow

The following information is adapted from Garcia Garcia et al (2004)[261].

Key assumptions

Production rate (t/yr)	Fish value (EUR/t)	Feed (EUR/t)	F.C.R.
45	6010	120	5.8:1

Financial model
1000's of Euros

10yr cash flow	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10
RECEIPTS ('000 €)										
Cash sales	218	218	218	218	218	218	218	218	218	218
From debtors		54	54	54	54	54	54	54	54	54
TOTAL RECEIPTS	218	272	272	272	272	272	272	272	272	272
PAYMENTS ('000 €)										
Working capital costs	222	222	222	222	222	222	222	222	222	222
Capital expenditure	673	0	0	0	0	0	0	0	0	0
TOTAL PAYMENTS	895	222	222	222	222	222	222	222	222	222
NET INFLOW/OUTFLOW	-678	50	50	50	50	50	50	50	50	50
Bank balance brought forward	0	-678	-628	-578	-528	-478	-429	-379	-329	-279
Bank balance at end	-678	-628	-578	-528	-478	-429	-379	-329	-279	-229
IRR (%)	-7.55									

Breakdown of operating costs	Annual costs ('000 EUR/yr)	% of total
Permanent staff	27	11
Maintenance	8	3
Permits	2	1
Fuel	5	2
Electricity	2	1
Insurance	3	1
Fixed taxes	0.3	0
Office costs	1	0
Juveniles	106	42
Feed	33	13
Production insurance	35	14
Depreciation	28	11
Total operating costs	250	100
Cost/kg (EUR)	5.53	
NB excludes finance costs		

261 Cost analysis of octopus ongrowing installation in Galicia. J. Garcia Garcia, L.M. Rodriguez Gonzalez and B. Garcia Garcia. 2004. Spanish Journal of Agricultural Research 2(4):531-537.

Capital costs	Cost ('000 EUR)
Cages	300
Galvanising of cages	24
Containers	54
Boat	150
Crane-truck	33
Auxiliary equipment	5
Onshore infrastructure	46
Containers for transport	0.6
Total capital cost	612
Contingency (10%)	61
Capital costs inc. contingency	673
Annual depreciation (10 yr av. life)	67

Sensitivity analysis - octopus

System	IRR (%)	Max funding (€)	Payback time (years)
Base model (see 6.3.1 above)	-7.6	677,531	>10
+20% sale price	8.6	634,028	8
Reported market price (€7.83/kg)	15.9	611,661	6
+20% feed cost	-10.0	684,049	>10
-20% feed cost	-5.3	671,013	>10
+20% fuel cost	-7.9	678,522	>10
-20% fuel cost	-7.2	676,540	>10

6.6.5 Environmental impacts

The octopus, like many aquatic species, is vulnerable to over-fishing. For example, octopus reserves off Morocco, the main supplier of octopus worldwide, have declined from 100,000 tonnes in 2001, to 18,000 tonnes in 2003, to only 8,000 tonnes in July 2004[262]. Aquaculture of octopus has the potential to reduce the pressure on wild stocks, but only if the complete reproduction cycle can be mastered. Currently, juveniles must be caught from the wild, further adding to the problem of over-fishing.

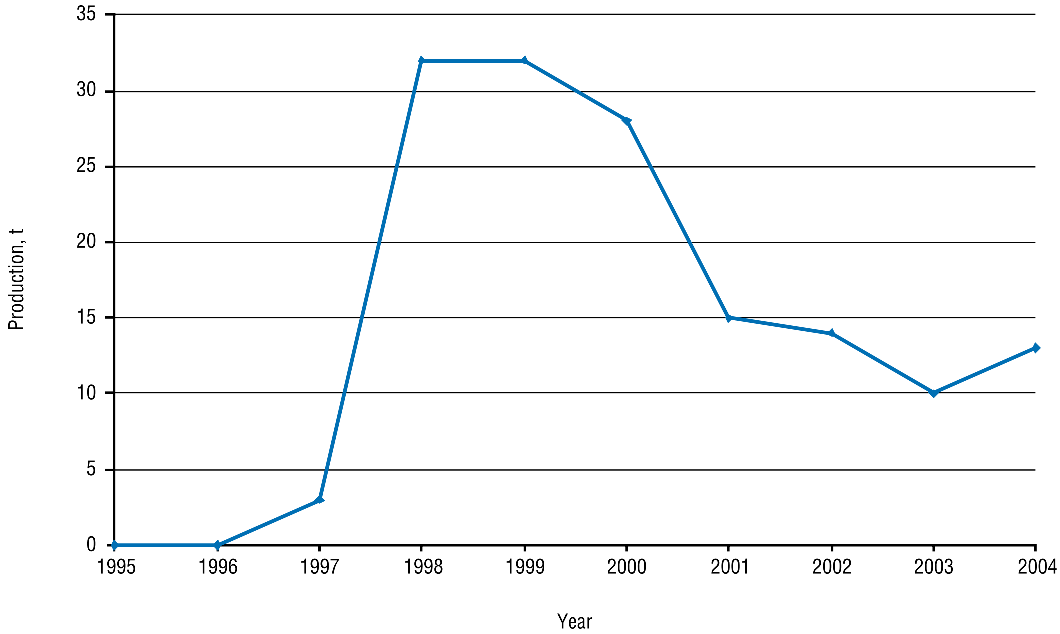
One of the major environmental questions about farming octopus is its feed requirements. It has a very high FCR, at 5.8:1, but currently the feed comes from by-catch of trawling, using a resource that would otherwise be wasted.

6.6.6 Prospects

Aquaculture production of octopus is still at the ranching stage, relying on juveniles from the wild. Much research is still needed to enable breeding in captivity and to reduce mortality rates and hence the risk associated with octopus culture. Even then, the reliance on trash fish remains a constraint, as do the problems of holding stocks at higher densities. The healthy demand for octopus, both in Europe and Japan, coupled with the shortage of wild octopus is likely to continue to push up prices, making the culturing of octopus more financially viable.

262 Octopus market report – April 2005. Globefish. www.globefish.org

Figure 6.8 Octopus - global production trends



6.7 Tuna

6.7.1 Introduction

Tuna farming involves the catching of juveniles from the wild, then fattening or growing-on in large offshore cages, since the full reproduction cycle has not yet been mastered. Tuna farming is also called tuna fattening or ranching.

Figure 6.9 Northern bluefin tuna (Thunnus thynnus)[263]

263 Photo by Gilbert Ryckevorsel www.npr.org

6.7.2 European overview

European countries currently involved in tuna farming include Cyprus, Greece, Italy, Malta and Spain. In 2005, Spain, Malta, Italy, Greece and Cyprus accounted for 71 percent of the officially registered tuna farming activity in the Mediterranean.[264] Production in the Mediterranean is likely to make up more than half of the world total and is almost exclusively intended for the Japanese market.[265]

Fishing fleets from several European countries supply much of the tuna for farming. The French purse seine fleet targeting tuna in the Mediterranean is the main single supplier of live tuna to the farms in the region.[266] Representatives from IFREMER (the French governmental fisheries institution) recently stated that several farming

264 Mediterranean fish at risk of exotic viruses. WWF News. 04 May 2005. www.panda.org/news_facts/newsroom/news/index.cfm?uNewsID=20232

265 Tuna farming in the Mediterranean: the ‘coup de grâce’ to a dwindling population? Sergi Tudela. WWF.

266 Tuna farming in the Mediterranean: the bluefin tuna stock at stake. Tudela & Garcia. 2004. WWF.

projects may be launched in France in the near future.[267]

Table 6.8 Tuna aquaculture current European production estimates[268]

Country	Production	Value	Percent exported
Cyprus	1400 t		100%
Greece	1000 t		
Italy	2000 t		Export & dom.
Malta	4000 t		
Spain	9000 t	~€190 million	

6.7.3 *Technical feasibility*

Purse seines are the only mobile gear able to capture tuna alive; a feature that makes the purse seine fleets a necessary element of the tuna farming industry. Once caught, tuna is transferred alive to special towing cages, which are then transported to the farm sites by means of tug boats (other boats than fishing vessels). Input season typically extends from May/June to July/September, depending on the country. Then fish are transferred to pens, where they are fattened for a relatively short time to improve the oil content of the flesh in order to meet the Japanese market standards. Fattening period usually lasts for no longer than 6-7 months, since the peak of the demand by the Japanese market occurs by the end of the year.[269]

As tuna ranching is still a new practice, research and development is still needed to improve technologies and practices. Significant stock losses still occur, due to varying causes such as bad weather conditions, anoxic upwellings, and poor feeding practices.[270]

The reproduction of tuna in captivity has been achieved recently in Japan under experimental conditions. Survival rates of larvae are very low and the process is considerably expensive, so the commercial production of tuna under full aquaculture conditions and independent of tuna capture fisheries is not likely in the foreseeable future. [271]

6.7.4 *Financial feasibility*

Tuna ranching is economically volatile. Prices for tuna exports to Japan, the largest market for European farmed tuna, have been falling since 2001, and towing and farming production costs have risen some 30% in the past three years. [272]

In 2002, 80% of Mediterranean tuna exported to Japan was of farmed origin. However, the Japanese tuna specialist P. Miyake warns that "the Japanese market is not as large as many people believe" and that "the price of high quality fish is very sensitive to the quantity of fish sold daily in the market". Tuna farming from the Mediterranean is shipped to Japan in large quantities at the end of the year, when prices are still high and there is a high demand for the New Year. In late 2003, there was a saturation of the Japanese market due to the overproduction of farmed tuna from the Mediterranean. As a result, in 2003 prices fetched by Mediterranean farmed tuna in the Japanese market fell due to an oversupply crisis. It would appear that the strong and extremely rapid development in the production of farmed tuna in the Mediterranean during the last few years has taken a purely short-term perspective, seeking immediate economic benefits, without taking

267 Tuna farming in the Mediterranean: the 'coup de grâce' to a dwindling population? Sergi Tudela. WWF.
268 Includes data from country contributors, and from 'The Tuna Ranching Intelligence Unit 2004, Advanced Tuna-Ranching Technologies, Spain'.
269 Tuna farming in the Mediterranean: the bluefin tuna stock at stake. Tudela & Garcia. 2004. WWF.
270 The Tuna Ranching Intelligence Unit 2004, Advanced Tuna-Ranching Technologies, Spain
271 Tuna farming in the Mediterranean: the bluefin tuna stock at stake. Tudela & Garcia. 2004. WWF.
272 The Tuna Ranching Intelligence Unit 2004, Advanced Tuna-Ranching Technologies, Spain

into consideration the economic sustainability of the business in international markets and the ecological sustainability of the fishery.[273]

European producers are competing with tuna farmers from outside Europe. EU tuna ranchers will have to face not only stiff competition from their Turkish and Tunisian competitors in terms of fish fattening, production and labour costs, they will also have to compete with other emerging tuna-ranching nations such as Malaysia, Oman, New Caledonia and Mexico.[274]

In the last few years, as the volume of farmed fish has increased and the price of fresh bluefin tuna has gone down, the volume of frozen fish has become increasingly important. Frozen products affect the market less than fresh since they can be stored and then sold when the supply of fresh fish is low. Since all the farmed tuna has the high oil content that is so appreciated on the Japanese market, the proportion of frozen fish sold later in the season is increasing.[275]

Costs of production

Juveniles cost €5/kg to buy from tuna fishing boats. They are caught at an average weight of 150kg and fattened up from June to October, with an increase in weight of 10-15%. Most of the weight gain is fat rather than muscle, since it is prized more by the Japanese market. The farm gate price of ranched tuna in 2005 was €11.50/kg frozen and €14.50 fresh[276].

273 Tuna farming in the Mediterranean: the bluefin tuna stock at stake. Tudela & Garcia. 2004. WWF.
274 The Tuna Ranching Intelligence Unit 2004, Advanced Tuna-Ranching Technologies, Spain
275 Tuna farming in the Mediterranean: the 'coup de grâce' to a dwindling population? Sergi Tudela. WWF.
276 Basciano, Pers. Comm.

Table 6.9 Production costs for farm producing 1000 tonnes per year

Item	Cost (€/kg)	Percentage of total cost
Juveniles	5.03	48
Feeding	2.84	27
Workers	0.63	6
Insurance	0.21	2
Other costs	1.47	14
Loan repayment	0.32	3
TOTAL	10.5	100

With total production costs of €10.50, producers make €1/kg profit on frozen tuna and €3/kg on fresh.

6.7.5 Environmental impacts

Tuna farming is currently environmentally unsustainable since juveniles must be caught from the wild for ongrowing, and tuna populations are declining due to over-fishing both for harvest and for farming. The practice of fishing vessels registered under one country catching the fish and then transferring it to farms registered under another country, and the lack of data on weight at capture can confuse catch statistics for bluefin tuna stocks, making their management more difficult.[277]

According to the available information, the focus on meat quality entails very low food conversion efficiency, thus resulting in an extremely wasteful practice having a very high ecological footprint. Conversion rates reported for farms in Italy, Spain and Turkey range from 10 kg to 25 kg of baitfish consumed to produce only 1 kg of tuna. So, the large amounts of fish fed to caged tuna (mainly small and medium pelagics, such as anchovy, round sardinelle, mackerel or herring) only result in a relatively modest increase

277 Tuna farming in the Mediterranean: the bluefin tuna stock at stake. Tudela & Garcia. 2004. WWF.

in tuna biomass.[278] In Murcia, Spain, the food conversion ratio is on average 4.26 per cent – a factor less than 20:1.[279]

As much as 225,000 tonnes of feed-fish – most of them alien to the region – are used annually by tuna farms in the Mediterranean, a higher number than the area's annual catch of sardines. This could lead to the introduction of new viruses that might affect the whole Mediterranean ecosystem. A WWF report highlighted the case of alien feed-fish imports dumped by tuna farms in Australia in the 1990s. Massive imports of small fish from other regions were at the origin of viral epidemics that in 1995 affected 5,000km of coastline and killed 75 per cent of the adult sardine population in Australia. It is technically impossible to analyze regularly frozen feed-fish imports to ensure that they are free from harmful viruses. Some scientists believe that the only solution is to have a total ban of such practices. In Denmark, use of feed fish in saltwater aquaculture has been banned since 1985.[280]

Spotter aeroplanes have been used to find tuna shoals for capture and farming. ICCAT has banned their use to try to protect tuna stocks, but it is well known that planes originally based at European airports have been moved to African airports instead to avoid the ban.[281]

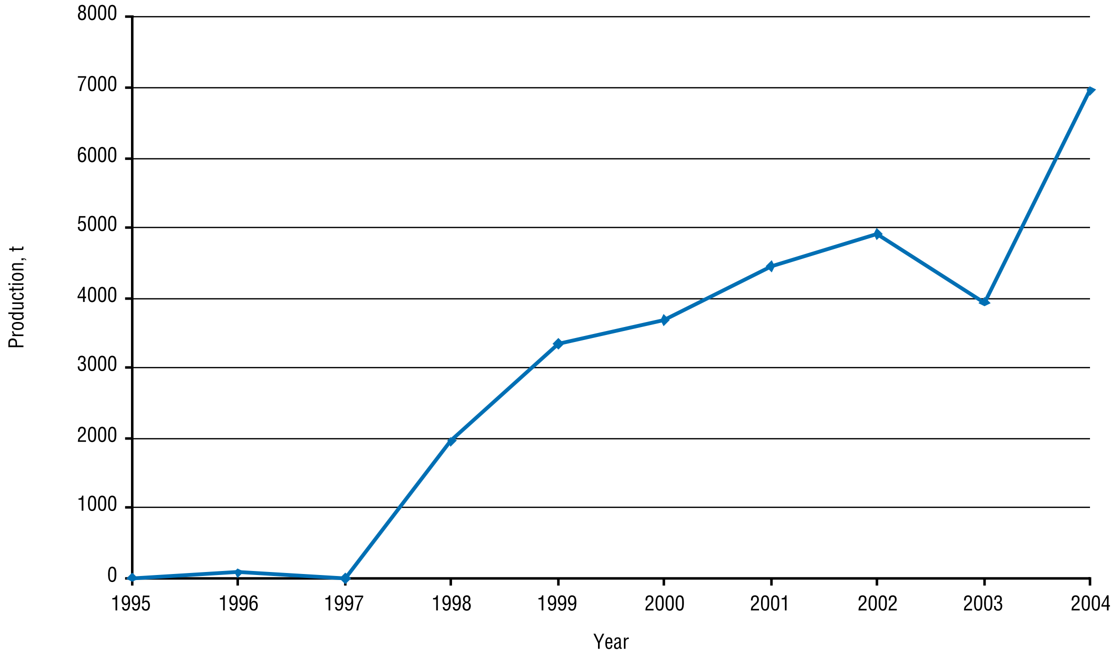
Over-fishing and over-farming of tuna in the Mediterranean is likely to have been encouraged by European Union subsidies of at least US$34 million (€26.4 million) since 1997.[282]

Guidelines on Sustainable Bluefin Tuna Farming (BFT) Practices in the Mediterranean have been prepared by the Ad Hoc GFCM/ ICCAT Working Group on Sustainable Bluefin Tuna Farming/Fattening Practices in the Mediterranean[283]. Recommendations include:

- Importance of regulating the amount of wild tuna caught, and strict adherence to quotas.
- Farming facilities should be licensed or registered to help prevent illegal, unreported and unregulated (IUU) fishing.
- Provision to the research community of fish specimens accidentally killed during fishing, transfer or transport, as they represent a significant biological sample from the wild stock.
- Studies for integrated coastal zone management should be carried out to avoid the possibility of conflicts between the BFT farmers and other resource users including those from the tourism, other aquaculture activities, and small-scale fisheries sectors.
- In some Mediterranean countries, subsidies for aquaculture development exist including funds for BFT farming. However, it remains unclear whether these will have a positive or negative impact on the development and sustainability of the BFT industry. This important issue certainly requires further monitoring and analysis.
- A standardized quality-control system should be developed to ensure the quality of baitfish [i.e. screened for heavy metals, polychlorinated biphenyls (PCBs), dioxin, etc.] and to ensure the absence of potential pathogens.
- Once an area is chosen for tuna farming, site selection should be preceded by an Environmental Impact Assessment (EIA).
- Environmental monitoring should be carried out. Standard analysis of the main

278 Op. Cit.
279 Tuna farming in the Mediterranean: the 'coup de grâce' to a dwindling population? Sergi Tudela. WWF.
280 Mediterranean fish at risk of exotic viruses. WWF News. 04 May 2005. www.panda.org/news_facts/newsroom/news/index.cfm?uNewsID=20232
281 Tuna farming in the Mediterranean: the bluefin tuna stock at stake. Tudela & Garcia. 2004. WWF.
282 The Tuna Ranching Intelligence Unit 2004, Advanced Tuna-Ranching Technologies, Spain.
283 Guidelines on Sustainable Bluefin Tuna Farming Practices in the Mediterranean. 2005. GFCM/ICCAT ftp://ftp.fao.org/docrep/fao/008/y8870e/y8870e00.pdf

Figure 6.10 Bluefin tuna – global production trend



water and sediment's physical, chemical and biological parameters at agreed distances from the farm site should be the norm, at an agreed-upon frequency. Environmental monitoring may also include the monitoring of ecological effects on (i) the benthos, including changes in biodiversity parameters, and deposition; (ii) the water column and water surface; (iii) interactions with attracted species and populations.

- The output data of the harvesting activity should be recorded and reported for stock assessment purposes.

6.7.6 Other impacts

Tuna farming is affecting the tuna fishing industry in two ways: increased high-tech purse seining is out-competing long-lines in the capture of the same fish resource; and farming activities, such as tugging floating cages hundreds of miles, is damaging set fishing gears.[284]

6.7.7 Prospects

The future of the tuna farming industry will depend largely on the development of appropriate and economic hatchery and nursery technologies. This will also need to be accompanied by developments in tuna diets and nutrition, as current feeds are bait fish with very poor food conversion rates of between 15:1 and 25:1 (wet weights). However, reproduction in captivity is still in its early stages, so tuna farming will rely on exploitation of diminishing wild stocks for at least the near future.[285]

The main market for Mediterranean farmed tuna, Japan, is volatile, as it is a premium species with prices easily affected by supply and changes in demand. Substantial growth in production would require new market development to avoid major price reductions.

284 Tuna farming in the Mediterranean: the bluefin tuna stock at stake. Tudela & Garcia. 2004. WWF.

285 Op. Cit.

6.8 Cod

6.8.1 Introduction

Atlantic cod (*Gadus morhua*) are a marine coldwater fish of the family Gadidae. They are migratory and can be found living as demersal shoals or deeper water fish on continental shelves. During the winter months, they congregate in large numbers to spawn. Maturation is temperature dependent and males reach maturity earlier than females. Their natural temperature ranges from -1 to +6ºC. Some species are thought to grow faster at 3-5ºC in summer and 2-3ºC in winter. Areas with temperatures lower than 2ºC are avoided with temperatures below -1.8ºC posing a severe threat to developing larvae. Cod reproduce for the first time between 4-9 years of age, with an average age of 6 years[286]. Females can lay upwards to seven million eggs per spawning. Their spawning is periodical, and each female will release 10 – 20 batches of eggs at intervals of 60 – 75 hours. Eggs are buoyant, and as larvae cod become part of the plankton for approximately 10 weeks. Subsequently, juveniles sink to the bottom until they commence migration in their second year.

Figure 6.11 Atlantic cod (Gadus morhua)

Cod are a top carnivore. The larvae are planktonic and feed on shrimp, shellfish, copepods and amphipods. Adults prey upon capelin, herring and flounders.

Their geographical distribution spreads from the east coast of North America, across the Northern Atlantic and to the east past Scandinavia (Figure 6-8).

6.8.2 European Overview

With the decline in natural cod stocks and the presence of a large and stable market for cod,

Figure 6.12 Global distribution of cod[287]

286 Kurlansky 1998 Cod: a biography of a fish that changed the world
287 www.norden.org

interest has turned to cultivation for both stock enhancement and commercial aquaculture[288]. The first serious attempts to farm cod were made in Norway during the 1970s, and at this point, the industry did not expand as profitability was low owing to high production costs. At present, the conditions for cod farming are considerably better and market prices for farmed cod have improved.

As a result some European countries are looking at production. The main producers are Norway, Great Britain and Iceland. As the industry expands, there should be market size fish available all year round. A slow expansion rate will provide time to sort out any technical, biological or operational bottlenecks in production, and will also keep prices stable maintaining profitability in the developmental stages.

Norway is still the main leader in cod production (83%) and research in Europe, followed by Iceland (17%) and Great Britain (<1%)[289]. The Murmansk region of Russia is showing good potential for the production of Arctic cod with estimated future yields of 50,000 t per annum[290].

In 2002, Norway had 17 facilities producing cod juveniles with Cod Culture Norway (CCN), in which Nutreco are the major shareholder as one of the biggest producers. They hope to increase to 25 hatcheries producing a total of 85 million juveniles and 50 million of these juveniles will be produced by CCN. Overall, Norwegian operations plan to produce 100,000 t by 2010, and 400,000 t by 2015, provided that the production of juveniles can increase.

In the UK, there are currently 14 companies farming cod on 20 sites. One of these operations (Johnson's Seafarm) is farming organic cod and at present is the only producer of organic cod worldwide. All of the production takes place in Scotland and some operations are working from adapted salmon farm sites. Their aim is to produce 25,000 t by 2010, which will require the production of 15 million juveniles.

Ireland is undertaking a project to create an experimental cod hatchery on the West Coast which will rear juveniles to 5g with the hope that they can go into cages for grow-out at this stage.

At present, cod in Europe is farmed by two methods, the capture of juvenile cod grown to market size or production of juveniles to grow-out stage. There are three systems in use for larval production which comprise nature dependent extensive to independent on-shore intensive systems. Extensive and semi-intensive were most important in the early development of Atlantic cod culture, but today there is more of a trend towards intensive production systems. However, semi-intensive methods are still in use with good results[291].

6.8.3 Technical Feasibility

In the main, intensive systems are used for production but good results have been shown by semi-intensive methods. Semi-intensive production does not provide the same amount of control or capacity as intensive production. However, juveniles produced by semi-intensive systems are stronger and do not have such a high incidence of head deformities compared with intensively produced hatched juveniles[292].

Intensive production of cod is a more reliable method of production and juveniles can be produced all year round. The system utilises

288 New Species Mariculture: Cod. British Marine FinFish Association www.bmfa.uk.com/species.htm
289 FAO, Fishstat database.
290 Voskoboinikov, 2004 Comparative Study of present situation and experience of cod in different countries Norwegian College of Fisheries Science

291 Op. Cit.
292 Op. Cit.

onshore facilities with a high degree of control. Zooplankton and algae are grown in high densities to provide food for larvae.

The condition of broodstock is important in intensive systems. At present, most broodstock originates in the wild and can spawn naturally or may be controlled by light and temperature. Many facilities house two or three different stocks of broodstock so that juveniles can be produced all year round. In Norway, research into selective breeding of strains that have better characteristics is underway. The work is investigating maturation, growth rates and disease resistance

Growth

Weaning onto formulated diets is a critical process and achieving maximum cost-effectiveness is key to a successful cod hatchery. Cod larvae are much smaller than salmon larvae are at this stage, approximately 140 times lighter, and for this reason the weaning process is more precarious. Live feed is introduced during the weaning period, which starts around day 25 and ends about day 50. Slowly, this problem is being overcome and experience gained from sea bass and seabream farming has helped to increase fingerling production in Norway.

The number of juveniles produced doubled in 2003, and production is expected to reach two to three million over the next few years. At farm level, juvenile production is temperature controlled and to promote growth is increased to 12°C post hatch[293]. Progress has been made to develop a dry feed for newly hatched cod and a survival rate of 80% has been reached using this feed in laboratory experiments. In the future, it may even be possible to do away with expensive live feeds used in production.

Growth of the liver is problematic. Contrary to salmon, energy derived from lipids accumulates in the liver and not as fat build-up in muscles. The liver has low market value, so it is more valuable if cod use energy from feed to build up muscle. In order to avoid enlarged livers the diet needs to be monitored and carefully balanced. Lipid levels should not exceed certain limits.

Cannibalism

Cannibalism at the weaning stage is problematic as larger cod will prey upon those that are smaller. It is important to ensure that larvae are fed regularly and that regular grading is carried out, approximately once every four days.[294]

Deformities

As mentioned above, intensive systems can lead to production of juveniles with head deformities. This arises as a result of a hyperinflated swim bladder during larval development which manifests as an upturned head in older fish. There are no negative impacts on the growth or the quality of the fillet.

Early Maturation

Early maturation is problematic in cod farming. In males, 30% reach maturity after 1 year and 100% after 2 years. Early maturation and spawning has a negative effect on growth as feeding is diverted into gonadal development and may stop altogether prior to spawning[295]. If photoperiod is managed maturation can be delayed until cod are 3 years old. Slow growth rates have been seen during grow out. Experience in Norway has shown it can take a 100g cod 20-24 months to grow to full market size of 3.5kg.

Escapees

At grow out stage, problems can arise as a result of net chewing and escapees. Escapee fish

293 Voskoboinikov, 2004 Comparative Study of present situation and experience of cod in different countries. Norwegian college of Fisheries Science

294 Richard Newton, Pers. Comm.

295 Cod's Big Potential, Coldwater Marine Finfish. Fish Farming International July 2003

are a particular challenge in cod farming which puts a strain on technology particularly the quality of the nets. Some cod will spawn in the cages and will disperse their genetic material regardless.

Disease

Well known fish parasites e.g. salmon lice and nematodes have not been seen in cod and infection with *Trichodina* and *Costia* can be effectively treated with formalin if they arise at the nursery stage. Bacterial infection with vibriosis has been problematic in the U.K. and Norway. Previous vaccines have been ineffective but new ones are on the horizon. The parasite *Lerneocera branchialis* which is known to be problematic in wild cod is now under investigation in Scotland. Experiments have shown it can infect farmed cod resulting in negative impacts on growth.

6.8.4 Financial Feasibility

At present, the demand and market price of North Atlantic cod is high as a result of falling fish stocks due to overfishing. North Atlantic cod are so overfished that it is predicted stocks may collapse by 2010. Recommendations from the International Convention of Exploration of the Sea (ICES) advise that all cod fisheries in the North Atlantic stop fishing, including fisheries that catch cod as by-catch[296].

Production in cod farming is on the increase but at present there is an imbalance in the value chain. The production of fingerlings has increased but the number of grow out facilities has not, limiting the demand for fingerlings. It appears that there is a lack of capital to fund the grow-out sector. This is particularly evident in Norway. Forecasted production figures for cod juveniles are 70-80 million per year, but it is unlikely full capacity utilisation will be achieved due to a lack of investment capital to develop grow out facilities[297]. Large scale fingerling production is possible and to date only some biological or technical obstacles have been seen, however there are some operational difficulties. Up-scaling of operations along with optimisation of various aspects of production will be necessary to provide juveniles for grow-out at a reasonable price.

As production prices are high, cod must target the high end of the market, particularly when the industry is on the development side. High quality production of standard size will be needed to supply the high end of the market. The high end of the cod market includes fresh gutted cod for restaurants and supermarkets, fresh fillets to consumer markets, and fresh fillets and loins as convenience packs.

Present demands on capital and technology are high and operations need to be large to achieve profitability. Annual production needs to be at least 2-4,000 t to be profitable, with an optimum of 20,000 – 30,000 t. Only then will capital investment pay off. The Norwegians are considering increasing the levy on cod for export to bring more money into the industry in order to give it a needed boost.[298]

6.8.5 Market challenges

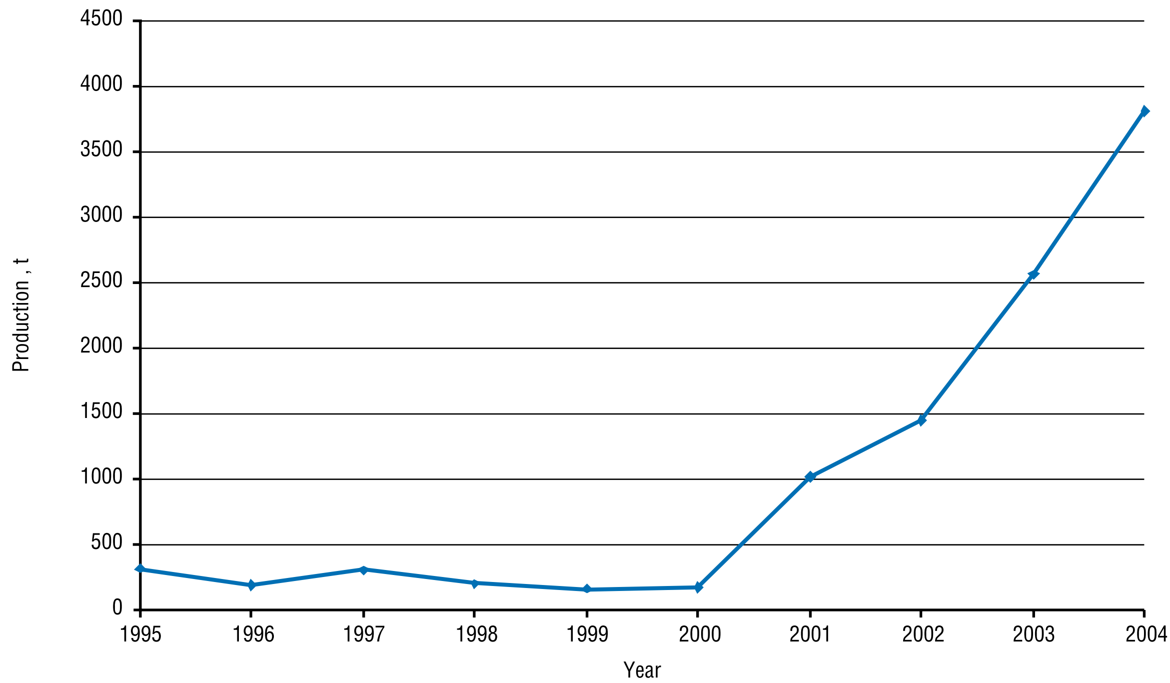
As the cod industry is able to utilise most of the technology developed for salmon, the industry is expected to expand relatively quickly. In addition, there is a developed market for cod, so a demand for the product will not have to be developed. Norwegian cod are available whole with or without the head on. A gutted cod with its head on is available in size classes 1-3kg and 3-5kg. Gutted cod without the head available in weight class 2-4kg and 4-6kg. Whole fillets with skin pin on the pin bone are available on request.

296 Voskoboinikov, 2004 Comparative Study of present situation and experience of cod in different countries Norwegian College of Fisheries Science

297 Cod's Big Potential, Coldwater Marine Finfish. Fish Farming International July 2003.

298 Can Aquaculture Solve Supply Problems? www.globefish.org/index

Figure 6.13 Atlantic cod – global production trend



Estimates made predict that present low production volumes will be maintained over the next few years, so no dramatic price cuts should occur. The Norwegian government invest nearly a million NOK per year on market analysis in order to avoid overproduction or other problems that have been experienced in the salmon industry.

As a result of overfishing many of the fishing communities of the North Atlantic coast have been destroyed. Some now classify cod as a threatened species and are taking action against the consumption of cod. A small number of restaurants have removed cod from their menu. In this case effective marketing and dialogue with the consumer will be required to improve the image of farmed cod.

6.8.6 Prospects

In order to continue growth in the sector, there is a need to secure long-term private and public investment that is independent of trends in the market. The size and quality of fish reaching the market will need to be standardised to maximise international trading potential. Although able to adapt technology developed for salmon farming, this developing industry will need to compete for many of the same sites and will need to address market concerns regarding disease and environmental issues experienced in the salmon industry. Additional technical issues relating to juvenile mortality and early maturation will need to be overcome.

Given current demand for cod the industry should have a head start in the market, but will need to remain cautious not to suffer from overproduction experienced in the salmon industry. The focus on organic production offers significant hope of maintaining suitable margins.

6.9 Arctic charr

6.9.1 Introduction

Arctic charr are slowly emerging as an attractive fish for aquaculture, as they can be positioned as a premium product but can be

Figure 6.14 Arctic charr (Salvelinus alpinus)[299]

grown at high densities due to their natural schooling behaviour. However, the industry is still very small and markets relatively undeveloped. Technical constraints to current production include limited fry and egg supply from a limited number of strains. Strain selection is critical as growth rate in many strains is very poor.

6.9.2 European overview

Research for this report has revealed differences from the FAO data shown in the table above. Arctic charr production is emerging in Sweden, with more than 10 farms producing around 500 tonnes per year, all for domestic consumption. Charr are also produced in Finland and Ireland, in recirculation systems. In Finland, one farm alone has been producing the country's domestically consumed total of 300 tonnes per year since 2004, with a value of €2.4 million. In Ireland, less than 50 tonnes of charr are being produced, with approximately 75% of this being exported. In the UK, there are five farms producing Arctic charr on eight sites. Production in 2004 was 3.25 tonnes, and estimated production for 2005 was 10.5 tonnes[301]. This includes production for both the table market and for angling restocking.

6.9.3 Technical feasibility

A significant genetic resource exists for the development of improved strains, with many isolated natural stocks available throughout the cooler regions of Europe. Arctic charr is a salmonid species with similar characteristics to the other cultured salmonids with the exception that it prefers lower temperature ranges. Unlike other salmonids, it is a shoaling species which gives the potential for culture at much higher stocking densities. Indeed, charr performance is much better at high densities with respect to growth and condition. Whereas species such as rainbow trout may exhibit aggressive behaviour at high densities, the converse is true of arctic charr. Growth rates and quality improve markedly with densities up to 40 kg/m^3 and steadily up to 70 kg/m^3. Densities below 40kg/m^3 are detrimental to growth. Reports of charr feeding behaviour from an existing charr

Table 6.10 Global production of Arctic charr[300]

	2000	2001	2002	2003	2004
Austria	2		1		10
Denmark			42		
France	36	36			
Iceland	927	1318	1479	1664	1338
Ireland	63	35			
United Kingdom		4	7	7	3
United States of America	65	75	44	40	38
TOTAL	1093	1468	1573	1711	1389

299 Maretarium www.maretarium.fi/mare/4_7_fi.php
300 FAO

301 Scottish Fish Farms Annual Production Survey 2004, Fisheries Research Services Marine Laboratory, SEERAD.

Figure 6.15 Norwegian farmed charr in a fish tank[302]

farm in the UK has suggested a large amount of feeding from the bottom of ponds or tanks. This suggests that nets with solid or fine mesh bases would be more suitable that would allow the fish to feed on pellets that settle at the bottom. This type of net is commonly used for rearing certain types of flat fish such as turbot and may have the advantage that there is less waste deposited under the cages.

6.9.4 Financial feasibility

Analysis of cage production in freshwater indicates significant returns on investment, providing technical and market difficulties can be overcome. For production of 200 tonnes per annum, investment of around £400,000 is required, with similar levels of operating costs. Potential revenue from sales could be as high as £900,000.

The following financial model and analysis are for a UK Arctic charr farm. As charr farming in the UK is a relatively new venture with a certain amount of risk involved, some aspects of the analysis have to be estimated. For example the loss due to normal mortality has been estimated at 10% per year (double that for rainbow trout). Also the market price for whole charr may be subject to substantial variation, although it is likely that the product will fetch a substantially higher price than rainbow trout can. Examination of FAO value data[303] suggests national average prices of between US$ 4 and $8.65/kg in 2004 with an average of US$ 7.03 (€5.49/kg). The Federation of European Aquaculture Producers[304] show average prices for Arctic charr ranging from €4.46/kg (1998) to €5.28/kg (2000) to €5.10/kg (2005). An Icelandic manual on Arctic charr[305] published in 2004 suggests Icelandic prices of Icel. Kr 380–500 (€4.25 - €5.60) for gutted fish and Kr 600–900 (€6.72 – €10.07) for fillets. The same publication quotes Canadian prices as between $4.50 and $5/lb (€6.04–€6.72/kg). However, these prices should perhaps be seen in the context of salmon prices, which were around €2.22 to €2.96/kg between 2003 and 2004. Charr has been reported to fetch £4.75/kg (€7.04/kg) in the UK, probably due to the low levels of supply compared to Europe.

302 The Charr Network. www.charnet.org/charrnet/template/page%2CViewPage.vm?id=4165

303 Fishstat database www.fao.org/fi/default.asp

304 Federation of European Aquaculture Producers www.feap.info/Production/euproduction/pricespecieseu_en.asp

305 http://holar.is/~aquafarmer/

Table 6.11 Arctic charr ongrowing 10 year cash flow

Assumptions

Prod.rate (t/yr)	Fish value (EUR/t)*	Feed (EUR/t)	F.C.R.
200	7040	731	1.1

**This value is likely to be lower in Europe where there is a greater supply of charr.*

Model

10yr cash flow	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10
RECEIPTS ('000 €)										
Cash sales	0	1,126	1,126	1,126	1,126	1,126	1,126	1,126	1,126	1,126
From debtors	0	0	282	282	282	282	282	282	282	282
TOTAL RECEIPTS	0	1,126	1,408	1,408	1,408	1,408	1,408	1,408	1,408	1,408
PAYMENTS ('000 €)										
Working capital costs	445	445	445	445	445	445	445	445	445	445
Capital expenditure	628	0	0	0	0	0	0	0	0	0
TOTAL PAYMENTS	1,073	445	445	445	445	445	445	445	445	445
NET INFLOW/OUTFLOW	-1,073	682	963	963	963	963	963	963	963	963
Bank balance brought forward	0	-1,073	-391	572	1,535	2,498	3,462	4,425	5,388	6,351
Bank balance at end	-1,073	-391	572	1,535	2,498	3,462	4,425	5,388	6,351	7,315
IRR (%)	77.8									

Breakdown of operating costs	Annual costs '000 EUR/yr	% of total
Fish feed	217	43
Wages	95	19
Fingerlings	106	21
Stock insurance	12	2
Electricity	7	1
Fuel	7	1
Depreciation	63	12
Total operating costs	508	100
Cost/kg	2.54	
NB excludes finance costs		

Capital costs	Cost ('000 EUR)
Cages (inc nets)	267
cage moorings	44
water pumps	2
Fish pumps	22
Sterner 50L hopper	4
Sterner 50L spreader	20
grader	18
counters	37
pipes	0.4
Pickups	44
trailers	7
boats (small)	12
jetties	9
storage sheds	1
treating tarpaulin	10
hand nets etc	3
anti predator nets	2
underwater cameras	2
monitors	0.1
hand tools	1
pressure washer	1
net drying frame	15
generator	1
office	22
EIAs etc	22
Total capital cost	571
Contingency(10%)	57
Capital costs inc. contingency	628
Annual depreciation (10yr av life)	63

Sensitivity analysis – Arctic charr

System	IRR (%)	Max funding (€)	Payback time (years)
Base model (see 6.9.3.1 above)	77.8	1,072,951	3
+20% sale price	100	1,072,951	3
Fish sale price in Europe in 2005 (€5.10/kg) (-28%)	45.8	1,072,951	4
+20% feed cost	71.3	1,116,303	3
-20% feed cost	84.8	1,029,599	3

6.9.5 Environmental impacts

The environmental impacts of farming Arctic charr are likely to be similar to those of farming salmon in cages or trout in tanks or ponds. However, as stocking densities are normally higher, the waste output per unit volume (or area) may be higher. This could have implications for freshwater cage sites with low currents.

6.9.6 Prospects

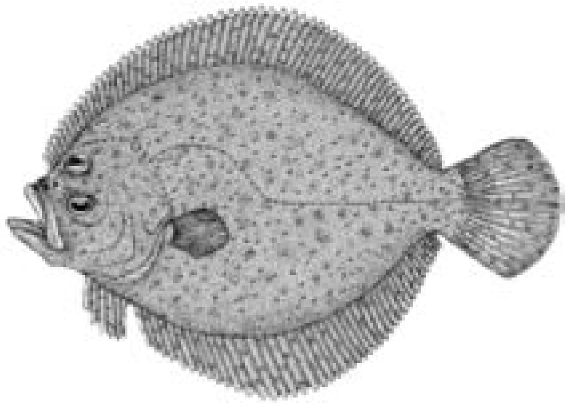
There is a low level of production in Europe at present with a high market price. The market is currently small, but it is generally preferred over salmon and trout. There is a limited supply of vigorous juveniles - especially in the UK. Concerns over interaction with individual wild stocks (as has been seen in other European countries) mean that the UK is not very keen on allowing faster growing strains into the country. If the juvenile supply problem could be overcome, and a greater number of environmentally appropriate sites (even with endemic populations) opened up, the industry could expand, but at present expansion will remain limited.

6.10 Turbot

6.10.1 Introduction

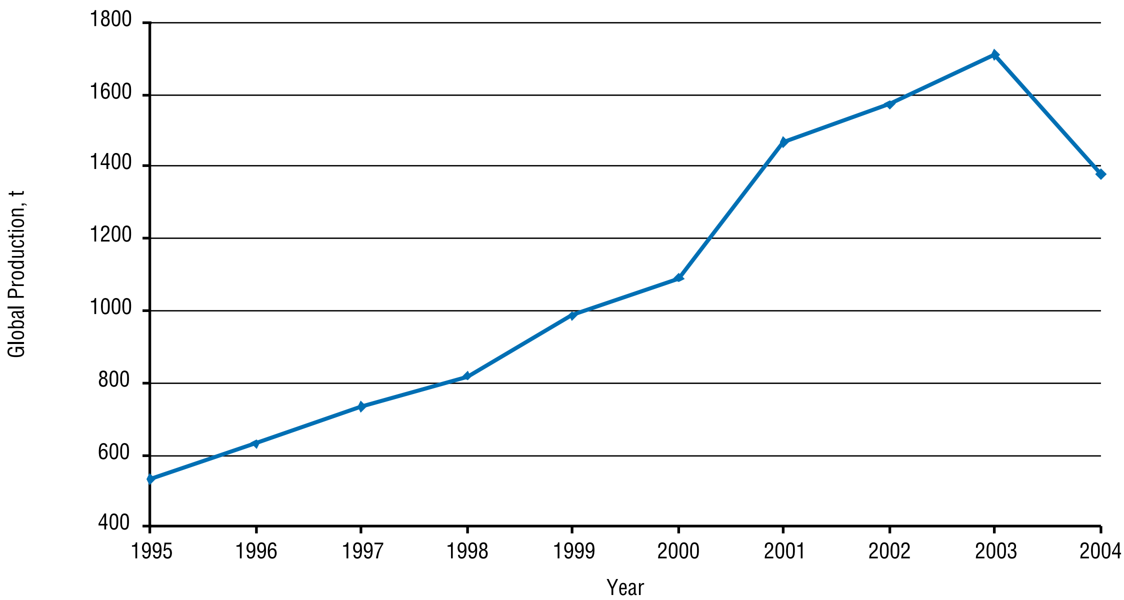
Turbot (*psetta maxima*) is a benthic marine species, found living in shallow water to 100 m depths, inhabiting sandy, muddy bottoms where it can camouflage itself by mimicking the colour of the substrate.

Figure 6.17 Psetta maxima Linnaeus, 1758 Scophthalmidae[306]



306 Cultured Aquatic Species Information Programme Psetta maxima www.fao.org/figis/servelet/static

Figure 6.16 Arctic charr - global production trends



Turbot is a flatfish with an asymmetric round scaleless body with its eyes located on the left side. The larvae are initially symmetric with a swim bladder but as metamorphosis progresses the swim bladder is lost and the right eye moves round to the left, giving rise to asymmetry. A fecund species, each female produces hundreds of thousands of eggs per spawning (3mm diameter approximately). Spawning takes place between February and April in the Mediterranean, and May to June in the Atlantic. Throughout their lifecycle they are carnivorous fish feeding on molluscs and crustaceans as juveniles, and cephalopods and fish as adults[307].

6.10.2 The production cycle

Post hatch larvae are approximately 3mm in length and may be cultured in intensive or semi intensive production systems. Both types of system use temperatures of 16 - 18°C. Newly hatched larvae feed on their yolk sac until they are introduced to live feeds, *Artemia* and rotifers. At weaning stage, formulated dry feeds are introduced either automatically of manually. Aeration systems are usually required to maintain oxygen saturation in nursery tanks. Nursery stage can last from 4-6 months[308].

On-growing facilities comprise either on-shore tanks or flat bottomed cages. On-shore tank facilities are the most commonly used. Few sites appear to provide the optimum conditions for use of cages and this form of production system is still at an experimental phase. Extruded pellets are fed either automatically or manually in grow out systems. Temperature and fry quality are important elements of production. Commercial feeds cost around €900/per tonne, and a typical FCR is 1.1-1.2. On-growing production costs are approximately €5-6/kg in tanks and €5/kg in cages. A 1.5 – 2 kg fish is produced at the end of a two year cycle.

6.10.3 European Overview

Farming of turbot originated in Scotland in the 1970s and was closely followed by France, Spain and Norway. Over the last two decades, production of hatchery reared juvenile turbot has rapidly increased mainly due to improvements in hatchery techniques for large scale rearing of turbot fry[309]. In 1984, 4 t were produced with an increase to 5,000 t in 2004. At present, turbot production takes place in Scotland, France, Spain, Germany, Denmark, Ireland, the Netherlands and Portugal.

The main production centres are in Southern Europe, especially Spain, due to more suitable sea temperatures. However, investment in recirculated turbot systems in Northern Europe is continuing with mixed commercial success. Other technological improvements include feeds development and vaccines to combat disease. Most of the turbot produced in the EU is domestically consumed. The fish are generally sold whole, however in some countries the product is gutted and before sale. The sector is not subject to any specific regulations, other than those covering all fish products. Gradual expansion of turbot production throughout Europe is predicted in the future.

France

In 2004, France produced 969 t of turbot and consumed 3,000 t turbot, mostly imported from Spain. It is also the world's leader for production of juvenile turbot most of which is exported to china. A proportion of French production is exported live. Otherwise, production is sold as whole or gutted fish and is domestically consumed.

307 Cultured Aquatic Species Information Programme *Psetta maxima* www.fao.org/figis/servelet/static
308 Turbot www.ifremer.fr/aquaculture/en/fish/turbot_en.htm

309 J. P. Coughlan, A. K. Imsland, P. T. Galvin, R. D. Fitzgerald,, G. Naevdal, and T. F. Cross (1998). Microsatellite DNA variation in wild populations and farmed strains of turbot from Ireland and Norway: a preliminary study. Journal of Fish Biology Volume 52 Page 916

Figure 6.18 Production cycle for turbot (*Psetta maxima*)[310]

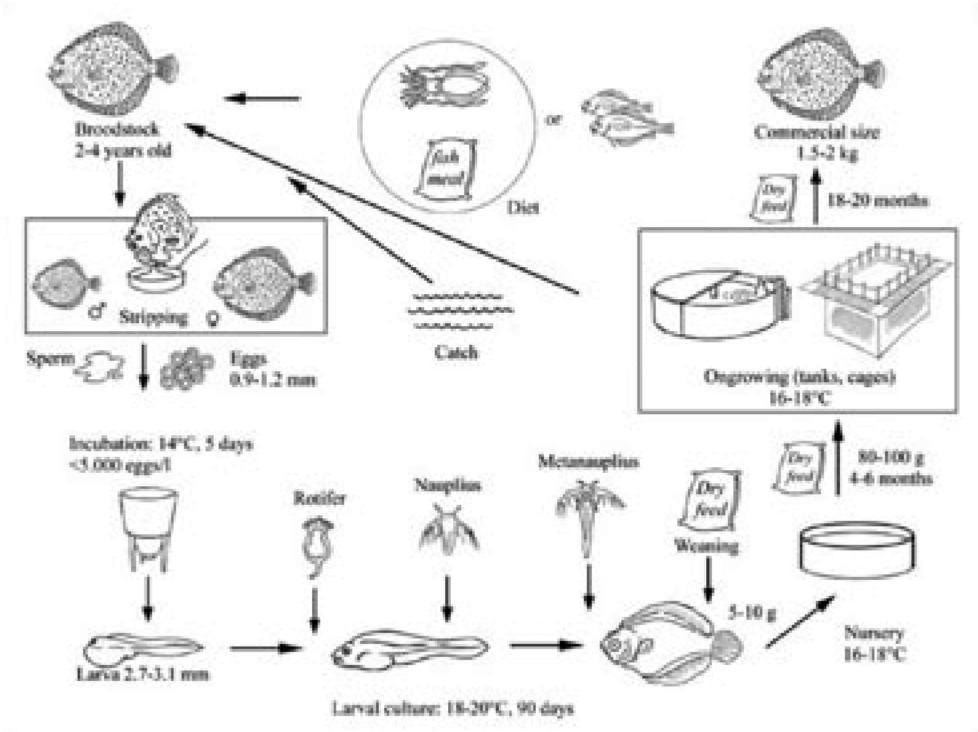


Figure 6.19 The main producers of turbot across the EU[311]

310 Cultured Aquatic Species Information Programme *Psetta maxima* www.fao.org/figis/servelet/static
311 Cultured Aquatic Species Information Programme *Psetta maxima* www.fao.org/figis/servelet/static

Spain

Worldwide, Spain is the largest producer of turbot and in 2004 produced 4,477 t. The waters, temperatures, environment and the local inhabitants have all made Spain, particularly Galicia an ideal location for the production of turbot. Stolt Sea Farm S.A. is the world's leading producer of farmed turbot. The company produces 1 million juveniles out of two hatcheries in Galicia, which in turn supply 5 grow out facilities in the region. Stolt Sea Farm S.A. is also the leader in a group of two other companies in France and Portugal[312].

Fish is either sold fresh, rounded or gutted. However, other presentations can be catered for. In the case of the EU, Spain has started to sell filleted turbot to satisfy market demand. Large fish can be filleted and sold in vacuum packs and demand is increasing for portions of turbot ranging in size from 500-750g[313].

Ireland

Ireland had one commercial turbot operation Turbard Iarthar Chonamara Teo (TIC Teo) which operated a reciculation system in County Galway. Údarás na Gaeltachta and BIM worked in close co-operation with TIC Teo, which expanded from its pilot phase in 2000 to full scale production, with a reported harvest of 50 tonnes of turbot in 2003 valued at approximately €400,000. With the addition of a new water treatment system in 2004, turbot production was expected to rise to 300 tonnes at a value of €2.5 million by 2009. Unfortunately the farm suffered a major system failure and went into liquidation in early 2005.

While Irish water temperatures are suitable for turbot farming cooler winter temperatures slow-down growth rates placing production at a competitive disadvantage. Production by a recirculation system helps to alleviate this problem with the added advantage of much reduced energy cost as the water is reused[315].

Portugal

The culture of turbot is relatively new in Portugal. All turbot production takes place on land based systems and the majority is operated by Stolt Sea Farm S.A.

Germany

One hatchery and cage farm producing turbot

The Netherlands

At present, there is no marine aquaculture operating out of Dutch coastal waters. Seafarm BV is the only company culturing turbot and is a land based operation. Turbot are raised from fry to market size. Fry are exported in from other European countries. Live fish are supplied to markets in China and Japan.

Table 6.12 Stolt Sea Farm S.A. production by country, system and output [314]

Country	System	Production (t)
Spain	Land based flow through	3,200
Portugal	Land based flow through	200
France	Land based flow through	200

312 www.stoltseafarm.com/products_turbot.php
313 Turbot www.ifremer.fr/aquaculture/en/fish/turbot_en.htm
314 www.stoltseafarm.com
315 Ireland's only Commercial Turbot farm to reach €2.5 Million Production by 2009 www.bim.ie

Denmark

Technology for turbot production in Denmark is well developed, particularly production of fry. In 2003, 500,000 fry were produced for export.

U.K.

One operation produces turbot in the U.K. with a yearly harvest of up to 250 tonnes. Fish are reared in a recirculation system. Production costs per kg are £3 with farm gate price ranging from £4-6, depending on the type of market. The company are currently building a larger farm with a capacity up to 1000 t. A second commercial turbot farm is also under construction. There have been at least three previous turbot farms in the UK, of which two were recirculated and one used the warmed effluent of a nuclear power station.

Figure 6.20 Turbot - global production trends)

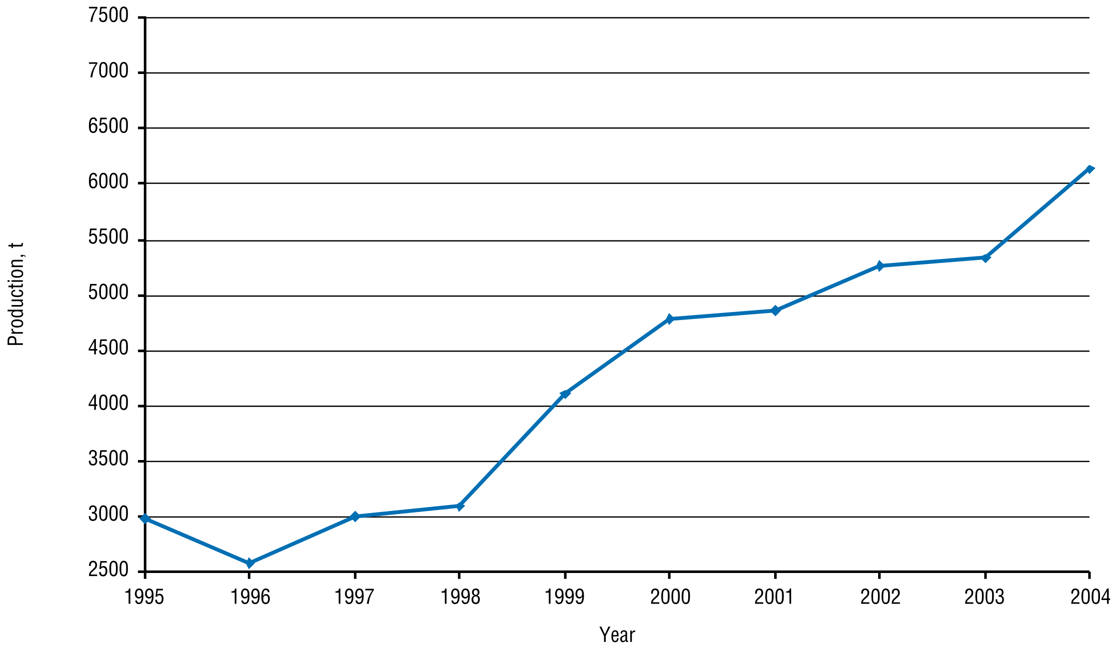
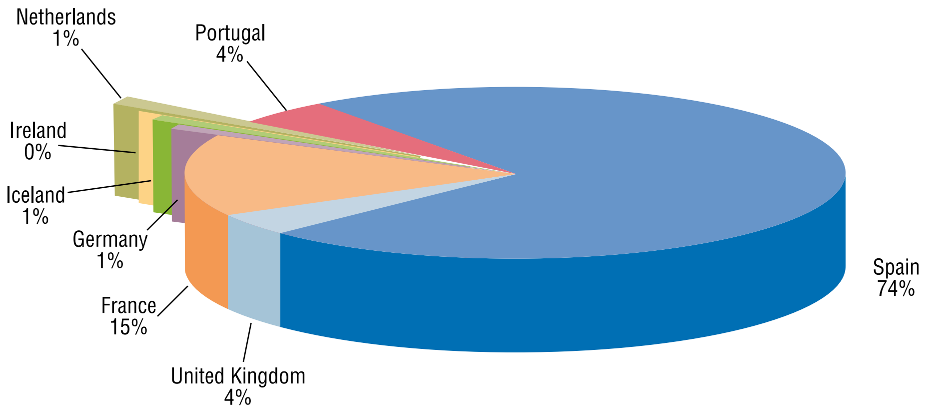


Figure 6.21 Turbot - global production by country, 2004 [316]



316 FAOSTAT 2004

6.10.4 Technical Feasibility

Turbot can be considered a mature technology seeing development of practices since the 1970s. During this time major developments were made to improve larval rearing and weaning, artificial seasonal and non seasonal breeding techniques, development of extruded feeds suitable for pond and cage fattening.

Females grow better than males and reach sexual maturity at 3 years of age and are capable of laying eggs in captivity. By regulating temperature and photoperiod offset egg laying can be achieved all year round. Turbot farming can be difficult with high mortality rates and problems with pigmentation. The production cycle duration is long and can be complicated by temperature modulation and the use of monosex females. Present technical research development goals involve genetic investigations looking at the effects of rearing on genetic variability and growth rates; behavioural considerations relating to water quality and nutrition (flesh quality).

Immunisation technology is developing providing protection against a number of bacterial diseases experienced in the culture of turbot.

6.10.5 Financial Feasibility

See sections 3.6.1 and 3.6.2 for turbot recirculation farm and turbot flow-through farm costings.

6.10.6 Market Challenges

Turbot have a good international reputation from Europe to Asia, mainly inhabiting domestic markets with potential for the luxury end of the market

6.10.7 Prospects

The sector is predicted to experience marked expansion in the future. Existing site capacity will increase along with construction of new rearing and hatchery facilities. The culture of turbot in cages is its pilot stage but could develop further depending on site availability. Turbot are a species well suited to high stocking densities and domestication.

Continued research and development is necessary to facilitate this expansion. Important areas of improvement include[317]

- Increasing larval survival rates
- Improving culture systems and automation
- Genetic management and improvement
- Health management and disease control
- Marketing
- Technical training for staff

6.11 Halibut Production

6.11.1 Introduction

The Atlantic Halibut is distributed throughout the Northern Atlantic, most commonly in the colder reaches around Greenland to Norway but as far south as the Bay of Biscay. They are a long lived species with individuals commonly reaching 50kg or more.

6.11.2 European Overview

The vast majority of Halibut farming currently takes place in Norway. Although the UK and Iceland have tried to operate halibut farms, they have not had the same success. UK production seems to have remained steady over the past few years, whereas Icelandic production has declined. Norwegian production continues to increase, probably because much of the juvenile production is situated there.

317 Turbot www.ifremer.fr/aquaculture/en/fish/turbot_en.htm

Figure 6.22 Atlantic halibut

Erling Svenson

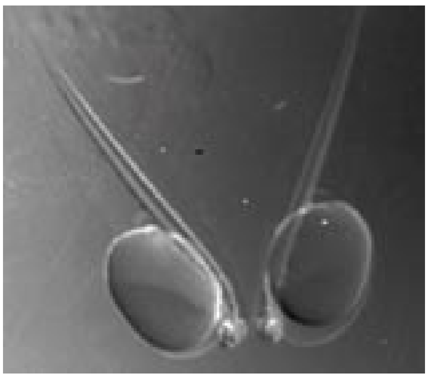
6.11.3 Technical Feasibility

The life cycle (and therefore the farming) of halibut is similar to that of cod, although there is a longer yolk sac period for halibut. This potentially makes their farming even more complicated. Another major difference is that halibut will not breed naturally in captivity but need to have their eggs and milt stripped manually like salmonids. Once the gametes are mixed, the fertilisation can be triggered by the addition of sea water where upon the fertilised eggs are incubated in darkness at around 6°C. Alevins hatch at around 2 weeks and spend another month feeding upon their yolk sacs until they are ready to go on to live feeds consisting of enriched artemia nauplii. Soon after this metamorphosis takes place and the halibut take on their characteristic flatfish appearance. Temperature can then gradually be set to ambient and it is then that they can be weaned onto dry diets. Post weaning the fish become much more robust and less sensitive to change, before this time, conditions should be kept as constant as possible. Mortality rates are currently very high and it is common to have only 2% survival up to this stage. It is only the large fecundity of the fish that makes the production of juveniles feasible although only a small increase in survival would probably make hatcheries very profitable. Juveniles should be grown to approximately 40g before transfer to sea cage sites. This takes around ten months.

Once transferred to the sea, good growth rates can be achieved. Cages need to be different to salmon or cod cages in that the bottom of the nets need to be solid to allow the halibut to rest, reflecting their flat fish behaviour. Halibut have no swim bladder and therefore no need to go to the surface so would make a good candidate species for offshore submersible cages because of this. They can also be susceptible to sunburn. This problem can be solved in surface cages by using top covers.

It is estimated that halibut will reach market size in about 2 to 4 years depending on the target

Figure 6.23 Atlantic halibut larvae



Institute of the Biology of the Southern Seas NAS of Ukraine size, between 3 and 10 kg and will achieve an FCR of around 1.1. They provide a good flesh yield at about 50%.

6.11.4 Financial Feasibility

Problems with halibut culture are most evident with regards to juvenile production and costly slaughter methods. Recently a major British producer of juveniles has consolidated its production by moving it all to Norway, resulting in the closure of 3 UK hatcheries. There also needs to be some more conclusive work on disease threats and vaccine production. However despite the problems associated with halibut farming, the farm gate market price provides the opportunity for good profits.

6.11.5 Environmental Impacts

The ongrowing of halibut is carried out in sea cages, similar to salmon with the exception that halibut uses solid bottom nets in the pens. The waste produced from halibut should therefore

Table 6.13 European Union and Norway production of halibut (tonnes)

	2001	2003	2004	2005
Norway			631	
UK	80	187	187	1,173
Iceland	93	120	95	

Table 6.14 Financial model for halibut

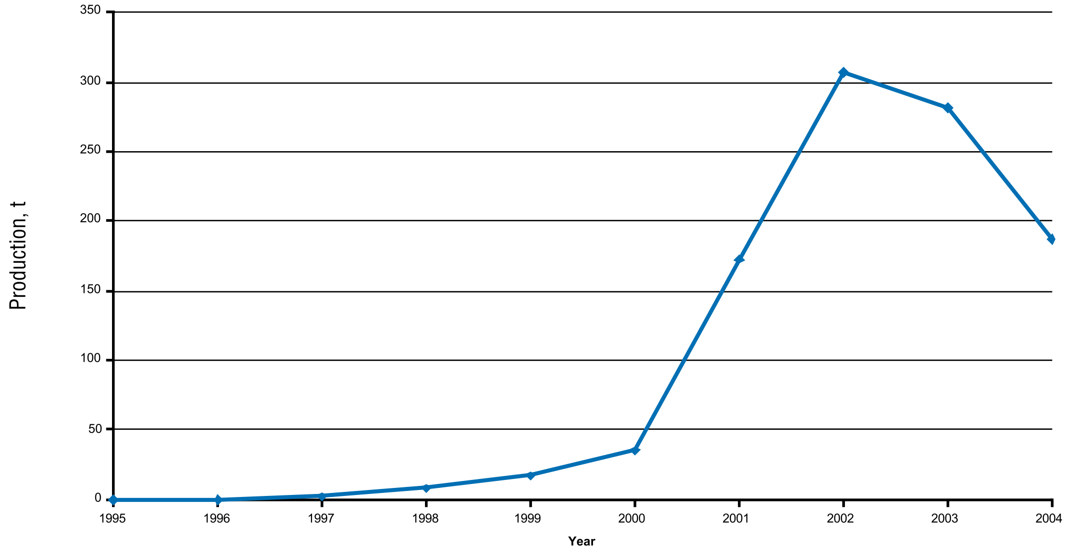
Key assumptions

Production rate (t/yr)	Fish value (€/t)*	Feed (€/t)	F.C.R.
1000	12,000	1400	1.1

Financial model

10yr cash flow										
year	1	2	3	4	5	6	7	8	9	10
(Euro '000)										
Income from sales	0	0	0	0	12,158	12,158	12,158	12,158	12,158	12,158
bank interest		0	0	0	0	0	55,925	406	770	1,149
total income	0	0	0	0	12,158	12,158	12,214	12,564	12,929	13,307
capital costs	3,531	0	0	0	0	0	0	0	0	0
operating costs	1,529	1,822	1,822	1,822	1,822	1,822	1,822	1,822	1,822	1,822
bank loan interest	918	1,278	1638	1,638	1,638	1,638	1,638	1,638	1,638	1,638
total costs	5,978	3,100	3,460	3,460	3,460	3,460	3,460	3,460	3,460	3,460
Profit	-5,978	-3,100	- 3,460	- 3,460	8,698	8,698	8,754	9,104	9,468	9,847
Profit Surplus	- 4,555	- 1,316	-1,316	- 1,316	10,841	10,841	10,841	10,841	10,841	10,841
Bank balance start	0.00	- 5,978	-9,078	-12,538	-15,999	-7,300	1,398	10,152	19,257	28,726
Bank balance fin	- 5,978	- 9,078	-12,538	-15,999	-7,300	1,398	10,152	19,257	28,726	38,573
IRR	47%									
NPV 10%	25,132		profit after bank loans		10,336					

Figure 6.24 Atlantic halibut - global production trends



be less. Halibut are not susceptible to sea lice in the same way as Salmonids are and wild halibut are unlikely to congregate near pens like wild Salmonids do before they migrate up river, therefore, the risk of disease spreading between populations is much less. Also the risk of adverse effects from farmed and wild populations breeding is likely to be less of a problem because of the sensitivities of gene pools associated with salmon populations.

6.11.6 Prospects

Despite the closure of several UK hatcheries, overall European prospects remain good. The main constraint to development is the reliable supply of juveniles for ongrowing. Norway has cornered the market with respect to juvenile production and it is possible that much of the ongrowing will stay there whilst juvenile availability remains low.

6.12 Sturgeon production

6.12.1 Introduction

Sturgeon have traditionally been a high value capture species for production of caviar,

Figure 6.25 Sturgeon

Rob & Ann Simpson, Stone Museum of Geology

mostly originating from the Caspian Sea. Their numbers have been in decline since the 1980s suffering badly from over fishing, pollution and habitat destruction to the point of collapse, exacerbated by the breakdown of the former Soviet Union which led to widespread poaching. This consequently led to a rise in the price of caviar and potential for sturgeon farming. Several species of sturgeon occur, the most famous probably being Baluga, however, for aquaculture, the most important species are the white sturgeon, *Acipenser transmontanus* and the Siberian sturgeon, *Acipenser baeri*.

6.12.2 European Overview

Currently, France and Italy are the largest producers of farmed caviar in Europe but other countries are also beginning production, especially in Eastern Europe and Germany. The USA and Uruguay are also developing as major producers and Bulgaria, Canada, China, Israel and the UAE have fledgling operations under development.

6.12.3 Technical Feasibility

Despite sturgeon being semi-anadromous, culture may be possible purely in freshwater systems. On-growing can be done in tanks, raceways, ponds or cages, using flow-through or recirculation technologies. Ponds will most likely suit the sturgeon's predominantly benthic lifestyle better, although much higher stocking densities can be achieved in tanks and raceways with oxygenation. Stocking densities in ponds is in the region of 5kg m^{-3} whereas in tanks or raceways, stocking densities of around 30-40 kg m^{-3} may be achieved. Sturgeon are very long lived fish and in the cold waters of their natural habitat, sexual maturity may not occur until they are 15 years old or more. In culture scenarios, this is much less at about 6 years. This has implications for culture in that the major income from caviar will not be realised until this time. Some supplementary income may be achieved from sales of sturgeon meat from male fish before then but will be small when compared to that which may come from caviar sales. Also, female sturgeon do not come into season every year, but on average every 2 years with approximately 35 to 65% of stock having eggs in any one year. The culture system therefore needs to employ good standards of biosecurity and cleanliness that will promote a long and healthy life for the fish. When fish are stressed, usually one of the first biological systems to suffer is the reproductive system, meaning a reduced yield of caviar. However, apart from a viral disease that affects white sturgeon, there have been few significant health issues affecting sturgeon species to date. They also have generally, a high tolerance of low oxygen levels and a high temperature tolerance, although this may be growth retarding.

Figure 6.26 Caviar

Temperature control of broodstock means that eggs can be produced from December to May for the production of juveniles. This can be done using the usual stripping method for salmonids, however an injection of the gonadotropin releasing hormone analogue (GnRHa) is usually required prior to egg stripping. Production of caviar however requires the removal of ovaries and therefore the death of the fish. The yield of caviar is in the region of 8 to 15% of the female's body weight.

Eggs must be treated with an anti-adhesive agent prior to incubation to stop them from clumping together. This is either milk or an aqueous clay suspension. Development is quick with hatching occurring after about six days at 14°C and subsequent first feeding after another twelve days. There maybe some abnormalities, with normal larvae showing positive phototropism but survival is generally good. Feeding is currently with a standard trout diet, which generally gives good results, although there have been reports of scoliosis (spinal deformities) which has increased pressure towards the development of a specialised sturgeon diet.

At harvesting, female selection is considered to be the most important factor. Once selected, the female is stunned to kill it, gutted, the ovaries are removed, cooled, rinsed salted, drained and then canned. The meat may then be sold on also.

6.12.4 Financial Feasibility

There is still a lack of confidence in the market, despite the high prices of caviar, partly due to the collapse of the Caspian Sea stocks not being anticipated fully but also lack of confidence in the farming procedures and perceived low profitability, probably due to the large time scales involved and difficulty in assessing the yield of caviar from female sturgeon. Given the time taken for female sturgeon to reach maturity and the general slow growth, an investor may not see any sales returns until the end of the fifth year or more in some cases. However, since the product currently fetches such large premiums, a well established farm may make very good profits. The United Arab Emirates and China are both establishing sturgeon farms on very large scales and this may subsequently bring down the price of farmed caviar. Assessment of the caviars ripeness is performed either by biopsy or by ultrasound in some cases. There may also be some elitism over the quality of farmed caviar compared to the wild. Prices of sturgeon caviar remain high, however, with one London retailer selling premium caviar at about €320 (£195) for 50g, one US sturgeon farmer with European links selling at €110 for 50g and a retailer of Italian farmed caviar selling at about €80 for 30g.

Table 6.15 Financial model for sturgeon

10 year cash flow, 1000's of Euros

10yr cash flow										
year	1	2	3	4	5	6	7	8	9	10
	0	0	0	145	8545	8545	8545	8545	8545	8545
bank interest	0	0	0	0	0	205	529	866	1217	1582
total income	0	0	0	145	8545	8750	9074	9411	9762	10126
capital costs	271	451	0	0	0	0	0	0	0	0
operating costs	240	331	331	331	331	331	331	331	331	331
bank loan interest	92	248	314	314	314	314	314	314	314	314
total costs	602	1030	645	645	645	645	645	645	645	645
Profit	-602	-1030	-645	-500	7900	8105	8429	8766	9117	9481
Profit Surplus	-471	-743	-292	-147	8253	8253	8253	8253	8253	8253
Bank balance start	0	-602	-1632	-2277	-2777	5123	13227	21656	30422	39539
Bank balance fin	-602	-1632	-2277	-2777	5123	13227	21656	30422	39539	49020
IRR	104%									
NPV 10%	23187									

Operating costs

	no.	cost per unit, €	total, €
Labour			
Manager	1	40000	40000
stockworkers	2	18500	37000
secretary	1	18500	18500
Feed, t			
year1	12.71	1776	22566.69
year2	59.63	1776	105895.13
year3	142.76772	1776	253555.48
year4+	231.49306	1776	411131.68
fingerlings	31032	1.5	46548.00
Miscellaneous			
insurance	100.00	40	4000
electricity	1	5000	5000
fuel	1	5000	5000
depreciation	1	39114.17	39114.17
total yr1 + 10%			€ 239,501.74
total yr2 +10%			€ 331,163.02
Total yr3 +10%			€ 493,589.41
total yr4 +10%			€ 666,923.23
Cost per kg, meat			€ 6.67
Cost per kg, caviar			€ 66.69

Capital costs

Equipment	no. units	cost unit, €	total, €
Nursery	10	2500	25000
Grow out	48	10000	480000
water pumps	2	1000	2000
Fish pumps	1	15000	15000
grader	1	14000	14000
counters	5	5000	25000
pipes	50	10	500
Pickups	2	20000	40000
trailers	2	3500	7000
storage sheds	1	2500	2500
seine net	2	5000	10000
hand nets etc	5	40	200
anti predator nets	10	200	2000
hand tools	1	1000	1000
pressure washer	1	1000	1000

Equipment	no. units	cost unit, €	total, €
generator	1	850	850
office	1	15000	15000
EIAs etc	1	15000	15000
	1st yr+ 10%		€ 270,655.00
	2nd yr + 10%		€ 451,000.00
	Total		€ 721,655.00

Sensitivity analysis

	IRR%	Max funding, €€	Pay back, years
base case	105	598	5
-95% caviar price	19	598	>10
-90% caviar price	31	598	8
-80% caviar price	47	598	6
-60% caviar price	68	598	5
-40% caviar price	83	598	5
-20% caviar price	95	598	5
+20% caviar price	114	598	5
-20% feed cost	106	592	5
+20% feed cost	104	602	5

6.12.5 Environmental impacts

The environmental impact of sturgeon farming will depend on the culture system employed. There is no reason to suggest that sturgeon farming in ponds should be any more or less environmentally damaging than trout farming except that sturgeon may allow for higher stocking densities. This applies to any other culture system that may be used.

6.12.6 Prospects

The growing of sturgeon for the production of caviar remains a niche market and is unlikely to grow to similar scales of more staple food

Table 6.16 Sturgeon Meat and Caviar Production, (tonnes)

	2003		2004		2005	
	Caviar	Meat	Caviar	Meat	Caviar	Meat
France	7	350			20	
Poland		180				
Germany	2	120			3.5	
Italy		100			20	
Belgium and Netherlands	2	20			21	
Spain	0.4	6			2.5	
Ukraine		5				
Global	12				67	

Figure 6.27 Sturgeon- global production trends

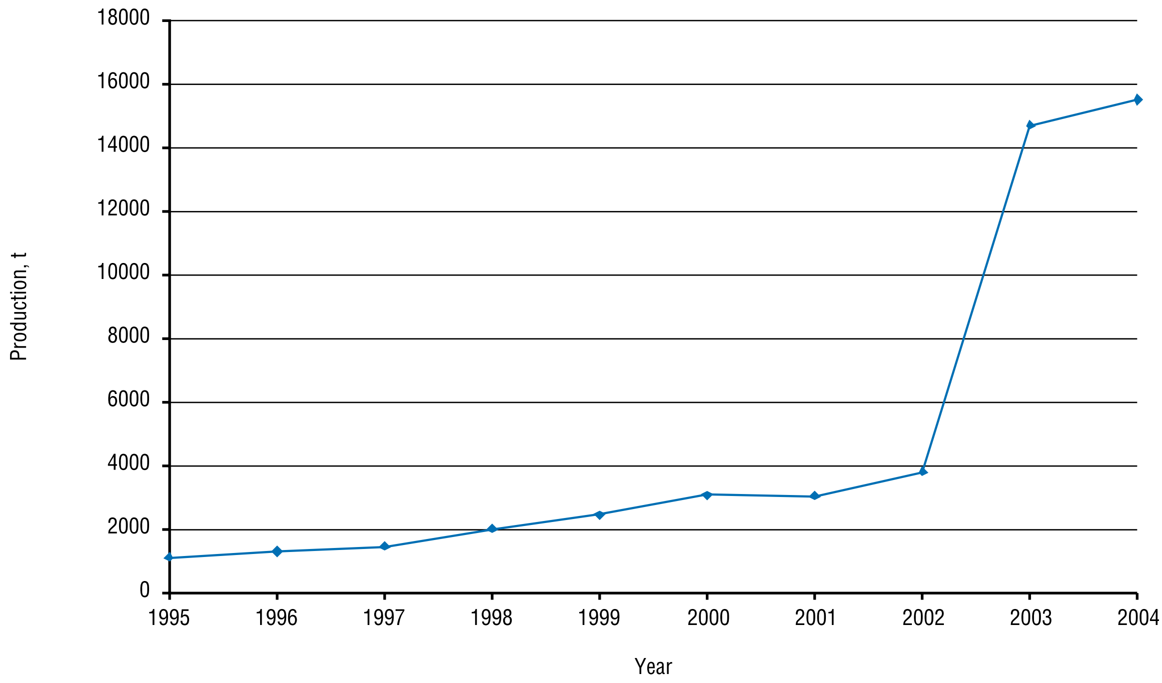
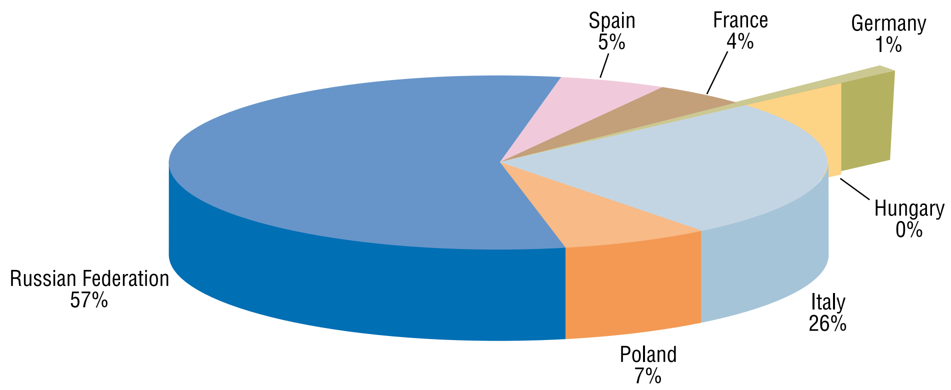


Figure 6.28 Sturgeon spp. – European production by country (including The Russian Federation), 2004



species such as cod or halibut for example. There is also the problem of the long start up times to produce caviar. It may take 6 years to grow fish to maturity in ponds or 4 years in RAS in higher temperatures, whereas sturgeon meat is essentially only a biproduct of caviar production[318]. The profit margin for caviar production is likely to remain high, however, whilst natural sturgeon populations continue to suffer.

318 Jones, Pers Comm.

6.13 Catfish

6.13.1 Introduction

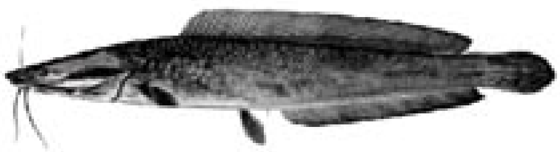
Catfish have been cultured in Europe for many decades with the focus on the European or Wels Catfish *Silurus glanis* in semi-intensive pond systems. Much of the Wels catfish production is as a secondary product in polyculture systems along with carp or other coarse fish. This is mainly in Eastern

Europe where the fish has a long tradition and here the market is likely to remain stable. Well established industries are developed in Hungary where low technology methods are used for production including natural spawning in specialised spawning ponds. These methods generally have had problems with high mortality. However increased demand has led to the need for more advanced hatchery techniques and broodstock management. These techniques are similar to those which are emerging for African catfish species, *Clarias spp.* which offer greater potential for super intensive systems. As the culture of Wels catfish is well established and the new hatchery techniques are similar to those for African catfish, the focus in this report will be on the African catfish. There has been substantial interest in the African catfish as a culture species, not only as an intensively reared species but also in small scale production across Africa and Asia for poverty alleviation.

6.13.2 European Overview

Croatia, the Czech Republic, France and Hungary all have established Wels catfish industries, each with steady production and no conceivable growth. Global production remains steady, also, at between around 700t and 800t a year. Meanwhile African catfish has seen a massive increase in production in Europe, from just over 1000t to over 5000t in ten years. This production is still dwarfed by the overall global production, dominated by Nigeria which increased production significantly between 2003 and 2004 from 4000t to over 15000t. Most production outside of Europe, however is destined for local markets to provide affordable animal protein sources. It is unlikely that the European market will become swamped with cheap African imports in the near future as long as demand remains high in Africa and catfish do not achieve status as a premium product in Europe.

Figure 6.29 Clarias gariepinus



6.13.3 Technical Feasibility

Traditionally, Wels catfish culture has been in flow-through pond systems in Eastern Europe. This may continue but it is likely that trends will continue towards African catfish as extremely high growth rates and stocking densities are achievable. The most usual species for culture is *Clarius gariepinus* or a hybrid of this with *Heterobranchus longifilis*. The African catfish is extremely tolerant of poor water quality conditions and low oxygen levels as it is a facultative air breather. Therefore when the fish are past the fingerling stage they are able to survive and grow with no dissolved oxygen in the water at all. They can also withstand much higher concentrations of ammonia and nitrite than any other culture species. This, coupled with the fact that their optimum temperature range is in the upper 20s degrees Celsius makes them an ideal candidate for growing in RAS. The high tolerance of anoxic environments and poor water quality means that it is possible to achieve stocking densities of over 600kg m^{-3}, unheard of with other species, and consequently expensive water quality treatment units are not required to the same degree. Other systems of culture are unlikely to be feasible because of the high temperatures involved unless there is a good source of geothermal water that can readily be tapped. These high water temperatures mean that fast growth rates are achievable, commonly growing fish from around 10g to a market size of about 500g to 600g or more in six months. This is an advantage over the Wels catfish which grows more slowly in lower temperatures. It is unlikely therefore, that Wels catfish will be grown at the same intensity and culture will continue in semi-intensive pond systems.

The major technical constraint to new catfish enterprises is likely to be the supply of juveniles in adequate numbers. Unlike salmonid seed production, sexual maturity is not triggered by photoperiod but by temperature fluctuations. Most high intensity catfish farms are most likely to have their own hatcheries therefore, as they can manipulate when they need to produce fry for all year production of adults. There are not enough catfish farms to justify the establishment of specialised catfish hatcheries in Europe, at this time. Females can be induced to spawn using carp pituitary extracts, GnRH or analogues, however males must be sacrificed and the testes removed. The fertilised eggs can be incubated in troughs similar to salmonids, except they are sticky and adhere to a mesh which is suspended in the troughs. When the larvae hatch, the egg cases are left attached to the mesh and can be removed easily, reducing the risk of disease or fungus such as *Saprolegnia*. Hatching is remarkably quick at between 16 and 60 hours where upon the larvae are usually fed a live diet of artemia nauplii although there have been examples of larvae rearing that have not used artemia. Fry may be transferred to rearing tanks when they reach a few grammes before which they must be graded several times to avoid cannibalism. There are already specialist catfish grow-out diets available in Europe, commercially.

6.13.4 Financial Feasibility and Market Potential

The cost of production of catfish in RAS is the lowest of any species. The biggest barrier to large scale success is much more likely to be consumer attitudes to the product and market resistance. The flesh, however, has the essential characteristics commonly sought: firm texture, white in colour with few bones and a mild taste offering versatility in the products that might be produced. There is some tendency for the flesh under the skin to be a darker colour, this can be removed through deep-skinning or masked through enrobed or in-sauce products. The fillets are considered to have an acceptable yield around, evidenced by some commercial availability and can be presented as either IQF or fresh.

Scope exists in a variety of product forms and could also be seen as raw material for a basic building block amenable to many different market positions This diversity should help overcome possible consumer resistance and with appropriate promotion should ensure acceptance in a number of segments. In Eastern European markets, the traditional Wels catfish is likely to remain popular and this may compete with African catfish products. Another similar species is the channel catfish, *Ictalurus punctatus*, with over 350,000 t produced in 2004, mainly in the USA and China. Some efforts have been made to export channel catfish to Europe in the past with little success. It is unlikely that it would be able to compete with large scale African catfish markets, should they become established. Possibly the greatest competition is likely to come from imports of *Pangasius*. The Vietnamese have placed increasing importance upon market diversification following the imposition of tariffs by the USA as a result of their dispute over imports of 'catfish'. *Pangasius*, marketed as basa and tra, has gained rapid acceptance within a number of EU markets and has extended into a number of former Eastern block countries where its attributes, very similar to those attached to *Clarias*, have been recognised. On the one hand this success may suggest the likelihood of adoption for *Clarias* but, clearly also highlights the risks of a potentially close competing substitute.

6.13.5 Prospects

There has been an increase in catfish production over recent years with new farms being established in the Netherlands, Hungary and Italy. Evidence suggests that the product is being accepted by consumers in these countries and should continue to gain status in other European countries too.

6.13.6 African Catfish 10yr Cashflow

Table 6.17. Financial model for African Catfish

Key assumptions

Production rate (t/yr)	Fish value (EUR/t)	Feed (EUR/t)	F.C.R.
1000	2160	990	0.9

Financial Model (All figures in 1000's of Euros)

Capacity	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Production (t)	500	1000	1000	1000	1000	1000	1000	1000	1000	1000
RECEIPTS										
Sales,€	1,079	1,727	1,727	1,727	1,727	1,727	1,727	1,727	1,727	1,727
From debtors,€	0	432	432	432	432	432	432	432	432	432
TOTAL RECEIPTS,€	1,079	2,159	2,159	2,159	2,159	2,159	2,159	2,159	2,159	2,159
PAYMENTS										
Working capital costs,€	996	1,442	1,442	1,442	1,442	1,442	1,442	1,442	1,442	1,442
Capital expenditure,€	876	0	0	0	0	0	0	0	0	0
TOTAL PAYMENTS,€	1,872	1,442	1,442	1,442	1,442	1,442	1,442	1,442	1,442	1,442
NET INFLOW/(OUTFLOW),€	-792	717	717	717	717	717	717	717	717	717
Bank balance brought forward,€		-792	-75	642	1,359	2,077	2,794	3,511	4,228	4,945
Bank balance at end,€	-792	-75	642	1,359	2,077	2,794	3,511	4,228	4,945	5,663
IRR		90.2%								
NPV (10%), €		3035								

Breakdown of Operating costs	Annual cost, €	% of Total
Food	891000	58.7
Fry	119777.8	7.9
Labour	110000	7.2
Medicines	16500	1.1
Stock insurance	16087.5	1.1
Power/fuel	49500	3.3
Rep and ren	33000	2.2
Gen insurance	16500	1.1
Admin	33000	2.2
Legal and prof	9900	0.7
Depreciation	76395	5.0
Consumables	8250	0.5
Other (10%)	137991	9.1
Total op costs	1517901	100.0
Cost per kg	1.517901	
Cost per kg fillet		
(no processing cost)	3.614051	

Capital costs, €	No. units	Cost Unit	Total cost	Total + contingency
6m bio filter housings	4	1900	7600	10260
2.8m degaser housing	2	100	200	270
treatment pumps	2	2092	4184	4184
fish return pumps	2	2092	4184	4184
media	120	330	39600	53460
belt filter / drum filter	1			28000
Water storage tank 100m3	1			6500
ph MONITOR	1	850	850	1105
pH buffer	1	1500	1500	1950
pH pump	1	540	540	702
blowers	4	1500	6000	7800
ozne montor	1	650	650	845
control panels	1	6500	6500	8450
oxygen monitoring system 8 channels	2	650	1300	1690
probes	10	135	1350	1755
flow meter	1	1000	1000	1300
containers	2	1700	3400	4420
ozone generator 2 x 30g/hr	1	7000	7000	9100
contact column	1	1750	1750	2275
engineering	18	350	6300	5250
Transport of equipment to site	sum			5000
fitting out biofilters (fluidised)				
pipework	10	350		3500
screens	8	220		1760
labour	30	350		10500
trickle and submerged filter				
pipewrk	2	500		1000
screen and supports	2	860		1720
labour	20	350		7000
Subtotal				183980
standby generator	1			13000
Feeders (small tanks)	26	300		7800
ongrowing feeders 3/tank	30	600		18000
heating system	1	10,000		10000
Fish tank assembly labour	30	350		10500
mechanical filter installation	6	350		2100
Subtotal				245380
tanks in GRP and circular				
2.3m x 0.7m deep	26	625		16250
6.6m x 1.85m deep	10	8300		83000
screens stand pipes etc sum	sum			2000
Subtotal				101250
Total				530610

Sensitivity Analysis

	IRR%	Max Funding, 1000s €	Payback time, yrs
Base case	90.26	1871.51	3
+20% Feed Costs	56.96	1978.43	3
-20% Feed Costs	133.20	1764.59	2
+20 Sales Price	199.35	1871.51	2
-20% Sales Price	24.33	1871.51	5

Figure 6.30 African catfish - European production trends

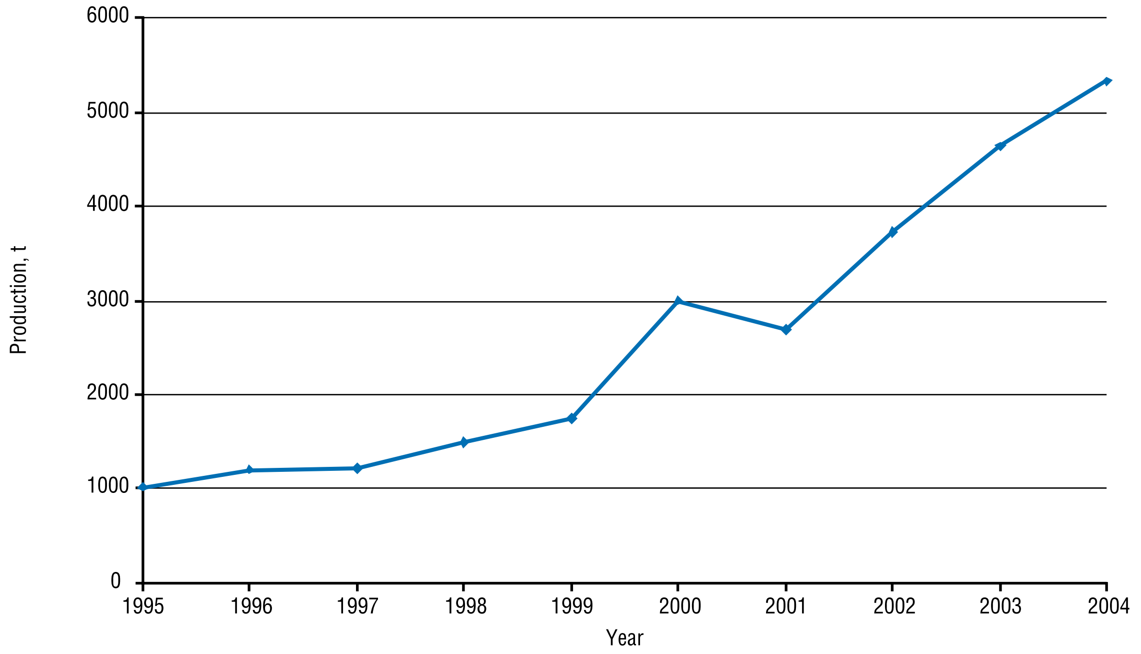
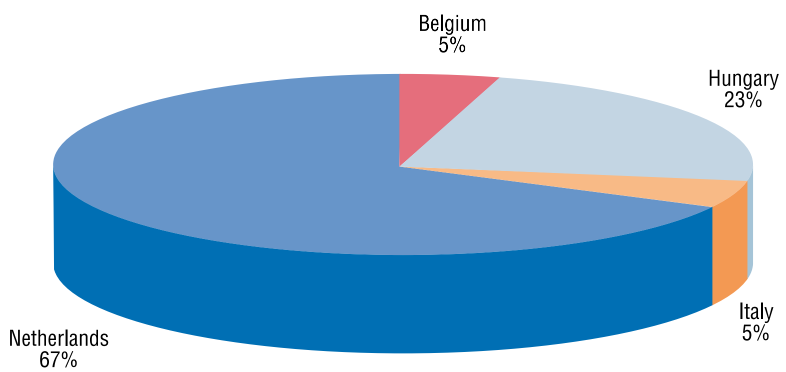


Figure 6.31 African catfish - European production by country, 2004 [319]



319 FAO Fishstat database

6.14 Tilapia

6.14.1 Introduction

Tilapia have been farmed for food in some form for an estimated 4000 years in Africa, pioneered by the ancient Egyptians and it has been an important commercial aquaculture species for several decades. It has been cultured in tropical regions in Africa and Asia using semi-intensive and polyculture systems since the 1940's. Traditionally, pond culture has been the usual method of culture but this has had problems with lack of control, particularly with respects to reproduction which occurs naturally if left unchecked and can lead to overcrowding, stunted growth and large variability in size.

Tilapia are a tropical species of cichlids that prefer temperature ranges between 25°C and 30°C and require temperatures over 22°C for growth which makes pond aquaculture unfeasible throughout most of Europe. They are also tolerant of poor water quality in terms of pH and oxygen levels needing only 2.0ppm dissolved oxygen for good growth compared to around 6ppm for salmonids. This requirement for high temperature and high tolerance of poor water quality combined with a generally good growth rate makes tilapia a good candidate for RAS technology. They are also an omnivorous species, feeding on a large variety of food items including plankton, benthic organisms, detritus, aquatic plants and small fish. This gives the species good potential for use in AST systems. There are three main species of tilapia that are commonly cultured. These are the Nile tilapia *Oreochromis niloticus*, the Mozambique tilapia, *Oreochromis mossambicus*, and the blue tilapia, *Oreochromis aureus*. Of these, the most important worldwide has been the Nile tilapia which has shown the best growth rates. In Europe the tendency has been towards other species which perform better at low temperatures and hybrids which produce interesting variations such as different colours or other culture advantages e.g. crossing *O. niloticus* with *O. aureus albino* produces red tilapia which resemble certain sea breams and are popular with consumers.

6.14.2 European overview

There has been increasing interest in Europe in the production of tilapia in recirculation systems using the cooling water from other industries such as dye or brewing. Using already heated water saves expenses in heating and also helps to mitigate environmental issues from the other industry. RAS technology allows the heat to be kept within the system and is the most promising for European production. Recently there have been efforts in using AST systems for tilapia culture in Europe but these are still in the experimental stages. Production in Europe is very low compared to worldwide production that stood at 1.8 million tonnes in 2004 according to the FAO. Belgium has produced around 200t a year for more than 10 years and a new facility in the establishment phase is looking to produce 3000t in the near future. The Netherlands has recently started with 300t produced in 2004 and Italy, Spain and Switzerland also produce. The UK currently has some small operations and is also currently involved in pilot operations to produce tilapia using AST.

6.14.3 Technical Feasibility

Given optimum conditions, it is possible to grow tilapia to a market size of 500g with 90% survival in about six months. They will breed naturally in tanks but unlike most culture species, produce eggs in small batches at intervals of between 4 to 6 weeks. A mature 400g female may produce around 500 to 600 fry a month. Usually, small numbers of conditioned fish are put into tanks in a 3:1 female to male ratio, making sure that the males are of similar size to the females to avoid any aggressive behaviour. When mature, males develop a beak on their upper lip which they use aggressively, especially if they are much larger and more dominant. Sometimes the upper lip of the males is removed to prevent this. Once the eggs have been fertilised, they are held in the female's mouth during incubation and for a few days after. Incubation takes about 6 to 10 days and mouth brooding a further 4 days during which time the female does not feed. After around 25 days post-hatch, the breeders are removed to conditioning tanks to make ready for the batch of fry. Fry may return to the females mouth during this time if they sense danger. Tilapia will accept a range of artificial food stuffs throughout their lives ranging from powdered mash to dry pelleted feeds. In developing countries with large semi-intensive operations, it is quite common for pelleted feed to be made on site from locally available feed stuffs such as various meals and brans. In Europe it is possible to buy prepared, pelleted feeds for tilapia commercially and an FCR of between 1.2 and 1.4 can be expected.

The biggest problem in tilapia farming is probably growing fish of uniform size with good growth rates. This is because females tend to grow much slower than males and much at much more irregular rates. Manual sexing of fish at an early stage is labour intensive and will always produce a certain amount of error, therefore there has been substantial development in methods to produce all or nearly all male offspring. This can be achieved in several different ways, most easily by sex reversal using hormone treatment, however this practise is banned by the EU. This is because of uncertainty of the effects of the effluent from sex reversal on the environment and fears over food safety. Some efforts involving hybrids have produced good result especially *O. niloticus* crossed with either *O. hornorum* or *O. aureus* which have produced upwards of 90% male offspring. This can be difficult to maintain, however as the hybrid offspring must be kept away from the broodstock to avoid them breeding and more importantly pure *O. aureus* and *O. niloticus* strains must be produced and maintained for broodstock each year. Currently the best solution is though to be the production of all male offspring by crossing normal females with YY super-males, however this also relies on some hormone treatment in the initial production of YY males, see section 7.4 on livestock manipulations. Most tilapia farms are likely to have to produce their own fry by some means as the current level of production is not enough to warrant the establishment of specialised hatcheries. Efforts to improve the performance of tilapia for aquaculture have been continuing for decades, most famously through the Genetic Improvement of Farmed Tilapia (GIFT) programme, initiated in the Philippines during the mid 1980's. The programme increased growth rates by around 80% cumulatively over five generations and survival rates by around 65% (World Fish Centre).

6.14.4 Financial Feasibility and prospects

In Europe the potential for tilapia farming in RAS is largely unknown as the product is niche and the market is still undeveloped. However, outside Europe it is extremely popular and has become established in the US very rapidly. Europe is seen by many as the next important target market for many producers, including those in the Americas and this has largely been fuelled by popularity of the fish amongst immigrant populations in Europe. Most producers are small and produce fish for the restaurant trade rather than for sale in supermarkets. There has been increasing interest in using the waste water from RAS in aquaponics in insulated buildings for the production of high value crops. This offers the potential for additional income, although it is very much in the early stages of development.

Table 6.18. Financial model for Tilapia

Key Assumptions

Prod.rate (t/yr)	Fish value (EUR/t)*	Feed (EUR/t)	F.C.R.
120200	5775	1155	1.3

10 Year Cash Flow

Capacity	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Year	1	2	3	4	5	6	7	8	9	10
Production (t)	500	1000	1000	1000	1000	1000	1000	1000	1000	1000
RECEIPTS										
Sales,€	347	554	554	554	554	554	554	554	554	554
From debtors,€	0	139	139	139	139	139	139	139	139	139
TOTAL RECEIPTS,€	347	693	693	693	693	693	693	693	693	693
PAYMENTS										
Working capital costs,€	327	420	420	420	420	420	420	420	420	420
Capital expenditure,€	1,600	0	0	0	0	0	0	0	0	0
TOTAL PAYMENTS,€	1,927	420	420	420	420	420	420	420	420	420
NET INFLOW/(OUTFLOW),€	-1,581	273	273	273	273	273	273	273	273	273
Bank balance brought forward,€		-1,581	-1,308	-1,035	-763	-490	-218	55	327	600
Bank balance at end,€	-1,581	-1,308	-1,035	-763	-490	-218	55	327	600	872
IRR		9.82%								
NPV (10%), €		-10.02								

Operating costs

Breakdown of Operating costs	Annual costs, €	% of total
Food	186536	38.0
Labour	66000	13.5
Medicines	8250	1.7
Stock insurance	1226	0.2
Power/fuel	49500	10.1
Repair and ren	13200	2.7
Gen insurance	16500	3.4
Admin	16500	3.4
Legal and prof	9900	2.0
Depreciation	70204	14.3
Consumables	8250	1.7
Other (10%)	44607	9.1
Total op costs	490673	100.0
Cost per kg	4.09	

Capital Costs

Capital costs, €	No. units	Cost unit	Total cost	Total + contingency
polytunnel m^2	1388	77.55	107639.4	129167.28
office building	1	82500	82500	99000
6m bio filter housings	4	3135	12540	15048
2.8m degasser housing	2	165	330	396
treatment pumps	2	3451.8	6903.6	8284.32
fish return pumps	2	3451.8	6903.6	8284.32
media m3	218.7	495	108280.0	129936.0
belt filter / drum filter	1	33000	33000	39600
Water storage tank 100m3	1	10725	10725	12870
ph MONITOR	1	1402.5	1402.5	1683
pH buffer	1	2475	2475	2970
pH pump	1	891	891	1069.2
blowers	4	2475	9900	11880
ozone monitor	1	1072.5	1072.5	1287
control panels	1	10725	10725	12870
oxygen monitoring system 8 channels	2	1072.5	2145	2574
probes	10	222.75	2227.5	2673
flow meter	1	1650	1650	1980
containers	2	2805	5610	6732
ozone generator	1	11550	11550	13860
contact column	1	2887.5	2887.5	3465
engineering	18	577.5	10395	12474
Transport of equipment to site	sum		8250	9900
fitting out biofilters (fluidised)				
pipework	10	577.5	5775	6930
screens	8	363	2904	3484.8
labour	30	495	14850	17820
trickle and submerged filter				
pipework	2	825	1650	1980
screen and supports	2	1419	2838	3405.6
labour	20	495	9900	11880
Subtotal				573503.47
standby generator	1	21450	21450	25740
Feeders (small tanks)	17	495	8415	10098
ongrowing feeders	31	990	30690	36828
heating system	1	16500	16500	19800
Fish tank assembly labour	30	495	14850	17820
mechanical filter installation	6	577.5	3465	
Subtotal				683789.47
tanks in GRP and circular				
1.5m x 0.7m deep	17	990	16830	20196
5m x 1.3m deep	31	9900	306900	368280
broodstock tanks	6	1650	9900	11880
screens stand pipes etc sum	54	165	8910	10692
Subtotal				342540
Total				1599832.9

6.14.5 Environmental impacts

The environmental impacts of tilapia culture using RAS or AST are likely to be very low as with all RAS and the use of cooling water means that the system may actually reduce the impacts from other industries. The use of aquaponics will further reduce environmental impacts by using the waste water effectively to take out nutrient loadings. The sludge from suspended solids may also be used as a fertiliser in other types of integrated schemes. The major problem with using the water from other industries is that it relies on a constant supply. Therefore, a fish farm may have shortages if using water from a brewery for example if it lowers its production. This also means that the fish farm may not be able to expand unless the brewery does so or the fish farm has another heat source, requiring extra capital and operational investment.

Figure 6.32 Tilapia spp. – European production trend

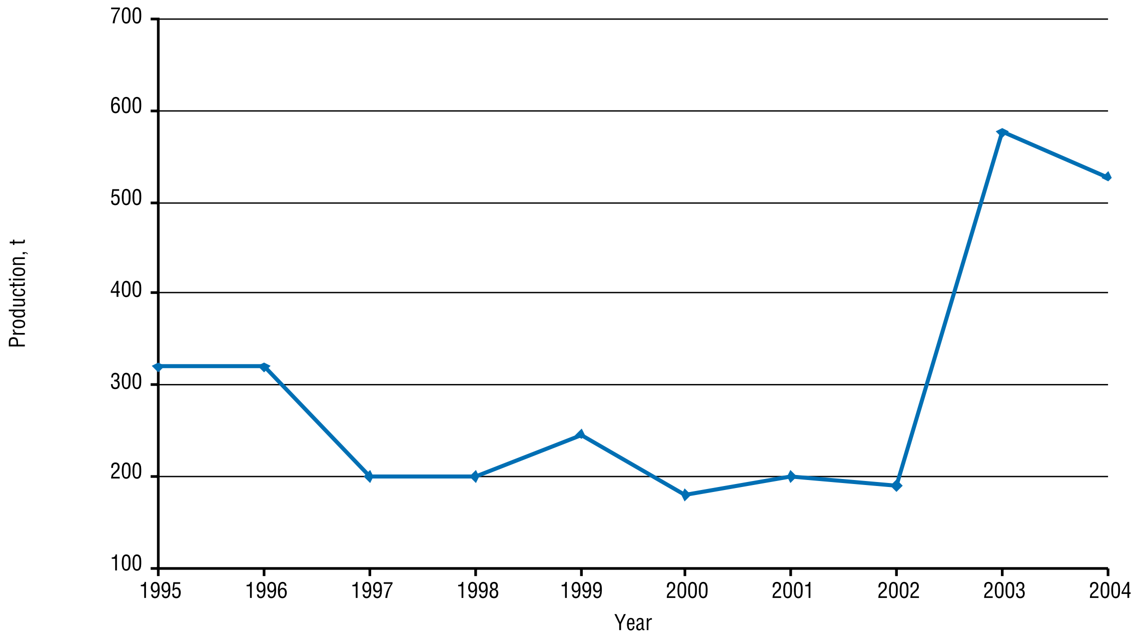
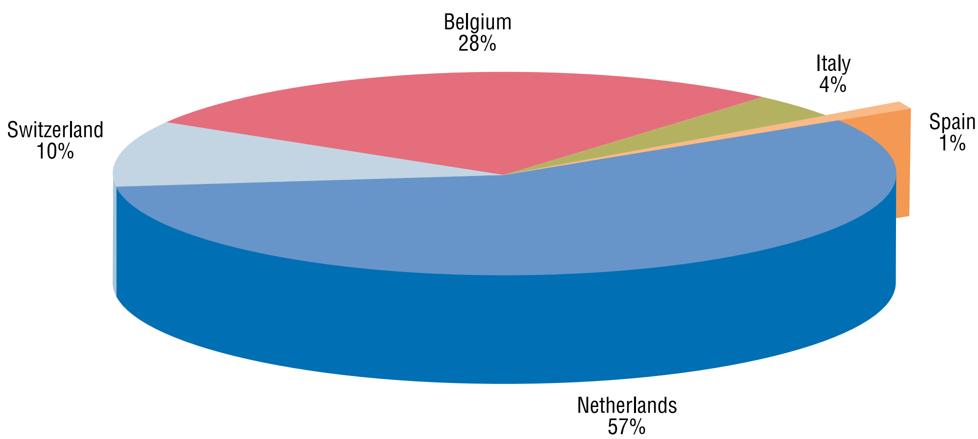


Figure 6.33 Tilapia - European production by country, 2004 (FAO)



6.15 Emerging species drivers and barriers

Czech Republic: Barrier: Severe legal restrictions prevent species introductions[320].

Denmark: The drivers for emerging species are: Profit; New product - more attractive to market, including environmental attributes; Changing cost structures; Cost of production advantage; Pioneers discovering if something can be done; Water availability and cost; Pollution controls and fees; Market demand; Technology overlap. The barriers are: Difficulty getting investment; Lack of demand for product; High costs of production; Energy costs[321].

Finland: Drivers: Better utilisation of lake-resources (novel species) resulting in enhanced rural livelihoods. Attractive to markets. Old traditions of native fish and fishery including excellent post-harvest technologies and practices (cold chain; processing; cooking). Profits of farming better than with bulk species. Ecologically feasible if fed with lake-born feed (food web manipulation). Barriers: Environmental restrictions. Lack of technology and know-how. Lack of intensive R&D[322].

France: The main barriers are: a lack of knowledge of the biology of most of the species, problems of the market and relationship with fisheries. For instance, cod farming has difficulties because the market price depends on fisheries; cobia farming is limited because of poor mastering of reproduction; and the meagre market is still questionable. The situation should improve quickly due to the impoverishment of wild fish stocks, but they are still in a 'hesitating period'[323].

Germany: Drivers: New product – more attractive to market. Barriers: Additional costs for testing of candidates; unknown market value and acceptance; protection of environment[324].

Greece: The need for species diversification in the Greek aquaculture industry emerged after the first price crisis, in the mid 1990's. Producers and research institutes experimented with a variety of species. Unfortunately, producers pressed for immediate results and the R&D departments (of the very few companies that had one actually operating) focused on species with similar culture requirements as the bass and bream. The sharpsnout bream (*Puntazzo puntazzo*) was the 'new species' for many years, without however really diversifying the product in the market (whole whitefish, plainly sold on ice, of similar size and appearance to the seabream). On the other hand, research institutes experimented with a much wider variety of fish species. Without the pressure for immediate results for commercial application (at a scale comparable to the bass and bream, which was what producers wanted) researchers worked with a more long term horizon. In brief, while almost all producers would wish to expand the gamut of fish produced, their financial status does not allow for adequate funds to be directed to R&D. They seem to merely wait for developments to be made by the institutes and once progress has been made then they will try to 'buy' that know-how, thus minimizing risk[325].

To better understand the Greek industry, you must realize that its development was one of limited risk, as it was based on existing technology (cage culture), and on firm scientific results (research for the culture of bass and bream dates back to the 1970's, and its commercial culture started in the early 1980's). The technology and know-how were initially imported and then further developed to the intensive level that we now see. The latter, along with the availability of the state and the EU funds for the development of the sector rendered the industry as one of limited-risk to the minds of the initial investors

320 Adamek, Pers. Comm.
321 Jokumsen, Pers. Comm.
322 Molsa, Pers. Comm.
323 Blancheton, Pers. Comm.
324 Brämick, Pers. Comm.
325 Triantaphyllidis, Pers. Comm.

and subsequent large producers. Producers are not willing to take 'unnecessary' risks, at least not in advance of a foreseeable problem[326].

Hungary: The main drivers are: profit; new product more attractive to market; pioneers discovering if something can be done; market demand; and availability of geothermal water resources. The main barriers are: competition from cheaper imports from outside the EU; lack of demand for product; and laws and 'overregulation'[327].

Italy: Drivers: Possibility to open new markets; increasing the quality of offer on the market; pioneers discovering new species; market demand. Barriers: New species may be concurrent for the market with the established species; need of new knowledge; lack of availability of juveniles[328].

Netherlands: This is basically driven by profit and diversification of future production[329].

Portugal: Better sale prices would be the key driver. Technological problems (fry availability and disease, mostly) would be key barriers[330].

Spain: The situation in Spain reinforces the fact that the industry is more interested in commercial species. The drivers for new species could be that such new species could demonstrate higher growth rate, easier management or lower disease susceptibility than commercial species in the pilot stage. The barriers are: the time taken to develop new species and the lack of tradition for consumers[331].

6.16 Environmental impacts

The development of new species for aquaculture has perhaps the most potential for reducing reliance on world fish stocks, so long as the complete reproduction cycle can be mastered. The discovery of species better suited to mass production, or able to tolerate certain conditions could potentially increase the amount and locations where cultured seafood can be successfully produced.

Aquaculture production of species that must be harvested as eggs or juveniles from the wild is not sustainable, and is likely to add to the depletion of world fish stocks caused by many capture fisheries. For example, tuna farming involves catching juveniles from the wild to be kept in pens for on-growing. Reports have highlighted that Mediterranean stocks of tuna are depleted, and that capacity for tuna ranching far exceeds the legal quota for wild catch, encouraging illegal fishing to maximise returns on the high investments required for tuna farms[332 333].

The majority of new species appear to be carnivorous marine fish, which require fish meal and fish oil in their feed. These species would potentially place further demands on wild fish stocks if their production expands significantly. It is also possible that research will produce new species that can be farmed on a herbivorous diet, removing the need to catch wild fish for feed.

6.17 Prospects

Continuing market pressure for increasing product diversity, a general increase in demand for fish and limited potential for expansion in capture fisheries will continue to drive diversification in range of species farmed. Most of the emerging species reported in detail here will probably become significant commodities in their own right, not just as supplements to a declining capture fishery. But some of those

326 Op. Cit.
327 Varadi/Ronyai, Pers. Comm.
328 Saroglia, Pers. Comm.
329 Schneider, Pers. Comm.
330 Bravo, Pers. Comm.
331 Tort, Pers. Comm.
332 Why is tuna ranching so bad? Greenpeace. 2006. http://weblog.greenpeace.org/oceandefenders/archive/2006/06/we_all_hate_tuna_ranching.html
333 Mediterranean fisheries: as stocks decline, management improves. FAO newsroom. 2005. www.fao.org/newsroom/en/news/2005/105722/index.html

listed in Table 6.1 at the start of this chapter will doubtless fail or still be 'emerging' in years to come. Technical barriers to production can be overcome with significant research effort, but to make this research worthwhile production needs to be financially viable.

Much of the global increase in demand for seafood will come not from within the EU, but from outside, giving EU producers the chance to increase exports[334]. However there will be increasing competition from developing countries, not least China, for a whole range of species and product formats. In order to remain at the forefront of aquaculture production in an increasingly competitive market the EU will need to invest in continuing research and development in emerging species. Equally important, once major technical constraints are overcome, is a business development model that raises productivity and lowers the cost of production in order to help drive market expansion.

334 Fish to 2020: Supply and Demand in Changing Global Markets. Delgado et al. 2003. WorldFish Center Technical Report 62

Table 6.19 Cost of production and farm gate price of major European species and systems.

Species/system	Cost of production €/kg	Farm gate price €/kg	% Profit	Comments
Salmonid inshore	2.60	3.00	15.4	Economy of scale and potentially higher stocking densities could make offshore competitive with inshore.
Salmonid offshore				
Salmon, flow-through				
Salmon RAS	3.50			Salmon RAS unlikely to be profitable unless can be marketed as more environmentally friendly.
Other salmonid RAS	2.20	3.00	36.4	
Salmon organic	4.15	6.60	59.0	
Other salmonid organic				
Sea bream offshore	4.05			
Sea bass offshore	4.15			
Blue-fin tuna offshore	10.50	13.00	23.8	Cost of production may be reduced if tuna seed is produced commercially.
Eel RAS	4.90	5.50	12.2	
Caviar RAS		1,000.00		No info available for caviar cost of production. Farm gate estimated.
African catfish RAS	1.70	1.70	0	Farm gate for catfish may increase if new markets are opened up in Western Europe.
Cod inshore	3.30	4.40	33.3	
Cod offshore				Cost of cod production may be lowered if juveniles are transferred to sea at smaller sizes than at present.
Cod organic				
Cod juveniles	20			
Tilapia RAS	2.25			
Halibut inshore	7.10	9.70	36.6	
Turbot inshore				
Turbot RAS	4.95	6.60	33.3	
Octopus	5.55	6.00	8.5	
Arctic charr ponds	2.60	5.10	96.2	
Barramundi RAS		14.00		

7 Emerging practices

7.1 Introduction

There are a number of key developments that are likely to have a significant impact on the future of European aquaculture sector but they are not going to develop into new systems, which we call 'emerging practices'. These tend to have a general or cross-cutting impact on a range of aquaculture based industries, gradually changing the way that day-to-day management is carried out and in some cases may be important enough to enable the development of new systems by improving profitability or reducing costs. The main emerging practices that were identified are:

- Vaccination
- Selective Breeding
- Lifecycle manipulations
- Genetic manipulation
- Use of Information Technology
- Reducing fish meal and fish oil levels in feeds
- Harvesting/processing innovations
- Packaging and retail innovations

While there are a number of additional, incremental, innovations taking place within the sector, that have been or may be important in the future, an effort was made to include the most relevant and with the widest application. A brief overview of these emerging practices is provided below for informative purposes, but without being comprehensive.

7.2 Vaccination

7.2.1 Overview

Vaccination has been one of the most effective approaches to combating disease problems in the European commercial finfish farming industry. While there are diverse emerging practices within health management in aquaculture, vaccination is considered the main emerging tool for combating diseases. Until the early 1990s, most fish vaccines were developed by small companies however production and research is now dominated by five main players; Intervet International, Novartis Animal Health, Schering –Plough Animal Health, Pharmaq and Bayer Animal Health.

The two main types of delivery system for vaccines are immersion in a diluted suspension of the vaccine or by injecting the vaccine into the body cavity. Immersion vaccines suit small fish whereas injection is easier in larger fish. This has lead to the development of specialised vaccination teams and machines to make the vaccination process easier.

A third delivery system is oral vaccination by including the vaccine in compounded diets. This would be the easiest method for farmers and the least stressful for the fish. However, so far only Schering-Plough has developed a commercial product, an oral booster vaccine for Enteric Redmouth Disease in trout. One of the main obstacles to oral vaccines has been the destruction of the antigens during passage through the stomach. This has been overcome by the company through an encapsulation technique to protect them until release in the intestine. However, it has not become a widespread technology as increased quantities of antigen are required, the duration of protection is shorter, and the manufacturing process is more expensive, making them less attractive to farmers.

7.2.2 Coverage

The development costs for new vaccines are high, so they have only been developed for the most common disease problems in relatively high value species – salmon, trout and other high value freshwater and marine species.[335] The effectiveness of vaccination also varies according to the type of disease. Vaccination has been particularly effective against bacterial diseases such as vibriosis, furunculosis, ERM, while its effectiveness against viral diseases (IPN, Pancreas disease, ISA, VHS) has been much more variable. Vaccines have not yet been developed against parasitic diseases.

The concentration of use of vaccines against bacterial problems in high value species means that vaccination is used most often in countries with intensive aquaculture industries including Norway, Scotland, Ireland and Chile.

7.2.3 Economic importance

The development of effective vaccines against vibriosis and furunculosis in the late 1980s played a crucial role in facilitating the growth of the Norwegian salmon farming industry. By 1987 it was estimated that the Norwegian industry was using around 50 tonnes of antibiotics and suffering huge mortalities due to these diseases. Ten years later this had dropped close to zero thanks to the development of multivalent oil-adjuvanted vaccines while overall salmon production had more than tripled.

For the fish farmer, the relative cost of vaccination must be weighed against the likely benefits – principally reducing the risk of fish loss through disease.

7.2.4 Constraints

There are severe theoretical constraints on the use of vaccines in fish as their immune systems are relatively primitive compared to other animals while the evolutionary distance between fish families is much greater than between mammals. This means that each new disease in each fish species will probably need to have its own specific vaccine. Fish also appear to require relatively large antigen doses making it impossible in some cases using conventional technology to develop cost effective vaccines. Concerns over environmental safety are limiting the development and use of live virus vaccines.

A major practical constraint to the development of new vaccines is the costs involved in research, development, testing and providing new documentation for licensing.

7.2.5 Prospects

There are new areas where vaccine development could have a major impact. Most fish vaccines are currently based on inactivated (killed) disease agents, although more recent products, such as a vaccine licensed in Norway against Infectious Pancreatic Necrosis Virus (IPNV) in salmon are using recombinant technology. Here, the specific components of the disease agent that causes a disease are isolated and the genes that are responsible are cloned and introduced into bacterial DNA where they are expressed to increase the amount of antigen. Another technique recently introduced is that of DNA vaccination, where the genes encoding the vaccine antigen are administered rather than the antigen itself. The genes are then expressed in cells of the fish itself, triggering an immune response. A product using this technology against IPNV is now available in Canada. Research suggests this approach can be highly effective, but as a new technology involving the transfer of DNA there are uncertainties over safety testing and regulatory requirements in many countries. A further approach that is now being researched is the use of proteomics and epitope mapping for the identification of vaccine antigens and the subsequent development of peptide vaccines. It is hoped that such approaches might also make

335 Vaccines for fish in aquaculture. I. Sommerset, B.Krossoy, E. Biering & P. Frost. Expert Rev. Vaccines 4(1), 89-101 (2005).

possible the development of vaccines against major fish parasites such as the salmon louse.

7.3 Selective breeding

7.3.1 Overview

The genetic composition of most strains of fish species used in aquaculture has changed little from that of wild fish. The main approach was to choose breeding stock from wild fish with particular characteristics, for example low grilsing stocks in salmon, however this is gradually being replaced by dedicated breeding programmes for a range of species. Researchers have reported significant year-on-year improvements in growth, meat yield and resistance to key diseases in salmon. Similar progress has been reported with trout and shrimp.

The high fecundity of aquatic organisms means that it is relatively easy to establish large scale breeding programmes using large family sizes, although a constraint has been the development of a reliable tagging system, especially for very small fish. This has been overcome to a large extent by implanting microchips (using Passive Integrated Transponder technology) in valuable animals and combining this with microsatellite DNA marker analysis and Amplified Fragment Length Polymorphism) for genetic fingerprinting (e.g. identification of specific parents/progeny and discrimination between populations).

7.3.2 Coverage

Genetic improvements require long-term commitments and there have been few organisations with the capacity to develop stock lines over a sustained period of time. Consolidation in the salmon industry means that specialist breeding companies are now starting to emerge, in the same way that they have developed in the global poultry and pig industries. Other attempts to improve European fish stock lines have been piece-meal in comparison although a notable exception is the development of carp stocks over several centuries.

7.3.3 Economic importance

The main advantage of breeding genetically improved stock is that it should be possible to maintain expression of the factor that has been selected for without further expenditure. For example, while it may be possible to treat fish with a vaccine against IPN, salmon which have been bred to be IPN resistant will maintain this trait throughout their lifetime and in future generations thereby saving future vaccination and disease treatment costs.

On the other hand, breeding companies that have invested in developing genetically improved stock will charge a premium for their stock, particularly if it has already been shown to have significant advantages in commercial situations.

7.3.4 Constraints

Selection for continuous traits such as growth rates, has always been difficult as they are affected may many genes, most of which of unknown and may affect several traits simultaneously. Selecting for disease resistance may for instance lead to reduced growth rates or poorer flesh quality for processing. A number of research techniques can be used to address this problem for instance using linkage mapping, Quantitative Trait Loci (QTL) analysis and ultimately genome mapping. However, more work needs to be done on these before they are able to yield substantial results in the commercial sector.

7.3.5 Prospects

Genetic selection offers long-term cumulative improvements in fish performance without the use of invasive biotechnologies such as genetic modification. The principles are the same as those used for the domestication of animals and improvements in crops over thousands of years, but with the prospect of much faster advancement with the assistance of modern tools for genetic analysis. It is anticipated that this approach will be increasingly applied in all commercial aquaculture species as it becomes worthwhile for breeding companies to make the necessary investments.

7.4 Lifecycle manipulations

7.4.1 Overview

Through the use of temperature, hormonal treatment, pressure shocks and light regimes it is possible to manipulate sex, ploidy state and advance and delay spawning times for many species. This is often desirable, for instance in order to achieve consistency in market supply, or to utilise single-sex stocks where mixed stocks lead to substantial production difficulties.

7.4.2 Coverage

Particular progress has been made with altered photoperiod regimes in trout and salmon which has meant that fish can be prepared for spawning at almost any time of year and smolts can be transferred to sea several times in the season at a range of sizes. This, combined with photoperiod adjustment used to extend daily feeding periods and hence increase growth rates in cages has allowed the salmon industry to develop from a highly seasonal industry to one which can supply steady quantities of good quality fish to the market on a year-round basis.

Various technologies are available to manipulate the sex of fish, the age at which they mature, or to induce complete sterility. These may be desirable in order to improve production rates and product quality. For instance in trout farming a major issue has been premature maturity before the fish reach suitable size for market, especially those destined for fillets. The growth rate and flesh quality deteriorate with the onset of sexual maturity. One approach has been the production of triploid fish through pressure or temperature shocks to normal diploid eggs at an early stage of development. Triploid fish do not mature, so can be grown to a larger size before harvest. Triploid fish are also increasingly used in stocked fisheries, or where there may be a risk of reared species escaping and damaging local ecosystems, as they will be unable to breed. An alternative approach in trout farming is to stock only female fish as females mature later than males. All-female stocks can be produced in specialised hatcheries by masculinising broodstock females (using a hormone treatment during early development) which are used to fertilise normal female eggs, thereby producing genetically all-female offspring. This has become the preferred approach for much of the rainbow trout industry.

For tilapia, it is the males that grow faster. Early use of hybridisation as a tool for influencing sex ratios was quickly replaced by the use of hormone treatments during the early life stages. As this would be illegal for product sold in Europe, this has more recently been replaced through the production of genetically all-male tilapia by crossing normal females with “supermales” which have two Y chromosomes rather than the usual X and Y sex chromosomes. The supermales can be produced through a sequence of hormone-based sex reversals and progeny testing. Other routes to chromosomal manipulations involve gynogenesis, androgenesis and cloning, which may offer cost reductions or other advantages in the future.

7.4.3 Economic importance

Chromosome level and photoperiodic manipulations have had a very significant impact on the farmed salmonid industries. They have ironed out seasonal fluctuations in the supply of juvenile fish for ongrowing and in fish for the market. Sex-reversal has also been a significant technology enabling the development of the tilapia industry in many parts of the world.

7.4.4 Constraints

Ethical issues including fish welfare and concerns over the use of emerging biotechnologies such as cloning may constrain the use of these technologies, especially if they are given greater focus in a seafood marketplace better educated on production issues.

7.4.5 Prospects

Environmental and chromosome level manipulations have had a profound impact on reproduction and growth in many commercially important species. Further research will undoubtedly reveal new opportunities in newly commercialised species.

7.5 Genetic modifications

7.5.1 Overview

Genetic modification, through the introduction of DNA into the genome - transgenesis - is relatively well established as an experimental technique in many fish species, due to the ease with which fertilised eggs can be manipulated. Various fish and human growth hormone genes have been incorporated in the genome of species such as Pacific salmon, rainbow trout, common carp and tilapia. For aquaculture, the chief objectives are similar to those for selective breeding, the production of faster growing fish with improved resistance to disease and better flesh quality or fillet yields etc.

7.5.2 Coverage

The most publicised promoter of these technologies is Aqua Bounty, a North American company involved in the commercial development of transgenic Atlantic salmon. This company uses only fish genes (DNA) that are injected into eggs with the hope that they will become integrated into the genome of the species they are trying to change. A number of genes that encode for growth promoting hormones (e.g chinook salmon growth hormone gene), along with promotor genes such as the antifreeze protein gene promoter from the ocean pout that allows the gene to be activated, have been introduced into a number of species. Where these genes have been successfully integrated into the genome of the recipient then between three to five-fold increase in growth rate has been reported, with some individual fish being 10- to 30-times larger in the early phase of growth. This early work was done on wild stocks, but in subsequent work using domesticated strains selected for growth rate, the gains are much lower. However, it must be remembered that this is a one-off improvement of a single trait and it currently takes several generations of breeding to develop commercial lines from the original single transgenic animal.

7.5.3 Economic importance

GM technology potentially offers major economic benefits. Production costs can be substantially reduced if the utilisation of resources is improved. In addition to improvements in growth rates and disease resistance, there is potential for improving the utilisation of terrestrial proteins and oils by marine fish species, thereby reducing the dependency of the marine aquaculture sector on industrial fisheries.

7.5.4 Constraints

Despite early promise, practical problems with transgenesis have been encountered and are being actively researched. These include the fact that most injected animals (G0) [336] or transgenes are mosaic, i.e. the inserted genes are not equally expressed in all cells and tissues, so it is important to confirm that they can pass on the gene in their gametes. At present the technology is serendipitous in that the numbers of gene copies

336 First generation stocks whose genetic material has been directly modified

and where they insert themselves in the whole genome is random. Each individual is therefore unique and the effect of the insert on subsequent performance equally so.

There is considerable concern expressed with respect to the potential biological impact of GM escapees on the environment, particularly if they were capable of breeding in the wild and with wild non-GM fish. If permits to farm GM fish are granted, it seems almost certain that a precautionary approach will be adopted and individuals will either need to be sterile, or farmed in highly secure landbased systems (possibly both). These precautions may result in higher production costs, which could counteract to some extent the economic advantages of the GM approach.

7.5.5 Market Challenges

The prospect of GM salmon has caused considerable public disquiet and it is notable that the Aquabounty product has not yet been cleared for sale by the US authorities. Within the EU, consumers generally have indicated reservations about GMOs, including GMOs in fish. Altering such perceptions faces many challenges, not least because of the diminished trust that many consumers have acquired through the various food scares. Alleviation of such concerns is likely to be lengthy and costly and is always liable to encounter ongoing resistance from greener elements of the market. However, this may change over the 10-30 year time horizon if the commercial rationale, and price advantages are compelling, consumer acceptance improved and ecological safeguards fully developed. In particular, recent developments of 'auto-transgenics', where genetic materials are introduced only from the same species, may offer a greater level of acceptance.

7.5.6 Prospects

Whilst it appears unlikely that GM fish will be cultured in Europe in the near future, it is likely that with increasing understanding of genomics, the potential uses for this technology will expand, and commercial pressures increase. Hopefully too, the benefits, threats and safety issues will be better understood. If the technology is introduced into commercial aquaculture, it has the potential to generate substantial change in established production systems and economics.

7.6 Use of Information Technology

7.6.1 Overview

The use of computers and information technology is spreading rapidly throughout the aquaculture production and marketing chain. Increased concern with the provenance of foods has been an emergent feature of EU markets over the past decade and given the current climate of concern with diminishing fish supplies this has become more prominent in fish products. Greater emphasis upon traceability has been enabled through IT innovation and a number of schemes currently exist and are under development to assist the tracking of product from the point of harvesting through to that of consumption. RFID tags, interactive encoded tags, biosensors and genetic coding, in addition to more standard bar coding and other paper based systems have all a role to play. At the consumer end increased attention is being given to mobile-based systems which will enable consumers to interrogate product detail at the point of purchase. It remains to be seen how this will sit within the increasingly congested retail queue for fish.

For aquaculture production, an integrated software system can be used to track batches of fish as they progress through the farm, to control stocking and feeding rates to decide on optimal harvesting strategies and to track the progress of fish from harvest through to ultimate point of sale. From a management perspective, this data collection and analysis can serve as a useful tool for optimising production and distribution efficiency and addressing batch related quality issues. This is particularly important where managers need to integrate information from a range of sources within a farm or across a range of farms. Central to these types of system are improved monitoring and measuring techniques, automated as far as possible for efficiency. For stock management, electronic fish counters, biomass estimators and feedback systems where the feeding behaviour of the fish can be used to control the feeding rate are now widely used. Environmental monitoring (temperature, water quality) is more important in recirculated systems.

Integration of traceability information across different companies within the production and market chain remains a significant challenge, as does the way that data can and should be accessed by different stakeholders including government agencies and ultimate consumers. The EU Tracefish project established a set of consensus-based standards for recording and exchange of traceability information in seafood chains based on XML files. This is now being further developed and gradually incorporated into software products.

7.6.2 Coverage

This is particularly important in the main commercial species where small improvements in performance can have very significant impacts on profitability. The rapid spread of IT in aquaculture has been spearheaded by the larger commercial companies, which through the current trend towards consolidation, particularly in the salmon industry, have tended to get even larger.

Although there have been many attempts to build integrated aquaculture management applications a few market leaders have come to dominate the industry. Examples are WiseFish by Maritech (www.wisefish.com) and FishTalk by the Norwegian company, AKVAsmart (www.akvasmart.com), not least because of the facilities they offer for integration into wider traceability and whole-chain management systems. Although these were originally developed for salmonid industries, the packages have been expanded for use in other species. Apart from these packages, farms are using a small number of less integrated stock management packages, or their own mix of spreadsheets and office databases, or in some cases, custom built applications. Many smaller farms still rely only on limited paper records.

7.6.3 Economic importance

Although the implementation of more complex information management systems are often seen as an additional cost overhead to farmers, if properly used they can also provide significant savings. Minor improvements in feed conversion or fish growth for instance, can result in major changes to company profitability. The economic benefits of integrated IT systems are likely to be more substantial for larger organisations, due to the size of the efficiency savings that might be made in comparison with the initial investment and staff costs.

7.6.4 Constraints

Cost could be a barrier to adoption of new IT systems in smaller companies as could attitudes to IT in 'non-IT literate' businesses. Another constraint could be the time taken to train employees in the use of relatively sophisticated systems, although modern programs tend to be more user friendly. This issue is of particular concern with the introduction of more rigorous traceability requirements as it could force the smallest businesses (of whom there are many in the freshwater and shellfish sectors) out of the mainstream markets.

7.6.5 Prospects

Technology itself is one of the driving forces behind the increasing use of integrated IT systems. Particularly the shrinking costs of computing power and recent improvements in communications making it easier to link information sources throughout the production chain. Broadband services are now affordable in most EU countries with commercial aquaculture sectors. Information from widely spread production sites can shared and integrated at the company headquarters or a dedicated processing factory. The other major driver is the pressure from market and regulators for full product traceability. With the IT sector continuing to develop rapidly, especially with respect to mobile computing (power and network connectivity), further impacts on the aquaculture sector appear inevitable.

7.7 Reduction of fish oil and fish meal levels in feeds

7.7.1 Overview

Most aquaculture diets contain significant amounts of fish meal and fish oil as these have suitable nutritional profiles for carnivorous fish species such as salmon, trout, cod, sea bass and seabream. Commercial salmon feeds contain around 45% fish meal and 25% fish oil. With the growing use of feeds for aquaculture, not just in Europe but worldwide, and a static supply of raw material from wild fisheries, many analysts predict a shortage of these products in the medium term future.

There are alternatives to fish meal and fish oil. Commercial salmon feeds are now available where a large proportion of the fish oil has been replaced by vegetable oils. Fish meal can also be largely replaced by processed plant proteins and supplementary amino acids. However this has not, as yet, been an economically viable alternative, particularly when concerns over digestibility are taken into account. There are other sources of marine derived proteins that could be used, however these are still at the research stage.

This research is continuing against a background where the fish meal manufacturers claim that there is unlikely to be a supply crisis in the near future and that the fisheries for these products are already well regulated. Retailers have also shown some resistance to changes in the diet. This appears at least in part to be based on concerns about fish welfare if carnivorous species are fed a vegetarian diet, with a different protein and fatty-acid profiles.

7.7.2 Coverage

The main species affected are those that require high protein and oil levels in their feeds (carnivorous species); such as salmon, trout, sea bass and sea bream, and including most emerging species in the EU. There is also an international context because the demand for high quality fish meal is international, and is currently being driven by the growth of animal rearing enterprises (including aquaculture) in countries such as China.

7.7.3 Economic importance

There are already clear alternatives to the use of fish meal and strategies which can be used to reduce the fish oil content of salmonid feeds. For most producers it comes down to a question of price – if fish meal and fish oil costs rise substantially, these approaches will be more widely accepted.

7.7.4 Constraints

One of the main issues is the quality of the meals and oils used in aquaculture feeds, particularly in salmonid feeds. The main feed manufacturers have developed very nutrient dense feeds which require very specific, low temperature processed fish meals to work effectively. These are difficult to replace without significantly decreasing the efficiency of feed conversion to fish flesh.

7.7.5 Prospects

It seems likely that there will be a continued trend towards the substitution of fish meal and fish oil with more sustainably sourced products, not just because of financial pressures but also because of increasing awareness by fish buyers and consumers of sustainability issues.

7.8 Harvesting/Processing innovations

7.8.1 Overview

Harvesting and processing innovations can have a major impact on the profitability of aquaculture operations. Larger fish farming companies are introducing integrated harvest-killing-transport systems that shorten the time taken to transport fish from the farm to the processing plant as well as ensuring that it reaches the plant in good condition.

Humane killing is another area which has grown in importance in recent years. Most salmon farms now use humane killing methods, usually percussive stunners combined with gill cutting which improves animal welfare because they are insensible when they are killed. Rapid death also results in better flesh quality. Electrical stunning devices have been developed for smaller fish such as trout – the main UK trout farmers' body, British Quality Trout now insists that electrical stunners are either installed or will soon be installed at member's farms.

Increased understanding of the relationship between flesh quality and a reduced stress environment prior to killing has acted as an important driver. As consumers become more discerning in their demands for higher quality fish products, practices pre and post harvest are liable to be increasingly recognised as opportunities to add value to the product.

Given the established interests in fish processing machinery and their prospects of diminished throughput from captured fisheries greater specific orientation towards farmed fish can be expected. A number of farmed species specific filleting machines have been launched and further refinements through improved yield controls and portioning technologies are evident. Another important innovation is the development of automatic pin-bone removal machines which can process fillets before rigor mortis – again this reduces the time taken during processing.

7.8.2 Coverage

While innovations have generally been led by the larger salmon farming companies, there has been rapid uptake of new practices by most salmon operations.

Marine Harvest Scotland now harvest almost all their salmon by transferring them live to well-boats which take them to a centrally situated killing station. During transport, the fish are chilled to 4°C and are then pumped into the land-based killing station. This is equipped with stunning machines immediately after which the fish are killed by gill cutting and transferred to a slurry-ice filled tanker for transport to the processing plant. The result is that handling is minimised, rigor mortis is delayed, primary processing can be carried out immediately and fish is despatched sooner and in better condition to their customers.

7.8.3 Economic importance

Any improvement in quality or shelf-life will have a big impact on profitability and competitiveness. Improved product yields hold considerable potential for further gains. Fillet and portion yields have been shown to be capable of further improvements through laser-guided systems and other more conventional routes such as flesh-bone recovery systems have also received growing attention.

7.8.4 Market challenges

The prospective range of products from farmed species has broadened considerably over the past 5 years and simple reference to those based upon captured supplies indicates that many further extensions might yet be realised. Advances in processing and handling technologies have created opportunities to produce a much wider range of added value products, in some cases with the added benefit of using flesh that was formerly disposed of for much lower unit value products. At the upper end of the market, technical progress has encouraged the adoption of machinery that can improve the consistency of delivery of attributes sought by consumers such as products guaranteed to be bone free.

7.8.5 Constraints

Practices that are deemed to be important in one country may have a much lower priority in another. For example, while humane killing is important in northern Europe, attitudes of producers and consumers in southern Europe tend to be more ambivalent.

7.8.6 Prospects

Economic pressures mean that all commercial producers will be looking for a competitive edge for their products in the marketplace which will include shelf-life and flesh quality. Harvesting and processing innovations offer ways to achieve this.

7.9 Packaging and retail innovations

7.9.1 Overview

Important packaging innovations such as modified atmosphere packs and vacuum skin packs mean that fresh aquaculture products such as fish fillets and shellfish can be distributed through conventional retail channels, notably supermarkets. This has allowed seafood consumption to grow and compete more effectively with alternative food choices despite the decline in specialist retail outlets such as fishmongers.

Aquaculture products such as salmon are also increasingly replacing capture fisheries products in fresh and frozen prepared meals. Farmed products have significant potential advantages related to their greater assurance of availability and quality at a given price. These characteristics were traditionally much less certain with wild fish supplies and did not sit easily within the contemporary retail food environment.

Retailers are increasingly requiring full traceability of food products. Methods under development to improve traceability capabilities include: fluorescence spectroscopy to differentiate between fresh and frozen-thawed fish; biosensors to determine freshness, such as smart packaging which changes colour as the product decays; and tests for determining properties of fish oils to test whether fish is wild or farmed.

7.9.2 Coverage

Packaging and retail innovations are now being used to expand market opportunities for a wide range of aquaculture species. Aquaculture products tend to be sold at the higher end of the fish product chain and are usually sold fresh. The most basic form of retailing is as whole fresh fish or unpackaged fillets however this severely restricts the type of retail outlet that can be used to specialist fishmongers and supermarkets with wet fish counters. Leak-proof packaging means that aquaculture products can be placed on self-service supermarket shelves thereby reducing the transaction costs for the retailer. The same applies to shellfish; new retail packaging systems mean that they can be sold through a much wider range of outlets.

7.9.3 Economic importance

New packaging systems offer a way for the aquaculture industry to increase the overall size of market sectors. More importantly packaging and presentation of the product in a format consistent with consumers' expectations for all foods enables fish to compete on level terms rather than as some inferior good that might only be purchased for variety.

7.9.4 Constraints

Packaging innovations primarily apply to species that are sold processed and can be supplied in sufficient quantities to retailers. However larger bulk handling systems, such as MAP, have also become increasingly popular throughout the chain and can be expected to continue to grow.

7.9.5 Prospects

This is an area which is driven to a large extent by available technologies. As new packaging technologies develop, new retailing opportunities will be created.

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8 Drivers and barriers to emerging systems

8.1 Overall drivers and barriers to development of the European aquaculture industry

The drivers and barriers to aquaculture development are perhaps well documented and broadly understood, but this study provides specific evidence for each of the main emerging issues identified and, therefore a summary of the main issues for the sector.

Barriers are largely driven by caution, which is to be expected where human beings are involved. Most interestingly, when considered in the context of the foci of both FP7 and EFF, the main barrier reported related to limited experience, knowledge and training of workers in the sector, closely followed by concerns about the use of non-proven technologies requiring further research before farmers would be convinced to try them. Beyond direct consideration of aquaculturists, the costs of diversification were often seen to outweigh immediate benefits, especially in a climate with cautious and perhaps ill-advised financing bodies unwilling to support emerging sectors.

Drivers were more directly related to market need – the chance to capitalise in niche sectors or to increase volumes to reduce costs. The limitation of very few new sites for existing aquaculture practices and species as well as concerns over limited water availability and other competition with potential resource users were also significant drivers. However, the most important driver, with both a push and a pull effect, was environmental pressure. At the 'push' end this was linked with increasing regulation (pollution control and fees) and at the 'pull' end with a desire to improve public image (to gain greater market benefits). Again, as a main driver this fits well with the overall aims of FP7 and EFF.

8.2 Economic viability/profitability of emerging aquaculture systems and species

8.2.1 Emerging systems

Much of the new technology in emerging aquaculture systems has much greater capital costs than existing operations. These systems may rely on economy of scale to achieve lower operating costs in the long term. This however, has the knock-on effect of making initial operating costs higher before a return is seen. This may be the case with offshore systems for example which may be able to achieve much greater site capacities than inshore systems could hope for. It is unlikely that a product that is grown offshore will fetch a higher price than the same product grown inshore unless some sort of certification is gained or much higher site capacities are used. However, sheltered offshore sites that can use inshore technologies may be able to produce for less if they can achieve higher capacities.

RAS systems are likely to encounter some of the same problems. Capital expenditure can be extremely high, therefore RAS operators tend to produce species for niche markets such as marine hatcheries. They have the advantage that they can save money on heating or cooling water and therefore offer the potential to grow more exotic species such as eel, tilapia and African catfish. Consequently, species selection for RAS is of utmost importance. The most successful ones will be those which can achieve extremely high stocking densities such as African catfish or those which can supply a very high value niche product such as sturgeon. The establishment of viable markets for these species may be paramount to their success as present consumption in certain areas is low.

With respects to Integrated Multi Trophic aquaculture, there are a number of factors that may affect its establishment. Firstly consumer attitudes to the safety of a product that uses the waste of other species for its food or nutrient source and also farmers may not wish to invest in a product that may have low commercial value and hinders the operation of the primary product. The most obvious example of this is shellfish culture associated with fish culture. The shellfish may not have high value in themselves because of their proximity to finfish farms although so far there have been no bad reports of any contamination in existing operations. They may however, make certain fish farm operations such as harvesting or treating more difficult. Conversely there is the prospect that these systems could clean up sufficiently to allow for extra capacity or possibly help towards organic certification. There is on going research into IMTA with the "Genesis Project" in Europe, which has shown some promising results supported partly by anecdotal evidence in Scotland, that reported oysters cultured near to a salmon farm grew twice as fast as in standard oyster farms. The regulations on organics are however, already complex and their application to multi trophic systems is unlikely to be any less so, at the very least.

8.2.2 Emerging species

Most species which are currently emerging in Europe use similar technologies to those which are already being used for established species e.g. ongrowing of blue-fin tuna in offshore sea cages in the Mediterranean Sea. They tend to be for niche markets and therefore the major constraint to their development is usually the supply of juveniles. In the case of blue-fin tuna and octopus, juvenile supply relies on wild capture and this will need to be addressed if the industries are to expand and remain sustainable. However, with wild stocks of many commonly consumed species declining fast the financial potential for new aquaculture species is potentially high. One of the species perhaps with most potential is cod. As it is already an established staple species, consumer acceptance is not a problem, but whether a competitive price can be extracted for large volumes of farmed cod remains to be seen . Currently however, it is still cheaper to buy wild caught cod than the farmed, despite the crisis in wild stocks. Farmed cod costs may reduce if the problems associated with juvenile production can be resolved, but a potentially strong competitor from wild stocks is stil liable to stalk the market.

Juvenile production may also pose problems for halibut, turbot and charr. Halibut and turbot have similar production problems to that of cod whereas charr may have problems because there are currently very few egg suppliers and additional problems with the many different strains of charr, some of which may be totally unsuitable for aquaculture. All carnivorous species, meanwhile, have potential problems with respect to nutrition as all rely on the supply of fishmeal in their diet. Fishmeal is by far the most expensive component of the diet and prices may fluctuate wildly depending on catches of species used within the fishmeal industry. Until there are alternatives to fish meal for aquaculture diets, all of these species will have a finite capacity. It should be pointed out however, that a large proportion of fishmeal is used outside of aquaculture activities, for terrestrial livestock that do not have the same dependency. Altering this pattern of demand may in turn prove possible, subject to the cost of alternative feeds for poultry and other competing user groups.

8.3 Technical/biophysical constraints on emerging aquaculture systems and species

8.3.1 Systems

Many of the technical and biophysical barriers to development of emerging systems and species have been mentioned above because they have a knock on effect to the financial feasibility. For offshore systems, the most important constraint is the ability of the system to be able to withstand the extreme environmental conditions that will be encountered. Other factors are the ability to service the facilities adequately in those conditions and the welfare and security of the stock. Only the most expensive submersible cages are likely to be able to cope with the sea and weather extremes encountered in the North Atlantic around the UK, Ireland, Iceland and Norway. The success of these systems will depend on economies of scale and possibly the ability to achieve a certified status as a result of better environmental impacts or a better quality product.

RAS should have very few biophysical constraints because it is the most highly monitored of all the emerging systems. It allows for the highest stocking densities and water is filtered and usually disinfected or sterilised through many advanced treatment units. The most likely constraint is the expertise needed to operate these systems. These high technological issues are not likely to be a problem with IMTA. They generally use cheap solutions to try to solve environmental problems. The most likely barrier in terms of biology is that the secondary species may introduce disease risk to the main culture species and in many cases this is unknown and as mentioned, the secondary species may be perceived as contaminated by the waste of the primary species and therefore worthless. For operators, technical difficulties and the cost of specialist expertise required for the production of more than one species may impact upon the feasibility of the project. Additional species grown will need to yield an adequate profit to attract and make investment worthwhile. At present, commercial operations are slow to invest in IMTA as a result of low profitability.

8.3.2 Emerging Species

For emerging niche species, the most pressing barrier is the supply of juveniles and possibly the juvenile supplier trying to find a market for the product. For certain species, as mentioned there is no juvenile production but a reliance upon wild caught juveniles. Even within some species where juvenile production is possible, there are still many problems that need to be solved to improve the overall viability of production. This is most evident in the marine species. For cod, halibut and turbot, mortality rates are all extremely high. Problems exist with egg quality, cannibalism, weaning onto artificial diets and labour intensive grading. If these problems can be addressed and production costs reduced, all of these species offer excellent potential as already established food products. Supply of juveniles is also a problem with charr. Not because of technical problems associated with juvenile survival as much but simply because there are so few suppliers of charr eggs in Europe preventing the production of charr to market size. This could be considered a market problem and demand will dictate the establishment of facilities for charr production as mentioned previously. There are well established suppliers in Canada and the USA, however it should be possible to set up supplies of reliable strains in Europe. Problems with early maturation exist in many species, whereby somatic growth is sacrificed for gonad development. This is the case with cod and other marine species but is also extremely important with tilapia as the majority of the females mature early and have to be graded out. Therefore a minimum of 50% of the stock will be lost and it will become increasingly costly if these females are not removed at an early stage.

The dangers of introducing alien invasive species is widely documented, not only within aquaculture circles. The case of the Nile perch in Lake Victoria is one of the most famous examples where it devastated many populations of the hundreds of unique native cichlid species in the lake. Therefore the interactions of new species with indigenous should be investigated and could be a barrier to their establishment as aquaculture species in some places. This could be solved by improvements to cages, rearing fish in closed systems such as RAS or producing sterile progeny through triploidy or other means. The technology for triploidy already exists in some species such as trout but is not widely used because of high mortality. Any new species that is developed to a large scale will probably encounter many biological and technical problems as the salmon industry did and the developers should be aware of thisand factor it into their investment plans.

8.4 The market: product demand, public acceptance/image, demographic factors

Some of the main market challenges to aquaculture include a fall in market prices due to high global competition, increased supplies and fluctuations in demand. High production costs in many European countries, especially due to labour, reduce the competitive advantage in relation to other global suppliers. This vulnerability is heightened with trade liberalisation. Market expansion and overproduction has saturated markets resulting in reduced prices, and therefore lower profit margins for producers. This has been clearly evident in the salmon and bass and bream industries.

New species of high unit value may have a finite capacity within the market place because demand is typically unlikely to be sufficient to warrant large scale development e.g. sturgeon farming for the production of caviar will probably not have the same potential as cod. In the case of species such as carp the same situation could arise. Carp is a fairly insignificant species in most parts of Europe, albeit with some notable exceptions, but is widely cultured in Asia. If a large market for carp was to be established in Europe, potential European producers may rapidly face stiff competition from Asian imports produced at much cheaper rates. Diversification of the species reared in the EU should help the EU to compete in more niche markets, possibly on a global scale.

There is also a stigma attached to certain species or farmed products compared to the wild in some countries. A number of factors contribute to this expressed preference. Aquaculture is still considered as a relatively recent food and many consumers have very limited understanding of the process. The locational characteristics of fish farming means that it tends to be outwith the sight of most consumers and leave them reliant upon indirect information sources. Within the media there has been a growing body of adverse opinion, much of it directed at salmon, which has compared farmed product adversely to wild. Whilst many of these claims can objectively be criticised for being unrealistic, bad publicity does tend to stick and diminution is costly and often beyond the capacity of smaller independent producers. Changing perceptions and attitudes to farmed fish is likely to take a long time. In some cases simple changes may be enough. Anecdotal evidence has suggested that African catfish, whilst difficult to sell in some markets if sold as catfish, may sell well if called *Clarias*. In most other cases it is likely that rather more complex approaches will be required. But with delivery of a product standard consistent with consumers' expectations, and the ongoing conditions in capture fisheries, there is seems little reason to doubt that more widespread acceptance of farmed product will occur.

Consumer concerns regarding the quality of food and its safety are increasingly important factors that influence purchase decisions, in addition to varying sensitivity to price. As noted above, many consumers currently believe farmed fish to be inferior to their wild counterparts. There are many issues that contribute to this relative perception, perhaps not least being the comparative novelty and limited experience with farmed fish. As awareness increases more traditionally tangential attributes such as the ethics of the production with respect to welfare, environment and sustainability are likely to play a larger role in food choice.

Intensive production systems often draw negative associations with the public, in particular raising concerns regarding animal welfare and disease treatments. RAS for example relies on economic output per unit rearing space and high value species in order to cover capital and investment costs. Whilst there may be an incentive to utilise the investment more intensively via high stocking densities, the downside is the greater likelihood of generating welfare concerns for consumers. Parallels with poultry are readily drawn to mind, despite the fact that most consumers have very little objective notion of what actually constitutes dense stocking in fish.

The introduction of biotechnology and genetic manipulation also tends to invoke adverse reactions. Such areas are commonly little understood by consumers and their trust in innovation has been eroded through the failure of communications in the past. Whilst such technologies may bring benefits, not least being the prospect of lower cost raw material, residual doubts often prevail and result in market rejection.

Offshore production of salmon has higher capital and operational costs than inshore production. In this instance, offshore producers may find it difficult to command a price premium as consumers will be inclined to view both as essentially the same product. However, experience from the poultry sector, such as free range chicken, would suggest that some consumers are willing to pay price differentials according to the type of husbandry. It may thus be a matter of communicating these differences in fish and attempting to gain greater awareness of the fuller price implications of such methods.

Differentiation could be enhanced using one of the certification schemes, possibly promoting greater sustainability. An extension of this trend has been witnessed with organic production where the currently high demand for organic produce generally has spilled over into fish. Organic salmon produced in the U.K. and Ireland command higher prices (typically around 30% more) and this is currently exceeded in the case of the more limited supply of organic cod. However uncertainty surrounds the marginal capacity of many of these markets, especially as they are without precedent elsewhere.

The identification of niche markets and early entrance into them before rapid expansion of supply leads to downwards price pressure is important for fish produced from high cost systems. Producers want to capture as much of their initial investment costs as soon as possible, but must set this goal against their longer term pricing strategy and, more likely, their ability to exert any influence over emergent competitors. The RAS production of barramundi in the U.K. is a good example of targeting a niche market whereby the operation aims to supply c400t per annum to restaurant markets in London. The high unit value species is intended for the upmarket foodservice and retail sectors whose prices can cover the extra capital and operational costs of the recirculation technology. Uncertainty however prevails about the impact of cheaper flown-in imports and the ability to retain a differential against other emergent competing species.

A number of emerging species in the EU are farmed on a small scale providing fish to local markets, e.g. meagre, Arctic charr, sturgeon and tilapia. Debate is currently emerging whether the better pattern is to try to expand the market through conventional market-led growth or to develop a more fragmented supply base which can satisfy more localised markets

In 2004, aquaculture in the EU provided 80,000 full or part time jobs, equivalent to 57,000 full time jobs and aims to create 8-10,000 secure full time jobs from 2003-2008. The EU has an estimated 100,925 km of coastline[337] however

337 http://www.eurosion.org/reports-online/part2.pdf

fisheries and aquaculture only account for only 1-5% of national employment. Nonetheless, in areas where fisheries and aquaculture occur much higher percentages can be found. Levels of 10-20% are shown for some countries e.g. Italy, parts of France and Scotland, and within some more narrowly communities these activities and the related services may be the only form of employment available.

There are no breakdown figures for aquaculture processing but overall processing for the fisheries sector employed 147,102ftes for 2002-2003. Employment in the seafood sector has remained stable with some growth in employment in the aquaculture sector at the country level. France and Spain employ the highest number and these figures are reflected in their production figures and the type of production systems used. In some parts of the EU there have been substantive falls in employment in all sectors of fisheries and aquaculture, not least through boat decommissioning, substitution of capital for labour in farms and reduced capacity in processing.

Growth in aquaculture employment may be expressed through more jobs in allied support services as capital investment in more efficient production. Conversely, more capital intensive processing may reduce labour requirements as processing factories become more specialised. As technology improves and farming operations become larger and more automated, fish farms may become less labour intensive. Consumers are spending less and less time preparing food and a direct result of this is an increased demand in value added goods. If present trends continue, Professor David Hughes of Imperial College predicts that by 2010, the average UK household will spend less than 8 minutes per day preparing food[338]. As this demand for value added products grows, the products processed are liable to be more suited to mechanised processing plants and so some debate exists as to the overall impact on employment in processing, handling and transport.

338 Cited in http://www.globefish.org/filedownload.php?fileId=215 and http://www.griequity.com/resources/industryandissues/foodanddrink/3ifoodanddrink.pdf

Table 8.1 Likely Investors in Emerging Aquaculture Systems in the EU

System/species	Likely Investors	Comments
Cod offshore (growout)	Already established major producers and SMEs looking to diversify or buy into new market.	Cod growout uses largely the same technology as salmon growout, therefore changing to cod from salmon should be easy. Offshore cages are more expensive than inshore so is much more likely in areas where inshore is not possible. Norway, UK, Ireland all offer potential esp. Ireland with already established offshore salmon industry.
Cod Juveniles, (RAS)	Large scale producers looking to supply developing growout markets. Innovators and venture capitalists.	High levels of investment required with some risk. Potentially a very high value product. Dependent on capture fisheries market. Still a lot of research needed to optimise production. UK and Norway already have established hatcheries, potential in any temperate country with coastline.
Salmonids offshore (growout)	Large companies wanting to improve their environmental image, certified producers.	Higher cost of production and capital costs than inshore. Unlikely to have investments within countries with established inshore sites. Other countries may find difficulties breaking into oversubscribed markets with cheap products. Tougher environmental legislation could force companies to change to offshore. Ireland, Denmark, Norway already have offshore farms.
Salmonid hatcheries (RAS)	Large established producers, who need to improve environmental aspects or cut down on space or water supply.	Little room for investment in an already oversubscribed smolt and trout market. Only stricter environmental legislation is likely to encourage investment. Faeroe Islands, Norway, UK, Denmark, Finland, France and Ireland have some sites.
Catfish (RAS)	Medium sized investors, venture capitalists and entrepreneurs.	Can achieve extremely high stocking densities, therefore price of production per tonne is lower than for many other RAS systems. Potential for the species in western markets is largely uncertain because of consumer attitudes. Czech Rep., Germany, Portugal, Netherlands, Poland and Hungary have farms and are establishing catfish markets. Good potential anywhere.
Sturgeon (RAS)	Medium sized investors, venture capitalists and entrepreneurs.	Potentially high value product form caviar. Higher capacities achievable than flow-through. Germany, Hungary, Italy, France, Finland. Potential across Europe.
Eel (RAS)	Potential for medium sized investors, venture capitalists and entrepreneurs in countries where no eel farming exists.	Finite capacity as sustainability of elver capture fisheries is an issue. Some farms have closed and market has stabilised in some countries with no room for extra expansion. Fairly reliable established product. Belgium, Estonia, Denmark, Germany, Spain, Netherlands, Czech Rep. Greece, Sweden have eel farms.
Offshore marine (Sea bream , sea bass, bluefin tuna)	Established producers looking to expand or diversify. New small scale investors in new areas.	Potential sites exist in countries that do not actively encourage aquaculture, e.g. Portugal and Italy. Offshore is cheaper in the Mediterranean because sites are less exposed than in the Atlantic and cages can be floating. Blue fin tuna market is finite because it relies on capture fisheries for “seed”, also largely relies on Japanese market. Cyprus, Greece, Italy, Malta, Portugal, Spain, UK.
Marine growout (RAS)	Established producers who wish to diversify into high risk niche markets.	Most likely in areas where inshore is unavailable and offshore is unsuitable. The product would need to be a high value species that could compete with the inshore market.
RAS marine hatchery (Sea bream , sea bass)	Large marine growout companies. SME investors looking to supply growout companies.	Fairly well established but more potential for marine hatcheries will arise with a growth in marine growout farms. More control over water quality possible than marine flow through farms which still require a lot of pumping energy. France, Greece, Italy, Portugal, Spain, Norway, UK, Denmark, Ireland, Netherlands, (Turkey).

System/species	Likely Investors	Comments
Salmonid growout (RAS)	State development, research institutions. Very large companies looking to diversify.	Must be on a very large scale or produce an absolute premium product to be economically viable and to compete with inshore, offshore and flow through systems. Finland, Denmark, Ireland.
Tilapia (RAS)	SMEs, venture capitalists looking to produce niche product.	Must be able to fetch a good price to make it viable. Netherlands, UK, Czech Rep.
Shellfish offshore		Little or no waste. Pseudofaeces may be a problem with inshore but little is known. Little reason to grow offshore except for avoiding land-based pollution or site availability issues.
Integrated Multi-Trophic Aquaculture.	Organic and other certified farm operators. Large companies looking to strengthen their position compared to offshore or certified producer or increase production. Other SME investors in niche markets.	There is currently little integrated aquaculture although there is a lot of polyculture. It is reasonable to assume that there will be a substantial increase in IMTA as producers look to improve their public perception. IMTA offers cheap solutions and the possibility of secondary incomes. Italy, Portugal and the UK are looking into IMTA.
Organic Marine and Salmon.	SMEs looking to buy in to niche markets and large producers looking to clean up their image in the long term.	The Soil Association has recently issued standards for organic salmon farming and cod have been produced for a while now. More organic producers may arise as consumer pressure increases, as long as there is a clear distinction from the usual farmed product. There are some problems with some aspects such as animal welfare, provision of fish meal and possible treatments. There is also some friction within certification agencies as to whether fish farming should have been allowed certification. UK.
Organic Shellfish	Existing bivalve producers looking to promote their product. Any other investor looking to get into bivalve market where it is currently undersubscribed.	Very contentious issue as to what the difference is between organic and non-organic bivalves. Soil association recognise there is little or no difference but are producing standards for organic bivalves. Standards already exist in Germany with Naturland. There is likely to be little investment needed for existing growers to achieve organic status.
Crustaceans (shrimp)	Unlikely to grow significantly as an industry until the culture cycle can be closed effectively.	Some shrimp culture already exists in Greece and France but negligible. Industry is still largely dependent on wild catches of juveniles or gravid females although there are hatcheries in existence. Market must compete with Asian production which is oversubscribed. Culture in Europe would need to be recirculation to maintain heat required.

9 Conclusions

The aim of this report was to identify and characterise the main emerging aquaculture systems. This has been carried out by collecting detailed information on the technologies, by outlining the geographical context, by analysing their technical and financial feasibility and by discussing drivers and barriers, environmental impacts and future prospects.

9.1 Main findings

9.1.1 Offshore systems

Much has been made of the potential for development of offshore aquaculture systems and these systems are already in use in Ireland and Norway for salmonids and in Spain, Portugal, Malta, Greece and Cyprus for sea bass, sea bream and tuna. Major growth of the sector is being seen in Cyprus and Italy whereas offshore production has been fairly static in other producing countries. There is a wide range of systems available and the technology can be used for the production of an increasing number of species.

The major drawback for offshore systems is high capital and operating costs compared to inshore sites. Cage and mooring system designs need to be more robust, larger service vessels are required, SCUBA divers are often involved in regular maintenance operations and the distance from shore base to the farming site adds extra transport costs. This means that offshore production systems cannot compete directly on price with fish produced at inshore sites. On the other hand, the relative difference in costs shrinks at larger sites and where all the available inshore sites have been allocated, offshore production provides a clear option for development.

Because the scale of development has a clear impact on feasibility, and it carries significant risks, offshore developments will probably only be carried out by companies that have already been involved in large-scale aquaculture production. It would be difficult to forsee openings for SME companies in future developments. Fish sale price will also have a major impact on the profitability of offshore systems. At the minimum sale price for salmon in recent years a new system would not have been viable, whereas more recent higher prices would suggest an enterprise of this type could be very profitable.

The main drivers for the establishment of offshore systems appears to be the shortage of available inshore sites and increasingly strict environmental legislation. In some cases this is because inshore sites have already been developed – in others there are official policies to separate aquaculture production from competitive uses for coastal zones such as tourism.

In summary, offshore aquaculture appears to have a bright future, if only because there are few other tried and tested options for substantially increasing aquaculture production. The key to its future development will be production scale, achieving competitive cost of production and product prices – if growth in demand outstrips supply from inshore systems, prices will tend to rise and offshore systems should be increasingly viable.

9.1.2 Recirculation systems

A wide range of recirculation systems have been developed for an equally wide range of species however commercial fish production using these systems has been fairly limited - only around 20,000 tons/annum in the EU25 + Norway compared to around 500,000 tons/annum from cage farming in Norway alone.

Experiences with recirculation systems have been mixed. They generally require a high degree of management expertise, have higher capital and operating costs compared to conventional farms and involve greater risks – a major system failure can very rapidly lead to the loss of the entire stock of fish. On the other hand, they make very efficient use of available water supplies and allow fish to be grown in optimal conditions in close proximity to potential markets. There have been minor booms in enthusiasm for recirculation systems over the years for relatively high value species such as salmon smolts, eels and turbot. Other farms have concentrated on species that perform exceptionally well in recirculated systems such as tilapia and catfish. Despite a relatively long history, proponents of recirculation technologies have found it difficult to sell the concept to large-scale fish producers. Environmental groups, particularly in the US and Canada, have frequently suggested that aquaculture production should be shifted from cage sites to land-based recirculation farms so that aquaculture pollution from be better managed. However, little research has been conducted into likely consumer responses to recirculated systems if they were to become more prevalent.

The financial feasibility model used in this study shows that a 120 ton/yr turbot farm should be viable, however this is at a fish sale price of €9.39/kg whereas salmon and trout prices are less than half this. For the main aquaculture species it is much harder for recirculation systems to compete with conventional production systems. However, recirculation systems offer a flexible way for niche producers to supply specialist, high value markets. There is also scope for further technical and cost optimisation as well as scale economies that could lower the barriers to adoption slightly.

9.1.3 Integrated systems

Although integrated systems offer the prospect of more efficient use of resources, the development of commercial systems is still at an early stage. The few commercial fish farms that have already embraced the concept of integrated production are still at a pilot-scale level and appear to value it more on ideological grounds than the purely financial point of view.

It remains to be seen whether integrated systems will develop into a significant sector in Europe. There appear to be legislative barriers to its adoption in some countries, potential risks concerning market image, and a reluctance on the part of some commercial fish farmers to accept that it may have a serious role to play in the future.

9.1.4 Certification systems

There has been tremendous growth in the range of labelling and certification systems used for aquaculture products in recent years. This mirrors trends in the overall food sector with consumers being offered greater choice and more information than ever on the source, attributes and quality of their purchases. In particular sectors, such as organically certified salmon, production has not been able to keep up with demand, however there is also evidence that the plethora of labelling and certification systems has left consumers confused. Producers need to weigh up the substantial actual costs and opportunity costs involved in producing specialist certified products against the potential increase in prices that they might obtain when they are fully certified. At present, very few large producers appear to be convinced that organic certification is worth pursuing. However a number of small, very committed producers clearly think it is worthwhile, and some larger producers have designated one or more organic production sties. More general certification systems are being applied to many other aquaculture products and this is likely to increase in the future.

9.1.5 Emerging species

European commercial aquaculture production is based on relatively few major species, although a wide range of species have been tested at experimental or pilot scales. The most significant developments in recent years have been the growth of marine finfish aquaculture in northern Europe and Norway to levels where cod and halibut farming could start to make a significant impact on markets, and the growth of tuna fattening in southern Europe. The sustainability of tuna fattening is questionable as it depends on severely depleted wild-caught stocks and wasteful feeding practices. The industry has grown due to the strength of the Japanese market which may not be sustained.

There are new possibilities for marine finfish farming in southern European waters through the development of farming systems for species such as meagre. The key requirement for new species development is a ready market for the product and this is a constantly changing factor. In some cases, markets are likely to improve as wild fisheries come under increasing pressure. In other cases, aquaculture production will have to fit in with seasonal fluctuations in fish prices.

The level of technical knowledge which is required for new species development should not be underestimated. Each new species presents a new suite of issues that must be investigated – not just feed and breeding requirements but more complex issues such as disease challenges and possible environmental impacts of large scale farming of that particular species.

The pressure to identify new species for aquaculture has also grown because regulatory authorities have become more worried about introducing new species or even new genetic strains of species from other geographical locations. These factors mean that research into new species development will continue, although market forces will determine which of these species can be developed into commercially viable industries.

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Title: Prospective Analysis of the Aquaculture Sector in the EU. PART 2: Characterisation of Emerging Aquaculture Systems

Authors: Helen Sturrock, Richard Newton, Susan Paffrath, John Bostock, James Muir, James Young, Anton Immink & Malcolm Dickson

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Abstract

This report is based on the outcome of the study on "Prospective analysis of the aquaculture sector in the EU", launched and coordinated by the JRC (IPTS) and carried out by the University of Stirling. The report consists of two parts:

1) "Prospective analysis of the aquaculture sector in the EU - Part 1: Synthesis report", and
2) "Prospective analysis of the aquaculture sector in the EU - Part 2: Characterisation of emerging aquaculture systems."

This second report is concerned with the identification and characterisation of emerging aquaculture systems. The overall aim of the study is to provide a detailed analysis of how the EU aquaculture sector may respond to the many challenges and pressures faced with respect to economic, social and environmental issues, technological changes etc. As has been the case in the past, these challenges may lead to the emergence of new approaches, products and in the widest sense, aquaculture systems. The degree and possible directions of development of these "emerging systems" will be influential for the future of the EU aquaculture sector. This report aims therefore to provide greater technical detail on emerging aquaculture systems, and has also fed to the development of the synthesis report (Part 2). It follows a format in which we:

- Provide detailed descriptions of the technologies, European overviews, detailed country perspectives, technical and financial feasibility, drivers and barriers, environmental impacts and prospects for each system.
- Give a brief overview of the drivers and barriers to emerging aquaculture systems including a discussion on economic viability/profitability, on technical/biophysical constraints and on market issues.
- Develop conclusions.

The study was conducted between January 2006 and November 2007, the data collection taking place in the early stages followed by the analysis in the later stages.

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