farming the deep blue

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Author's Preface

James Ryan, Author

I have vivid memories of my first encounter with offshore aquaculture. Back in the mid 1980s when I was operating a salmon farm in sheltered waters off the west coast of Ireland,I was asked one day to assist a sister-company with its smolt transfer. Their site is located about 6 kilometres off the mainland and is only partially sheltered by Clare Island to the southwest.It may well be one of the world's most exposed sites using surface cages.

We arrived with our 12-metre workboat to the appointed mainland pier, transferred the smolts from a truck to deck-mounted tanks, and headed west towards Clare Island against a stiff Force 6 and a swell that increased dramatically as we entered exposed waters.

On arrival at the farm it took some time to tie our 'rocking and rolling' boat to the undulating hexagonal rubber collar Bridgestone cage. We began offloading the smolts into the cage, while to me the swell assumed enormous proportions.

Within minutes, the heavy mooring lines from the boat to the cage were threatening to break and I was feeling decidedly seasick. The farm foreman grinned at my discomfort and assured me: "We have weather like this most days."

It is a source of amazement and encouragement to me that 17 years later, the Clare Island farm is still operating and going from strength to strength,although both its technology and operating methods have changed considerably since those early years. The farm's crowning achievement is the quality of its fish,which is renowned worldwide and is marketed under its own brand as 'organic salmon' throughout the Wild Oats retail chain in the United States. I believe that the high quality end product is largely attributable to the offshore location of the farm,supporting the theme of this report that offshore is better.

But the offshore environment is a challenging one for people. We must,therefore, apply more sophisticated technology in order to make offshore farming easier. And,not only easier, but safer. It is deeply shocking to remember that the Clare Island farm lost its site manager, Tom Ryan,some years ago in a tragic bad weather accident.

The process of preparing this report forced me to look up, out and away, from my own securely held notions. Consultations with farmers, equipment suppliers and industry technical advisors from every corner of the world's oceans and with particular assistance from Andrew Storey who acted as technical consultant,have resulted in my ideas and preconceptions undergoing radical change.

I began this project convinced that we would be confined to farming with surface structures for many years to come and that a commercially viable submerged approach was a far-off pipe dream. Now I believe that submerged is the only way to go - avoiding as it does the worst effects of wind and wave action,therefore being better for fish, and people.

I am aware that submerged technologies require much further development,but my point is that partaking in debate across the world educates, stimulates, changes views and leads to progress. This is why I hope and pray that the principal outcome of this report, and of the 'Farming the Deep Blue' conference, will be a new strategy of international co-operation towards making offshore aquaculture easier and safer.

I also hope that this document will serve as a kind of celebration of the strivings and achievements of many visionary lovers of the oceans over the last few decades.

James Ryan, Westport, Ireland, September 2004.

Executive Summary

This report was jointly commissioned by BIM (Bord Iascaigh Mhara - The Irish Sea Fisheries Board) and the Irish Marine Institute in order to assess the potential for the further development of offshore farming of finfish in Ireland and internationally. It has been produced to coincide with an international conference in Ireland on offshore finfish aquaculture on October 6&7 2004 entitled 'Farming the Deep Blue',organised by BIM.

The Need

- The case for the urgent development of offshore finfish farming is overwhelming,both from a commercial and food security perspective. The FAO has carried out a study of future trends in the supply/demand balance of fishery products to 2030.On the demand side, a combination of two factors - the world's growing population,and the increasing per capita consumption of fishery products - will push the overall requirement for fishery products to a total of 180 million tonnes by 2030. This represents a 40% increase on the 130 million tonnes available in 2001 from the capture and aquaculture fisheries.

- On the supply side, the capture fishery at best will remain static, with output expected to remain at 100 million tonnes. It is therefore predicted that this will lead to what is becoming known as the 'FAO Gap',which is simply the gulf between expected demand and expected supply from the capture industry. The conclusion is that aquaculture production will have to increase even further in order to meet demand.Production levels in 2001 of 37 million tonnes will therefore need to increase to approximately 80-90 million tonnes by 2030,or 50% of the world's total fish requirements.

- Only a portion of this required increase in aquaculture output can come from the freshwater sector or from the inshore zone of the marine. Freshwater is becoming an increasingly valuable resource as world population levels grow, aquaculture output from it will be limited as a result.A global mega trend that will also impact on this situation is that human populations are increasingly aggregating on the coastlines of the major continents. The competition for space in the coastal zone is going to intensify and this will constrict output increases from inshore fish farms.

- Thus the shortfall in production capacity will have to be made up by developing the technologies required to farm offshore. This will pave the way for aquaculture to fulfill its potential as the 'Blue Revolution' in food production following on from the agricultural 'Green Revolution'.

- This report concentrates on offshore finfish farming as that will undoubtedly be the lead sector in offshore aquaculture development. Further, because this drive into the open ocean will,in the first instance, be based on high value carnivorous species the report focuses on this area of marine fish farming.

- Following analysis of the figures for the marine finfish sector, the report reliably concludes that the potential increase in annual production by 2030 is 3.15 million tonnes, valued at €9.5 billion in the Atlantic and 3.85 million tonnes, worth €11.5 billion in the Pacific. There is without doubt a major market opportunity. These levels of increased production can only be achieved by developing offshore finfish farming at a large scale.

The Benefits

- A key finding of the report is that there are major environmental benefits to be gained from a move offshore. The scientific evidence shows that benthic impacts are reduced,if not eliminated,from offshore or exposed sites. Potentially negative interactions with migratory fish stocks and any significant visual impacts are also minimised.In addition,from the farming perspective, conditions offshore are conducive to the production of healthier and faster-growing fish,with significantly lower mortality rates. Fish grown at offshore sites are also known to have firmer flesh and lower fat levels, resulting in a higher quality end product.

- The report shows that at the current level of technology, it is feasible to envisage large scale offshore farms being developed in the near future in Class 3 (or semi-exposed) sites. It postulates that these operations will serve as the next generation technology incubators for a further move out into open ocean locations, described as Class 4 type sites. A financial analysis of a 10,000 tonne model operation demonstrates its potential economic viability and a detailed discussion is presented on how the required ancillary technologies might be developed to make such an operation a reality.

- From an Irish perspective, the report concludes that if the next steps in offshore finfish farming development were taken to make the operation of Class 3 sites economically viable, Ireland could potentially increase its current output by **150,000 tonnes,** with a first sale value of **€500 million per annum.** Such an increase in raw material supply would support downstream processing and ancillary activity, creating a further **€250 million per annum** and supporting approximately **4,500 extra jobs.** All of this wealth creation and employment would be located in Ireland's most vulnerable peripheral coastal communities. Irelands finfish farmers already lead the way in operating in exposed conditions and it is proposed that this expertise be built upon.

- A key conclusion of the analysis is that due to the high fixed costs associated with this type of activity, offshore farming must be carried out on a large scale. A minimum level of 10,000 tonnes per annum, per operation,would be required in the case of Atlantic salmon, for example. Due to the quantum leap in the scale of offshore operations, the report emphasises the importance of an early engagement with industry regulators and the public.

- An exciting prospect arising from the scale of the envisaged offshore farms is that the establishment of even one of these units would form a significant node of development for a coastal community. The proposed offshore farms would become major engines of wealth creation via employment in processing and ancillary services ashore.

How should it be done?

- The report concludes that the multifaceted technological challenge of successfully moving finfish farming offshore is too great for any single company or indeed any single country to address. Finding the right development model for the offshore industry is proving to be elusive. The failure rate in technology trials has been high and valuable information has been lost because of the piecemeal nature of experimental work to date. The necessarily long lead time, high cost and lack of an existing end user market have discouraged many would be developers. The solution proposed is the formulation of a coordinated international strategy that will embrace all previous initiatives.

- The key recommendation of this report is that an international body should be formed as quickly as possible, which would exist primarily in the form of a global community operating in a high-tech virtual environment. That body would serve as an international focal point for the development of offshore aquaculture and it would seek to accelerate and galvanise the process through coordination and the provision of financial and knowledge capital.

The author suggests that it be called: **The International Council for Offshore Aquaculture Development (ICOAD).**

ICOAD'S mission statement might read as follows:

ICOAD will promote and facilitate, through all means possible, the development of suitable technologies and methodologies for successful aquaculture operations in the offshore zone. The ultimate aim is the creation of a major offshore aquaculture industry, which produces a significant proportion of the total world fish requirements in an economically and environmentally sustainable manner.

Detailed proposals for the formation of ICOAD will be presented to delegates at the 'Farming the Deep Blue' conference in October 2004. These proposals have been developed by leading experts in the field of building Virtual Communities from the University of Limerick,Ireland.

ICOAD would lead the way for aquaculture moving offshore, thus fulfiling its potential as the new 'Blue Revolution' and providing a means of increasing and enhancing the ocean's bounty.

Foreword

As a food marketer with many years experience and most recently as managing director of Salmon of the Americas (SOTA),I have come to realise the absolute importance of good communications in the food production sector.

Very often,the consumers of our product know little or nothing about how it has been produced,and it is vitally important that the true and positive image of modern fish farming is communicated effectively to them.

This report,and the upcoming 'Farming the Deep Blue' conference, will serve a vital purpose in explaining this exciting new chapter in aquaculture development to the public at large. It will get a good message to the consumer about offshore fish farming right from the start.

Equally, it will serve as the beginnings of what I hope will be a fruitful international dialogue between all the parties interested in bringing forward the development of offshore finfish aquaculture.

I am particularly pleased to see the publication of this report at this time, when the world demand for high quality fish products is growing rapidly.

The market urgently needs the extra fish that can only come from these offshore farms, and I am convinced that the long-term future of finfish aquaculture lies in the open ocean,built on the firm foundation of today's excellent inshore industry.

The common sense approach of this report really appealed to me. It is realistic in that it faces up to the many problems that will be encountered in a move to the open ocean.At the same time, it offers practical solutions and most importantly, a workable strategy for encouraging international offshore finfish farming development.

Read it,think about it,and play your part in the evolution of the 'Blue Revolution'.

Alex Trent
Managing Director, Salmon of the Americas

For the past 22 years, Alex Trent has been involved in production agriculture and commodity association promotions. His firm's commodity group has included organising and providing ongoing programme management services for the American Soybean Association's marketing programme in Europe.

Other commodity group work has included evaluations for various programmes funded by the United States Foreign Agricultural Service, the US Feed Grains Council and the Alaska Seafood Marketing Institute. He is currently the managing director of Salmon of the Americas.

Chapter 1

Introduction

This report was jointly commissioned by BIM (Bord Iascaigh Mhara - The Irish Sea Fisheries Board) and the Irish Marine Institute in order to assess the potential for the further development of offshore farming of finfish in Ireland, and internationally. It has been produced to coincide with an international conference in Ireland on offshore finfish aquaculture on October 6&7, 2004 entitled 'Farming the Deep Blue', organised by BIM.

The initiative was inspired by a number of key drivers, which include:

- The need for aquaculture to fulfil its role in world food production and truly become a 'Blue Revolution' to succeed the agricultural 'Green Revolution',which has largely run its course. The urgent requirement to provide more high-grade protein to the world's growing human population is explored in Chapter 2.
- The fact that the existing world capture fisheries, even when combined with all of the globe's freshwater and inshore aquaculture resources, will not be sufficient to meet future demand. The reasons why are set out both in this Chapter and in Chapter 2.
- The shortage of suitable sites inshore for large-scale aquaculture operations and competition for space. These issues are outlined in Chapters 2 & 5.
- The twin pressures to reduce the unit cost of production through achieving economies of scale, and to take advantage of the more suitable husbandry environment offshore. These issues are examined in Chapters 5 & 8.
- The global experience to date that initiatives to develop offshore finfish technologies have largely failed to reach their potential because the current model for progress is too fragmented and under-resourced.Experiences in this regard are detailed in Chapters 4,6 & 7.

These pressures apply equally to the Irish situation and in the wider international context.Such trends are having the effect of making offshore aquaculture a reality ever more urgent,in spite of the many issues that have to be faced in moving out into this challenging operating environment.

The shellfish farming industry is experiencing similar pressures and is also taking tentative steps towards moving offshore, particularly in the case of suspended mussel cultivation.While there are potential synergies between the finfish and shellfish culture industries such as polyculture and joint marketing,which may emerge in the future, finfish cage farming is seen as a discreet industry with available technologies having cross-species applicability.

Thus, new technology developed in Norway for salmon farming can also be transferred directly to Mediterranean waters for use in sea-bass or sea-bream farming. There is, therefore, a definable global community of finfish cage farmers and their technology suppliers, and it is this sector that is the focus of this report.A review of the currently available technologies is set out in Chapter 3.

Furthermore, it may appear that this report has a 'Western bias'. This simply reflects the reality that most finfish cage farming currently targets carnivorous species that require feeds made from fishmeals and fish-oils from the capture fishing industry. These species are expensive to produce, and markets for them are therefore confined to Western industrialised nations and a few wealthy Eastern nations such as Japan. Thus to date, the progress in marine cage farming techniques has largely been spearheaded by developed countries such as Norway, Scotland and the U.S. The global status of offshore finfish development is reviewed in Chapter 4.

A number of international meetings on the topic of offshore aquaculture have occurred in recent years. In 1997 and again in 2004,the International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM) organised workshops on Mediterranean Offshore Aquaculture at Zaragoza,Spain.Again in 1998,the Faculty of Mediterranean Engineering,Haifa, Israel, ran a workshop entitled Offshore Technologies for Aquaculture.

The best-known meetings on offshore aquaculture were probably the four international conferences on Open Ocean Aquaculture held respectively in Maine (U.S.) in 1996,Hawaii in 1997, Texas in 1998 and New Brunswick (Canada) in 2001. The U.S. Sea Grant Programme was the main sponsor of the first three events, and the World Aquaculture Society ran the fourth conference.

These conferences and workshops focussed primarily on the technical issues central to offshore operations, and served to act as forums for the presentation of academic papers on possible solutions to very specific problems. In contrast,however, the theme of the upcoming conference 'Farming the Deep Blue',is more of an overview of offshore aquaculture, to assess current trends and to examine possible directions for the future.

In particular, the 'Farming the Deep Blue' conference will address the concern that offshore aquaculture is failing to reach its potential. A principal outcome would therefore be a consensus to establish an integrated international strategy aimed at injecting vigour into the sector on a global basis, thus accelerating the pace of development. Recommendations in this regard are proposed in Chapter 9.

Report approach

The report includes a snap-shot of current worldwide trends in offshore aquaculture. It also reflects discussions with many industry experts, and suggests routes to a viable and dynamic future. It is, therefore, a discussion document,not an exhaustive academic treatise, and relies in the most part on information and opinion from fish farmers, their technical advisors and technology suppliers. The report is also intended to act as a companion document to the 'Farming the Deep Blue' conference, and serves to set the agenda for the event.

1.1 Definition of offshore aquaculture

Critical to this discussion is the development of a clear understanding of what is meant by 'offshore aquaculture'.Within the finfish farming community it is generally accepted to mean the execution of activities in sites that are subject to ocean waves. This increased exposure to higher wave energy is linked to distance from shore or lack of shelter from topographical features such as islands or headlands, which can mitigate the force of ocean and wind-generated waves.

In order to understand the issues associated with developing offshore aquaculture in earnest,this broad definition needs further refinement so that technology capabilities can be better matched with site characteristics.

A site classification system based on the sea state spectrum or energy spectrum of the local wave climate therefore needs to be devised and cross referenced to cage and equipment capabilities. It is possible to conceive of up to four, or possibly five site classes within this system. Traditional surface-based cages might be deemed suitable for Class 1 and Class 2 and probably Class 3 sites, with submersible cages or other novel technologies being preferred for the more extreme conditions characteristic of Class 4 and Class 5 sites.

The Norwegian government has introduced a new classification system for fish farm sites using significant wave height. This system however does not take into account other factors critical to the correct selection of equipment such as wave period and water current speed. **(Fig 1.1)**

Site Class	Significant Wave Height (Metres)	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

Fig 1.1 Norwegian Aquaculture site classification scheme.

In the absence of a more sophisticated classification system and for the sake of simple illustration in this report,the adoption of a conventional system based more on geography than wave energy is proposed. This comprises four site classes with Class 1 being sheltered inshore and Class 4 being offshore. **(Figs 1.2 & 1.3)** The classes of site that are the focus of this report are Class 3 and Class 4,i.e. exposed and offshore respectively.

Class 3 sites are of particular interest in the Irish context given the number of unexploited locations that fall into this category along the west coast. This situation is mirrored in other countries such as Canada, Scotland and Norway. These sites, despite being close to the open ocean, benefit from the shelter provided by proximity to nearby headlands, islands or subsurface features and can accommodate the use of conventional technologies albeit with some adaptations and new methodologies.

Other countries such as Italy, the Canary Islands and the U.S. have little option but to operate in Class 4 or offshore locations and are of necessity trailblazing the use of novel technologies. Inevitably as production expands, most countries will want to avail of offshore sites.

This site-classification system needs to be used cautiously. For example, it is commonly accepted that a cage system that may be adequate in a Mediterranean setting would not survive on a site off the west coast of Ireland,although both locations might have similar proximity to the nearest land.

Further development of an universally acceptable offshore site classification system is urgently required to bring about a more refined approach,which adequately describes and quantifies all the significant sources of energy that impact on offshore farm structures and stock. Recommendations on these issues are detailed in Chapter 9.

The report therefore focuses in particular on the technologies used and the problems being encountered by operators in Class 3 sites, and proposes solutions and new strategies to enable development of large-scale offshore operations. Class 4 sites are also of great interest but being open ocean,they require long-term development strategies using novel technologies such as submersible cages.

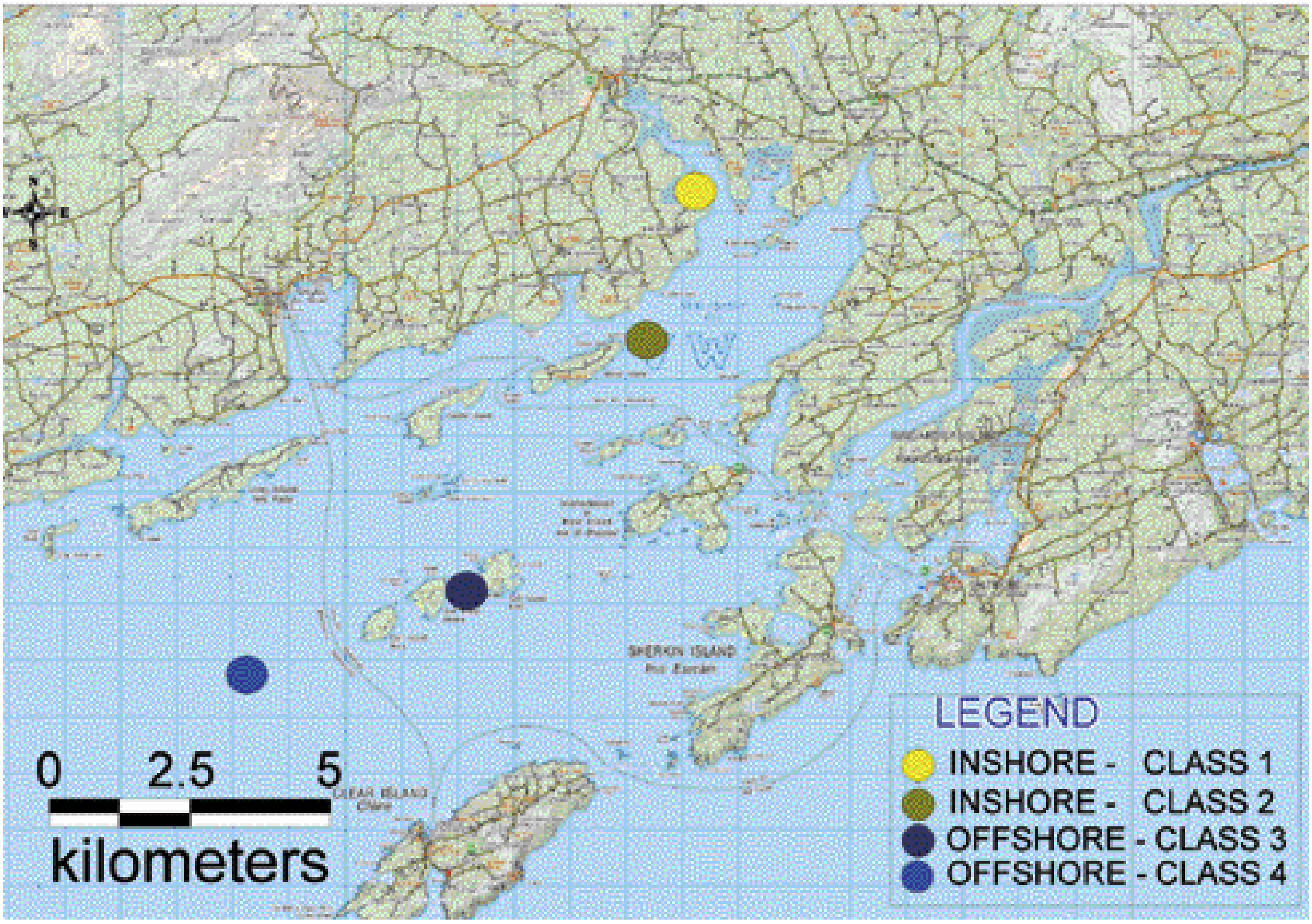


Fig 1.2 The site classification scheme proposed for the purpose of this document.

Class	1	2	3	4
Conventional Description (In relation to site exposure)	Sheltered Inshore Site	Semi-Exposed Inshore Site	Exposed Offshore Site	Open Ocean Offshore Site
Cage Type Used	Surface Gravity	Surface Gravity	Surface Gravity, Anchor Tension	Surface Gravity, Surface Rigid, Anchor Tension,Submerged Gravity, Submerged Rigid

Fig 1.3 Cage types likely to be found in sites of Classes 1 to 4. For an explanation of cage types referred to here go to Chapter 3.

1.2 Fish farming worldwide

While finfish aquaculture has been carried out for thousands of years, it has been largely confined to freshwater and brackish water locations. This type of farming is generally carried out on an extensive or subsistence basis. For example, it is used to augment food production on a family farm and is also characteristic of fish farming in developing countries.

Exceptions to this are trout in Europe and North America,and tilapia in several Latin American and Asian countries. Nevertheless, the output of individual operations is small compared to those of seawater-based farming.

Since the late 1960s and early 1970s, intensive fish farming in the sea has mushroomed,resulting in worldwide marine finfish production of three million tonnes in 2000.

For the most part,this type of farming is based in developed countries and is generally characterised as being 'industrial-scale farming'.Indeed, Atlantic salmon farming in north Atlantic countries and in Chile accounts for about half of this intensive output,with a large portion of the rest being sea-bass and sea-bream in Mediterranean countries. Warm water species such as cobia, various types of snapper, and Pacific threadfin, plus cold-water marine fish species such as cod,halibut and haddock, are also in the pilot stages of intensive farming.

Whilst freshwater farming still accounts for 85 per cent of total global finfish production,farming in the sea is increasing at a faster rate and is considered to be 'high value',currently worth approximately €8 billion annually. Also, the freshwater resource is limited and is the subject of increasing competition for usage as the world's population continues to grow.

Seawater-based farming conforms to a fairly standardised format worldwide. Sites are generally located in sheltered or semi-sheltered inshore waters, and the cages used consist of either a steel or plastic floating collar with net enclosures hanging beneath. These can be described as 'gravity cages' because they depend on weights hanging from the nets to keep them open and have no underwater structural framework.Gravity cages are extremely successful and have supported the development of fish farming for the past 30 years. **(Fig 1.4)**

Steel collar cages are usually square in plan view and are configured within a framework comprising four to 24 individual units. **(Fig 1.5)** Plastic or rubber collar cages are usually circular in plan view and can be assembled in groups within a grid work of rope and chain moorings. **(Fig 1.6)**

Fig 1.4 Square plastic collar gravity cage in rough conditions, Norway.
Polarcirkel, Norway.

Depending on the surface area enclosed within each collar and the depth of the net enclosure, individual cages can contain between 50 and 1,000 tonnes of finfish,with the principle operating challenges centred on feeding,net changing and harvesting.In the past twenty years, the industry has made great strides towards solving these issues through advances in technology and research. For instance, most feeding is now carried out by automatic feeding systems, and routine operations are performed with the assistance of highly specialised workboats equipped with powerful cranes. Harvesting procedures have also been greatly enhanced and are now carried out by purpose-designed well-boats that have pumps for delivering live harvest fish from the cage into the well. **(Fig 1.7)**

Typical seawater farming sites for salmon have annual production levels ranging from 1,000 to 4,000 tonnes. At a current world value of approximately €3.50 per kilo, a 4,000-tonne ocean farm would turnover in the region of €14 million.Mediterranean sea-bass and sea-bream rearing sites have lower production levels ranging from 400 to 2000 tonnes, but with a higher selling price than salmon, can achieve annual turnovers in excess of €10 million.

1.3 Fish farming in Ireland today

Ireland has had a relatively long involvement with offshore aquaculture, making the Irish experience an interesting model in the context of this report.

Ireland's current National Development Plan (2000-2006) envisages that salmon and trout production has the potential to increase to 33,432 tonnes by 2008.Furthermore, with increasing knowledge of the requirements for commercial cultivation of alternative species, steps are now being taken towards diversification into cod,halibut, and turbot.Developments in Ireland have generally mirrored those of the rest of the world.Seawater farming of finfish began there in the early 1970s with the rearing of salmon and rainbow trout in cages of between two and five tonnes capacity.

Fig 1.5 Steel collar cages, Ireland.

Fig 1.6 Rubber collar cage, Clare Island, Ireland.
Marine Harvest, Ireland.

Fig 1.7 Highly specialised work boat with lifting crane and feed cannon feeding a 120-metre circumference plastic collar cage, Norway. Aqualine, Norway.

Since then the industry has grown,and production peaked at 25,000 tonnes in 2001. Twenty-nine sites owned by 13 separate companies currently contribute to the annual turnover of approximately €54.2 million (2003).

Where Ireland differs from much of the rest of the world is in its pioneering work in offshore fish farming. This has been necessitated by the lack of suitable Class 1 and Class 2 farming sites. More than 30% of Ireland's production comes from Class 3 sites. These are located at Bantry Bay, Co Cork; Kenmare Bay, Co Kerry;Galway Bay;Clew Bay, Co. Mayo and Donegal Bay. **(Fig 1.8)**

In moving out to these zones, fish farmers have tended to rely on traditional technologies and have used reinforced versions of the gravity cage and conventional feeding equipment in the absence of gear and methodologies designed specifically for the much more hostile offshore environment.

The result is that ocean swells have caused difficulties for maintenance schedules, work programmes and staff morale. Operating costs can therefore be significantly higher than at inshore sites. The offshore farm at Clare Island in Clew Bay, Co. Mayo, has successfully addressed this problem by producing organically reared fish and selling it at a premium price. Given that this is a niche market,however, the premium would soon be eroded if all producers turned to organic farming.

Fig 1.8 Location of offshore aquaculture sites, Ireland.

Notwithstanding the above, experience to date indicates that significant husbandry and environmental benefits will be gained from developing an offshore industry. It is widely accepted that environmental impact, fish quality and growth rates would all be greatly improved in the offshore environment. These potential benefits are explored in Chapter 5.

There is, therefore, general agreement amongst fish farmers in Ireland and elsewhere that although operating outside the inshore zone using conventional approaches has been somewhat marginal to date, there is an urgent need to crack this technology challenge.

In this regard,operational difficulties need to be resolved in existing offshore sites so as to encourage operators to consider expanding their production.Increased confidence brought about by successful offshore operations should result in the establishment of many new offshore sites around the Irish coast. The author of this report estimates conservatively that there are at least 15 potential Class 3 sites around the Irish coast,which could be exploited if the required offshore technology is developed.

Benefit for Ireland

Thus, if the next steps in offshore finfish farming development were taken as detailed in Chapters 6 & 7,making the operation of Class 3 sites economically viable, Ireland could potentially increase its current output by **150,000** tonnes, with a first sale value of **€500 million per annum.** Such an increase in raw material supply would support downstream processing and ancillary activity, creating a further **€250 million** per annum and supporting approximately **4,500 extra jobs.** All of this wealth creation and employment would be located in Ireland's most vulnerable peripheral coastal communities.

1.4 Report focus

Because of burgeoning market demand for more fish and the constraints on supply from capture fisheries, the opportunity now exists for the aquaculture industry to engage in large-scale production. In many countries however, there is serious opposition to further expansion inshore because of both competition for space with other stakeholders such as the marine leisure sector and public opposition to new cage farming projects located close to land. There is also the trend of increasing scale by individual operations, brought about by the drive for reduced production costs. Indeed,some farms are becoming so large as to outgrow the capacity of their location inshore in terms of both space and adequate water exchange.

Forward thinkers in the industry are therefore looking towards the offshore zone;however, due to the destructive effects of wave action,aquaculture operations in these areas must cope with ongoing wear and tear and occasional failure of nets and equipment.

Nonetheless, some farmers have faced down these challenges so that in Ireland and indeed worldwide, farms are managing to survive in the offshore zone, particularly in Class 3 sites. Many of these have experienced better fish rearing conditions offshore. This report therefore focuses on the art of the possible whilst mapping out a strategic route to future success.

It is therefore apparent that offshore aquaculture is indeed feasible; however progress has been sporadic because the equipment and methodologies used have been based on what has been successful in the inshore zone. Thus for almost 20 years, offshore farmers have had to improvise with poorly adapted equipment and operating systems that do not take full advantage of the benefits which properly tailored modern technology could provide.

Some equipment supply companies have attempted to address this problem by applying resources to design and development of technologies specifically intended for the offshore zone (Chapter 3).

Relying on individual fish farming or equipment supply companies is unlikely to bring sufficient investment in research and development (R&D) in offshore fish farming technology as the commercial risks involved are too high to yield a reasonable return in the short-term. A new paradigm is required,which will bring to bear a much higher level of resources on a long-term basis. This report will conclude by making recommendations in this regard,and the topic will be explored in depth at the 'Farming the Deep Blue' conference.

Bearing in mind the increasing consumption of fish and the projected rise in demand of approximately 30% by 2030 (Chapter 2),there is little doubt that the markets for farmed finfish will continue to grow. The marine cage farming industry will then find itself tasked with supplying this growing demand and in order to do so, farmers will need access to both offshore sites and to appropriate technologies.

As a vehicle for systematically examining the proposition of creating an economically viable offshore finfish farm,this report postulates a model 10,000 tonnes operation. The assumptions and logic behind this proposed venture are set out in Chapter 8,while the practical and logistical considerations, which have to be borne in mind,are detailed in Chapters 6 & 7.

In taking this approach,this report examines the technical feasibility of what is possible now, and what developments are required to successfully exploit open ocean locations in the years to come.

This report proposes that the technological challenge of successfully moving finfish farming offshore is too great for any single company or indeed any single country to address. The solution is for a coordinated international strategy that will embrace all previous initiatives which, so far, have been piecemeal and insufficient in scale.

A radical new model for the development of offshore finfish farming is urgently needed if it is to fulfil its requirement in the 'Evolution of the Blue Revolution'.A recommended approach is set out in Chapter 9.

Chapter 2
Offshore Aquaculture - The Context

2.1 Introduction

Over the past 15-20 years, commercial offshore farms have been established around the globe, and operators have been able to avail of improvements to gravity cage technologies and operating methodologies. Novel or alternative technologies however are also being developed, and there is a trend towards using submerged systems, particularly in open ocean (Class 4) situations.

Although progress in offshore aquaculture has been somewhat sporadic to date, there are indications of a gathering momentum in mankind's determination to harness the oceans for large-scale production of food. For example, a recent European Commission policy statement on aquaculture states: 'Fish cages should be moved further from the coast, and more research and development of offshore cage technology must be promoted to this end. Experience from outside the aquaculture sector, e.g. with oil platforms, may well feed into the aquaculture equipment sector, allowing for savings in the development costs of technologies'.

In addition,a report from the Food and Agriculture Organisation (FAO) entitled **The State of World Fisheries and Aquaculture, 2002**, states that aquaculture in general (not offshore aquaculture) is growing more rapidly than all other animal food producing sectors: 'Worldwide, the sector has increased at an average compound rate of 9.2% per year since 1970, compared with only 1.4% for capture fisheries and 2.8% for terrestrial farmed meat production systems'. **(Fig 2.1)**

This growth story has been described as the 'Blue Revolution',and puts aquaculture development on the same scale as the advances made in agriculture during the 'Green Revolution' over the second half of the twentieth century.

Before assessing the strategies required to develop offshore aquaculture in earnest, a critical question must be addressed:Will there be sufficient demand for additional fish to justify this major new departure?

2.2 The Supply/Demand Outlook for Fishery Products

Between 1970 and 2001,the world supply of fish has doubled from approximately 65 million tonnes to more than 130 million tonnes. That this astonishing rise was met by matching demand can largely be explained by two strong trends:increasing population and increasing per capita consumption.

Between 1979 and 1999,world population increased from 4.4 billion to 5.9 billion, and the FAO is forecasting a further increase to 8.2 billion by 2030 with some stability being reached by the end of the twenty-first century. **(Fig 2.2)**

The second trend relates to increasing per capita fish consumption as indicated by the following excerpts from the FAO report, **The State of World Fisheries and Aquaculture, 2002:**

> The total food fish supply for the world excluding China, has been growing at a rate of about 2.4% per annum since 1961, while the population has been expanding at 1.8 % per annum. Since the late 1980s, however, population growth outside China has occasionally outpaced the growth of total food fish supply, resulting in a decrease in per capita fish supply from 14.6 kg in 1987 to 13.1 kg in 2000.

Contribution of Aquaculture to World Fisheries Landings - 1970 - 2000

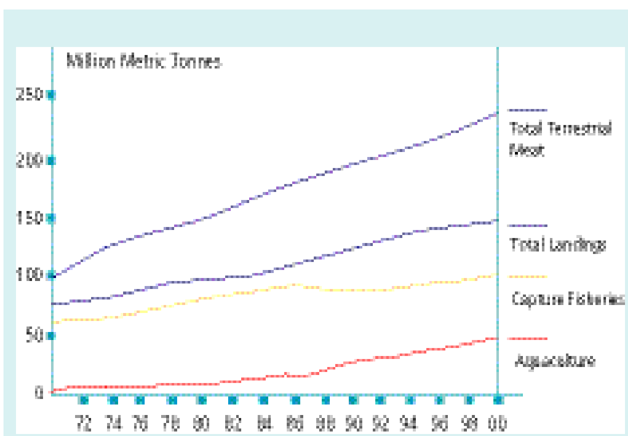


Fig 2.1 Production increases for aquaculture, capture fisheries and terrestrial meat 1970-2000. After FAO.

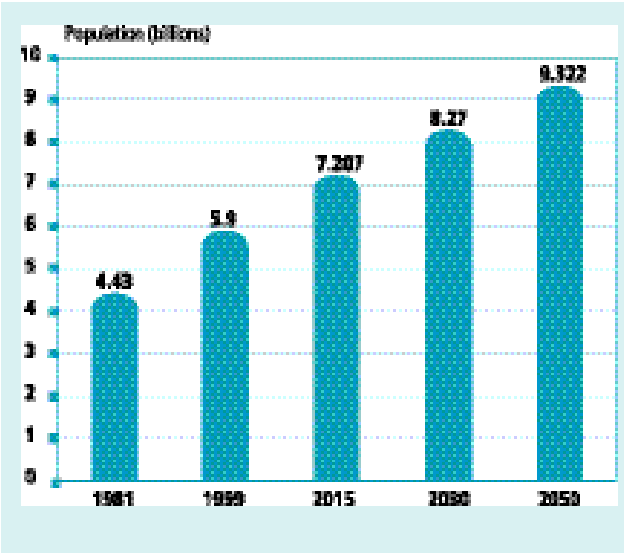


Fig 2.2 World Population Growth 1981-2050. After FAO.

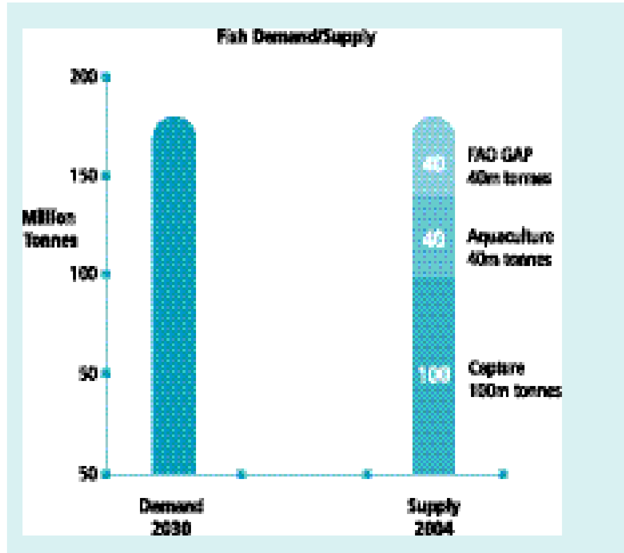


Fig 2.3 The FAO Gap. Aquaculture will need to at least double its current production in order to fill the supply gap arising from increased demand in 2030.

The report adds:

> In industrialized countries, where diets generally contain a more diversified range of animal proteins, the supply increased from 13.2 million tonnes in 1961 to 25.4 million tonnes in 1999, implying a rise in per capita provision from 19.9 to 28.3.

The report goes on to forecast that world per capita consumption will increase from 16kg in 2002 to 19-22kg by 2030.

Increases in per capita consumption of fish can largely be attributed to two developments:

(a) Health: Throughout the world,fish is perceived as a healthy food option,and this perception is backed up by numerous research findings and health reports. It is now an accepted medical fact that eating fish is good,if not essential,for both brain and body. (See Appendix 1 for discussion and examples.)

(b) Increased Supply:Due to modern,sophisticated technologies, the supply of fish from capture fisheries continued to rise until the mid 1990s. Since then capture fishery output has been more or less stable, with aquaculture output supplying an ever-increasing proportion of the world's seafood requirements. In 2001 it was estimated that aquaculture produced close to 30% of total fish supply.

Furthermore, the FAO carried out a study of future trends in the supply/demand balance of fishery products to 2030.On the demand side, a combination of two factors - the world's growing population, and the increasing per capita consumption of fishery products - will push the overall requirement for fishery products to a total of 180 million tonnes by 2030. This represents a 40% increase on the 130 million tonnes available in 2001 from the capture and aquaculture fisheries.

On the supply side, the capture fishery at best will remain static, with output expected to remain at 100 million tonnes. It is therefore predicted that this will lead to what is becoming known as the 'FAO Gap',which is simply the gulf between expected demand and expected supply from the capture industry. The conclusion is that aquaculture production will have to increase even further in order to bridge the gap. Production levels in 2001 of 37 million tonnes will therefore need to increase to approximately 80-90 million tonnes by 2030,or 50% of the world's total fish requirements. **(Fig 2.3)**

2.3 The Future of Marine Finfish Aquaculture

Out of the total 2001 aquaculture production of 37 million tonnes, finfish accounted for 23 million tonnes and the balance consisted mostly of molluscs and crustaceans. Of these 23 million tonnes, however, only three million tonnes was marine finfish,with the rest being freshwater finfish produced primarily in China and southeast Asia.

If it is assumed that marine finfish aquaculture production will increase at the same rate as projected for aquaculture as a whole i.e. 3%,an annual production level of seven million tonnes will be reached by the year 2030. A number of factors exist,however, which may result in the marine finfish sector growing at a higher rate than other aquaculture sectors:

(1) While the world's oceans offer almost unlimited capacity for growth,freshwater resources are likely to face escalating pressure from competing users, making it increasingly difficult for freshwater aquaculture production to sustain its past level of growth.
In fact,the noted economist,Professor Lester Brown,at the second AquaVision conference predicted that the next major world conflict will be fought over freshwater resources as the world's human population continues to grow. Major growth in finfish aquaculture output will have to take place in the sea.

(2) Although freshwater finfish yields 62% of all aquaculture output, freshwater fish from both capture and aquaculture sources tend to be consumed locally, have relatively low yields of edible meat and low per unit values. In addition,freshwater finfish husbandry practices are generally more extensive and require larger amounts of water and surface area for production.

Anadromous (salmonids, eels etc) and marine finfish species are, on the other hand,suitable for large-scale intensive culture. They have both high yield and high value, and can therefore be targeted towards processing and marketing in more affluent western countries. Thus, they have significant potential for growth in their contribution to aquaculture finfish output.

(3) Husbandry knowledge and practices for producing marine finfish species are developing rapidly. Of equal importance is the mounting sophistication in current feed processing technology, which enables increased substitution of vegetable proteins and oil for ocean-sourced feed ingredients. There is also exciting potential for the cultivation of marine fish that are more or less herbivorous, such as milkfish. In contrast with freshwater aquaculture, marine finfish farming depends almost entirely on the culture of carnivorous fish whose diet must include supply-limited fishmeal. The development of herbivorous species would therefore be highly welcomed.

Taking these and other factors into account,marine finfish aquaculture can be predicted to grow at a faster rate than the 3% estimated for aquaculture as a whole. Therefore, projecting a moderately increased growth rate of 4% would result in a forecast for annual marine finfish production of 10 million tonnes by 2030. This represents a seven million tonne increase over today's production level of three million tonnes.

If this increase is divided between the Atlantic and Pacific Oceans on the basis of the current ratio of 45%:55% respectively (1.35m tonnes in the Atlantic and 1.65 million tonnes in the Pacific),the potential for production increase in marine finfish aquaculture by 2030 is 3.15 million tonnes in the Atlantic and 3.85 million tonnes in the Pacific.

2.4 The Case for Offshore Fish Farming

Following the analysis and assumptions presented so far, marine finfish aquaculture production in the Atlantic region will need to increase by some 230% from its current 1.35 million tonnes to 4.5 million tonnes by 2030 in order to meet projected world demands. Similarly, production from the Pacific region will need to increase from 1.65 million tonnes to 5.5 million tonnes.

Chapter 1 refers to constraints on expansion within inshore aquaculture areas and to the high costs associated with pump-ashore systems. It is unlikely that these methods alone will produce enough marine finfish to meet the demand forecasted.A global mega trend that will also impact on this situation is that human populations are increasingly aggregating on the coastlines of the major continents. Thus, competition for space in the inshore zone, characterised by Class 1 and Class 2 type sites, is set to intensify, forcing expansion in marine finfish farming further and further offshore.

Assuming that production in the Atlantic inshore zone increases to 2.7 million tonnes (1.35 million tonnes doubled),and that pump-ashore tank systems will account for a further 100,000 tonnes, this leaves a production shortfall of 1.7 million tonnes (4.5 million tonnes minus 2.8 million tonnes).A similar exercise for the Pacific indicates a shortfall of approximately 2.1 million tonnes. Offshore finfish aquaculture will therefore need to increase its global production to approximately 3.8 million tonnes by 2030.Given this outlook,offshore farming is a compelling and logical continuation of the 'Blue Revolution' to fill the FAO 'gap' in marine finfish production. **(Fig 2.4)**

The case for the urgent development of offshore finfish farming is overwhelming,both from a commercial and food security perspective. Given that it will be a long-term undertaking,the first steps in this vital process need to be taken immediately.

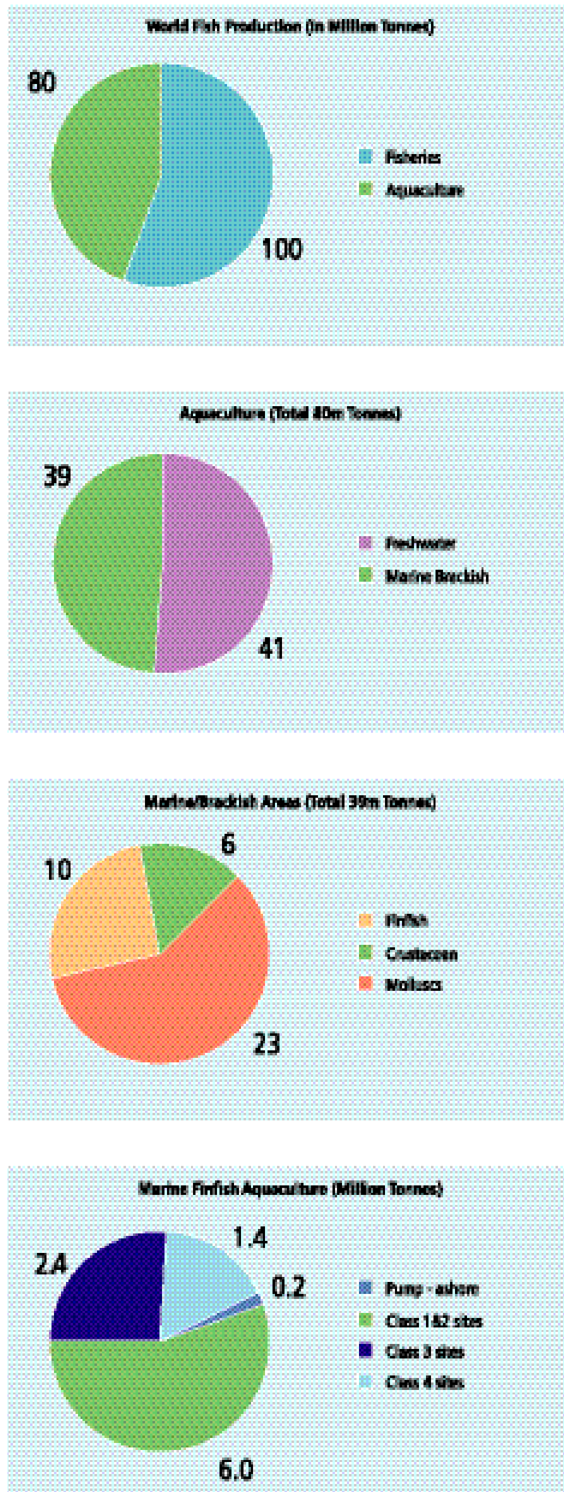


Fig 2.4 Possible fish supply scenario in 2030.

Chapter 3
Aquaculture Technologies

3.1 Introduction

To date, growth in offshore farming has lagged behind that of inshore farming because of the significant gap in knowledge, technology and experience that exists regarding cage systems, ancillary equipment and the husbandry practices required for reliable, large-scale offshore farming. This gap exists for a variety of reasons and is mostly related to the sheer cost of designing, developing, testing and marketing the technology.

If one were to follow the model pursued in the inshore sector, development of offshore technology could only take place where there was a robust offshore farming sector capable of sustaining the necessary R&D costs. The irony is, however, that the sector is having great difficulty evolving in the absence of any significant level of output.It is in fact a classical 'chicken and egg' situation.

Therefore, a central tenet of this report is that this scenario must be addressed by a new approach encompassing both state and private funding of the long-term R&D costs necessary to make offshore finfish farming a viable reality in the public interest.

Finding a successful infrastructure development model for the offshore industry has proven to be elusive to date. In addition to high technology development costs, there are the unknowns relating to growing - not just new species but also existing species in the high-energy offshore environment.Several generations of fish will therefore need to be raised before a concept is proven,commercialisation can occur and cash flow is generated.Such a scenario would be unattractive to a commercial investor acting alone.

These issues combined bear out the author's view that it is difficult for any one company or entity to take on the challenge and that a new paradigm is required.Notwithstanding the above, a number of development initiatives have taken place around the world.

Whilst most equipment suppliers and operators will admit that adequate offshore technologies do not yet exist,the industry has developed a wealth of knowledge and experience, which the right model could capture, forming the basis for the successful development of this sorely needed technology. Prior to reviewing these initiatives, a consideration of the essential criteria necessary for success is presented below.

3.1.1 Consideration of the necessary characteristics in offshore projects

The hostile, high-energy environment that characterises the offshore zone requires that a number of key considerations be catered for in order to make finfish farming operations both feasible and economical.

Firstly, and most obviously, the structures and moorings envisaged must be capable of tolerating the loads to which they will be subjected. Therefore, stronger versions of conventional inshore technologies or alternative concepts altogether will be necessary.

Secondly, it must be assumed that because of weather and sea conditions, access will often be difficult if not impossible. Highly specialised,remote control and monitoring capabilities via leading-edge telemetry systems must therefore be a major component of the operating methodology. In particular, it must be feasible to feed and observe the fish regardless of whether staff are present on site. Large feed storage capacity will also be an essential feature.

A third consideration must be the higher capital and other fixed costs that need to be offset by economies of scale. For this reason,cage structures with operating volumes and output far higher than those currently found inshore will be required. This will require a change in mindset on the part of industry regulators.

Finally, the planning of offshore aquaculture operations requires an holistic approach,which must take into consideration all aspects and components of the proposed operating system.In this respect,far more rigorous management and forward planning regimes will be required than are currently the norm at inshore locations.

These four criteria must be included in any meaningful assessment of available technologies and they are employed as the backdrop to the following review of equipment currently in use or at development stage for offshore finfish aquaculture.

For clarity, existing offshore technologies are firstly examined in terms of containment systems or cages and secondly, in terms of the supporting equipment necessary to carry out essential aquaculture operations.

3.2 Containment Systems

In order to understand much of the progress to date, some knowledge of containment systems is required.In a report published in 1998,Loverich and Gace 'attempted to establish sea cage classifications based upon the structural means used to fix the growing volume', and proposed four sea cage types, namely:gravity cages, anchor-tension cages, semi-rigid cages and rigid cages.

Within this classification system,type 1 or gravity cages are by far the most widely used containment technology in the fish farming industry, accounting for the vast bulk of marine and freshwater-farmed output. Gravity cages rely on the force of gravity to maintain net volume, by providing a surface buoyancy element and an underwater weighting system for the net. The surface buoyancy element is usually incorporated into some sort of surface structure that doubles as a work platform for operators. Over the years, wood,plastic, rubber and steel have all been used in many variations for the surface element. **(Fig 3.1,Fig 3.2a&b)**

The only type 2 or anchor-tension cage currently manufactured is the Ocean Spar cage, which relies on a tensioned mooring system to maintain the growing volume of the net as there is no rigid framework. **(Fig 3.3)**

Similarly, the Sea Station cage is currently the only example of a type 3 or semi-rigid cage. This classification comes from the fact that it uses ropes to connect rigid steel components in order to maintain volume. **(Fig 3.4)**

Finally, type 4 or rigid cages are those where net volume is maintained by rigid structural components made of steel and other materials.

Fig 3.1 Plastic collar cage, Marine Construction, Norway.

The netting,which is made of traditional twine based materials, or in some cases rigid materials such as galvanised steel,is attached to the rigid components to maintain net shape. Examples of this type of cage are the semi-submerged platforms produced in Spain and the Norwegian concept cage, the Byks OceanGlobe. **(Figs 3.5)**

Examples of project employing these four cage types are reviewed in the next section.

3.2.1 Type 1: Gravity cages

Much of the offshore industry experience to date has been with gravity cages that are either reinforced versions of existing plastic and steel cages or somewhat specialised variations of the gravity cage. Companies such as Fusion Marine (UK); Polarcirkel (Norway); Aqualine (Norway);Corelsa (Spain) and Plastic Fabrications (Australia) all have plastic pipe products targeting the offshore farming sector.

In the mid-1980s and early-1990s, Bridgestone (Japan) and Dunlop (now Bonnar Engineering, Ireland) adapted components from the offshore oil and gas industry to use in place of plastic pipe for offshore conditions. Cages such as the Farm Ocean (Sweden) **(Fig 3.6)** and the Storm (Norway) **(Fig 3.7)** are very different approaches but are variations of the gravity cage.

An intrinsic characteristic of the gravity cage in conventional (i.e. not tuna,see discussion below) configuration is its susceptibility to net deformity and volume loss in currents and wave action,which is a result of a lack of support structure for the net.In certain types of gravity cage, much of the wave activity is transferred through the water to the net,causing excessive motion and leading to wear and tear. Indeed in some cases, more work has probably gone into net design to overcome the wear and tear factor than into the cage collar. **(Fig 3.8)**

Whilst the gravity cage is the favoured type of cage in almost all commercial offshore operations, this situation has arisen both because of a tendency to use familiar technologies when moving from the inshore zone, and the perception that there is no viable alternative.

The results, however, have been mixed,with operators being challenged to stay apace with essential repairs and maintenance arising from inherent design flaws. Occasionally a cage can suffer catastrophic damage from wave action,resulting in the loss of most or all of the fish. These events have been explained through computer modelling of gravity cage designs, indicating an inadequacy in coping with wave conditions in offshore sites. **(Fredriksson et al.2000)**

Despite these issues, however, significant amounts of fish are produced from gravity cages in offshore sites in Mediterranean countries, the Faeroe Islands, Shetland,the Canary Islands, Norway and Ireland amongst others.

Of particular interest is the apparent 'overnight success' of the tuna industry. Of all of the offshore aquaculture sectors, tuna farming is one of the more successful when measured by output value. Over the past

Fig 3.2(a) Sadco Shelf cages awaiting launch. Sadco Shelf, Russia.

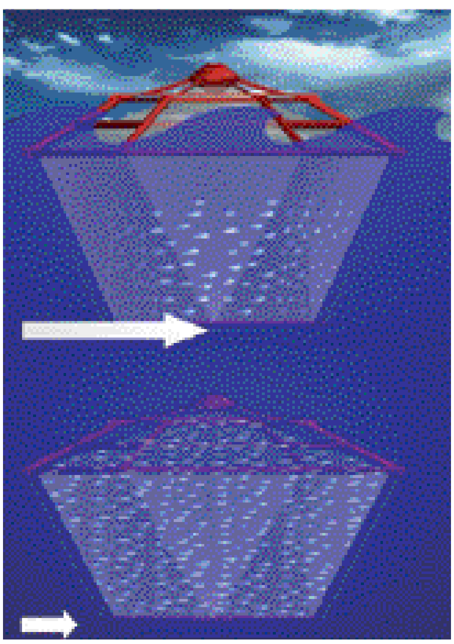


Fig 3.2(b) Sadco Shelf cage concept. Sadco Shelf, Russia.

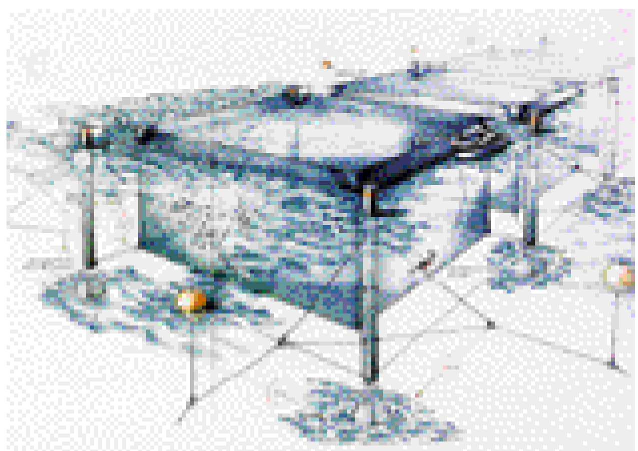


Fig 3.3(a) Ocean Spar cage, Net Systems Inc.

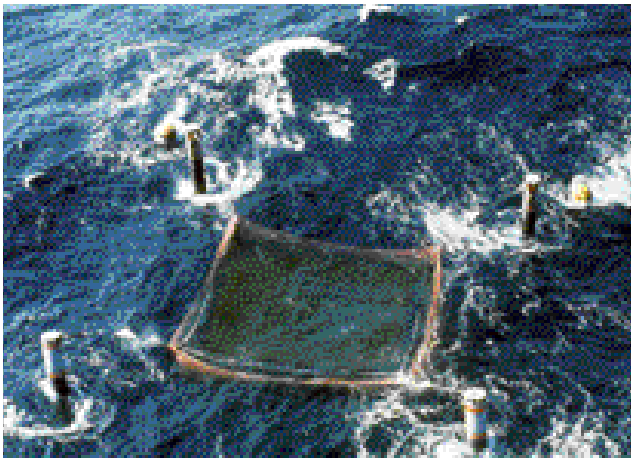


Fig 3.3(b) Ocean Spar cage, Net Systems Inc.

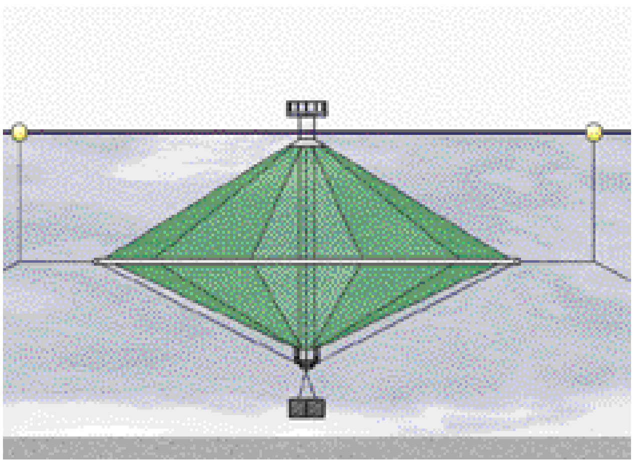


Fig 3.4 Sea Station Cage, Net Systems Inc.

Fig 3.5 Semi-submerged platform behind plastic collar cage, Spain. J Ryan photo.

five years the industry has grown significantly to a harvest in 2003 of approximately 34,000 tonnes, with values ranging from US$20 to $50 per kg.In Japan,over 30% of the tuna supply comes from farmed sources. Other countries farming tuna include Australia,Mexico, Spain, Malta and Croatia.

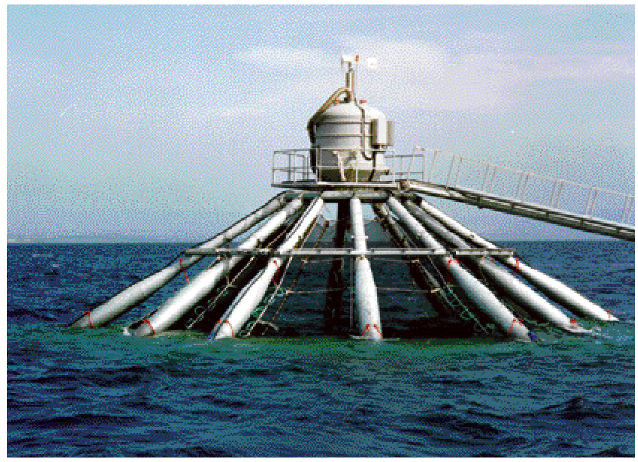


Fig 3.6 Farm Ocean cage. Farm Ocean, Sweden.

Fig 3.7 Storm cage. Marine Construction. Norway

Just ten years ago, tuna fishermen began experimenting with gravity cages to fatten wild fish and experienced an almost instant success using adapted gravity cage technology. **(Fig 3.9)**

The tuna industry relies almost exclusively on floating plastic collar cages for both towing across oceans and farming operations. Most of the tuna on-growing sites are either Class 3 or Class 4 and are located anywhere from exposed near shore to three or four miles offshore.

The industry has developed a collapsible cage collar for transportation to the fishing grounds where it is assembled for the return trip to the farm.In some cases, the fishing grounds are hundreds of kilometres from the on-growing sites, and gravity cages with live fish must therefore be towed across open ocean for periods of up to 30 days. With this mix of success and failure of offshore gravity cages in mind, Bonnar Engineering,supported by funding from the Irish Government and the insurance company Sunderland Marine, is currently running a research project off the west coast of Ireland aimed at establishing the loadings on a rubber collar cage in an offshore site. Load cells have been attached to key points on the net and on the mooring lines, and the results to date indicate that certain computer models, which have hitherto been used to predict the loadings on fish cages, are inadequate.

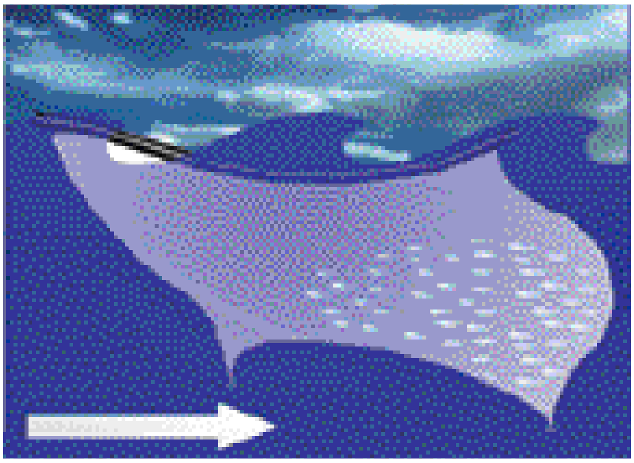


Fig 3.8 Illustration of wave and current effects on a conventional gravity cage. Sadco Shelf, Russia.

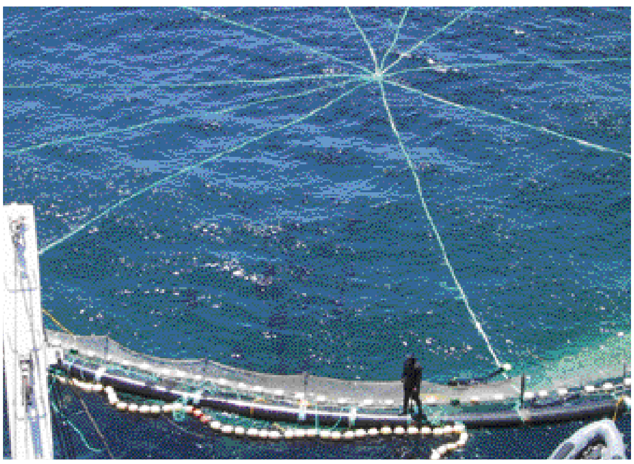


Fig 3.9(a) Fresh caught wild tuna swimming into tow cage. Ted Dunn, Paula Sylvia.

Of the other types of gravity cages, the Farm Ocean was one of the pioneering attempts to develop a cage for more exposed conditions; however high capital cost,low volume and difficult access for harvesting render them unlikely candidates for farming lower value fish species such as cod or salmon.Nevertheless, the cage design has shown promise in a variety of situations, particularly in offshore Mediterranean sites farming sea-bass and sea-bream.A significant advantage of this cage type is the integrated feed silo, which facilitates computer controlled feeding regardless of operator access being prevented by sea conditions. **(Fig 3.6)**

The SADCO Shelf is another variation on the gravity cage theme, having a heavy top framework from which hangs a net and weight ring. This cage again suffers from the drawbacks of small volume, (4,000m^3 maximum); however it has proven successful as a submersible cage and has survived in extreme conditions. It also has the advantage, similar to the Ocean Farm cage and unlike the Sea Station, of having an integrated automatic feeding system,but it does require resurfacing at intervals for filling. SADCO Shelf has plans to increase cage sizes to 8,000m^3 and 12,000m^3. **(Fig 3.10)**

Fig 3.9(b) Tuna cage under tow with dive boat in attendance, Mexico. Ted Dunn, Paula Sylvia.

3.2.2 Type 2:Anchor-tension cages

Of all of the alternatives to gravity cage systems, the anchor-tension cage has possibly the greatest capacity for up-scaling. For example, Ocean Spar Technologies has installed four of these cage types in Ireland since 1998, three of which have a 20,000m^3 capacity **(Fig 3.11)** and a fourth has a 15,000m^3 capacity. These cages are hexagonal in plan view with a vertical steel pipe (or spar) at each of its six corners. The company has indicated that larger volume cages up to 60,000m^3 could be supplied.Because the Ocean Spar cage has steel spars and no flotation collar, it has the potential to be more 'transparent' to wave action than gravity class cages. Also, the high-tension framework ensures that the net retains its full volume in strong currents and severe conditions.

Development and commercialisation of the Ocean Spar cage system represents a classic case study of the difficulties that can be encountered when developing novel cage designs and supporting technologies for offshore farming.While somewhat adaptable to existing handling and husbandry practices, the system is different enough from traditional gravity cages that a number of new operating practices related to net cleaning,fish handling,harvesting and mortality collection are required. Although none of the issues are insurmountable, tackling them requires time, money and commitment.

For example, as the Ocean Spar is not fitted with a floating collar, one problem to emerge at an offshore Irish site related to the conventional feeding method whereby workboats convey feed via a cannon. The work-boat therefore had nothing to lie against and was in danger of being forced onto the net by wave action. This had the effect of discouraging regular feeding of the fish.

Furthermore, the requirement of staff to keep up with all the other chores on the farm,plus a shortage of resources meant that the problem was never adequately addressed.Ultimately the project failed,largely because of the poor performance of the fish,and the cage was taken out of the water.

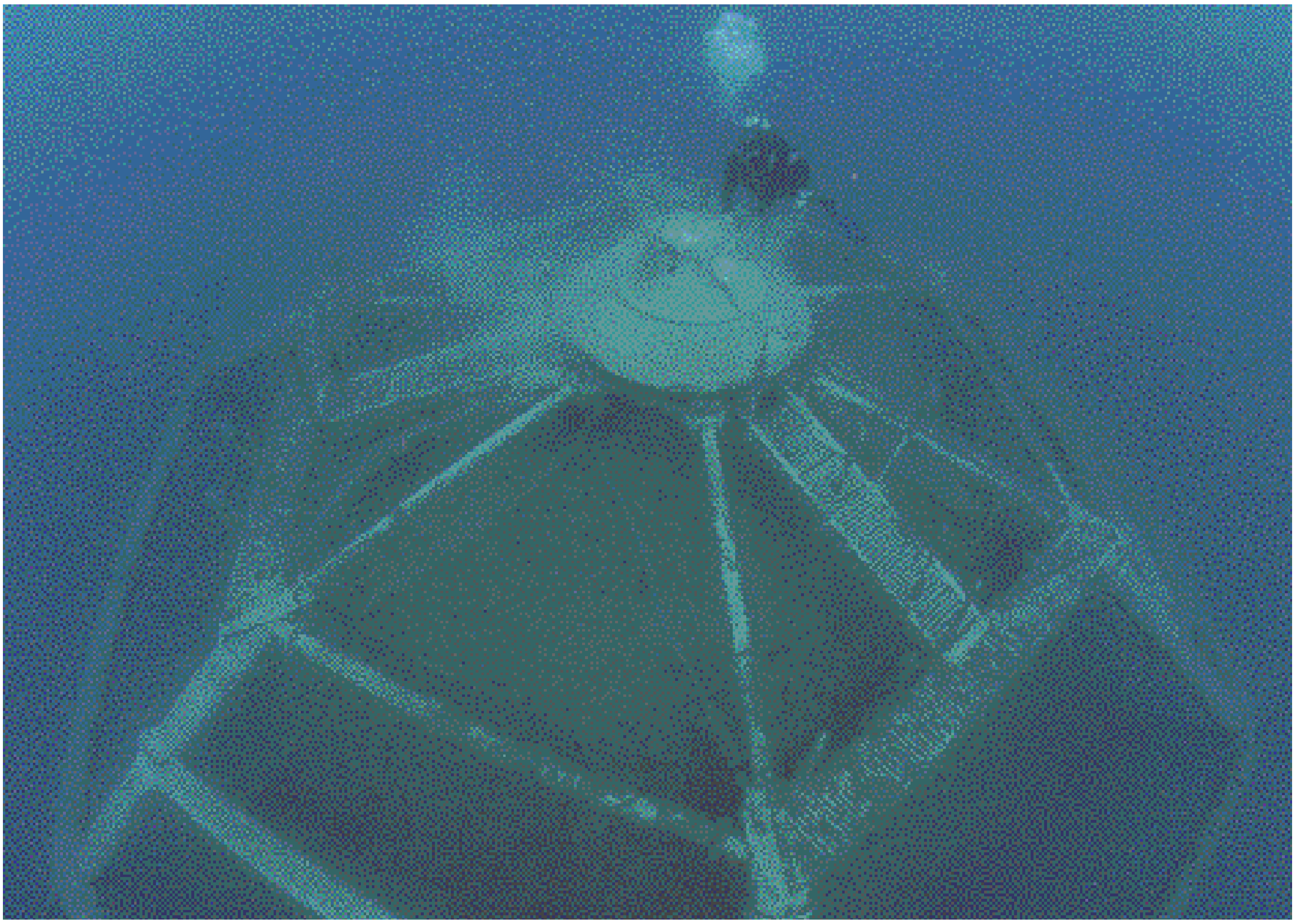


Fig 3.10 Submerged cage, diver servicing feed system. Sadco Shelf, Russia.

Fig 3.11(a) Brother of the author, Abdon Ryan, on the taut top net of an Ocean Spar cage, Killary Harbour, Ireland.

This occurred in spite of indications that the new concept had potential, thus highlighting the need for an holistic approach involving careful consideration of all issues ahead of installing new technology. It is also necessary to ensure that the proper monetary, material and human resources are in place once the project is embarked upon.

3.2.3 Type 3: Semi-rigid cages

The Sea Station consists of a single central spar of steel pipe inside a circular steel collar. These two elements are joined by non-stretch rope under tension,and the netting is fitted around this framework. **(Fig 3.12)**

The scope of the Sea Station is currently limited to relatively small volumes of 3,000m^3 although with more development this could be increased to 6,000m^3. It is one of the very few cage types that has endured totally submerged operations in Class 4 sites.

Similar to the Ocean Spar, the Sea Station requires further development of its methods for fish handling,feeding,net cleaning and harvesting. These issues, however, are more challenging in this case because the cages are deployed in open ocean and submerged conditions.

3.2.4 Type 4: Rigid cages

Rigid cages comprise a solid framework of steel or other suitable material to which the fish containing net is attached.Rigid cages can be surface-based,as in the case of those constructed by Marina System Hibernica in Spain. Trials of surface-based rigid cages in exposed water, however, have resulted in nets being destroyed due to the rigidity of the framework.

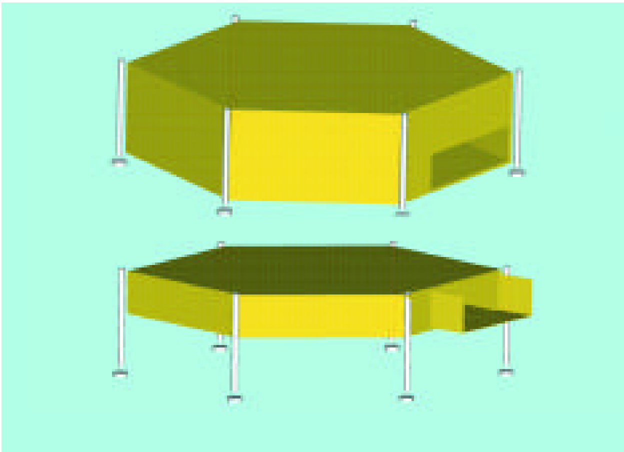


Fig 3.11(b) Diagrammatic representation of the 20,000 cubic meter Ocean Spar cage installed in 3 sites in Ireland. At harvest the net is raised and the fish swim through an unzipped panel and net tunnel into a waiting transport cage. Net Systems Inc, USA.

Fig 3.12 Top of semi-submerged Sea Station cage, Net Systems.

Rigid cages therefore show far more promise in submerged situations and a rigid submersible cage that as yet is only at the concept stage is the OceanGlobe from Norwegian company, Byks. The OceanGlobe comprises a plastic framework configured in a spherical shape and has an optional landing platform pivoting on the main axis of the cage. The promoters assert that units capable of retaining up to 1,000 tonnes of fish can be built,and that the cage can be either submerged or surface-based. **(Fig 3.13)**

3.2.5 Proposed Type 5:Tension-leg cages

The Loverich and Gace cage classification scheme allocates the RefaMed tension-leg cage to the gravity cage category on the basis that having a ring on the bottom to keep the tension legs properly spaced, they resemble an inverted gravity cage. Tension-leg cages, however, are so radically different to conventional gravity cages, and have so much potential for offshore applications, that in the opinion of the author, an additional fifth category is justified.

By having only a small flotation collar at the surface with no mooring lines attached,the RefaMed tension-leg cage avoids the high loadings suffered by conventional gravity cages in extreme wind and wave conditions. In strong current situations, whether caused by high winds or tidal movement,the cage is deflected sideways to assume a position of least resistance. Although the largest cage to date is only 4,000m^3, RefaMed is confident that cages up to 15,000m^3 could be produced. Sizes beyond this would need further development. **(Fig 3.14)**

A factor that needs consideration in the case of tension-leg cages is that most oceanic areas outside the Mediterranean have tidal ranges anywhere from 2 to 10 metres. In those locations, a tension-leg cage, because its depth is fixed by being vertically attached to the seabed, is either completely submerged at high tide or has a lot of slack netting near the top at low tide.

During recent trials in Cadiz,this issue was addressed by opting for slack netting in the top section at low tide and maintaining net shape by adding extra flotation buoys. An alternative approach would be to develop self-correcting tension legs but this may be introducing unnecessary complications. **(Fig 3.15)**

3.2.6 Other cage designs

Other cage concepts exist but are difficult to categorise. These include:

- **Enclosure systems**
  This is simply a single panel of net hanging from surface buoys and weighted to the seabed.It has no flotation collar or bottom horizontal panel,and the overall shape is maintained by flotation buoys and mooring tension.Advantages of this system include the potentially large rearing volume that can be enclosed and its flexibility in high waves. The disadvantages are that it has no jump net and that it needs a smooth,level seabed.

- **Untethered cages**
  This cage type drifts at the behest of the currents across the world's great oceans as the fish are fed and fattened inside. Such cages would be very large, incorporating crew quarters and massive feed storage capacity. They would also be fitted with their own propulsion system,thereby allowing the crew to have some control over the direction of drift and so as to ensure adequate water exchange through the cage. It may be possible to locate these cages in circulating currents that are relatively local in extent so that the drift area would be confined to more manageable proportions than entire oceans.

  The advantages of this system include minimal licence and compliance requirements plus remoteness from other farms and consequent protection from infectious diseases. Another important benefit would be the absence of any attachment to mooring lines, which would significantly reduce the loadings on the cage, thus allowing for a lighter, cheaper structure than might otherwise be the case.

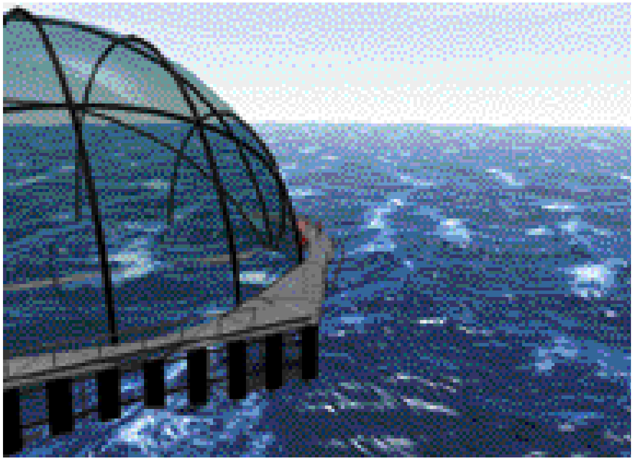


Fig 3.13(a) Oceanglobe submersible cage. Byks, Norway.

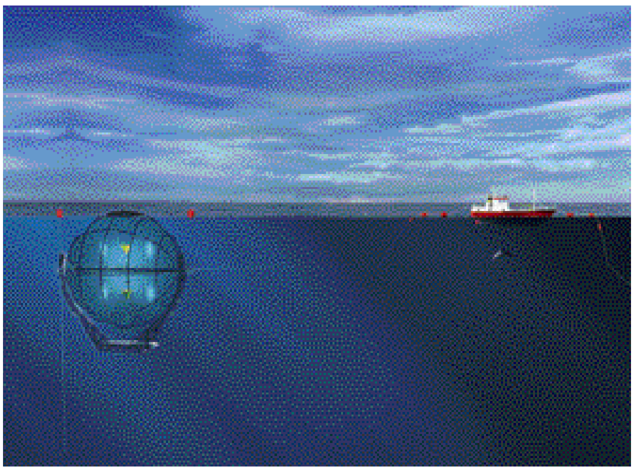


Fig 3.13(b) Oceanglobe submersible cage. Byks, Norway.

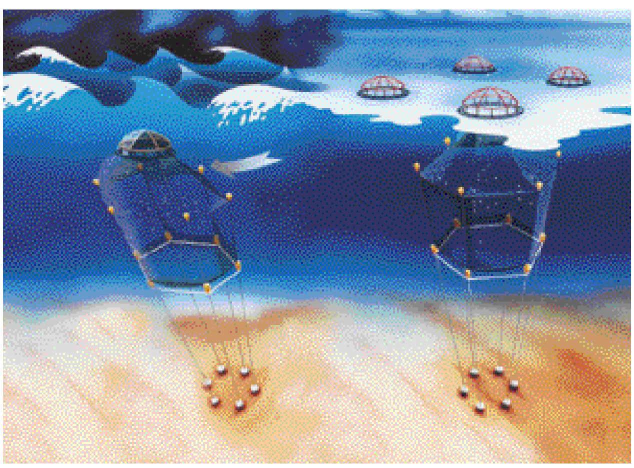


Fig 3.14(a) Tension-leg cage. RefaMed, Italy.

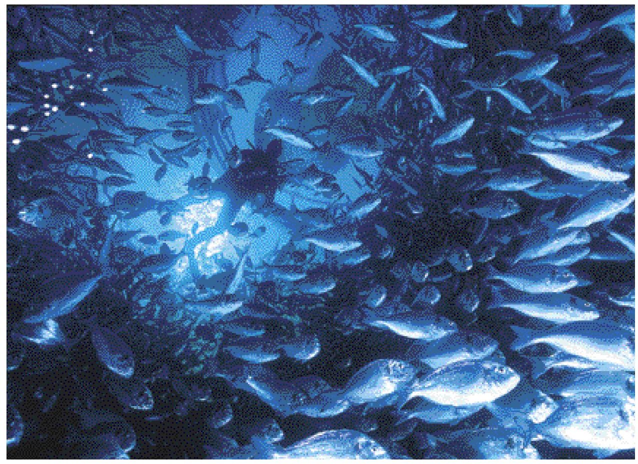


Fig 3.14(b) Looking up through a tension-leg cage. RefaMed, Italy.

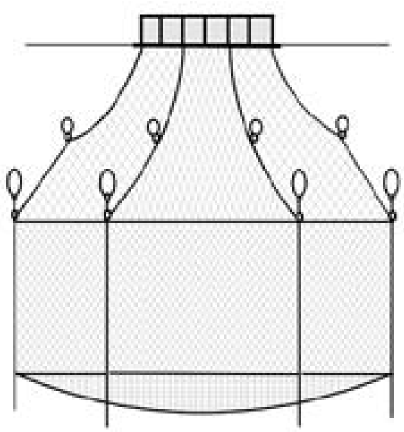


Fig 3.15 Tension-leg cage adapted for tidal waters. Refamed, Italy.

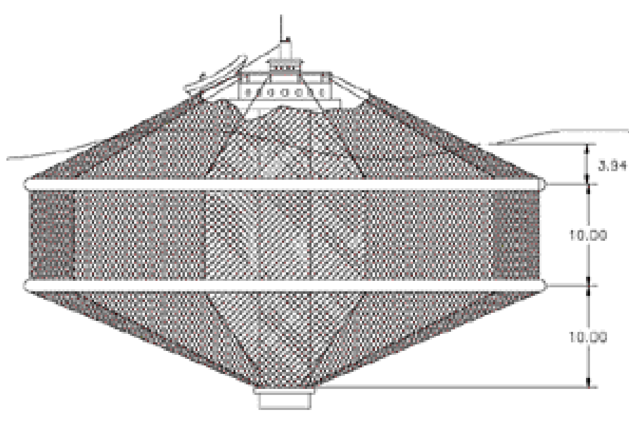


Fig 3.16 The untethered cage concept, Ocean Drifter. Net Systems Inc. US.

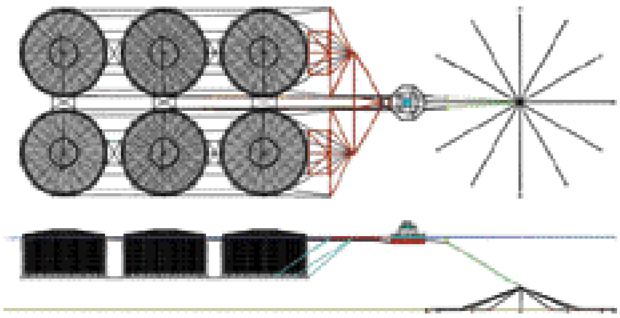


Fig 3.17, 3.18 A novel mooring system for conventional cages. Aquaculture Engineering Group, Canada.

Untethered cages contd.

- The best-known example of this concept is the Ocean Drifter cage designed by Gary Loverich and Clifford Goudey. (1996) The Ocean Drifter is a scaled-up version of the Ocean Spar Sea Station and has two rings and a 64,000m^3 capacity. **(Fig 3.16)**

- A further novel approach to large-scale offshore aquaculture is being developed by the Canadian Aquaculture Engineering Group, (AEG). The three company principals are experts respectively in exposed aquaculture, engineering design and custom metal fabrication, and their intention is to develop an entire offshore system, including feeding and monitoring technologies.

The design envisages conventional plastic collar cages moored in flotillas of six or eight.An aspect of this concept,however, which is far from conventional,is that there are no mooring lines attached to the cage collars. Instead,the cage net bottoms are attached to an extensive rigid framework located beneath the nets. **(Figs 3.17 & 3.18)**

The front end of the framework is attached via a vertical component to a custom-designed hexagonal feed barge, which in turn is attached to a single point mooring. Thus, the cage collars can flex freely without shock loadings, and the entire system is able to adopt the mode of least resistance to wind, waves and currents.

The collars also have minimal positive buoyancy so that in storm conditions they sink below the surface. The feed pipes and monitoring cables are completely submerged and attached to the subsurface framework.In addition,the feed,which is carried by water rather than air, is delivered through a unique spreading system to the fish.

AEG intends to deploy a trial system comprising six 100-metre circumference cages plus a feed barge in an exposed site in the Bay of Fundy over the winter of 2004-2005.

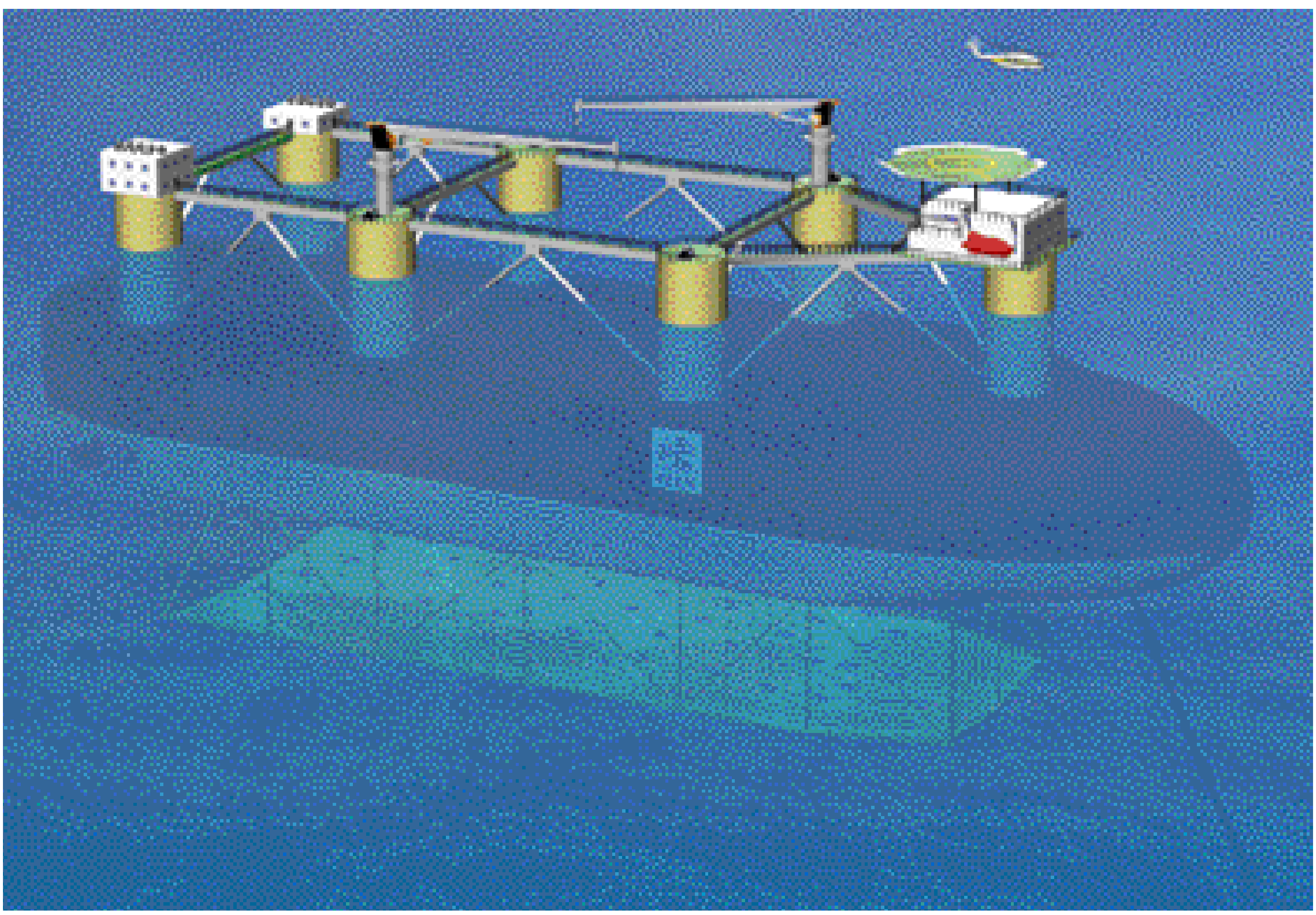


Fig 3.19 Semi-submersible tuna ship. Izar Fene, Spain.

The test site will be monitored and findings will be published on the firm's website throughout the trial. (www.aquacultureengineeringgroup.com)

- **Semi-submerged structures**
  One of the most spectacular concepts regarding novel approaches to offshore aquaculture is being promoted by Spanish shipbuilding company, IZAR FENE. This involves a semi-submersible ship - 189 metres long and 56 metres wide - with fish tanks in the hold and rigid cages attached beneath the hull. The idea is that the ship travels to the tuna fishing grounds in any of the world's oceans, collecting live tuna as they are caught and then fattening them up while transporting them to market in Japan.Another proposed use for the same vessel is to rear juvenile fish for restocking depleted capture fisheries. **(Fig 3.19)**

  Izar Fene is also promoting a concept based on a large semi-submerged platform.A giant cage net hangs beneath the platform whilst on deck there are hatchery and rearing facilities for juvenile fish. **(Fig 3.20)**

It may be seen from the above review that whilst many concepts are being explored,the perfect 'mouse-trap' has not yet been developed for offshore finfish farming.Undoubtedly, the type 1 gravity cage approach has been the most successful to date.

The jury is still out as to which of the other cage types, if any, may ultimately succeed the type 1 systems. The most likely future scenario is that there will be a 'horses for courses' approach,depending on the nature of the location and the chosen fish species to be farmed. The next section of this report reviews the required supporting technologies that will have to be deployed in tandem with the chosen containment system.

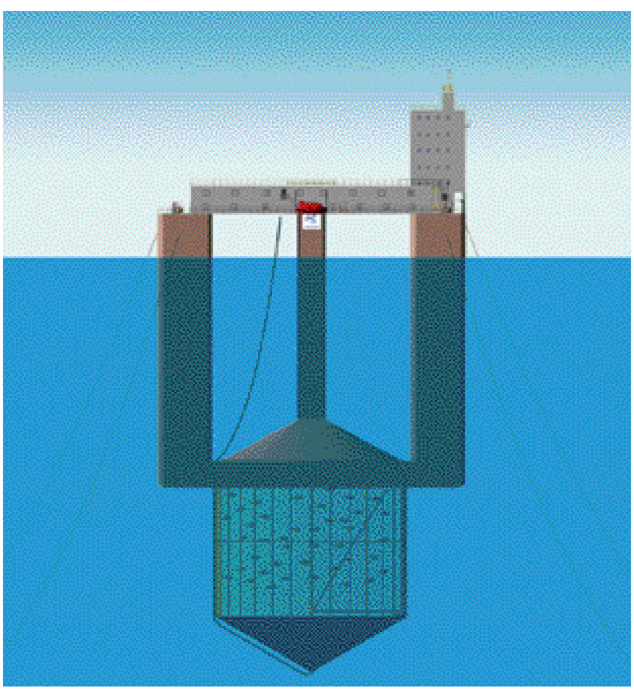


Fig 3.20 Semi-submersible platform. Izar Fene, Spain.

3.3 Supporting Technologies

As outlined at the beginning of this chapter, an holistic or systems approach is critical to successfully operating in the offshore zone. It is therefore necessary to briefly review the supporting technologies that can be matched with the offshore cage types considered above.

3.3.1 Feeding systems

Apart from the cages themselves, the most important component of the entire offshore operation is the feeding system.As feed cost can amount to 50%-70% of total running costs, the feed delivery method must ensure adequate supply as required,and wastage must be kept to a minimum or be non-existent.(See Chapter 7 and the paragraph on 'High Cost of Technology',which highlights the significant savings that can be made with efficient feeding.)

The types of feeding systems currently employed in the sector are critically reviewed below:

- **Cannon feeders**
  As previously outlined,feed delivery to the fish in offshore sites is often by means of a workboat tying up alongside the cage and spreading the feed across the surface via a deck-mounted feed cannon. The principal disadvantage of this system is that it is critically dependent on operator diligence in order to avoid waste. (A bored or uncomfortable operator has the option of speeding up feed delivery beyond the consumption capability of the fish). In addition,this system relies on workboats having daily access to the cages, and this is not realistic for many offshore situations.

- **Centralised feeding system**
  This can address the shortcomings of cannon feeders. It usually consists of a permanently moored feed barge with feed storage capacity of up to 400 tonnes and a computer-controlled feeding system that delivers the feed to the fish via compressed air in floating plastic hoses to each fish cage. **(Figs 3.21, 22,23)**

  Normally the operator sits in a control room in the feed barge and adjusts the amount of feed going to each cage according to sonar-based or video-based monitoring of fish appetite and feed

Fig 3.21 Feed barge in steel with high storage capacity. Akvasmart, Norway.

Fig 3.22 Feed barge control system. Note monitors for cameras, appetite, and feed administration. Akvasmart, Norway.

consumption.While this would appear to be a better solution than the feed cannon workboat visiting each cage, the problems associated with this system include:

- unsuitability of many feed barge designs for safe offshore use
- frequent damage to floating feed hoses by wave action
- the necessity to get an operator on board the barge on a daily basis and
- the relatively small feed storage capacity of many barge types

The ideal system for offshore aquaculture should be independent of operator access for up to three weeks at a time and should be capable of storing enough feed to supply the entire site for a period of this duration.

One feed barge type that appears to be proving itself for offshore use is the Gael Force Sea Cap (Scotland).It is a vertical concrete cylinder with a feed storage capacity of up to 250 tonnes. These barges are an appropriate design,both in terms of shape and weight distribution, and are thus more stable and have a more sea-kindly motion than the conventional rectangular steel box barges. Gael Force also has a design for a Sea Cap barge, which has feed storage capacity of 600 tonnes. This has not yet been built but the concept goes some way towards what might be ideal for a large offshore farm.

A potentially ideal solution for offshore feeding is to have the feeding system integrated into the cage structure. Both the Farm Ocean and Sadco Shelf cages have this feature incorporated into their designs. Maximum feed holding capacity is only five days, which means that frequent operator access to the site is required.In the case of the submerged Sadco Shelf, the cage must be resurfaced at regular intervals to replenish stored feed.

Thus, it may be seen that existing solutions are all,to a greater or lesser extent,deficient in comparison to what will be required for efficient offshore finfish farming operations. Having critically reviewed the feeding system types, consideration is now given to appetite monitoring and control,which must be a component of feed delivery systems if cost efficient operations are to be achieved.

3.3.2 Appetite monitoring systems

The cost of feeding finfish in marine farms is the single biggest operating overhead,and a major concern in this regard is matching the rate of feed delivery as closely as possible to appetite so as to eliminate waste.

There are many systems available for monitoring the amount of feed that fish consume. These include:

- **Submerged camera**
  This is the most straightforward and probably the most popular appetite-monitoring method. The camera is located beneath the feed delivery outlet allowing the operator to observe feeding behaviour and feed wastage via a boat or barge-mounted monitor. The disadvantages of using the currently available camera systems is that proper application requires a high level of operator diligence and a reasonable level of visibility in the water column.

  Whilst camera systems for appetite monitoring, as currently available, will require further development for use in the offshore zone, there is no doubt that this type of technology will play a crucial role. Refinements in data transfer via radio linkages, together with improved optics and durability will be the key technology elements that need to be upgraded in this regard. **(Fig 3.24)**

- **Feed pellet counting systems**
  These reduce the need for operator diligence by automatically counting uneaten feed pellets and adjusting the feeding rate accordingly. Well-known examples of these kinds of systems are the AkvaSensor CAS and the Storvik 'Appetite Feeding System', which use a subsurface in-cage funnel to concentrate waste feed pellets, sending them through an electronic pellet counter. A potential drawback with funnel-based systems is that they can be clumsy and difficult to deploy and operate in exposed conditions. **(Fig 3.25)**

- **Doppler hydro-acoustic system**
  The AkvaSensor Doppler is located beneath the feed outlet and senses uneaten feed pellets. Accuracy of this system in high-energy offshore sites is questionable, however, as strong currents can sweep uneaten food out of the cage before it is detected.A solution might be the AkvaSensor current meter, which can be used to automatically switch off the feeding system when the current becomes too strong.

It may be that the ultimate solution with regard to appetite monitoring systems in the offshore zone will include a bundled approach employing elements of all of these technologies. Bespoke systems specially modified to allow efficient data transfer via radio telemetry to the shore base and featuring a high degree of automated interactivity between themselves and the feed delivery system will be required.

3.3.3 Other core activities

Not only is it necessary to develop effective containment,feeding and feed monitoring systems, approaches to dealing with other core farming activities must also be carefully thought out and planned for in the design of an offshore finfish farming installation.Consideration must be given to the following:

Fig 3.23 Workboat moored to concrete cylinder feed barge, Shetland Islands. Note floating feed pipe to each cage. Gael Force, Scotland.

- **Harvesting**

  Harvesting at offshore sites is generally difficult.Given the vagaries of weather, it is often impossible to guarantee continuity of fish supply to the market. Well-boats can be used to pump live fish out of the cage into a water-filled hold or alternatively, the fish can be loaded onto the deck of a workboat and killed as they come aboard.Both of these methods require large boats to be berthed for long hours beside the fish cages, often in conditions that threaten the well-being of the fish and/or the integrity of the equipment.An increasingly popular solution is to tow cages to sheltered inshore sites for harvesting.

  It may certainly be concluded that a working solution to the harvesting of fish offshore will involve a system whereby good weather windows can be exploited,moving large volumes of harvest-size fish quickly and efficiently to an all-weather holding station of some description.

- **Net-cleaning**

  Net fouling by sessile marine organisms such as mussels, hydroids and seaweed is a major logistical problem for cage farmers, both inshore and offshore. There are currently only two control methods: divers or site operatives that manually wash the nets in situ,and/or regular changing of nets before fouling becomes too heavy. Both of these methods present enormous logistical challenges, particularly to the offshore farmer who is dependent on fine weather windows to apply either control method.

  Currently available and permitted marine anti-fouling paints are not effective. Approaches that may bear fruit in this regard include the development of new and effective eco-friendly net coatings, remotely controlled cleaning robots or net systems that rotate.

Fig 3.24(a) Submersible camera for monitoring fish appetite and behaviour. Akvasmart, Norway.

Fig 3.24(b) Data transmission system for submersible camera and doppler system. Akvasmart, Norway.

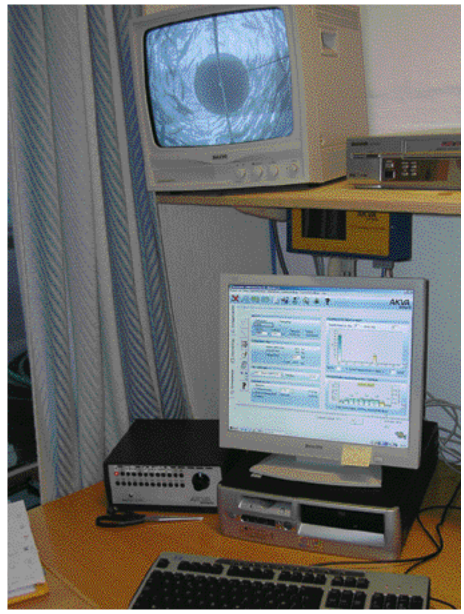


Fig 3.24(c) Submersible camera and feed control monitors. Akvasmart, Norway.

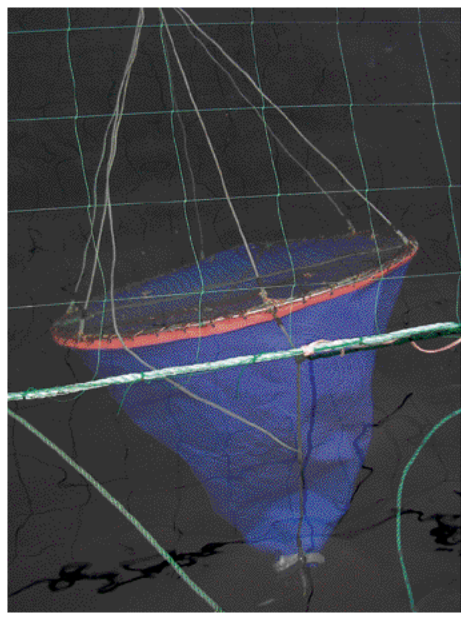


Fig 3.25(a) Funnel with sensor for counting uneaten feed pellets. Akvasmart, Norway.

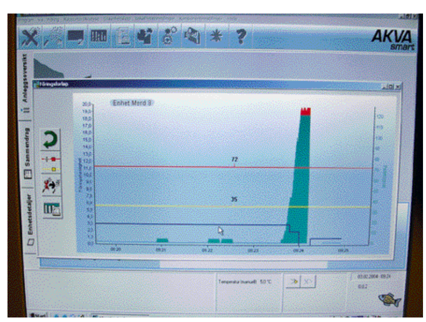


Fig 3.25(b) Monitor for uneaten feed pellet counter. Akvasmart, Norway.

Chapter 4

Global Status of Offshore Finfish Farming

4.1 Introduction

Countries such as Spain, Italy, the U.S. and Ireland, although having strong fishing traditions and burgeoning aquaculture industries, do not have the fjords of Norway and Chile or the sea-loughs of Scotland. Thus, by necessity, these countries are having to locate many of their fish farms in exposed waters and are as such spearheading the adaptation of technologies and methodologies for operations in the offshore zone.

The following is a brief review of the status of offshore aquaculture in a number of key countries around the world.

4.2 Australia

The main offshore farming activity in Australia is tuna farming out of Port Lincoln. The industry catches a wild quota of 5,300 tonnes. The living fish are towed back to Port Lincoln in plastic cages, covering distances of over 300km within 14 days. The on-growing sites are up to 12km offshore, however being located within the Spencer Gulf, they are only exposed to the open ocean from the south and are thus probably Class 3 rather than Class 4. **(Fig 4.1)**

The fish are on-grown over the following five or six months in conventional plastic circular cages - usually large single ring versions of 125-metre circumference with heavy-duty 150mm mesh nets. At the end of this period up to 10,000 tonnes are harvested,achieving a total export value of Aus$250m.

4.3 Canada

New Brunswick on the east coast and British Columbia on the west coast account for 90% of Canada's farmed finfish output. Nova Scotia and Newfoundland also contribute tonnage. Most of this output is Atlantic salmon although there are the beginnings of a cod industry in Newfoundland and New Brunswick.In New Brunswick,most of the industry is currently contained within traditional Class 1 farm sites. The industry, however, is very constrained geographically, and there are no new sheltered sites available.

Consequently, there is very little room for expansion,and the majority of new site approvals over the past few years have been for sites operating in Class 2 environments. **(Fig 4.2)** Although New Brunswick saw the first commercial installation of Ocean Spar cages in 1997,these new sites generally use large circumference (90m-120m) plastic circle cages within reinforced grid systems, and rely on automatic feeding barges.

Recognising the need to venture out into more exposed sites, the New Brunswick Salmon Growers Association recently commissioned a study to determine a development strategy for Class 3 sites in the Province with regard to site selection,suitable technology and the economics of offshore farming. **(Bridger 2004)**

While still in draft form,one of the more significant conclusions from the study is that for New Brunswick at least,an adequate offshore cage and associated technology system does not yet exist. The study suggests that the industry would be best served by investing in a programme that would provide better understanding of conditions at potential offshore sites. This programme would,in parallel,assess the suitability of available technologies through modelling and tank tests, and propose appropriate modifications.

While British Columbia does not have the same geographical limitations as found in New Brunswick,it suffers from many of the symptoms described earlier with regard to public perception.In the late 1990s, several attempts were made in more exposed locations using large catamaran-type steel cages from Norway. Although early results were encouraging,the very challenging financial environment has curtailed further development activity.

Fig 4.1(a) Harvesting Tuna, Port Lincoln, Australia. Chris Kennedy, Sunderland Marine Mutual Insurance.

Fig 4.2 Plastic collar cages, Grand Manaan Island, Bay of Fundy, New Brunswick, Canada. Nell Halse.

Fig 4.1(b) Feeding Tuna, Port Lincoln, Australia. Chris Kennedy, Sunderland Marine Mutual Insurance.

Fig 4.3(a) Sea-bass and sea-bream farm, Class 4 site, Canary Islands. ADSA, Gran Canaria.

4.3 Canary Islands

A sea-bass and sea-bream farm in Gran Canaria in the Canary Islands installed two 6000m^3 Ocean Spar cages some years ago. These were recently taken out of the water for various reasons. The proprietor, however, still has faith in the concept and is prepared to try again, provided trials are adequately resourced.Meanwhile, the farm carries on with conventional plastic collar cages. **(Fig 4.3)**

4.4 Caribbean and South America

Dominated by island nations with significant tourism activities, there is a lot of interest in developing submerged offshore culture in the Caribbean, particularly with a view to operating with reduced visual impact.Snapper Farms Inc.has been using two submerged Sea Stations for the past two years at its farm in Puerto Rico. The company has aggressive expansion plans for up to 40 cages at this site, which is several miles offshore. The company is focusing its efforts on cobia and red snapper, and has already harvested its first crop to great acclaim in the marketplace. **(Fig 4.4)** An experimental teaching operation is underway in the Bahamas using submerged Sea Stations. Demonstration projects in both Brazil and Argentina are also scheduled for the near future.

4.5 Faeroe Islands

A number of exposed sites have been trialled in the Faeroe Islands. One particular farm on the south coast is so exposed that it may be a candidate for Class 4 classification. This farm uses large plastic circular cages and a Gael Force Sea Cap barge. In 2000,an Ocean Spar anchor-tension cage was tested in a high current location and while the cage performed adequately, the current proved far too strong for the fish,resulting in mortalities and poor growth. **(Fig 4.5)**

4.6 Iceland

Farms in Iceland are currently located in relatively sheltered waters, however, the industry is in expansion mode and is keen to persuade its government to allow new operations to be installed in more exposed waters.

4.7 Ireland

'Ireland leads the world in open ocean aquaculture production and has gained the greatest amount of experience with technological development/innovation and logistics mitigation' **(Bridger, 2004).** Because of its gently sloping continental shelf, most of Ireland's sheltered inshore waters are too shallow for finfish cage farming and nearly all of the farming companies operate a mixture of inshore and offshore sites. Thus, Irish farmers are only too familiar with the unsuitability of inshore technologies for offshore use, and were amongst the earliest to test cages specifically designed for use in exposed sites. These were rubber collar cages assembled by the Japanese company, Bridgestone, from pipes originally designed for the offshore oil industry. **(Fig. 4.6)**

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. **(Fig 4.7)**

By the late 1980s, however, problems had been experienced with the metal corners connecting the rubber flotation tubes. This created an opening for an improved design by Irish company Bonnar Engineering, using rubber hoses from Dunlop (UK).Since 1990,the favoured offshore cage has been the Dunlop octagonal cage, each of the eight sides being 16 metres long. **(Fig 4.8)**

In 1988,Carrols Seafoods installed two Farm Ocean cages at one of their exposed Connemara sites;however, manufacturing flaws in the steelwork resulted in major structural damage after a short period at sea,rendering them unusable.

1999 was a busy year for innovation in offshore technologies in Ireland when a giant 20,000m^3 Ocean Spar cage was installed at a sheltered site in Connemara,and Bonnar/Dunlop successfully tested a submersible version of a hexagonal rubber collar cage.

The technology transfer trial involving Ocean Spar cages is worthy of more detailed consideration as a particular case study, given that many of the problems encountered were generic to such trials worldwide. Thus, a number of valuable lessens for future development work may be gleaned from this example.

Case study

The Ocean Spar installation was the first stage in a two-part plan to apply this novel technology. The intention was that management techniques would be developed over a 12-month period at the sheltered site and that a second similar cage would then be installed at an offshore site nearby;the crew at the offshore site benefiting from experience gained at the sheltered site. The second cage was eventually installed but for reasons that will be explained here and in Chapter 3, this part of the project was not totally successful.

Interestingly, because of economies of scale and the encouraging performance of the fish (750 tonnes of 4.9kg fish) achieved with the large cage in the original sheltered site, the management subsequently installed a second Ocean Spar cage of similar dimensions but of a different shape. The new shape has flattened, rather than pointed ends so that the access portals are perpendicular to the current rather than oblique. During stocking and harvesting,this greatly assists the process of encouraging the fish to swim into or out of the cage through the portals as required. **(Fig 4.9)**

A very successful innovation on these cages was the addition of rings and rollers that could slide up and down the spars. When the floor of the net is tied to the rings it can be raised with relative ease using yacht winches installed on top of the spars. This system is a further aid to the operator during harvesting. **(Fig 4. 10)**

The requirement to develop this novel solution arose from difficulties experienced by farm staff trying to carry out the first harvest.It took three weeks of frustrating trial and error to empty the cage. What started as an embarrassing experience for the fish farmer not being able to catch his own fish,culminated into a classic example of the benefits of close cooperation between fish farmer, equipment supplier and the State development agency, BIM,(the Irish Sea Fisheries Board).

Nevertheless, despite overcoming this particular difficulty and being able to transfer the fix in advance to the offshore site, the system was not successful in the exposed location for a number of other reasons. These included difficulties in feeding the cage and a wholly avoidable error in the mooring set up whereby dissimilar metals were mixed in the mooring components causing failure due to electrolytic corrosion. As a result,the exposed site operator lost confidence in the system and did not pursue the trial at a full commercial scale.

In effect,the extremely promising results were not translated from one site location to the other, and the system's reputation was tarnished for the wrong reasons. The phrase 'giving a dog a bad name' could be applied to this situation. The other key observation to emerge from this trial was the all-too common situation whereby a piece of equipment or system is sold as being fully operational.Whereas in fact,it was still at an early stage of development in the context of the holistic approach required for successful offshore finfish farming operations.

With regard to the submersible Dunlop cage, the methods for submersion and resurfacing were successfully developed but funding ran out before management issues such as feeding and fouling of the top net could be addressed.

Both of these projects illustrate yet again the central problem of developing technologies and methodologies for the offshore zone:the will and the spirit of innovation are there;however, unless an adequate development period has been built into the project planning,it is likely that commercial pressures will overwhelm such innovative projects.

Fig 4.3(b) Another view of same farm, Canary Islands. ADSA, Gran Canaria.

Fig 4.6 Crane lowering rubber pipe section for assembly of Bridgestone cage, Clew Bay, Ireland, 1987. Marine Harvest, Ireland.

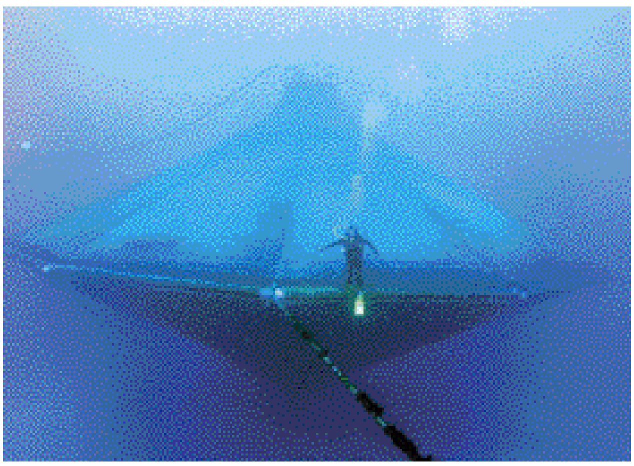


Fig 4.4 Sea Station cage, Puerto Rico. Snapperfarm, US.

Fig 4.7 First Bridgestone cage at Clare Island, Ireland, 1987.
Marine Harvest, Ireland.

Fig 4.5 Ocean Spar, 20,000 cubic meters, Faeroe Islands.
Net Systems Inc.

Fig 4.8 Octagonal Dunlop cage, with Clare Island behind, Ireland, 2004. John Costelloe, Aquafact International Services.

Fig 4.9 Ocean Spar, 20,000 cubic meters, with flat (not pointed) end, Killary Harbour, Ireland. Note feed pipe and solar powered transmission system for sub-surface video camera signal. Abdon Ryan photo.

4.8 Mediterranean

The bulk of offshore farming in the Mediterranean is for sea-bass and sea-bream and the remainder for bluefin tuna. The industry has tested most types of offshore cage including Bonnar cages, plastic circles from various suppliers, Sadco Shelf, Farm Ocean, Sea Station, Ocean Spar, and RefaMed tension legs. The favoured feeding method is by hand or feed cannon,with Greece being the only country relying extensively on centralised feeding systems. For various logistical and husbandry reasons, smaller cages ranging from 70-80 metres circumference are favoured for sea-bass and sea-bream.

The principal marine cage farming countries in the Mediterranean are Greece and Turkey. Both of these are fortunate to have heavily indented coastlines so that farming is generally carried out in sheltered waters. Given that tourism is a major industry in both countries and because of increasing opposition to aquaculture, it is likely that most future development will have to be offshore.

Most other Mediterranean countries are not so well endowed with sheltered inshore areas, and the bulk of cage farming takes place in offshore locations, many of which would qualify as Class 3 sites.

Due to a vibrant tourism industry in both Malta and Cyprus and the need for low visual impact,almost all sites are located in the offshore zone. Many Maltese farmers are in the process of changing from sea-bream and sea-bass farming to tuna farming,and are therefore graduating from 70 metres to 150 metre circumference plastic cages. One farmer in Malta worked with four Farm Ocean cages over an extended period;however these are now not being used due to various logistical difficulties.

Most of the sites in Spain might also be classified as Class 3 or even Class 4. The favoured cage for sea-bass and sea-bream is a 70-80 metre plastic circle supplied by local manufacturer, Corelsa.Many farms in Spain have experienced severe storm damage from time to time, particularly those located north of Alicante. Government-assisted trials have been carried out in the Bay of Cadiz to compare the performance of a Corelsa plastic cage, a RefaMed tension-leg cage and a submerged Sea Station. The results are not yet available but will be of great interest due to this area's open Atlantic location. **(Fig 4.11)**

Italy is working towards self-sufficiency in sea-bass and sea-bream supplies. The favoured farming area is off the coasts of Sicily and Calabria where a number of new sites are being developed.Fusion Marine of Scotland is currently building a heavy-duty tuna cage for one of these sites. It measures 150 metres in circumference and has three rings of plastic piping,450mm in diameter. The entire structure weighs 27 tons. **(Fig 4.12)**

The RefaMed tension-leg cage is particularly popular in these areas and in Sardinia.A total of 42 units are currently in use in what are ostensibly Class 3 sites by four different farming companies. This represents full commercial use of a novel cage system and is possibly the first case of widespread adoption of an alternative to the gravity

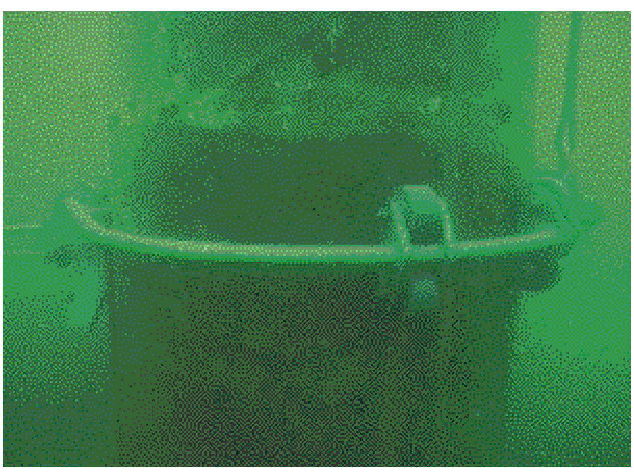


Fig 4.10 Underwater view of rolling ring on spar of Ocean Spar cage. Net Systems Inc.

Fig 4.11 Open sea bass and bream farm off the coast of Barcelona, Spain. On the seaward side of this farm the nearest land is Corsica, 600 kms away. J. Ryan, photo.

Fig 4.12 Fusion cages of the type being installed in Sicily. Fusion Marine, Scotland.

Fig 4.13 Tension-leg cage farm with centralised feeding system in open water off Salerno, Italy. Refamed, Italy.

cage. Only one of the farms using tension leg cages has a centralised feeding system. The remainder are fed by hand or by cannon. **(Fig 4.13)**

In Libya, Tunisia and Morocco on the north-African coast,small offshore projects are under way growing sea-bass, sea-bream and tuna.Again, these are ostensibly Class 3 sites with plastic circular cages being the favoured system.

4.9 Mexico

Off the coast of Baja California in the Pacific Ocean are a number of farms dedicated to fattening tuna. These are using the same technology as outlined for Australia and are operating in very exposed conditions some of them being located in more or less open water. **(Fig 4.14)**

4.10 Norway & Chile

Because of topographic similarities, the nature of the marine finfish industry in both Norway and Chile is virtually identical with respect to the degree of exposure to which their sites are subjected.Both countries have an abundance of sheltered deepwater and as such can deploy the proven technologies for Class 1 and Class 2 operations successfully.

Fig 4.14 Tuna farm facing open ocean, Mexico. Ted Dunn, Paula Sylvia

This similarity has had a further fundamental effect on the rate of development of offshore fish farming as the market for the supply of finfish farming equipment has largely centred on these two countries, as they are the pre-eminent practitioners. Thus, the equipment suppliers have naturally concentrated their efforts on developing technologies to service the needs of Class 1 and Class 2 operations, rather than having to fund the R&D costs of developing true offshore farming techniques.

Thus, the commentary and conclusions drawn below with regard to the Norwegian industry are also broadly applicable to Chile.

According to a survey carried out in 2000,only 17% of marine cage farming licences in Norway are located in sites with significant wave height of over 1.5 metres. There are no licences in open water. As both scale and production levels increase, however, a trend is emerging towards moving beyond the mouth of the fjords to more exposed areas amongst the islands and reefs just off the coast.

In these areas, plastic collar cages are greatly favoured over steel cages. Collar cages are generally 90 to 120 metres in circumference with double rings of heavy-walled pipe 400mm in diameter. Nets are up to 30 metres deep. Trials are currently underway using a 156-metre circumference cage, and the results are encouraging. **(Fig 4.15)** Similar trials have been carried out before using large circular cages but these have generally failed due to a lack of adequate net handling equipment and methodologies.

It is interesting to consider that a 156-metre circumference cage with a net depth of 30 metres has a theoretical maximum volume of 58,000m^3. With a biomass per cubic metre of 20kg,this cage should be capable of holding over 1,100 tonnes of fish,and in terms of scale is potentially an ideal candidate for offshore aquaculture.

The general industry view in Norway is that whilst there is little pressure to move offshore at present,there will be a need to go in that direction within the next couple of years. With this in mind,a number of strategies aimed at developing suitable technology for offshore sites have been initiated. These include the Storm cage system from Marine Construction A/S, which is a gravity cage consisting of a steel platform with nets hung beneath and is designed to withstand significant wave heights of 4-5 metres.

Another system is the Subfish cage, which is a submersible cage with a single point mooring. The Norwegian Institute of Technology is developing this system for use in open waters. **(Fig 4.16)**

Plastic cage collar supplier, Polarcirkel,has produced a submersible cage and is developing a new plastic/steel square cage for more exposed waters. **(Fig. 4.17)** Another radical concept is the spherical submersible cage, being developed by Byks A/S. (See paragraph on rigid cages in Chapter 3.)

In summary therefore, with regard to both the Norwegian and Chilean finfish farming industries, there remains a considerable resource of Class 1 and Class 2 sites as yet unexploited.Nevertheless, successful exploitation of these areas will require similar techniques to those being developed for the emerging offshore finfish sector in other countries. These areas have little or no infrastructure, and will present similar operational challenges such as the provision of large feed storage capacity and remote operational capabilities.

4.11 Scotland

Scotland's west coast is deeply indented,and its sheltered sea-loughs have facilitated the country's rapid growth in salmon farming.As the industry has grown,however, most of the available and suitable sites have now been exploited.As a result of increasing levels of environmental awareness, suggestions have been made that some areas are over impacted,particularly at the heads of the longer sea-loughs. It is now a policy of the Scottish Executive to move any further expansion of the industry offshore, and over time to shift a proportion of the existing production to higher energy locations.

Farmers are now converting from small steel cages to plastic circular cages, ranging in size from 80-120 metres in circumference. These are serviced by a centralised barge-mounted feeding system.
The concrete cylinder feed barge, Sea Cap from Gael Force, has proven particularly suitable, especially in the more exposed locations. These are located in the channel (The Minch) between the mainland and the Outer Hebrides Islands. Additional offshore sites are located around the Shetland Islands where plastic cages and Sea Cap feeding barges are also used. **(Fig 4.18)**

Fig 4.15 Norway's largest salmon cages,1000 tonnes per cage. Aqualine, Norway.

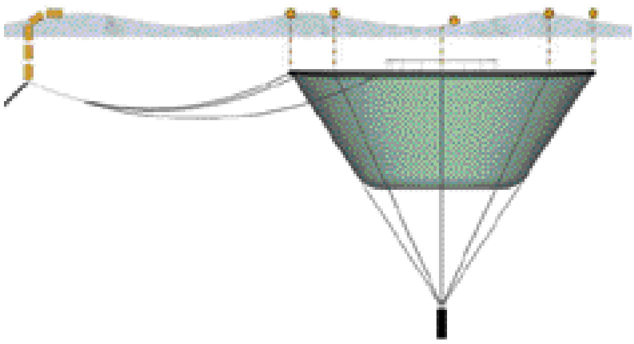


Fig 4.16 Subfish submersible cage concept. Technology Institute, Norway.

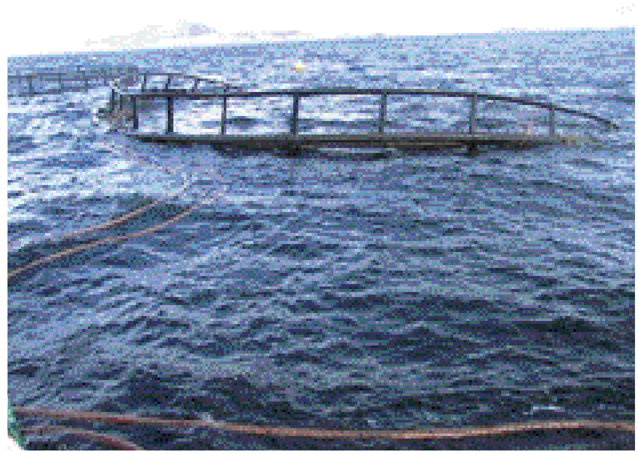


Fig 4.17 Polarcirkel cage being submerged. Polarcirkel, Norway.

4.12 United States

Due to federal policies and regulations in the U.S. that discourage the use of inshore locations for finfish cage farming,there is a major drive to develop offshore or Class 4 sites. Several centres of activity have already been set up in Hawaii,Puerto Rico, Gulf of Mexico and on the northeast coast.

From a commercial point of view, Hawaii is most developed. The State has now licensed a third offshore finfish farm,and all are using or propose to use submerged 3000m^3 Sea Station cages. Several more sites are at the planning stage. Hawaii has a modest goal of just 10 such sites. These are being closely monitored for environmental impact and results to date have been favourable. The sites are quite small by salmon standards, with the scale of production per site being limited to between 500 and 1,000 tonnes, harvested from 6 to 10 submerged cages. **(Fig. 4.19)**

The industry has developed around juvenile rearing programmes run by the state and the Oceanic Institute. Whilst availability of juveniles is now a limiting factor for growth in production,the industry is confident that the relative success to date demonstrates the positive economic, operational and marketing issues associated with offshore farming.

The industry will farm many different indigenous marine species such as Pacific threadfin (moi),and amberjack. These species, which are both scarce and valuable, occupy specialised niches in local and Asian markets. This factor, allied with planned restrictions on production levels, should protect the industry from the price instability that has plagued salmon, sea-bass and sea-bream farmers.

In the Gulf of Mexico over the past 15 years, a number of aquaculture projects have endeavoured to employ redundant oil and gas platforms as feeding and crew stations to support finfish cages moored close by. For a variety of reasons, such as logistical problems associated with sites being located up to 40 miles offshore;equipment failure;poor planning and inadequate finance, none of these projects achieved long-term commercial or developmental activity. Several of the projects were strictly engineering exercises, with no fish placed in the cages. The cage technology tested included plastic rings, Dunlop/Bridgestone, small Ocean Spar cages and Sea Stations.

Off the mouth of Portsmouth Harbour is the Open Ocean Aquaculture Project,operated by The University of New Hampshire and funded by NOAA.A true Class 4 site, the project is operated as a test bed to demonstrate and develop offshore cage and ancillary technology as well as fish husbandry techniques. Although run by an academic institution and not as a commercial enterprise, much effort is put into operating the site with realistic commercial practices and up-scaling in mind. The project grows Atlantic halibut,cod and haddock in its three submerged Sea Station cages.

Associated with the project is the Jere A.Chase Ocean Engineering Laboratory, which provides engineering and modelling services. Significant developmental effort has been applied to the design, construction and operation of a spar type feed buoy, incorporating associated remote telemetry competence and feeding capability in submerged cages. **(Fig. 4.20)**

A similar programme, sponsored by Hubbs Sea World, is now in the middle of a long licence application process. The project will be centred around an offshore oil rig located in a Class 4 situation 10 miles off of the coast of California,and will grow tuna, California yellowtail and striped bass. The project will employ a large surface plastic cage for the tuna and submerged Sea Stations for the other species, with a view to demonstrating the various technological aspects of offshore farming.

4.13 Western Pacific

In the Western Pacific,plastic gravity cage technology has been tested, but with limited success due in part to typhoon damage to sites.

Taiwan has significant goals for its fish farming industry and as an island nation will need offshore farming to realise these goals. The country has built up a comprehensive infrastructure for juvenile production,which, as yet,it has been unable to exploit.Some trials have been carried out at offshore sites using plastic collar gravity cages but these have failed due to exposure levels and the usual shortcomings associated with gravity cages, as previously discussed.

Since early in 2000,China has engaged in a number of projects in recognition of the potential that offshore farming represents for increasing

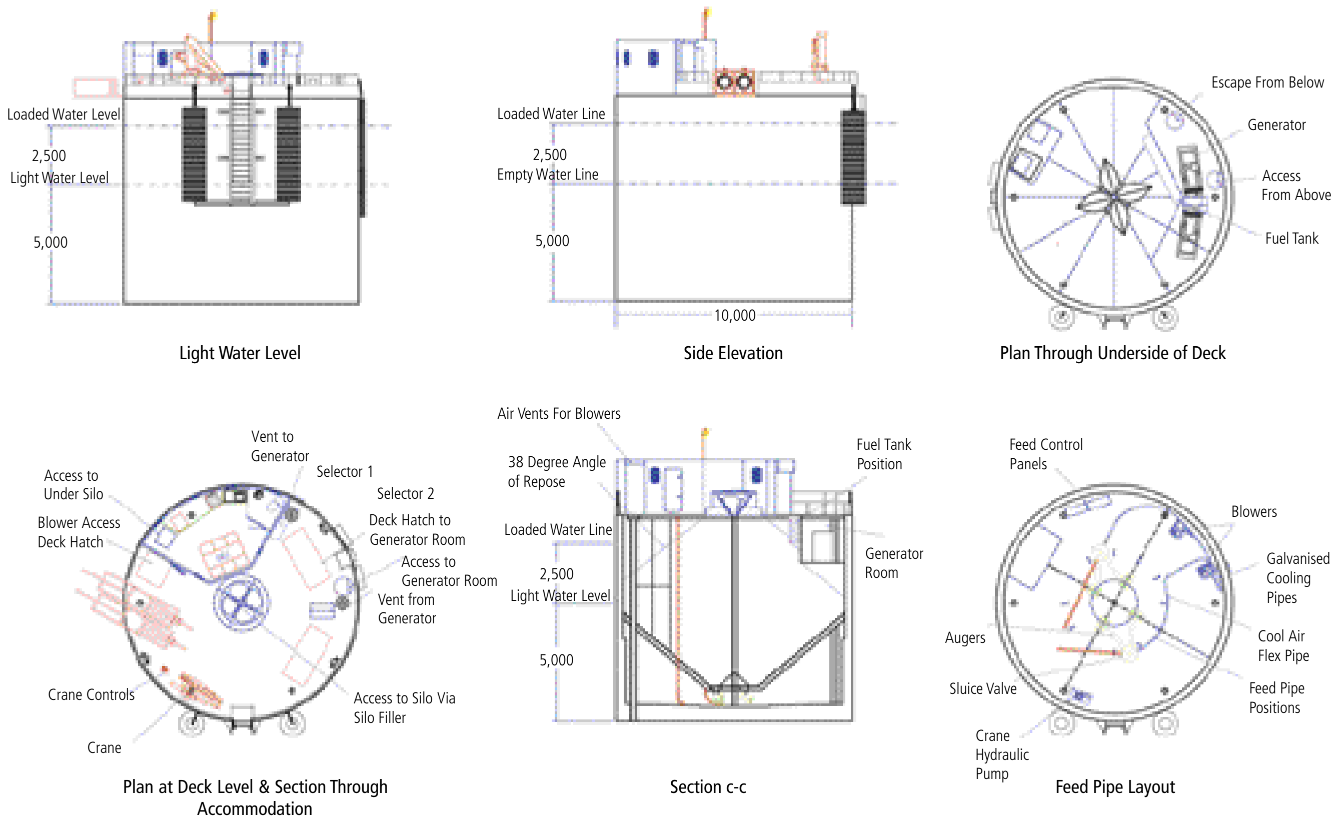


Fig 4.18 General lay-out drawings of 200 tonne Sea Cap concrete feed barge. (see also Fig 3.23) Gael Force, Scotland.

aquaculture output to feed its growing population. The projects, which involve both plastic surface cage technology and submerged Sea Station cages, have not yet resulted in any significant large-scale operations.

In the Philippines, submerged Sea Stations growing milkfish have had limited success but this has not yet translated into a commercial offshore industry. Likewise in Korea and Vietnam,interest in offshore farming is developing but is in the early planning stages.

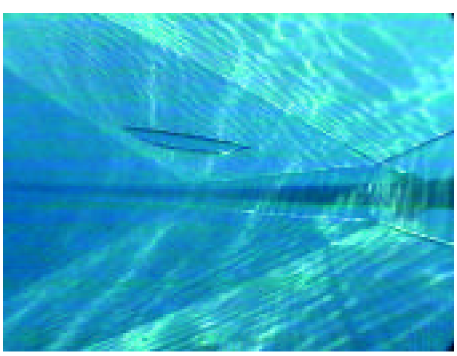


Fig 4.19 Inside view of Sea Station cage in the clear waters of Hawaii. Net Systems Inc.

4.15 Global trends

Having reviewed offshore aquaculture in practice around the world, it is appropriate to consider the emerging trends and the conclusions that might be drawn.

In the first instance, probably the most confusing issue that needs to be addressed is the varying cage types that are employed in different ‘open ocean’ situations.

For instance, the Mediterranean has extensive operations located in what are ostensibly Class 4 or open ocean sites around the coasts of Spain, Italy, Cyprus and Malta,mostly using gravity cages.

On the other hand,there are few, if any, Class 4 operations around the coasts of Ireland,Scotland and North America,and it is quite certain that Mediterranean gravity cage technologies would have little chance of long-term operation or survival in open ocean sites in these countries.

Thus, open ocean conditions vary hugely with respect to location,and are dependent on climate as well as topography. Obviously therefore, there are different grades of Class 4 sites. This applies to Class 3 sites also, and the need for a more refined site classification system,based on an analysis of wave characteristics and tidal currents, is apparent.

Fig 4.20(a) Cod in a submerged Sea Station cage off the coast of New Hampshire, USA. University of New Hampshire.

With regard to which cage technologies are favoured by offshore fish farmers, gravity cages are by far the most prevalent.Although problems continue to occur, the design of offshore gravity cage collars and nets is evolving.While this may eventually culminate in the availability of trouble-free systems, it is more likely that other approaches will be needed.

As already outlined,there are many alternatives to offshore gravity cages in the form of a variety of novel cage options. Only two of these to date, however, show any sign of extensive take-up by commercial operations. These are the RefaMed tension-leg cage in Italy and the Sea Station, which is being used in offshore sites in many parts of the world.

Widespread adoption of novel cage technologies has been slow to date for a variety of reasons. In most cases, the designs have not been adequately proven,and the cage units are too small.Also, it is often unclear as to how they will accommodate a full operating system that must include feeding,harvesting and general husbandry procedures.

Cost is another important factor. Alternative systems are either going to have to match the cost of offshore gravity cages, or offshore farmers will need to be convinced that the higher cost will be money well spent.

With regard to supporting technologies, it appears that most offshore sites require daily visits by crew feeding by hand or by feed cannon. Farmers remain to be convinced that there are fully automated systems that can do the job at a reasonable cost.

A good example of a country anxious for these issues to be satisfactorily resolved is Iceland,whose farmed salmon industry is confined to sheltered waters on the east coast. There are two problems with this area:lack of space for expansion and poor fish growth due to low water temperatures. The waters of the south coast,being visited by the Gulf Stream,are much warmer but are very exposed.Icelandic farmers for a long time have had ambitions to expand into this area but believe that appropriate technologies are, as yet, unavailable.

4.21(b) Prototype spar feed buoy for supply of feed to submerged cages off the coast of New Hampshire, USA. University of New Hampshire.

In summary it may be seen that 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.

It is not commercially feasible to expect that the returns from the sale of fish reared in an experimental set-up in the short-term would be sufficient to fund the 'full chain' development of new offshore technologies. Because the equipment suppliers are not in a position to offer fish farmers systems that are fully mature in all respects, there is in effect no established market for offshore finfish farming technologies. Thus, a new paradigm for the development of such technologies is required,which incorporates a long-term approach allowing the suppliers and farmers to work together in a business environment that does not expect a short-term return.

A possible approach is set out in chapter 9.

Chapter 5

Environmental Aspects of Offshore Aquaculture

5.1 Introduction

There has been much debate in the media over the past 20 years regarding the potential environmental impacts of marine finfish cage farming. During that period, however, as numerous environmental audits and scientific studies were carried out, it has become apparent that appropriately-sited farms pose minimal risk, particularly with regard to water quality and benthic (seabed) impacts.

In Ireland for example, most farms are now located in areas of high water exchange so that extensive dispersion mitigates waste accumulation. For instance, fish in a cage in a typical Irish coastal situation will experience average current speeds of 0.1 metres per second or 0.36 kilometres per hour. This equates to 8.6 linear kilometres of water passing through the cage daily, resulting in a volume of up to 2.35 million m^3 (or 2.35 million tonnes) of water passing through a typical cage of 100-metre circumference.

In the case of sites located offshore, dispersion effects are even more pronounced.Offshore operations therefore experience advantages in terms of husbandry benefits and benthic impacts, by virtue of a higher rate of water exchange.

These issues are discussed in this Chapter, along with aspects relating to the wider environment such as consideration of the potential for fish escapes from offshore units.

5.2 Husbandry Benefits

As previously outlined,whilst there are technology challenges associated with moving offshore, significant advantages also exist,especially with regard to husbandry. These include:

- Greater water exchange through the cages, brought about by a combination of wind and wave action,and tidal currents. The advantages conferred include greater oxygen availability and minimal levels of ammonia,which although excreted by the fish themselves, can be toxic to them at high concentrations.

- The open nature of offshore sites further improves dispersion, as a particular body of water is unlikely to pass through the cages more than once. This is in contrast with the situation in many inshore sites, which because of topographical confines can experience a portion of the same water returning with each tidal cycle. **(Fig 5.1)**

  Offshore sites therefore can expect to experience lower levels of ecto-parasitic infestation because the planktonic juveniles tend to be swept away, never to return. This means that in the case of offshore salmon farms, for example, there is a significantly lower rate of build up of sea-lice levels. Experience in Irish offshore operations already shows that they rarely have to medicate against lice.

  This scenario not only confers major advantages in terms of husbandry, logistics and cost,but also helps in establishing eligibility for 'organic' certification,as has been the case at the farm at Clare Island off the Irish west coast.A low incidence of ecto-parasites is also a major contributory factor to low mortality and high growth rate in the farm stock.

  It should also be noted that because of their location,ecto-parasitic juveniles swept away from offshore cages are unlikely to encounter any wild hosts, and thus will die harmlessly in the plankton.

- Less extreme and more stable water temperature regimes. The offshore zone does not experience extreme temperature oscillations, which can severely compromise fish at inshore farms. For example, the peak summer temperature in oceanic waters off the Irish west coast is usually around 17ºC, ideal for optimum growth of Atlantic salmon.On the other hand farms in coastal bays on Ireland's west coast can experience highs of 23ºC during the summer, which may result in fish losses due to anoxia (lack of oxygen).

  Similarly, extremes in low water temperatures during the winter period would also be avoided if farms were located in offshore situations. This combination of higher winter temperatures and lower summer peaks, in the Irish situation for example, results in an average regime, which is conducive to maximum fish growth and feed conversion rates. **(Fig 5.2)**

  The potential economic advantages in this regard are illustrated in Chapter 8.)

Fig 5.1 The open nature of offshore sites improves dispersion - Clew Bay, Ireland. John Costelloe, Aquafact International Services.

- Salinity is also more stable in the offshore situation because of the remoteness from sources of freshwater.
- Another benefit of good dispersion,open locations and distance from extensive shorelines and reefs, is that there tends to be a lower rate of net fouling from sessile organisms such as mussels, hydroids and macro-algae (seaweeds). This not only ensures a better environment for the fish but can also result in significant savings in net cleaning costs.
- Lower impact on the seabed. This is another benefit of greater water exchange and is so pronounced that many offshore operations in Ireland for example, record little or no measurable benthic impact. This is significant to the welfare of farmed fish as there is no risk of the toxic gas, hydrogen sulphide (H^2S),being released from decaying organic matter on the seabed.

These factors combined will result in an environment conducive to the production of healthier and faster-growing fish,with significantly lower mortality rates. Fish grown at offshore sites are also known to have firmer flesh and lower fat levels, resulting in a higher quality product. These implications are discussed in more detail in Chapter 7.

The following section examines the question of benthic impacts using Irish marine finfish cage farms as a case study. Inshore and offshore sites were compared during the research,and the key findings are reported below, on the basis that they can be applied internationally. The results graphically illustrate the difference in benthic impacts between inshore and offshore locations.

5.3 Seabed or Benthic Effects: Irish Case Study

Since 1989 there has been a statutory requirement in Ireland whereby any marine cage farm wishing to expand production or to occupy a new site is obliged to carry out an Environmental Impact Study (EIS) as part of the licence application process. This study must include an assessment of the impact on water quality **(Fig 5.3)** the seabed and the surrounding area.

In the intervening years, almost every Irish farm site has been the subject of at least one if not two or three EIS's. A comprehensive picture of the real environmental effects is now available. This shows that the main impact is on the sea floor beneath the cages, principally caused by organic waste dropping from the cage above. In addition to the requirement for an EIS, the study also used data arising from the annual benthic audit,required by the Irish regulator, as a source of information. **(Fig 5.4,5.5,5.6)**

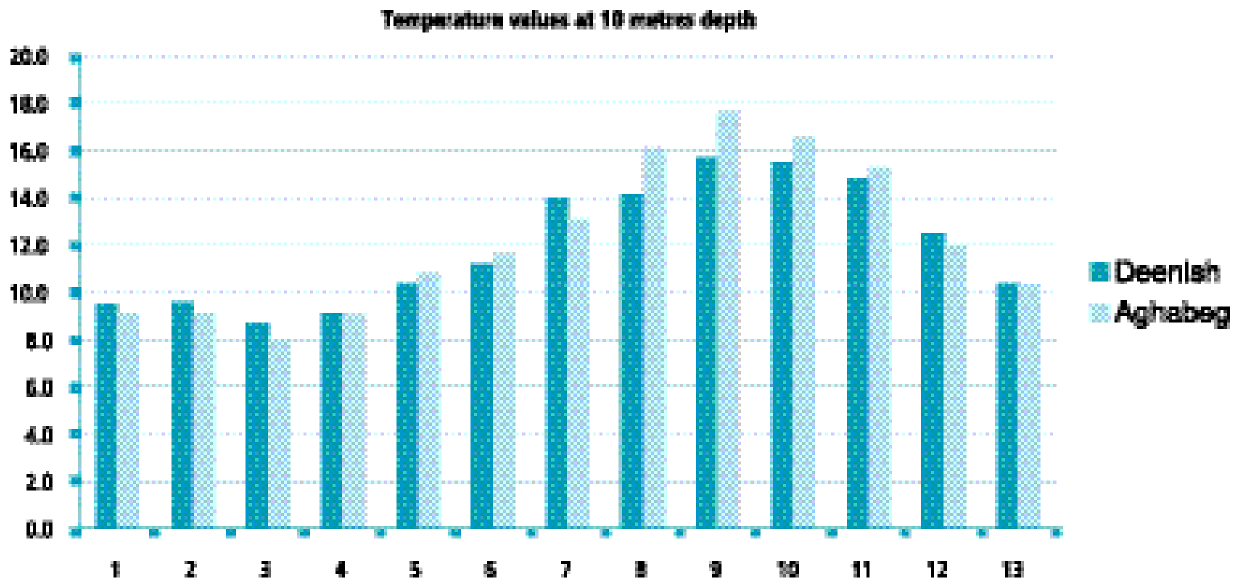


Fig 5.2 Comparison of temperature regimes (degrees Celsius) over a 13 month period (Jan. 2003- Jan. 2004) at 2 adjacent farms off the South West coast of Ireland- Deenish being offshore and Aghabeg being inshore. Though inshore, Aghabeg is adjacent to oceanic water and a more enclosed site would have greater extremes of temperature. Glan Uisce Teo, Ireland.

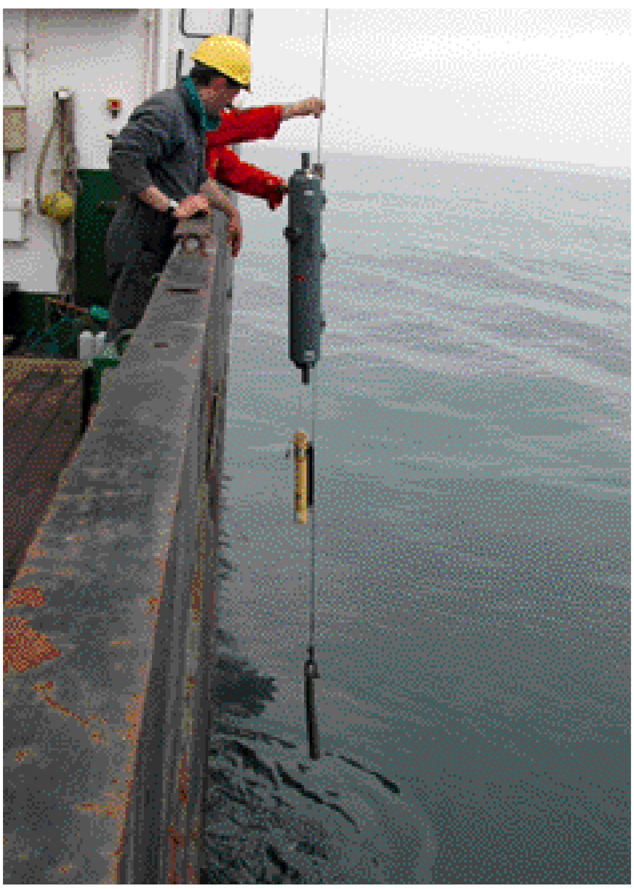


Fig 5.3 Water sampling on a monthly basis is required by Government regulation at Irish fish farm sites. Samples are analysed for temperature, salinity, nutrients, oxygen and chlorophyll. John Costelloe, Aquafact International Services.

In 2001,a review of benthic conditions at Irish fish farms was carried out,which incorporated data from twelve years of EIS's and benthic audits. In all,109 environmental reports referring to 53 marine fish cage sites were studied. The results were then compared with available data from other countries with marine finfish industries.
The authors of the report concluded:

In general, the conditions recorded under Irish salmon farms are notably better than those from under cages in Scotland and Norway. This is attributed to the different oceanographic and morphological characteristics of the bays where fish farming is carried out in Ireland. Along the west coast, the tidal range is circa 5m during highest Spring tides and the flushing effects of this volume of water creates tidal velocities that not only sweep away uneaten food but also dilutes any B.O.D. or low oxygen water in the vicinity of farms. This in turn helps to reduce any negative effects that the seabed experiences due to the addition of uneaten fish food to the benthos. Furthermore, the bays on the Irish West Coast are not silled systems such as are found in parts of Scotland and Norway. With the exception of Killary Harbour and Mulroy Bay, entire bays can be entirely flushed over a short period of time.

(Review of Benthic Conditions at Irish Fish Farms, September 2001, Aquafact International Services Ltd)

A key finding of the Aquafact review is that benthic impacts are reduced,if not more or less absent altogether from offshore or exposed sites. **(Fig 5.7)**

Having examined the husbandry benefits and the local impacts of offshore operations, it is now appropriate to consider what implications there might be for the wider environment if an extensive offshore farming strategy was pursued.

Fig 5.4 Sediment Profile Imager (SPI) for assessing sea-bed conditions. The entire apparatus is lowered to the sea-bed whereupon the wedge-shaped structure in the centre is catapulted into the sediment. A camera located behind the glass panel then photographs the sediment profile. John Costelloe, Aquafact International Services.

Fig 5.5 A grab for retrieving sea-bed samples. The variety and number of animal species present in the samples indicates benthic conditions. John Costelloe, Aquafact International Services.

5.4 Other Environmental Considerations

The other major environmental considerations with regard to offshore finfish aquaculture are:

- **Visual impact**
  This will obviously be reduced because of increased distance from the shore and will be almost completely eliminated in the event of widespread use of submerged structures. It needs to be borne in mind,however, as outlined in Chapter 6,that offshore farms must have access to inshore sites for harvesting purposes. These could also ultimately avail of submerged structures for live fish storage once the required technologies have been perfected.

- **Competition for space**
  In moving offshore, competition for space should be less of an issue than in the inshore zone, particularly from tourism/marine-leisure operators and other stakeholders such as inshore fishermen and shellfish farming activities.

  Nevertheless, offshore farms will need to be very well marked and located away from shipping lanes and major fishing grounds. Given the vast areas of space available, this should not pose a problem.

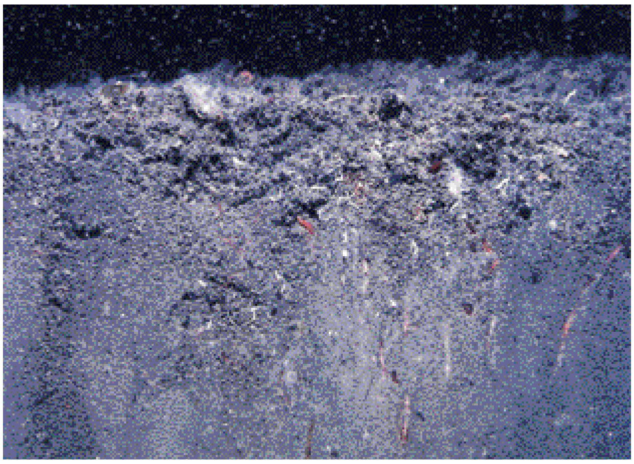


Fig 5.6 A sediment profile image (SPI) of an enriched sea bed beneath an inshore Irish farm. Here, a dense carpet of worms (Malacoseros sp) processes the waste from above and ensures the oxygenation of the sediments. John Costelloe, Aquafact International Services.

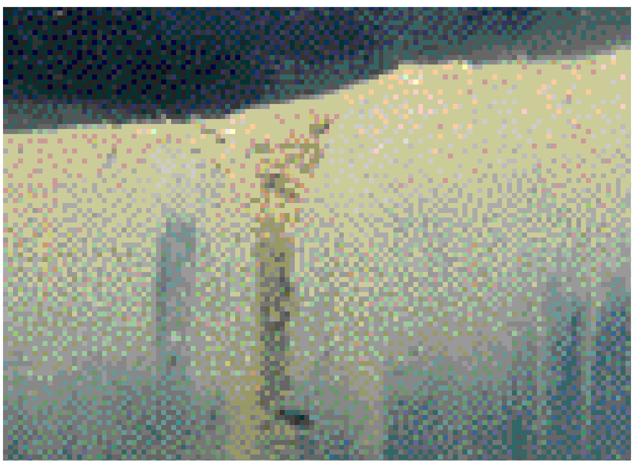


Fig 5.7 A SPI photo of a non-impacted sea bed beneath an offshore Irish farm. The large burrowing worm imaged here is typical of un-enriched sites. John Costelloe, Aquafact International Services.

- **Escapees**

  When promoting a large-scale offshore finfish industry, concern over the threat of increased escapee numbers needs to be addressed. (Escapees have the potential for cross breeding with wild members of the same species, which can result in reduced genetic diversity, the dilution of genes with local adaptations and a reduction in population sizes.)

  Although this particular consideration is of less importance in the offshore context because most escapees will fall to natural predation before reaching the breeding locations of migratory stocks because of sheer distance. Escapes are highly undesirable from an economic point of view and must be avoided.

  One major survey has indicated that the greatest proportion of escape events from marine fish farms is caused by weather conditions and holes in the nets. **(Fig 5.8)** Both of these are equipment failure issues.

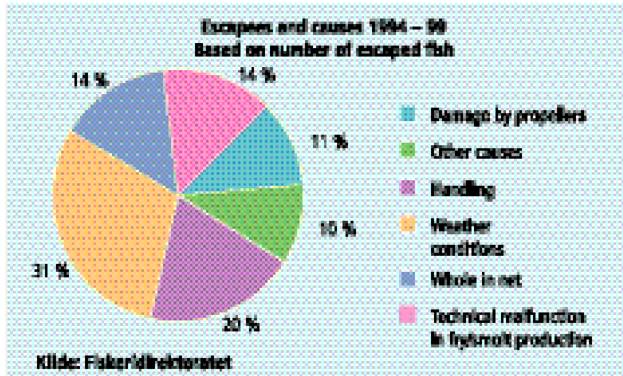


Fig 5.8 Analysis by the Norwegian Ministry of Fisheries shows that a significant proportion of escape events are caused by equipment failure.

  Escapee prevention must therefore be a major consideration in the selection of appropriate equipment for offshore aquaculture. A discussion on how these events could be avoided by the deployment of higher specification systems, specially designed for the offshore environment has been presented in Chapter 3.

  Further risk minimisation measures are discussed in Chapter 7 paragraph 7.4.2

- **Restoring or enhancing capture fisheries.**

  There has been a long-standing practice of enhancing migratory fisheries by the rearing and release of juveniles. It is not unreasonable to postulate that large-scale offshore finfish units would play a similar role in the re-stocking of certain high value marine species that may have been depleted in particular areas of the ocean. The ability of offshore finfish containment units to rear and release very large numbers of juveniles would make them ideal incubators for stock recovery.

In summary, accumulated knowledge and understanding within the industry suggests there are major husbandry benefits associated with locating large-scale finfish farms offshore. Significant investment opportunities are therefore possible in the offshore zone, and Chapter 6 examines the state-of-the-art as regards likely technologies and methodologies required to avail of these.

Chapter 6
The next step

6.1 Introduction

Previous chapters have demonstrated the need to consider an integrated offshore aquaculture strategy and have also reviewed progress in most of the world's oceans. Much experience has already been gained in the daily operation of exposed ocean fish farms but there is some way to go before this aspect of salt-water farming becomes a mature industry.

This chapter will review what has been learned as well as what technologies are now available, in an attempt to visualise the ideal offshore fish farm.It will explore the equipment likely to be used, and the daily procedures and infrastructure that might be required. The principal focus will be to consider improvements that could be made to current methods of operating Class 3 sites. In addition, suggestions will be made towards successful exploitation of Class 4 sites.

Most attempts to move offshore have involved technologies and methods already used at inshore sites. This approach regularly fails to fully appreciate the significant differences that prevail between the two environments, namely:exposure of offshore sites to ocean swell, and the consequent challenges to both the integrity of equipment and to the execution of essential daily operations such as feeding and harvesting.

The Irish industry has a good deal of experience of the harsh realities imposed by wave action in Class 3 sites. As outlined in Chapter 4, Ireland's coastal topography provides few locations suitable for farming inshore so that offshore aquaculture has been in operation there since the mid-1980s. It has proven difficult however 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.

At a meeting of offshore operators in Ireland in 2003,three principal challenges to successful daily operations were identified,namely: wear and tear, feeding and harvesting.It may be observed that these challenges are not unique to Ireland and are arguably common to all offshore operators regardless of their global location.

As outlined in Chapter 1,this report postulates a model of a 10,000 tonne operation,which is described in detail in this chapter. The practical and logistical considerations, such as wear and tear, feeding and harvesting,are set out hereunder.

6.1.1 Wear and tear

To date, offshore farms have favoured gravity cages, mostly using hexagonal or octagonal rubber collar cages or plastic circular collars.

As outlined in Chapter 3,the components of a gravity cage comprise the flotation collar, the net pen with its weighting system and the top net,which is used to keep preying birds and marine mammals at bay. In the offshore situation,relentless wave action causes these components to constantly move and rub together, causing abrasion.

There is also the cage mooring system to consider, which usually comprises a grid work of heavy lines attached at one end to anchors on the seabed and at the other to the cage collar. Each time a wave passes through a cage, shock loadings are applied to the cage collar, particularly at the point where the mooring lines are attached. Shock loadings also affect both the cage net and the mooring lines. This constant movement,abrasion and shock-loading results in progressive wear and tear, which can become particularly severe during storm conditions. **(Fig 6.1)**

Experience has shown that much of the day-to-day work on an offshore farm revolves around keeping ahead of ongoing damage, through adherence to a never-ending maintenance and repair programme. Problems start mounting as bad weather arises and essential repairs cannot be carried out. The longer poor conditions prevail,the worse the damage becomes.

When a weather window finally appears, all available time must be spent repairing breaks and tears at the expense of feeding the fish, which might already have been without feed for many days.

Fig 6.1 Storm at a Scottish salmon farm with plastic circle cages and Sea Cap feed barge. Andy Johnson, Sunderland Marine Mutual Insurance.

6.1.2 Feeding

The normal feeding method employed at many offshore sites is by means of a workboat travelling from cage to cage delivering the feed via a water or compressed air-powered cannon,supplied from deck-mounted hoppers. This method works satisfactorily in reasonable weather. In adverse conditions however, workboats can encounter severe difficulties when attempting to tie up to a cage, and may be forced to forego feeding altogether rather than risking damage to both cage and boat.

This is a serious issue. Take for example a farm needing 10 tonnes or more of feed per day. Given a normal feed conversion rate of 1.3kg of feed returning 1kg of farmed fish,one missed day could result in the loss of approximately 7.5 tonnes of production. Thus, 10 days of lost feeding would mean the loss of 75 tonnes of production.

Typically, an offshore farm could lose anything up to 50 days of feeding, and thus our example above would lose 375 tonnes of production annually. At a value of €3.50 per kilo, this amounts to €1.3 million eliminated from the annual turnover.

6.1.3 Harvesting

This operation is critical in that it represents the culmination of up to two years of careful husbandry, so it is vitally important that the fish are not damaged or lost at this stage. Harvesting can only be carried out in reasonably fine weather as it involves tying the workboat to the cage, bringing a quantity of the fish to the surface with a sweep net and then scooping them out with a crane-mounted brailer, or pumping them out with a fish-pump.

As excessive wave action can result in damage to the fish,the boat and the cage flotation collar, harvesting at offshore sites is largely a summer activity or is confined to weather windows at other times of the year. This means that the supply of fish from offshore farms can be unreliable, making it difficult to continuously supply the market.

6.1.4 Other issues

Additional challenges facing offshore farmers using conventional technologies and methods include live grading of fish in situ;predation prevention;net-cleaning;adequate monitoring of fish health and appetite, and ongoing assessment of equipment integrity. Perhaps, however, the greatest challenge is to operator morale.

The offshore fish farmer and his crew must operate in a constant state of alert for equipment failure. They must also struggle against the vagaries of weather to carry out essential repairs, feed the fish and harvest as required. They are under constant pressure to try and get everything done within available weather windows, regardless of prevailing wave conditions. Eventually, morale can start to suffer.

In summary, with the current available operating technologies, the offshore finfish farmer is disadvantaged with regard to his inshore colleagues. Lost feeding days at sea can never be replaced,and in the highly competitive world of modern marine finfish farming,all of the above elements lead to a higher unit cost of production and thus lower returns for the offshore operator. Clearly, the offshore finfish farms of the future will have to overcome these operational challenges.

6.2 The Next Step

There is mounting consensus within the industry that implementing offshore aquaculture effectively involves going back to the drawing board and treating offshore aquaculture as an entirely new adventure, quite unlike that of growing fish inshore.

Every aspect of going offshore needs to be carefully considered and assessed ahead of installation.In a report on the feasibility of farming offshore in New Brunswick,Canada,Bridger (2004) states, 'Exposed aquaculture will require a more holistic perspective of how individual components fit together unlike near shore operations that could function in the absence of a well planned system design'. In addition,Muir (2000) points out that 'a major challenge for future systems may be to overcome the psychological dependence on human-based management, allowing greater reliance to be placed on automatic monitoring, control and management systems'.

Fig 6.2 Preparing a sea-bed located, current and environment monitoring device for deployment. John Costelloe, Aquafact International Services, Ireland.

The implication of the above statements is that the process of deploying a successful offshore finfish operation requires a degree of pre-planning quite unlike that required for an inshore farm.A major component of this process is the acquisition of a very detailed understanding of the real operational conditions that will be encountered at a proposed site. Thus, an extensive survey process will be required before any equipment purchase decisions could be considered.

An outline of the necessary process is set out below:

6.2.1 Understanding the site

Just as probes are sent to planets and moons in advance of man's planned visits, it is essential to ascertain precise information on every aspect of the environment at the proposed offshore site. This can be achieved by locating on-site or near-site devices throughout the water column to monitor and record current speed and direction,temperature, salinity, oxygen levels and chlorophyll.It may also be advisable to install a wave buoy - if only to validate what computer-generated wave climate models might already be indicating. **(Fig 6.2,6.3)**

A comprehensive site profile can be obtained by combining at least 12 month's site monitoring data with data from other sources such as that regularly collected by research vessels and oceanographic monitoring buoys. This must include predictions of what kind of extremes might be expected - particularly with regard to wave energy, current speeds and temperature.

When carrying out a full assessment,what is being sought is a site with favourable characteristics under the headings of wave climate, topography, water-exchange, temperature, salinity, oxygen levels and plankton regime.

The following are guidelines as to what these characteristics might be:

- **Wave climate**

  Having established the wave climate at a site, it is critical to select equipment capable of long-term operation within those conditions. The problem,however, is that many suppliers are not in a position to provide full operating parameters for their equipment.

  In developing an offshore aquaculture strategy, this is obviously an issue that must be addressed.Equipment will have to be built to recognised standards and rated to withstand specified conditions. In the meantime, experience would suggest that the best approach is to assess what equipment is surviving in established sites with similar wave climates, and to then make well-informed investment decisions on that basis.

  What can be stated with some certainty at this stage is that Class 4 or open ocean sites in the North Atlantic and other similar areas are off limits for large-scale aquaculture operations using currently available technologies. Therefore, installations in Class 3 sites represent the boundary of contemporary technological feasibility for these areas. Nevertheless, large-scale commercial exploitation of more exposed areas should be possible in the not too distant future, and is therefore discussed at the end of this chapter.

Fig 6.3 Retrieving a wave monitoring buoy.
John Costelloe, Aquafact International Services, Ireland.

- **Topography**
  Topography is a major influencing factor in the operational suitability of offshore sites. For instance, water depth needs to be at least 25 metres in the case of Class 3 sites, in order to avoid large waves of oceanic origin breaking or becoming steeper as they pass through a cage.

  In the case of Class 4 sites, the minimum water depth may need to be 50 metres or more. In addition,every effort must be made to locate a site in the lee of as many topographical features as possible. These might include reefs, islands, headlands or combinations of all. These modest sheltering features can greatly extend the duration of weather windows, thus allowing more time for essential on-site operations.

- **Water exchange/current speed**
  A top quality computerised hydrographic model should be used to predict the water exchange at the proposed site, based on real data collected over a long period (at least six months continuous, including the winter period). It is important that this model indicates adequate current speeds for fish rearing and that extreme highs or lows will be rare.

  Depending on local topography, strong winds that occur during storms may cause dangerously high currents;however an effective hydrographic model will predict this. Equally, sites with prolonged periods of slack water must be avoided as this can result in low oxygen conditions.

  Optimum average current speeds will vary depending on the species of fish being farmed,but should lie within the range of 0.1 to 0.5 metres per second. **(Petrell and Jones 2000;Reidy et al.2000)** Average speeds beyond this range may challenge the well-being of the fish,although farms in the Bay of Fundy, which is famous for its strong tidal currents, have carried out successful trials with current deflectors. These consist of large panels of netting anchored on the up-current side of flotillas of fish cages and have been observed to achieve significant amelioration of the current speed. On the other hand areas that experience average speeds below 0.1 metres per second may not provide adequate water exchange for the scale of cage and biomass that is required in the offshore situation.

- **Temperature**
  The optimum temperature varys from species to species but significant fluctuations must be rare occurrences, if a site is to be suitable. This is probably not a major issue given that most existing offshore sites are known to experience more stable temperature regimes than those found inshore. (See Chapter 5)

- **Salinity**
  Salinity is probably not going to be an issue, given that oceanic salinities are the norm in offshore sites. Nevertheless, most marine fish species do not appreciate brackish conditions, and sites subject to these must be avoided.

- **Oxygen**
  Adequate oxygen levels are critical for all fish species. While it might be assumed that offshore sites will automatically offer full saturation, some offshore locations adjacent to zones of up welling can routinely experience oxygen levels as low as 3mg/l.Long-term advance monitoring must therefore indicate a minimum of 90% saturation as the norm.

- **Algae blooms/jellyfish**
  In the North East Atlantic in recent years, a number of incidents have occurred at both inshore and offshore sites, resulting in damage to the gills of farmed salmon.Mortalities have often ensued,and the health of surviving fish has been compromised.Planktonic algae or jellyfish usually cause this problem,and studies have been carried out to identify the agents and risk factors involved.Initial indications are that the risk of damage from jellyfish may be reduced at some offshore sites and that the ill effects of harmful algae blooms are more likely at inshore sites due to the concentrating effect of shallow enclosed bays. It may be possible to use current deflectors, as developed in the Bay of Fundy, (see above) to divert jellyfish away from cages. Assessment of site chlorophyll profiles and historical research vessel data will indicate whether harmful algae blooms pose an unacceptable risk factor at a given location.

- **Other site-selection criteria**
  Additional site-selection criteria exist,which may be critical to the success of the licence application or the ongoing operation of the site. These include:distance from known fishing grounds;not being a navigational hazard;low visual impact;access to harvesting sites, discussed late in sub-section 6.2.5 and section 6.3,and deepwater landing facilities with adequate road access.

Having considered the required site characteristics, this report now discusses the factors that would influence the selection of a particular species to be farmed at an offshore finfish farm.

6.2.2 Which species?

Unlike agriculture, which concentrates on a few food animal species, aquaculture can choose from literally hundreds of species that might lend themselves to husbandry. Industry interest in temperate Atlantic zones is currently focused on the following species:

- **Salmon (Salmon salar)**
  Approximately 750,000 tonnes are produced annually in the North Atlantic.Demand for this fish is steadily increasing,and it has already proven its suitability for large-scale production,being grown successfully in many offshore situations. Salmon,however, may not be suitable for culture in submerged cages because they possess a physostomic swim bladder that is connected to the oesophagus, and therefore the fish must surface to take in air. A number of contradictory reports have been published on whether salmon can live for extended periods without access to the surface. A definitive answer is required before large scale submerged salmon cultivation should be considered. **(Ablett et al,1989: Rubach and Svendson,1993)** On the other hand,it is possible to trap air in a kind of bell over the top of a submersible cage, as can be achieved in the case of the Sadco Shelf cage.

- **Rainbow trout (Salmo gairdneri)**
  This fish has many of the same suitable features as salmon but suffers from a lack of differentiation from salmon in the marketplace. Moreover, as rainbow trout has a history of husbandry difficulties in a full salinity environment,it is unlikely to be considered as a potential offshore species.

- **Cod (Gadus morrhua)**
  Although there are still issues regarding early maturation and the cost of juvenile production,cod can be successfully reared using the same kinds of sea cage technologies as have been applied so effectively in the case of salmon.Furthermore, it thrives in large-scale production systems. Indeed,the industry view in Norway is that in order for farmed cod to compete in the marketplace with other whitefish species and with salmon,economies of scale are essential. To this end,the Norwegian plan is to increase production to 100,000 tonnes by 2010 and to 400,000 tonnes by 2015.It would appear, therefore, that cod is an obvious candidate for large scale offshore farming.

  Controversy exists however over whether the market will support large-scale cod farming. The principle concerns relate to poor fillet yield and price fluctuations. Compared to salmon,which can yield 60% or more of the gutted carcass as skinless fillet,the cod has a large head and only returns a yield of around 45%. Therefore, the cost of production per kilo of usable cod flesh may be higher than that of salmon,and the worry is that the market will baulk at having to pay more for what is traditionally considered a cheaper fish.

  Furthermore, the annual variation in catches of wild cod can result in dramatic price fluctuations so that sometimes it is sold at prices below the cost of production of farmed cod.It has been suggested that long-term fixed price supply contracts with processors and retail multiples would be one way for farmers to hedge against this effect.

Not withstanding these issues, some major fish farming companies are pressing ahead with developing a cod farming industry. During 2004, three million juveniles will be produced in Norway. In 2005,Fjord Marine expects to harvest up to 2,500 tonnes, and Nutreco has predicted it will have produced 30,000 tonnes by 2007.

Over the last few years, Johnson Sea Farms in Shetland has been transferring its focus from growing salmon to cod,and plans to install 1.5 million juveniles in 2004. The company expects to harvest 1,000 tonnes during the same year and has established that its farmed fish are higher quality and return a greater yield than wild cod. The farmed fish are thus achieving a premium price over wild.

Nascent industries in Newfoundland and Nova Scotia have solved most of the issues associated with the production of cod juveniles and are seeking significant public and private investment in the development of large scale on-growing.

- **Haddock (Melanogrammus aeglefinus)**
  The haddock is closely related to the cod and should therefore be equally suitable for intensive aquaculture. New Brunswick,Canada, is to the forefront in developing haddock farming.In a partnership between government and private industry, techniques for juvenile production and on-growing in inshore sea cages have been established.Several thousand juveniles are also being on-grown by the University of New Hampshire in submerged cages off the coast. To date, haddock farming has not achieved commercial scale, however, an encouraging feature of this species is that the fillet yield is somewhat better than that of cod.

  Other gadoids such as pollack (Pollachius pollachius) and saithe (Pollachius virens) may be suitable for offshore aquaculture in the future, however, their current market price is often less than half that of cod and this prohibits their consideration at this time.

- **Halibut (Hippoglossus hippoglossus)**
  The current annual production of 2,000 tonnes of farmed halibut is concentrated in Norway, Iceland and Scotland. The prevailing view within the industry is that halibut should be grown to 300g in pump-ashore systems and should then be transferred to sea cages for further on-growing.Being active swimmers, halibut lend themselves quite well to cage farming but need to be able to rest

on the bottom of a cage or on a rack system that is not subject to the violent motions resulting from wave action. Therefore, they are not suitable for cultivation in surface-based systems offshore but are a candidate species for submerged systems. The University of New Hampshire is currently on-growing halibut in submerged Sea Station cages at an offshore site off the U.S. east coast. **(Fig 6.4)**

- **Other species**

  The discussion on poor meat yield from cod is central to the whole question of what species should be the focus of attention for marine fish farmers wishing to diversify from salmon.It is quite possible that what the market requires is a relatively cheap, firm white-fleshed fish,suitable for all kinds of processing and that it is immaterial from which species this comes. In this regard,the Chilean fish-farming industry is now focusing on cultivating austral hake (Merluccis australis) because it has good quality white flesh,and having a small head, returns a considerably higher fillet yield than cod.

  A review of the hundreds of fish species natural to the Atlantic region might indicate a few candidates with characteristics making them more favourable for large-scale aquaculture other than cod. One suitable species might be the European wreckfish, Polyprion americanus, which is rare but highly valued.In trials carried out by the French development agency, IFREMER,at Brest,this fish grew at a rate of 1.5-2kg per annum.

It should be born in mind that taking a wild species and turning it into a farmed animal is in itself a very lengthy and complex process. Thus it is likely that those fish species, which are already well understood from an aquaculture perspective, will be the lead candidates in offshore finfish farming development.

Having outlined the site characteristics and species choice, the report now reviews the technologies that need to be considered when developing an offshore finfish farming operation.

6.2.3 Offshore sites: technology required

A central tenet of this report is that careful pre-planning and analysis of critical site factors such as wave climate and prevailing weather conditions is a pre-requisite for successfully developing an offshore site. This process should result in a comprehensive assessment of all available technologies, and the judicious selection of those suited to particular sites and applications as detailed below:

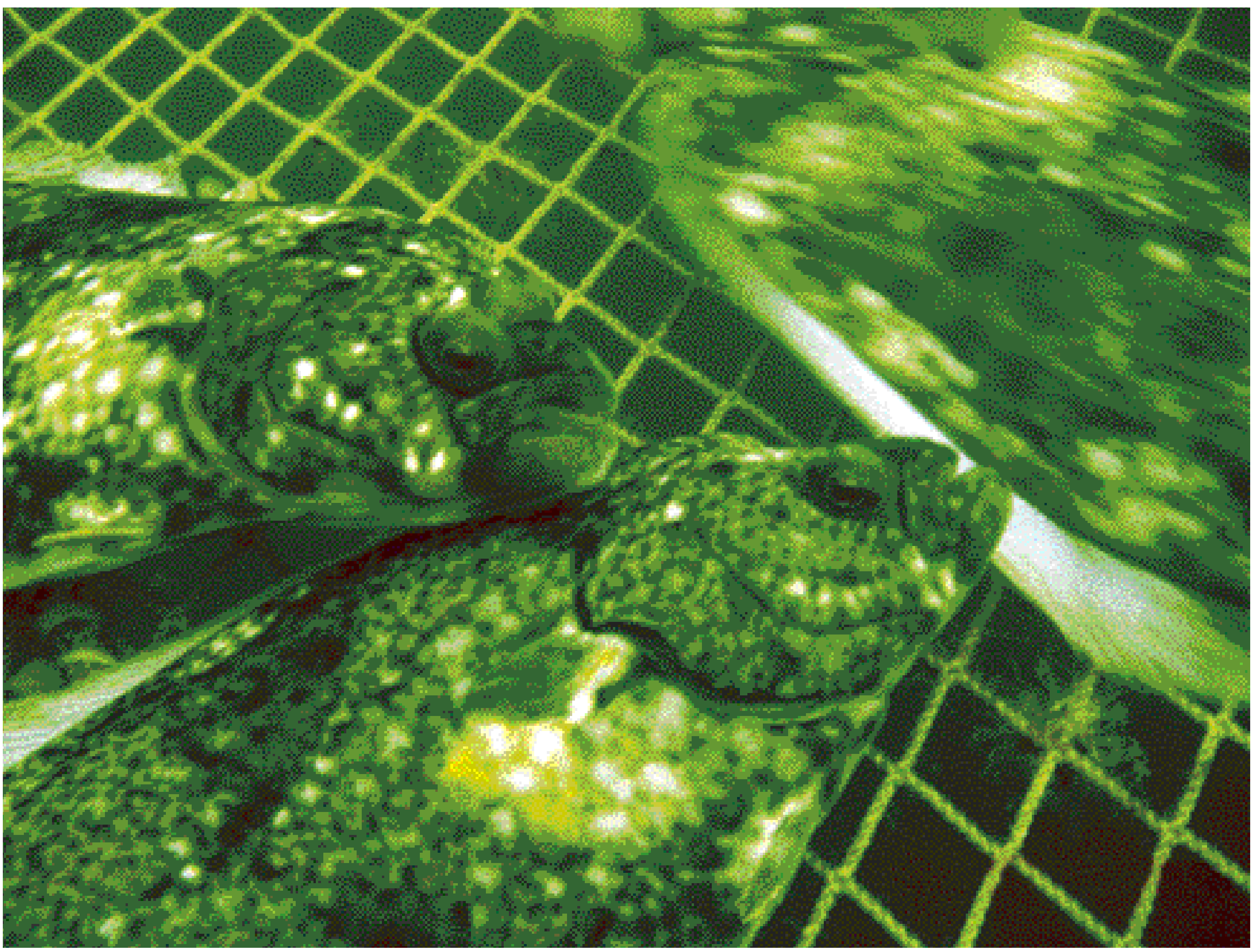


Fig 6.4 Halibut in a submerged Sea-Station cage off the coast of new Hampshire.
University of New Hampshire, U.S.A.

- **Cages**
  Wear and tear and daily maintenance are the biggest problems facing offshore operators using conventional technologies. Therefore, the choice of cage is crucial in order to reflect a design that is durable and has been proven capable of withstanding offshore weather conditions. The major cage types are discussed below in this regard.

- **Gravity cages**
  Since coming on the market,the rubber and plastic collar systems have undergone design modifications, resulting in significantly lower abrasion to both net and collar. Nevertheless, the characteristic common to all gravity cage designs is that the flotation element is concentrated at the surface, which is the zone of greatest wave energy. Therefore, the system is subject to constant movement and shock loading.

  In addition,collar systems depend on heavy weights or weight rings hanging from the bottom of the net to assist in maintaining its shape and volume. This not only adds to the shock loading on the net but also sometimes fails to maintain the full net volume due to tidal or storm current effects. Violent movement of the net and repeated reduction in volume can compromise the performance of the fish.Notwithstanding these inherent flaws, the gravity cage approach to offshore aquaculture has been used with some success, not only in Ireland but also in Spain,Italy and Australia amongst others. (See Chapter 4)

  As outlined in Chapter 3,many alternatives to the gravity cage approach are available or are in the course of development. None of these, however, are in widespread use for various reasons such as inadequate cage volume, high cost,and lack of clarity as to how they might fit into modern operating practices. Furthermore, the industry is currently functioning in a climate of severe cost consciousness and is inclined to favour 'the familiar' over potentially expensive adventures with novel technologies.

  Nonetheless, it must be recognised that one of the constraints on the expansion of offshore aquaculture is the failure by suppliers to address the heavy maintenance and repair requirements of currently available gravity cage types. If this can be dealt with,then the gravity cage could be ideal for the purposes of offshore farming, given that it is capable of significant up-scaling and is a familiar technology to the industry.

  As discussed in Chapter 4,the Irish industry has experience of four different cage types designed for offshore use, namely: rubber collar systems (Bridgestone and Dunlop),heavy plastic cage systems, the Farm Ocean semi-submersible and the Ocean Spar from Net Systems. Of these, only rubber collar and plastic collar systems are in widespread use.

  As outlined in that chapter, the Aquaculture Engineering Group (AEG) in Canada is proposing a novel method of configuring gravity cages, which they believe will obviate the shortcoming of this technology. The gravity cage, therefore, must be regarded as a possible component of the proposed expansion of offshore aquaculture, at least in Class 3 sites.

- **Alternatives to gravity cages**
  The review in Chapter 3 indicated only one cage type that has been shown in practice to be capable of matching the gravity cage in terms of scale. This is the Ocean Spar or anchor-tension cage, of which only a few have been built and are in current use. While these are being used in fully commercial situations, there have been indications of some greater than predicted wear and tear, and further operational issues need to be addressed.
  The RefaMed tension-leg cage is widely used in Italy and is showing promise in terms of up-scaling;however only units up to 4000m^3 have been deployed to date. Again further developmental work is required.

  The Byks Oceanglobe rigid cage is also a possibility in terms of adequate scale but again,no full-scale version has been built.

  In summary, the cage options for expanding large-scale offshore aquaculture are gravity cages, anchor-tension cages, tension-leg cages and the rigid Oceanglobe. All require further development and/or need to be proven. To be pragmatic,a farmer wishing to establish a large offshore farm in the near future would probably have to choose between either gravity cages or anchor-tension cages, or employ a combination of both.A true pioneer, with deep pockets, might commission the first full-scale Oceanglobe.

- **The question of scale**
  As indicated above, scale is a major consideration when selecting an appropriate cage type. In an assessment of the economies of scale as highlighted in Chapter 8,the optimum annual production level for an offshore farm is estimated to be in the order of 10,000 tonnes. To simplify logistics, and taking into account the level of investment in monitoring equipment required per cage, this would have to be produced in a maximum of 10 cages. Thus, 1,000 tonnes would be harvested from each cage. Given a final stocking density of 25kgs per cubic metre, each cage will be required to have an enclosed volume of 40,000m^3.

  A suitable gravity cage of 20 metre net depth will therefore need a circumference of approximately 160 metres. Tuna farms in the Mediterranean are currently using cages on this scale and above, and a cage of similar dimensions is being tested for salmon in Norway. (See Chapter 4)

  The largest anchor-tension cage currently in use has a design volume of 20,000m^3. In plan view, this cage has the shape of a flattened hexagon with a vertical steel spar at each of its six nodes. By the addition of two extra spars, a barrel shape would be achieved and the volume would increase to 38,000m^3. Given that up to 750 tonnes of salmon have already been harvested from 20,000m^3 anchor-tension cages, 1,000 tonnes from a 38,000m^3 version should be achievable. **(Fig.6.5)**

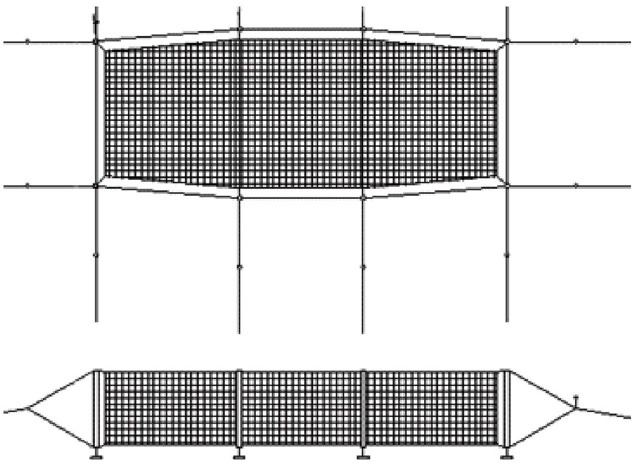


Fig 6.5 Plan and side view of 38,000 cubic meter Ocean Spar cage. As yet, this cage has only got as far as the drawing board. Net Systems Inc, U.S.A.

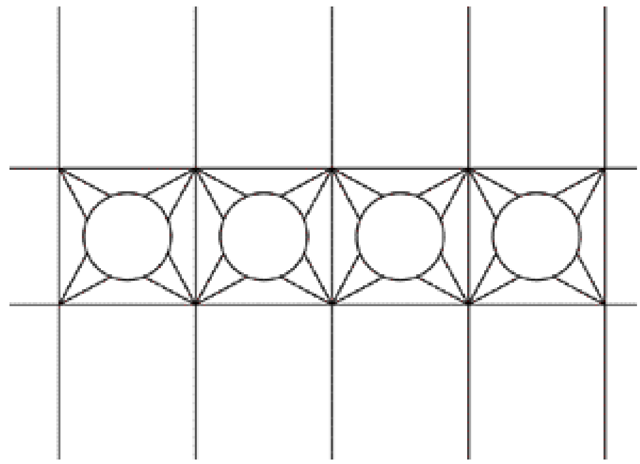


Fig 6.6 Grid mooring system for 4 circular collar cages.
Gael Force, Scotland.

- **How many support sites? How many support cages?**
  In the case of salmon and cod,which currently have a grow-out phase of more than one year, at least two sites would be required in the interests of good husbandry practice in order to maintain separation between different age classes. A third site inshore would also be required to facilitate harvesting.(See 6.2.5)

  Thus, an offshore farm producing 10,000 tonnes of cod or salmon per annum would therefore require a juvenile on-growing site with four 40,000m^3 cages along with a finishing site containing 10 such cages, together with an inshore sheltered harvesting/holding site.

  It will be a prerequisite of licensing policy that any offshore licence will require these additional juvenile and holding sites as part of an integrated approach.

- **Moorings**
  Given that gravity cages or their derivatives are the most prevalent cage systems used,the considerations below largely deal with the moorings of this type of containment system.

  Fish cages can be moored singly or in pairs with mooring lines radiating out in all directions to anchors on the seabed.In most inshore locations, however, mooring grids are used. These anchor an entire flotilla of cages, with lines radiating outwards on all sides. The principal reason for using this system is to confine the farm within a defined lease area.It is a simple system requiring less space than mooring cages individually. **(Fig 6.6)**

  Nonetheless, there are significant disadvantages with mooring grids and these include:

1. The pull on an anchor must be as near horizontal as possible, the length of the mooring line between anchor and surface (the scope) must be at least three times the maximum depth. This significantly increases the area taken up by the fish farm,especially in the case of one using a mooring grid. The situation is exacerbated with the greater depth found at offshore sites.
2. The zone of benthic impact is concentrated in one area.
3. Every part of the system has to be engineered to be capable of bearing the load of the entire system,given that both wind and current can come from any direction.
4. Mooring grids are expensive and complicated because of multiple components.
5. Many things can go wrong in such an extensive system,and inspections and maintenance are laborious.

An alternative to the mooring grid is the single point mooring or SPM.(see Fig 3.18,Chapter 3) In this case, a cage or cage flotilla is attached to a single point on the seabed and can swing around this point depending on the directions of wind and current forces. Such systems were in common usage in Scotland in the early and mid 1980s and the experience of them was good. Their usage was phased out as the individual cage dimensions and the number of cages linked together increased. The necessary development work to up-scale the SPM systems was not carried out.

The SPM concept is once again gaining favour within the industry and may well be the system of choice for the offshore operation of the future. The advantages include:

1. Less space is taken up by the seabed portion of the SPM than is the case with the mooring grid system. This can be a particular advantage in the case of territorial issues with capture fishers.
2. Although it has been shown in Chapter 5 that benthic impacts at offshore sites will be negligible, whatever impact there is will be spread over the wider 'swing area' of the SPM.
3. Because the same part of the surface structure is always bearing the load of the entire system,the rest of the structure can be more lightly engineered.

Fig 6.7 Pairs of circular collars cages attached to single point moorings (SPM's). Aqualine, Norway.

4. A reduced number of components implies that SPMs should be simpler and cheaper than mooring grids.

5. The simplicity of fewer components should result in lower inspection and maintenance costs.

6. Where current deflectors are used for shelter or against jellyfish attacks, it is only necessary to locate them at the front of the system rather than all around as might be the case with a mooring grid.

7. It is easier to set up feed distribution and monitoring systems as the current will always be travelling in the same direction through the cages.

A number of equipment suppliers are developing SPMs. These include: the Aquaculture Engineering Group (AEG),whose entire novel cage flotilla concept is based around the use of an SPM and the Norwegian plastic cage manufacturer, Aqualine, which is testing SPMs for mooring its cages in paired configurations. **(Fig 6.7)**

Where cages are moored with SPMs, either the feed reservoir or barge must be part of the entire system,or a workboat mounted feed barge must be used. This reduces the amount of feed distribution pipe-work required,which is a major advantage in the offshore situation (See Chapter 7).

It should be noted that the SPM concept will not work with anchor-tension cages as the entire structure must be free to swing in accordance with prevailing tide/wind conditions. There is great deal of accumulated experience with SPM systems, particularly within the oil industry. This approach is worthy of further investigation and recommendations in this regard are highlighted in Chapter 9.

A feature of both the SPM systems and anchor-tension cages is the amount of space that is required in a licensed area to accommodate both their swing area and their moorings. Although,in the case of anchor-tension cages, it may be possible to reduce this by using a flotilla approach and by having cages with shared mooring lines.

This should not be a constraining issue, as it has been in inshore locations, given that space is not at a premium offshore. This factor, along with the need for support sites and scale, should be taken on board as a fundamental policy matter by the regulators-to-be of the offshore finfish industry.

Another approach to mooring is the tension-leg system,as outlined in the profile of the RefaMed system.(See chapter 3) This method ensures maximum space conservation,and requires little more area than that taken up by the cage itself. Tension-leg moorings could also be used for feed barges.

Fig 6.8 Ship type feed barge. Akvasmart, Norway.

Fig 6.9 Concrete box feed barge. Marine Construction, Norway.

6.2.4 Feeding

An essential element in successful farming is that fish feeding must be easy and uncomplicated. This results in fast growing,unstressed fish and a good feed conversion ratio. At its core, fish farming is about converting the minimum amount of expensive fish feed into the maximum amount of quality fish flesh in the shortest possible time.

Yet on many marine farms today, both offshore and inshore, the biggest daily challenge is feeding the fish. Feed must be delivered to the nearest mainland pier, loaded into workboats, transported to the farm and cannon-fed to each cage individually. Given that this system relies on fair weather and complicated logistics, it can result in too many missed feeding opportunities. This model will not be viable for large-scale offshore farming ventures.

What is required is long-term feed storage capacity at each site with the capability to dispense feed to each cage automatically. Many farms around the world already have these facilities in the form of feed barges. (See Chapter 4) These have revolutionised inshore fish farming over the last 10 years but few are being used in offshore farms because of farmers' doubts over the sea-keeping qualities of many of the barge types available and difficulties with wave damage to floating feed pipes.

The model offshore farm described in this chapter and analysed in Chapter 8 has an annual production of 10,000 tonnes and thus has an annual feed requirement of approximately 12,000 tonnes. Such an operation cannot be efficiently carried out using anything other than fully-automated feeding technology.

The finishing site of the envisaged farm will need to achieve a peak feeding rate of 45 tonnes per day. Assuming a two-week gap between feed deliveries and allowing for delays, a storage capacity of at least 900 tonnes will be required. This capacity would be divided between two barges each of which would be set up to feed all 10 cages, thus ensuring a fail safety procedure in the case of breakdown of one of the barges. The feed barges will have to be capable of being operated remotely as it might not be possible to have personnel on board in anything more than light weather conditions.

A consideration of the necessary characteristics of offshore feed storage barges is given below:

- **Feed barge options**
  Whatever type of feed barge is ultimately selected,it is critical that the design has been thoroughly tested and proven in terms of loading,feed delivery and ability to withstand the prevailing weather conditions. It must also be fitted with the latest in safety systems. These would include a variety of emergency bilge-pumping mechanisms and water ingress warning systems.

  Currently there are three basic types of feed barge on the market:

  Ship type barge: This is a rectangular box of steel and is the most common type of feed barge in use, ranging in capacity from 50 tonnes to 400 tonnes. **(Fig 6.8)**

  The concrete box: This is a concrete version of the steel box but tends to be squarer in shape and is generally a lot larger. It is designed with a lot of accommodation and working deck areas so that it can assume most of the functions of a shore-base at sea. The largest concrete barges can carry up to 400 tonnes of feed. **(Fig 6.9)**

  Concrete cylinders: These are built in the shape of a vertical cylinder by Scottish company, Gael Force. The current design has storage capacities ranging from 100 tonnes up to 250 tonnes. (For more detail on feed barges see Chapter 4)

  Whilst either a ship-type barge or a concrete cylinder could be used in exposed situations, a preliminary assessment carried out by the Irish Sea Fisheries Board (BIM) indicates that the concrete cylinder would be more suitable for the more exposed sites.

  Concrete cylinder barges have been operating successfully in very exposed sites in the Faeroe Islands and in Shetland for a number of years. The largest barge designed but not yet built by Gael Force has a maximum storage capacity of 600 tonnes. The calculations above indicate that this would be more than adequate for the envisaged offshore farm. Two such barges would be required at the finishing site and one at the juvenile site. A pictorial representation of the envisaged model farm can be seen in **Fig 6.10.**

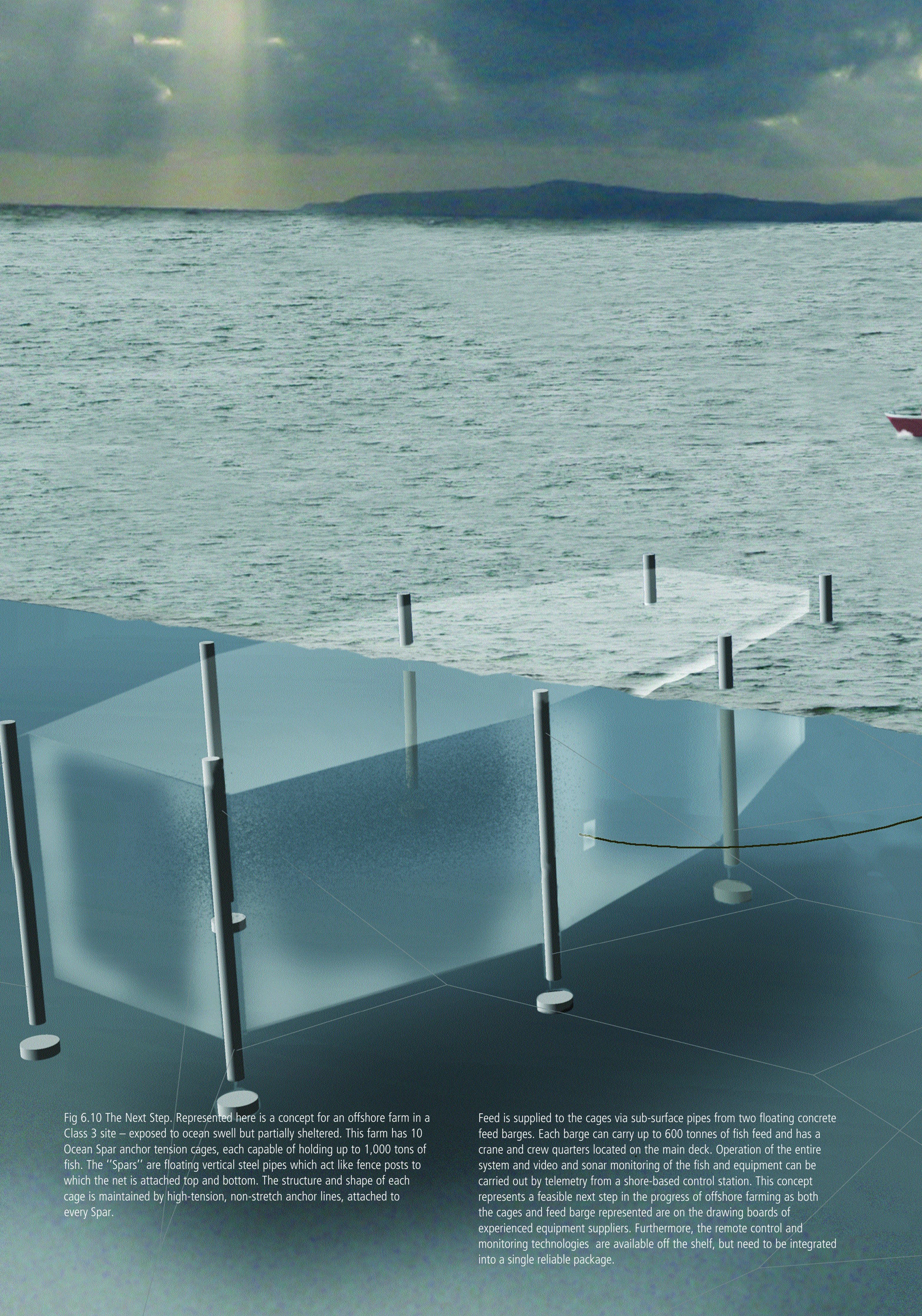


Fig 6.10 The Next Step. Represented here is a concept for an offshore farm in a Class 3 site – exposed to ocean swell but partially sheltered. This farm has 10 Ocean Spar anchor tension cages, each capable of holding up to 1,000 tons of fish. The ''Spars'' are floating vertical steel pipes which act like fence posts to which the net is attached top and bottom. The structure and shape of each cage is maintained by high-tension, non-stretch anchor lines, attached to every Spar.

Feed is supplied to the cages via sub-surface pipes from two floating concrete feed barges. Each barge can carry up to 600 tonnes of fish feed and has a crane and crew quarters located on the main deck. Operation of the entire system and video and sonar monitoring of the fish and equipment can be carried out by telemetry from a shore-based control station. This concept represents a feasible next step in the progress of offshore farming as both the cages and feed barge represented are on the drawing boards of experienced equipment suppliers. Furthermore, the remote control and monitoring technologies are available off the shelf, but need to be integrated into a single reliable package.

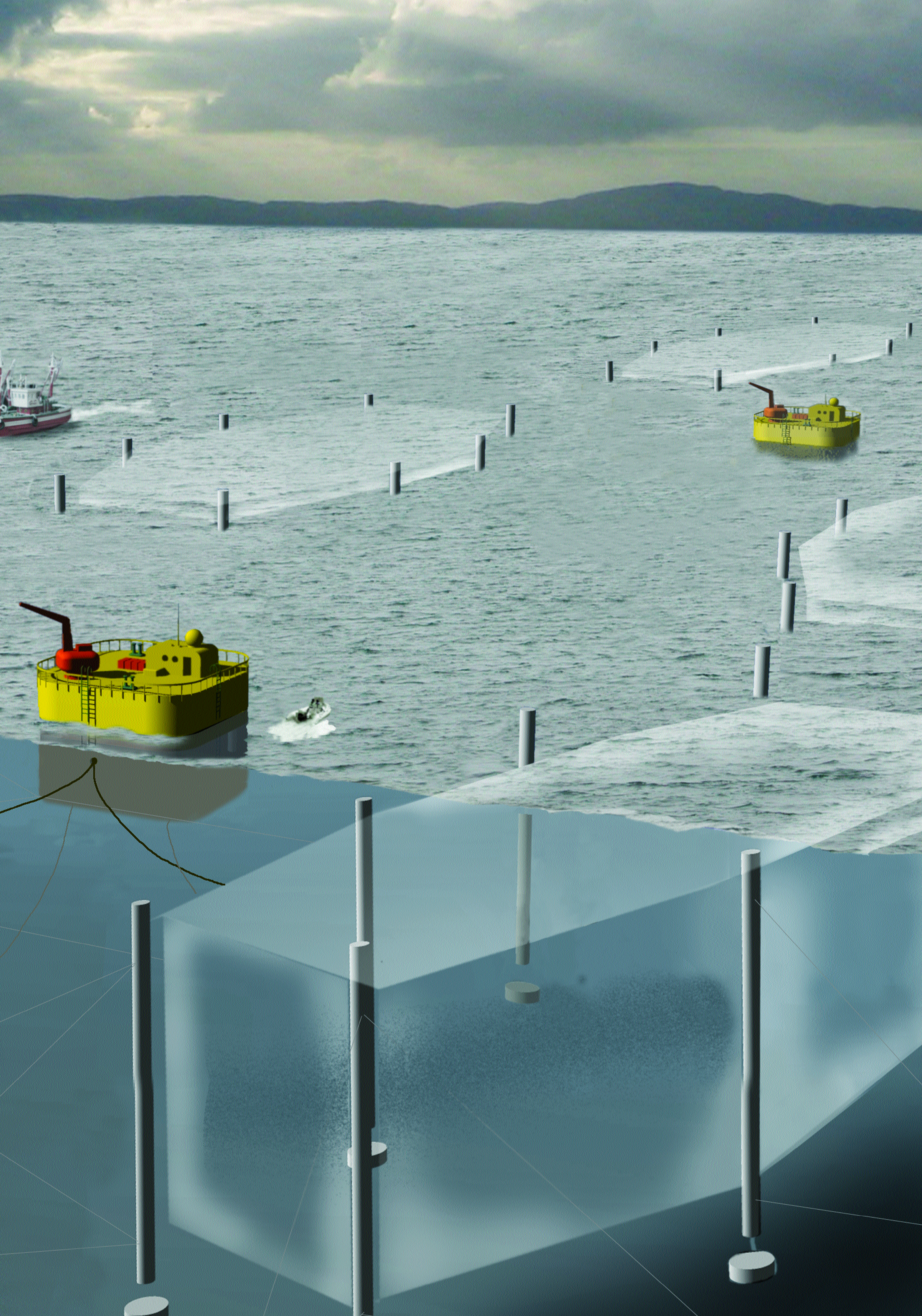


Fig. 6.11 Plastic circle cage temporarily attached to Ocean Spar cage. Fish, ready for harvest, are encouraged to swim into the plastic cage which can then be towed to the harvest site.

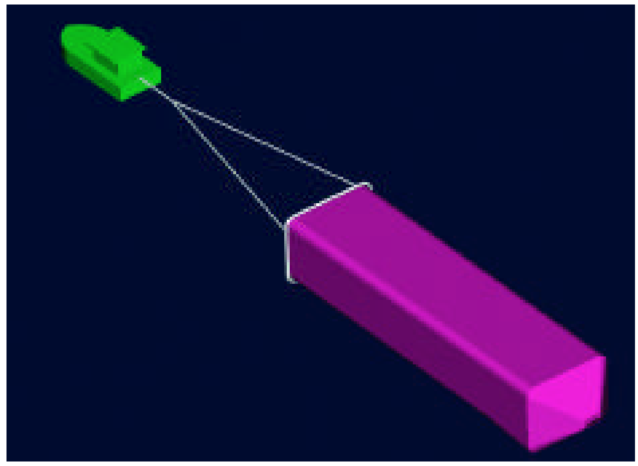


Fig 6.12 Conventional cages are not ideal for towing. Represented here is a concept, the ''Fishrocket'', which is a specialised cage for towing live fish from a growing site to harvest site. While this cage could be towed at up to 10 knots, water would pass through the live fish inside the cage at only 0.5 knots. Net Systems Inc, U.S.A.

6.2.5 Harvesting

Having proposed solutions to such major issues as the choice of containment,feeding and mooring systems, this report now discusses concerns associated with harvesting.

The problem with harvesting at offshore sites is that all conventional methods involve crowding the fish at the surface in order to provide the increased fish density required to operate the fish-pumps or crane-operated brailers. These are used to transfer the fish from the cage to the harvest boat where they are either immediately slaughtered or stored alive in a well.Excessive wave action during this procedure can result in damage to the fish,and therefore harvesting can end up being confined to periods of fine weather. Consequently, supply to the market can be unreliable.

The best available solution to offshore harvesting problems is to transfer live fish to a sheltered inshore site during favourable weather. This can be achieved with a wellboat but a better method may be to use an intermediary transfer cage. In this case, a conventional cage such as a plastic circle is temporarily attached to the offshore cage so that the fish can swim from one cage to the other. **(Fig 6.11)** The transfer cage, with its cargo of live fish for harvest,is then towed by workboat to the inshore site.

This might require the development of a specialised transfer cage designed for towing,with a view to minimising stress on the fish. **(Fig 6.12)** Fish would be harvested over an 11-month period at an average rate of 250 tonnes per week.Ideally therefore, the transfer cage will carry 250 tonnes of fish per trip from the offshore site to the inshore site.

At the harvest site there would be 6 x 250-tonne cages. These would ensure the potential to carry up to six week's supply for harvest at any one time, thereby providing the required continuity of supply, even during the vagaries of winter weather. Harvesting would be carried out by conventional methods using specialised slaughtering vessels, or the fish would be delivered by wellboat to a shore-based processing plant.

6.2.6 Operating plan

In summary, the envisaged model offshore farm,using salmon or cod as exemplar species, will produce 10,000 tonnes of fish annually at two separate sites and will operate as follows:

Each year, the juvenile site would be stocked with young fish in four 40,000m^3 cages serviced by a 600-tonne feed barge. These would then be on grown for up to 11 months, and subsequently moved to the finishing site where they would continue growing in 10 x 40,000m^3 cages. The first site would then be left fallow for a minimum of one week prior to restocking. The fish would then be harvested over an 11-month period after which the finishing site would be left fallow for at least one month.A fallow period must also be applied at the harvest site.

6.2.7 Monitoring/control

The most critical requirement of the envisaged model offshore farm will be an operating methodology that does not depend on daily access to the site. This will be achieved by incorporating remote operational capability via 'real-time' telemetry with regard to feeding and monitoring of the fish and equipment.

- **Feeding/appetite monitoring**
  Feed is transported to the fish by means of compressed air via a hose from the feed barge. A computer located in the feed barge controls feeding rate and the amount of feed delivered.Consumption and fish behaviour is then monitored by submerged video cameras and sonar devices mounted inside the cages. (See Chapter 3) All of these devices must be capable of being remotely operated from a shore-based office.

- **Fish monitoring/site monitoring**
  While much can be learned from observing fish behaviour by means of in-cage video cameras and sonars, it would be preferable if there was a more direct method of monitoring the status of fish health.

This could be achieved by attaching low-impact probes to a few indicator fish to monitor critical physiological parameters such as heart rate, blood oxygen levels, or the stress-indicating hormone, cortisol. These probes would transmit a signal to an in-cage receiver, which in turn would transmit to the inshore office via the feed barge.

As good quality water is critical to fish health,in-cage probes could constantly monitor oxygen,ammonia levels, turbidity and temperature, and then transfer the data ashore in real time. Such water-quality monitoring systems already exist on permanently moored buoys installed along the coasts of many countries. Data from these buoys could be combined with farm data to give a comprehensive picture of unfolding events in the offshore environment.

- **Equipment monitoring**
  Maintaining the integrity of cages and moorings in a hostile environment is essential,and therefore a regular inspection programme would be required. The programme could be enhanced by data collected from load meters installed on mooring lines and nets. This data would then be transmitted to the onshore office and would indicate whether mooring or net failure had occurred or was imminent.

- **Security monitoring**
  The value of fish at a 10,000 tonnes farm would reach in excess of €30 million, with the cages, moorings and feed barges representing another €8 million.It is important therefore that offshore farms are protected from theft, vandalism and accidental damage arising from collision. This could be achieved by locating video cameras and radar scanners on feed barge mastheads. Boats detected by radar in the vicinity of the farm would trigger an alarm that would alert onshore staff. During night-time hours, barge masthead floodlights and searchlights would also be triggered.

  Shore staff would then observe events as they unfolded by means of signals relayed to the shore via radar and video cameras. At the AquaNor aquaculture industry exhibition in August 2003,equipment supplier, Arena,displayed a security system involving video surveillance of a Norwegian salmon farm hundreds of miles from the exhibition hall.

- **Communications**
  All of the sophisticated solutions that have been discussed depend on the efficient transmission of many different kinds of data from the offshore site to the shore base, and the transmission of control data back to the site. In-cage video cameras, sonar devices, fish and equipment monitors and water quality probes would transmit to a processor mounted on the barge. The data would then be forwarded to the shore office along with further data from the barge computer that controls the feeding system.Data from the security system and the barge safety systems would also be transmitted.Shore-based staff would then respond to this data by sending control instructions via the processor to feed systems, cameras and emergency systems.

  Thus, the provision of high data capacity, 'real-time',reliable telemetry systems will be a critical developmental area for offshore finfish farming operations. Currently available systems tend to lack range and may not be sufficiently robust.

6.2.8 Methods of data handling and transfer

- **Power requirements**
  Technology and communication systems require electricity to operate. Cage-mounted systems such as cameras, sonar and probes will need to be powered from in-situ batteries recharged by wind generators, solar panels or even wave generators. These systems would have to be capable of operating all year round in the offshore environment.

  The feed barge will have both single-phase and three-phase electricity provided from its own diesel-powered generators. In order to be self-sufficient for long periods, it will need generous diesel storage capacity and a high degree of system duplication and redundancy.

  In so far as possible, power generation in offshore sites should be from renewable sources such as wind, wave and solar.

6.3 Infrastructure

A major consideration when selecting a suitable site is proximity to essential infrastructure such as a deep-water pier for cargo handling, ice-making facilities, and good road access. In some situations the provision of adequate infrastructure will need to occur in tandem with the installation of new offshore operations.

Other essential elements would be a modern processing plant,offices and stores, a marine engineering workshop and a dry dock for repairing and maintaining the workboats. In an ideal situation,such infrastructural elements would be strategically located so as to be able to service the needs and production of more than one large offshore site.

6.4 People and Offshore Finfish Farming

It has been the experience worldwide that as the scale of finfish farming increases, most of the consequent employment arises downstream in such activities as processing,marketing, sales and distribution, rather than directly on the farms themselves. This would also be the case with regard to the envisaged offshore production unit.

The production crew would comprise management,fish health experts, maintenance craftsmen,commercial divers and professional seafarers. Given the combination of a difficult work environment and complex technologies, all of these staff will have to be highly trained specialists. A crew rostering approach more typical of the oil industry rather than the current inshore aquaculture work practices will be required to provide continuous servicing on a round-the-clock basis. For example, favourable weather windows will have to be exploited on a 24-hour basis. Experience from the oil and related marine industries will need to be taken on board in this context.

An exciting prospect arising from the scale of the envisaged offshore farm is that the establishment of even one of these units would form a significant node of development in a coastal community. In effect, one or more offshore farms would become major engines of wealth creation via employment in processing and ancillary services in the locality of the supporting infrastructure.

Given the nature of the infrastructure requirements and the design of the offshore units, it would be quite feasible to envisage the locating of several 10,000 tonne units in a radius that could be serviced by a single support structure ashore, but which would not result in any significant environmental impacts.

Considerations of this kind should be incorporated into new licensing and regional development policies, which will need to be formulated for offshore finfish operations as distinct from existing inshore farms. recommendations in this regard are put forward in Chapter 9.

Another major issue when considering offshore finfish farming is whether the systems should be located on the surface as at present, or be submerged.A discussion on the relevant factors is set out below.

6.5 Surface or Submerged Operations?

As indicated throughout this report,the principal problem encountered in offshore fish farms is wear and tear caused by wave action on the surface-based structures. In contrast,submerged structures would be far less vulnerable because the power of waves decreases markedly with depth.A rule of thumb employed by marine engineers is that at a depth equivalent to half a wave length, wave-induced water movement is negligible.

A secondary (but nonetheless potentially lethal) problem for floating surface structures is the threat of storm-induced currents in the upper layers of the water column. These can achieve a speed many times greater than the normal current experienced at a site. The critical factor in this case is that the drag force on the structures increases as a function of the square of the multiple. For example, a current speed increase from 0.5 knots to 1.5 knots will cause a nine-fold increase in drag force. Similarly, an increase from 0.5 to 3 knots will result in a 36-fold increase in drag force. The effects of these forces can be avoided or mitigated by submerging the farm structures to appropriate depth.

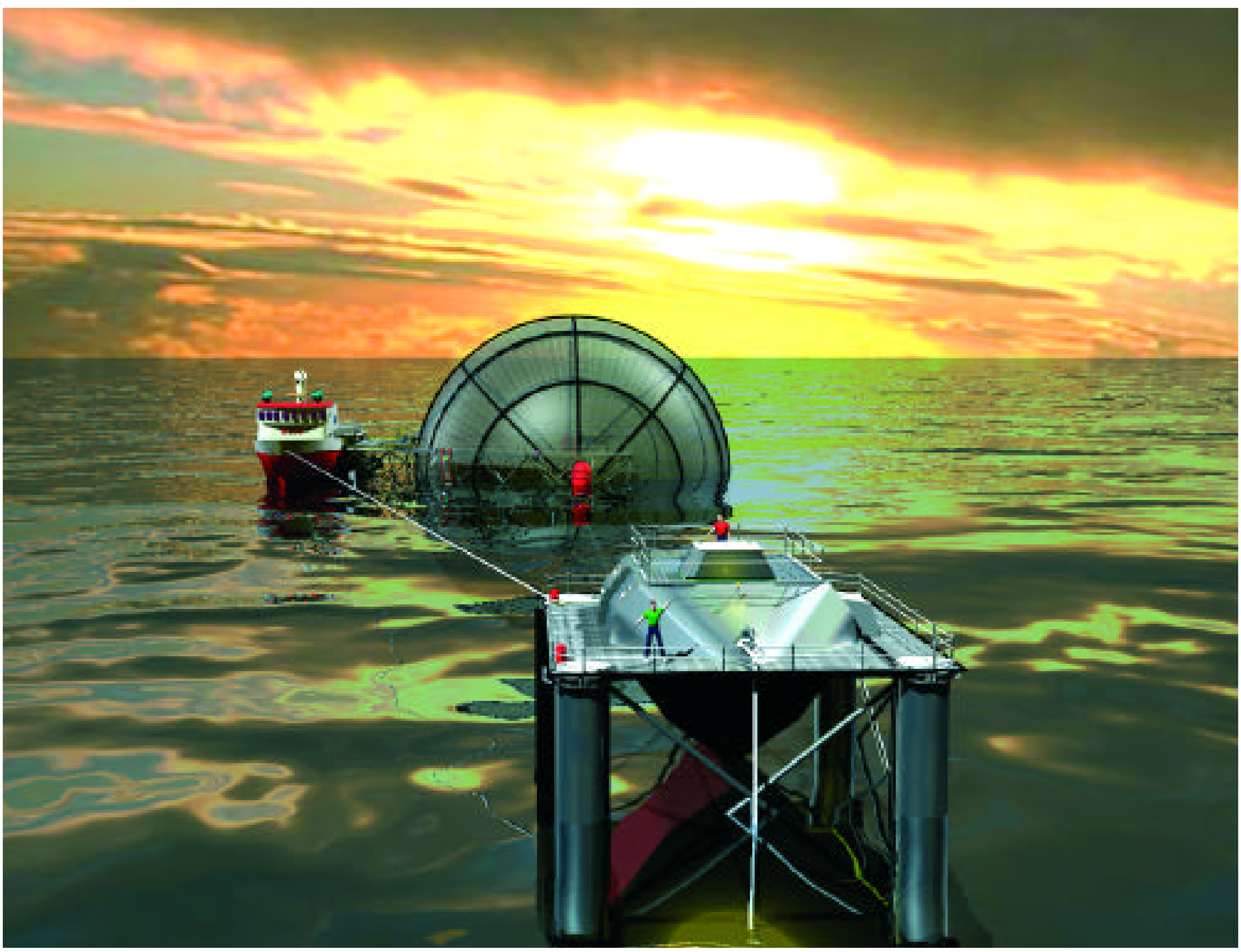


Fig 6.13 The Ocean Globe concept from Byks envisages using a semi-submersible feed barge in exposed locations. Byks, Norway.

These are compelling arguments for locating offshore finfish farming structures beneath the surface, or building an ability to submerge into the system.

Thus, as the development of offshore sites progresses along an axis of increasing energy impacting on the farm structures, the arguments for submerged operations and associated technologies become more compelling.Inevitably at some point along that hypothetical axis, the cost of constructing a surface cage, which could survive in very extreme conditions, would make such systems uneconomical. Undoubtedly, submerged finfish farming technologies will be required in the not too distant future.

At present there is no proven submersible technology of adequate scale to support the expansion strategy proposed.Nevertheless, technologies such as the RefaMed tension-leg and the Sea Station have demonstrated that submerged operations can and do work,albeit on a small scale. The problem is that there is a technology gap. Large-scale submersible cages and appropriate operating technologies such as feeding and monitoring systems need to be developed.

Current methods of feeding submerged cages include;daily pumping of feed down to the fish from a surface workboat (Hawaii and Puerto Rico); a cage-integrated feeding system that has to be replenished every few days (Sadco Shelf);and feeding from a surface-based feeding buoy (New Hampshire, US).While these methods suffer from a lack of adequate scale they do serve the essential purpose of providing a test bed for further development.

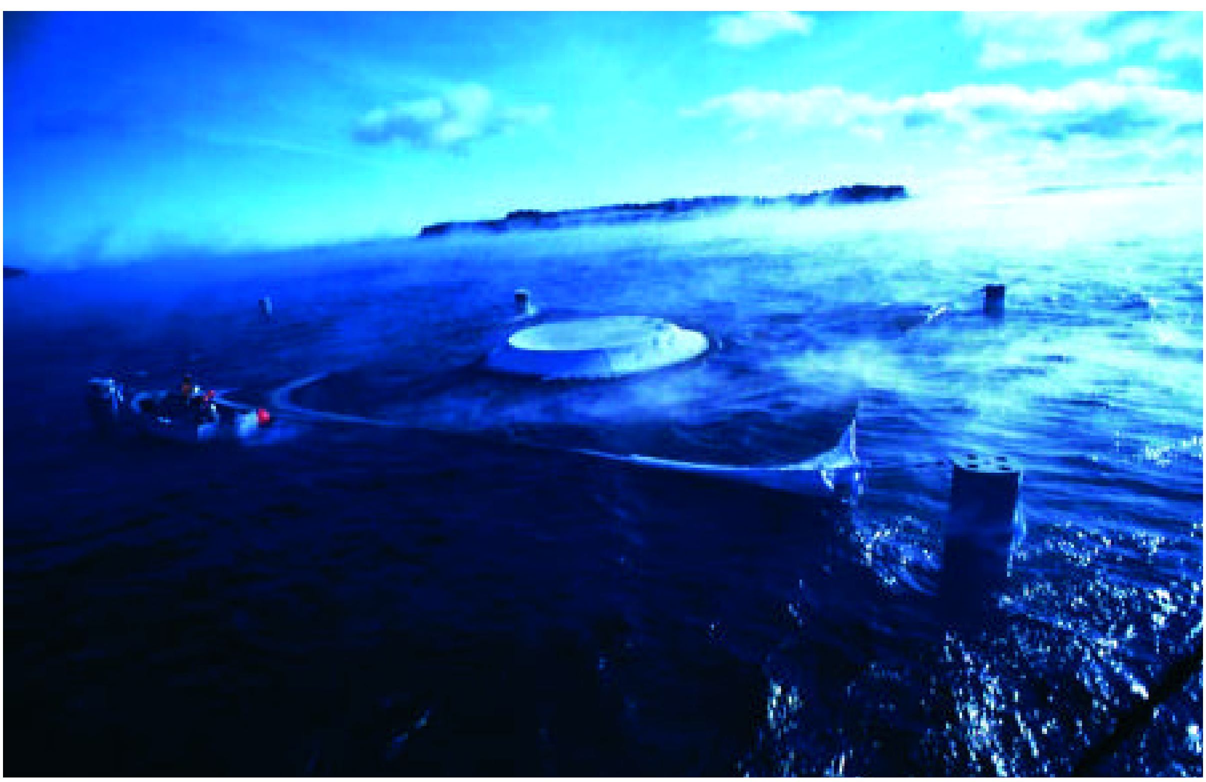
Filling the submersible technology gap with adequately scaled cages and supporting technologies could ultimately be the panacea that offshore aquaculture has been waiting for. Based on the feedback from current offshore practitioners, there is no doubt that every effort must be made to encourage the development of submersible systems. One possible scenario would be to install experimental submerged systems alongside the fully commercial operations in the Class 3 offshore site envisaged above.

The 10,000-tonne farm could therefore serve as a test site for developing the technologies suitable for exploiting Class 4 sites, and significantly reduce both the cost and time required.

Once very large rigid-framed cages, either resting on the seabed or floating in mid-water, such as the Oceanglobe concept have been developed,these could be fed from submerged feed stores or from semi-submersible vessels such as those envisaged by Byks and Izar Fene. **(Fig 6.13)**

It is very likely that for a given site the need for submergence will vary. In some locations, it may only be necessary to submerge the farm structures from time to time, to avoid extreme weather incidents;in other cases the submerged mode may be the norm.In the case of prolonged submergence, further development of the monitoring technologies will be required to achieve full remote control. The systems developed for the Class 3 site envisaged above would provide a firm basis for this process.

An artist’s impression of what a fully submerged farm might look like is presented in Chapter 9.



Ocean Spar Cage in Bay of Fundy, Canada. Net Systems Inc, USA.

Chapter 7

Operational Issues and Potential Obstacles

7.1 Introduction

Chapter 6 explored how the model 10,000 tonne offshore farm should be planned with regard to site location, technology and candidate fish species. Other outstanding issues including stock grading, net cleaning, predation, mortality removal and feeding equipment failure are addressed in the first part of this chapter. Issues common to both inshore and offshore finfish farming such as stock genetics, disease control and growth rates are also considered.

The Chapter concludes with a discussion on controlling the level of risk in offshore finfish farming operations, together with considerations on projected savings in the unit cost of production that will be achieved by virtue of locating finfish farms in the open ocean.

7.2 Operational and Technical Issues

- **Grading**
  Most finfish farmers are accustomed to grading their stock at various stages of the life cycle. Regular grading helps to avoid discrepancies in fish sizes and consequent bullying of smaller fish,which can result in runting,i.e. poor growth induced by stress.

  Taking salmon as an example, the market will generally pay a higher price for the larger grades, i.e. fish with an average weight of 4-6kgs consistently fetch higher prices than fish in the 1-3kg grades. Also, fish at a higher average weight have a lower unit cost of production because the juvenile cost is spread over a greater weight. Thus, selling smaller fish,which are more expensive to produce and fetch a lower price, is doubly disadvantageous to the fish farmer. These principles also hold true for the other finfish species in marine cultivation.

  Normal grading procedure either involves 'passive grading',(sweep nets fitted with slatted panels through which the smaller fish can escape back into the cage),or pumping fish across a grading grid on the deck of a service vessel. **(Fig 7.1, 7.2)** For various logistical reasons associated with both site exposure and the scale of cage required,these procedures would be difficult in the proposed model offshore farm.

  An alternative option might be to have a slatted grading panel in the floor of the swim-out tunnel between the on-growing cage and the transfer cage to deliver live fish to the inshore harvest site. (See Chapter 6) Harvest size fish would not fit through the slatted panel and would continue through the tunnel until they emerged into the transfer cage. Smaller fish would swim into the tunnel and down through the slatted panel only to arrive back into a cordoned-off section of the cage being harvested.

  Another option might involve installing a partition containing a slatted grading panel in the on-growing cage. Over a period of days or even weeks, smaller fish would be encouraged to swim through the panel by means of an artificially induced current.Larger fish would be unable to fit through,and the ultimate outcome would be two size-classes of fish on opposite sides of the partition in the cage.

  For example, the promoters of the Oceanglobe cage concept envisage that their spherical cage could be partitioned so that all the fish are confined to one side of the partition.(See Chapter 3) A slatted grading panel would be incorporated into the partition so that by bringing the cage to the half-surfaced position and then rotating it slowly, the fish would be motivated to swim down through the panel.Fish small enough to go through would end up on the other side of the partition.

  As part of an integrated strategy to develop offshore finfish farming techniques, projects to deal with this issue will need to be commissioned.Recommendations in this regard are made in Chapter 9.

- **Net cleaning**
  One of the greatest headaches for fish farmers, be they inshore or offshore, is net fouling. Fouling is the growth of unwanted flora and fauna on the netting. The ensuing clogging of the meshes impedes the passage of water through the cage, and this reduction in water exchange, combined with the metabolism of the fish,can result in depleted oxygen levels and elevated ammonia levels. Heavy fouling can also increase current-induced drag forces on all submerged equipment,potentially resulting in gear failure, because of overloading.

Fig 7.1(a) Fish grading panel sown into seine net.
Grading Systems (UK) Ltd.

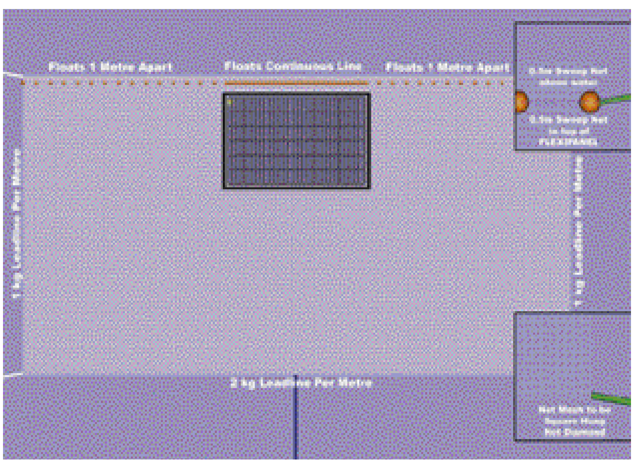


Fig 7.1(b) Diagram of grading seine net. This net is deployed within a fish cage so that a portion, or all, of the fish are captured within it. The smaller fish swim out through the grading panel near the top of the seine and the larger fish are retained for harvesting. Grading Systems (UK) Ltd.

In many inshore sites, particularly during late spring,summer and early autumn,a cage net can become almost completely clogged with an assortment of algae, hydroids, and mussels within three to four weeks. If this situation remains unchecked, the fish can become so stressed due to oxygen depletion that major growth penalties and even mortalities can occur.

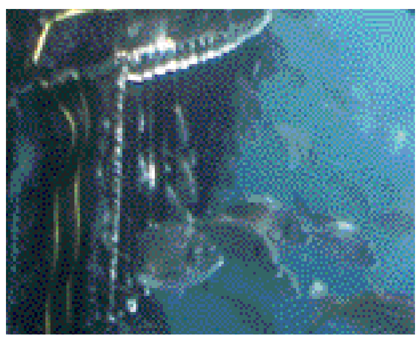


Fig 7.2 Sea-bream swimming through a grading panel in a Mediterranean farm. Grading Systems (UK) Ltd.

Fouling is a particular problem inshore because of the proximity to shorelines and reefs where the spores and larvae of fouling organisms originate. Offshore sites are less prone to fouling, however, if the fouling organisms are allowed to develop on even one cage, they can quickly spread to adjacent cages. Once fouling becomes established at a site it can be difficult to manage, particularly at times of high water temperature. Normal methods of control include changing the nets at frequent intervals, diver or surface operated power washing and the use of anti-fouling paint. **(Fig 7.3)**

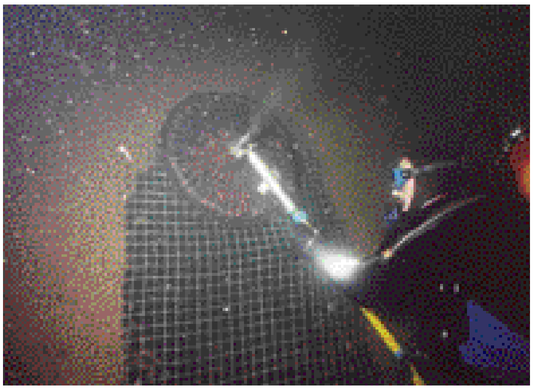


Fig 7.3 Diver using a water-jet powered washer to clean a fish cage net .
Net Systems Inc. U.S.A.

Anti-fouling paint is expensive and only gives a few weeks grace to a net before it has to be either washed or changed again. This makes its use on giant nets almost pointless because these can normally only be changed after harvest,when they are empty. By using special lifting gear, it may be possible to change a net on the giant gravity cages proposed,but this is not an option in the case of anchor-tension cages.

In-situ washing of offshore cage nets, probably by divers, is perhaps the only option at present. This exercise is expensive and presents significant health and safety considerations where deep nets are used.

A number of novel approaches have been suggested.One envisages using wave action to create constant movement of brushes suspended from surface floats to clean the cages. Another solution would be to employ specially designed submarine robots to patrol and clean the cage net on a continuous basis. This approach to cleaning would prevent newly settled fouling organisms from becoming established. The robot would have a crawl mechanism appropriate to mesh size and brushes or water jets or a combination of both for cleaning. It could be either autonomous or have an umbilical tether for power and control signals. This device could also be equipped with cameras and other sensory devices.

The development of a specialist robotic net-cleaning system would be an attractive commercial proposition even now, as the inshore industry badly needs such equipment.A project in this regard might form a useful vanguard in bringing together the multi-disciplinary personnel necessary to address the other challenges posed by offshore finfish farming.

A recommendation in this regard is made in Chapter 9.

- **Predation**
Predators such as seals, sea lions and diving birds can wreak havoc in gravity cages systems, which are vulnerable to attack.Anchor-tension cages are more or less impregnable to predator attack because of the tautness of the net and because they have a roof or top net of the same small mesh size as the rest of the cage. **(Fig 7.4)** Similar advantages apply to other systems such as AEG and submersibles like the Oceanglobe and the Sea Station.

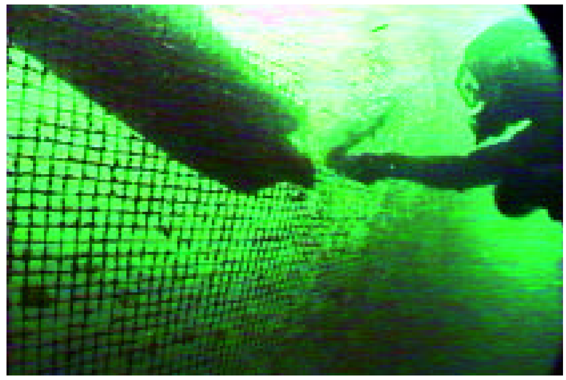


Fig 7.4 Taut netting protects farm fish from predator attack. Here, a diver inside an Ocean Spar cage in British Columbia tempts a sea-lion with a tasty morsel.
Net Systems Inc. U.S.A.

Because gravity cages are vulnerable, if they are to be employed in proposed offshore operations, they will need to be rendered predator-proof through incorporating small mesh top nets with adequate floating supports and using weight-rings below the net to keep them taut. **(Fig 7.5)**

It may be that by locating large biomasses of finfish in offshore locations, they will attract the attention of much larger marine predators such as sharks or carnivorous cetaceans. Such incidents are currently without precedent and may require new deterrent methodologies.

The current range of non-destructive deterrents such as acoustic pingers will need further refinement and it will be important in assessing site suitability that the likely occurrence of large predatory species be ascertained.

- **Mortality removal**
Given that a single cage in the finishing site of the envisaged farm could contain up to 300,000 fish,even a relatively low natural mortality rate of 0.1% per month would result in more than 80 dead fish,which would have to be disposed of in any given week.

Mortality removal on conventional farms is carried out either by scuba divers or by in-cage passive collection systems. The proposed offshore farm would most likely use a combination of these methods, and would rely for the most part on passive collection systems.

In systems of this kind the fish-cage is sloped towards a pocket that holds a container into which dead fish gradually tumble as tidal currents ebb and flow. The giant cages would have one of these passive collectors located in the centre of each one. The containers will need to have a capacity of at least one tonne in order to accommodate the build-up of mortalities that could occur during extended periods of weather-induced absence of a service vessel.

On a regular basis or as weather windows allow, farm workboats would haul the containers to the surface for emptying.At this stage, divers would also carry out inspection visits to each cage and gather any mortalities that have missed the collection system.

The promoters of both the Oceanglobe and AEG's cage concepts have included automatic mortality collection systems in their designs. These pump the dead fish from passive collectors to storage systems in the integrated feed barges.

The net cleaning robots referred to in the previous section could carry out a valuable ancillary role of picking up dead fish encountered on their travels, and dropping them into the collection system containers.

- **Problems with feed pipes**
  Maintaining the integrity of the floating pipes that deliver the feed from the barge to the fish cages is a problem even in sheltered inshore sites. The solution to feed pipes kinking and breaking must lie in the use of heavily reinforced rubber hosing with flexible fixings to moorings and cage structures. A further development would be to locate the pipe-work below the surface away from the damaging effects of waves.

  Sub-surface pipe-work would be rendered easier to engineer if pumped water, rather than air, was the transport medium. The promoters of both the Oceanglobe and the AEG concept cages include this approach in their concepts. A parallel development in feed pellet technology would also be required to maintain pellet integrity over a longer period of immersion than is usual.

- **Equipment failure**
  Being automated, the envisaged offshore farm is dependent on an assortment of machinery and sophisticated systems. As every marine farmer knows, however, machinery by its very nature breaks down and electronics are particularly prone to malfunctioning when in proximity to saltwater.

  Because of the scale of the proposed operation, breakdowns could be costly. For example, if, due to equipment failure, the proposed farm was to lose just 10 days per year of feeding 30 tonnes per day, annual production would fall by approximately 230 tonnes, thereby reducing the bottom line result by at least €400,000. Within 10 years this could accumulate to €4 million.

  Fail-safe procedures and a high degree of system redundancy must therefore be integrated into the overall package wherever possible. Thus, on the envisaged finishing site there would have to be two feed barges, each of which would be equipped to feed the entire site in the event of one being out of action.

  Each would have twin feeding systems and standby generators along with back-up emergency bilge pumping etc. Other critical systems such as communications and monitoring would also be duplicated. Despite the initial high costs, such fail-safe systems would quickly pay for themselves.

  This level of equipment cost is factored into the capital cost projections in the envisaged farm in Chapter 8.

7.3 Fish Genetics and Health Issues

So far, this report has examined how established methodologies of fish rearing in the inshore zone might be successfully transferred to offshore operations. Although marine-farmed finfish production has consistently expanded since the 1970s, problems still exist with regard to certain elements of farmed fish genetics and disease control in the inshore zone. These may also pose challenges in the offshore zone.

- **Stock genetics**
  When any organism detects a consistently plentiful supply of food in its environment, its response is to produce more offspring. In the standard well-managed fish farm, food rains down on the fish as fast as they can consume it, and the natural response of the fish is to sexually mature as early as possible so as to take advantage of the apparently bountiful environment.

  If a sizeable proportion of fish mature earlier than expected, the farmer is faced with disaster because the maturation process induces physiological changes that compromise both flesh quality and appearance. In this case, the market value of the fish can be reduced by as much as 60-70%.

  Where salmon are concerned, it is commonplace for up to 15% of harvested fish to be downgraded because of early maturation. Occasionally, levels of 25% or more can be experienced if the stock is not graded early enough to remove these fish whilst still in prime condition. The issues surrounding the grading of fish in the offshore setting have been discussed earlier in this Chapter, and it is clear that an extra pressure such as unwanted maturation would only compound the existing challenge.

  Similar problems occur with other species such as cod or haddock. At an industry level, the solution to early maturation lies in carefully breeding out early maturation tendencies. Sterile fish can also be used but trials of these have indicated compromised growth performance.

  For the individual farmer, particularly offshore, it would be vitally important that fish strains with the lowest possible rate of early maturation are selected. A 10,000-tonne harvest containing 2,500 tonnes of mature fish would be economically catastrophic for the proposed operation.

  The experience of the long established family-breeding programme, for salmon farming, shows that it is possible to 'tailor-make' strains of farmed fish for particular locations and environmental circumstances. As indicated in Chapter 6, planning an offshore farm requires a totally integrated approach, and this would extend to the genetics of the stock as much as to the choice of equipment.

- **Stock diseases control**
  Widespread use of fish vaccines has not only resulted in reduced reliance on antibiotics but has also made the fish-farmer's life easier in that predictability is greatly improved and fish mortalities are less likely to reach epidemic proportions. Nevertheless, fish diseases are still a significant risk in marine finfish farming.It is likely that disease risk will be somewhat lower in offshore farms because of the optimum environment for the fish and the distance from neighbouring farms. (See Chapter 5) This however does not rule out the absolute requirement for careful selection of disease resistant fish strains, and for excellent husbandry and health monitoring practices thereafter.

  At industry level,realisation of the increased production levels proposed would support a stronger service and supply sector. This would inevitably include a comprehensive fish health component devoted to disease prevention and treatment.If marine finfish farming realises its developmental potential and achieves the volumes of output as predicted in Chapter 2,then the industry as a whole will have achieved a scale comparable with that of animal agriculture. This will incentivise the pharmaceutical companies to invest in the necessary compliance research,so that appropriate vaccines and other products are made available to the marine finfish farming industry in the same way that they are to terrestrial farm animals.

7.4 Other Key Elements to Developing an Offshore Aquaculture Strategy

7.4.1 Licensing/site availability

The expansion of offshore aquaculture proposed here is critically dependent on the support of the regulators who determine licence or lease applications. For this reason they will need to be included in discussions around developing an offshore strategy. The regulators will also need to be made aware of the supporting scientific data that confirms the minimal environmental impact of offshore finfish farming as outlined in Chapter 5. This is important given they will be receiving site applications containing previously unheard of production tonnage targets.

Regulators must therefore be comfortable with the notion that a 10,000 tonnes offshore farm can be environmentally sustainable. They will need to understand that high fixed and capital costs require that offshore farming is carried out on a large scale. For this very reason,any proposed compromise towards temporary or pilot sites on a smaller scale would not be viable, as clearly demonstrated in Chapter 8.

While consultation with other stakeholders is a mandatory part of the environmental impact assessment process, which is a feature of the Scottish and Irish licence application system,it is important not to take a minimalist approach. If a policy of large-scale offshore aquaculture is to be successfully pursued,the only way forward is partnership with local communities. This requires early consultation and negotiation with opinion formers and key organisations such as fishing co-operatives and tourism bodies in the local area.

The process must clearly demonstrate the significant benefits to the local community regarding employment,improvement to infrastructure and business opportunities. Equally important,it must show that there will be no unacceptable impact on scenic amenity, water quality or the environment.Ideally, local communities should be given a minority equity stake in large fish farm ventures so as to create a partnership that is more than simply 'aspirational'.

Even in jurisdictions where the licence application procedure is different to that outlined above, the same principles will hold true. In keeping with the policy of adopting an holistic approach to planning offshore installations, this element of the implementation strategy should be fully included.

Recommendations with regard to licencing policy issues are brought forward in Chapter 9.

7.4.2. Managing the risk in offshore operations

Insurance companies, shareholders and banks may be apprehensive about the proposal to have up to €3 million worth of fish in a single cage as postulated in the 10,000 tonnes model,outlined in Chapter 6. Their biggest concern would likely centre on catastrophic failure of the cage caused by damage to the net or mooring lines and consequent loss of the fish. They would also be concerned about incidents resulting in smaller escapes of stock and breakdowns in the operating system, leading to loss of production efficiency.

These concerns and others will need to have been taken into account in the detailed pre-planning process, and contingencies will also need to have been made to deal with them.As stated earlier in Chapter 6 (6.2.3),the level of site investigation and equipment specification will be of a much higher order than has been customary at inshore operations.

The proposed offshore farm will lend itself to this approach,in that it involves a smaller number of large containment systems. This scale of growing justifies a high level of investment in each cage unit,in terms of netting materials, net-failure detection systems and in-cage robotic inspection cameras. All equipment will have been rigorously tested and will be supplied with appropriate rating and warranties from the manufacturers.

Recommendations in this regard are offered in Chapter 9.

The same principle will hold true with regard to the staff, in so far as there will be relatively few personnel,but each will be highly trained in various technical specialities. The support vessels and ancillary equipment will also be to a very high specification,and fully certified.As discussed in Chapter 6 all systems will incorporate a high degree of duplication and redundancy.

If such an approach were followed and the necessary equipment and systems were available, then the level of risk would be no higher than that experienced by inshore finfish farmers at present. Valuable lessons in this regard could be learned from the offshore oil and gas industries.

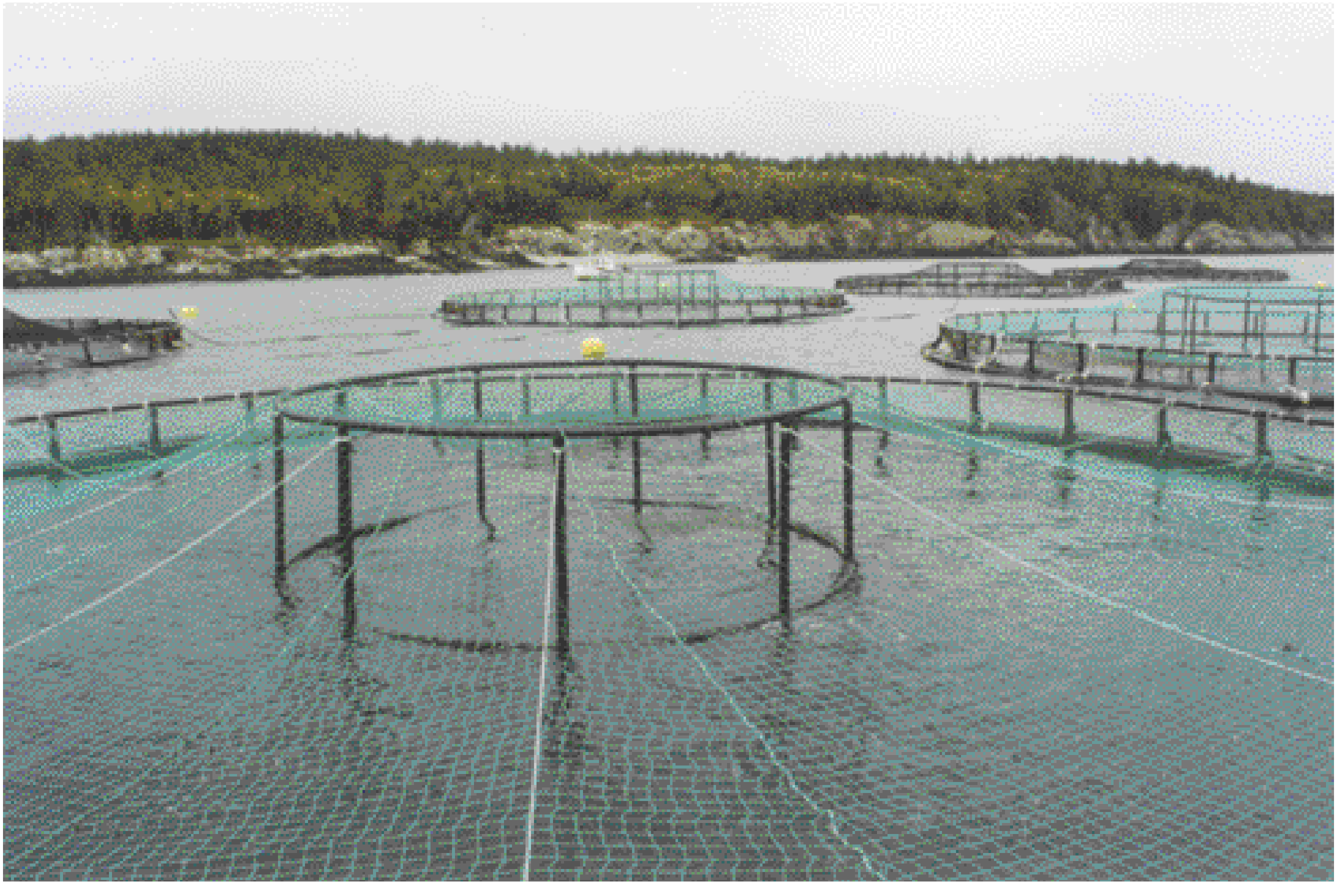


Fig 7.5 To prevent bird and seal predation, gravity cages in offshore locations need well-supported small mesh top nets, as in the case of this farm in New Brunswick, Canada. Nell Halse.

7.4. 3 Justifying the investment in specialist equipment and stocks

As illustrated in Chapter 6,if one considers the cost of equipment failure, more expensive but reliable technology will pay for itself very quickly, with the offshore scenario. The salmon farming industry has already committed to the high-tech route, particularly with regard to feeding systems and appetite monitoring. These strategies have resulted in increased scale and in significant reductions in cost per kilo of fish produced.

In the next Chapter a detailed scenario is presented,which examines the production costs in the postulated 10,000 tonnes offshore finfish farm.Interestingly, if certain modest assumptions are made regarding fish growth rate and fee conversion ratio, it may be seen that production costs per kilo in the offshore may in fact be considerably lower than current industry averages, as a result of the advantages of scale and the superior growing environment.

Chapter 8

Can Offshore Finfish Farming Be Profitable?

This Chapter presents a production model based on the widely known and accepted costs associated with farming Atlantic salmon in sea cages. All costs are on a per cycle basis not annual.

The advantage of using salmon as a model species is that the production costs have a high degree of inter-comparability across a wide range of locations worldwide. The core conclusions that will be drawn from the model will be broadly applicable to other marine farmed finfish species such as cod, sea-bream and sea-bass.

It is acknowledged by the author that the approach used is based on a developed country end-market price for the production from the offshore unit,and assumes that raw material costs for fish feed formulation will remain broadly stable out into the future.

8.1 The Scenario

The model presented envisages an offshore marine cage operation with an annual production capacity of 10,000 tonnes as set out in Chapter 6. Thus, the facility described is based on assembling a package of the best currently available technologies, with some further development and locating them in a Class 3 'type' site. It would not be possible at this time to construct a meaningful model of production costs for Class 4 or Class 5 sites given that the technologies have not been developed to a point where realistic financial projections are possible.

The model describes an Atlantic salmon farming operation,utilising anchor-tension type cages, a 30m workboat with a large capacity deck crane and automatic spar-type feeding barges. A pictorial representation can be seen in Chapter 6.

8.2 What Scale of Production?

Figure 1 summarises the projected financial performance of operating our model farm at either an output of 5,000 tonnes per annum or 10,000 tonnes per annum. **(Fig 8.1)**

Assumptions (Fig 8.1)

FCR 1.3:1 18 month grow out cycle

Projected Fixed Capital Costs €M

Production unit	Unit cost	Quantity	5,000 t	Quantity	10,000 t
Workboat	1.25	2	2.5	1	2.5
Feedbarges	0.9	3	2.7	3	2.7
Cages and moorings	0.6	8	4.8	14	8.4
Shore infrastructure	2.5	1	2.5	1	2.5
Monitoring/robotics			0.8		1.2
Small boats	0.04	5	0.2	5	0.2
Vehicles	0.05	5	0.25	5	0.25
Harvest cages	0.1334	3	0.40	6	0.80
Total			**14.15**		**18.55**

Projected Working Capital million €

Direct	Unit cost	Quantity	5,000 t	Quantity	10,000 t
Production unit			**5,000**		**10,000**
Smolt,millions	1.1	1.2	1.32	2.4	2.64
Feed cost, € x tonnes	900	6500	5.85	13000	11.7
Veterinary			0.3		0.6
Direct wages			1.56		1.56
Operating costs			1.17		1.69
Stock insurance			0.3		0.6
Selling costs @ €0.45 per kg gutted fish			2.03		4.05
Total			12.53		22.84

Projected Overhead Cost €M	Unit cost	Quantity	5,000 t	Quantity	10,000 t
Production unit			**5,000 t**		**10,000 t**
Administration			0.46		0.46
General insurance			0.26		0.26
Marketing etc			0.06		0.06
Total			0.78		0.78

Summary Table €	Unit cost	Quantity	5,000 t	Quantity	10,000 t
Production unit			**5,000 t**		**10,000 t**
Set up cost			14,150,200		18,550,400
Depreciation cost per annum		10%	1,415,020	0.10	1,855,040
Depreciation cost per unit tonne		5000	283	10000	186
Unit tonne cost of production					
Total direct cost		5000	2,506	10000	2,284
Total overhead cost		5000	156	10000	78
Total			**2662**		**2362**
Sales price per tonne (RWE)			2,970		2,970
Total cost of production per unit tonne plus depreciation			2,945		2,548
Margin per tonne			**25**		**422**

The key assumptions in examining this proposition are that three sites will be required for the entire operation.A large grow-out site with two feed barges, a secondary juvenile site with a single feed barge and a third inshore sheltered harvesting/holding site, as postulated in Chapter 6.

The schedule of capital expenditure for the two levels of output is given as the first section of Fig 1.It may be seen that the same workboat would be required,and that that the major variable is in the number of cages. It is estimated that eleven cages would be required for the 5,000 tonnes output,while the 10,000 tonnes output requires twenty.

The 'working capital' and 'overhead costs' are projected in the next two sections of Fig 1. Feed conversion rate is set at 1.3:1 (economic) and the other variable costs are set pro rata to the level of output.

It may be seen from the summary table that there is a significant advantage in terms of margin per tonne to the operator at the 10,000 tonnes per annum level of output. The unit cost of production and the return on capital invested arising from the 5,000 tonnes per annum projection would make this an uneconomical proposition.Alternatively, at 10,000 tonnes, the economics of production start to become attractive.

Thus is may be seen that an annual output level of at least 10,000 tonnes will be required to generate sufficient turnover to make the necessary contribution to justify the investment in fixed costs.

8.3 The Advantages of Going Offshore

The conclusion above regarding the scale of output would hold equally true in an inshore location and the projection in Fig 1 does not take into account any of the possible benefits that might accrue from the superior environmental conditions that would be experienced in an offshore location.

Figure 2 runs the same model again but incorporating some changes in the core assumptions. **(Fig 8.2)**

Given the high-water exchange environment experienced in the offshore and the very high level of expenditure in feed monitoring and control equipment,it would not be unreasonable to project a feed conversion ratio of 1.1:1 and a reduction in juvenile cost because of increased survival and higher yield per smolt.When these factors are considered, it may be seen from Fig 8.2 that there is a marked improvement in the margin per tonne and a substantial reduction in the unit cost of production,to the point where it represents an internationally competitive position.

Assumptions (Fig 8.2)

FCR 1.1:1 18 month grow out cycle

Projected Fixed Capital Costs €M

Production unit	Unit cost	Quantity	10,000 t
Workboat	1.25	2	2.5
Feedbarges	0.9	3	2.7
Cages and moorings	0.6	14	8.4
Shore infrastructure	2.5	1	2.5
monitoring/robotics			1.2
Small boats	0.04	5	0.2
Vehicles	0.05	5	0.25
Harvest cages	0.1334	6	0.8004
Total			**18.55**

Projected Working Capital €M

Direct Production unit	Unit cost	Quantity	10,000 t
Smolt,millions			1.92
Feed cost, € x tonnes	900	11,000	9.9
Veterinary			0.6
Direct wages			1.56
Operating costs			1.69
Stock insurance			0.6
Selling costs @ €0.45 per kg gutted fish			4.05
Total			**20.32**

Projected Overhead Cost €M	Unit cost	Quantity	10,000 t
Production unit			**10,000 t**
Administration			0.46
General insurance			0.26
Marketing etc			0.06
Total			**0.78**

Summary Table €	Quantity	10000 t
Production unit		**10,000 t**
Set up cost		18,550,400
Depreciation cost per annum	10%	1,855,040
Depreciation cost per unit tonne	10000	185.504
Unit tonne cost of production		
Total direct cost	10000	2032
Total overhead cost	10000	78
Total		**2110**
Sales price per tonne (RWE)		2970
Total cost of production per unit tonne plus depreciation		2296
Margin per tonne		**674**

8.4 The Art of the Possible

It may been seen from Fig 2 above, that it is feasible to produce fish at a very competitive unit cost of production in an offshore farm of 10,000 tonnes per annum.Further improvements would be achievable if the integrated approach suggested in Chapter 6 & 7 were extended logically to the juvenile production phase of the operation.If a specially bred 'jumbo' smolt (cira.180g average weight) were available twice yearly as S1 and S1/2,then a scenario could be envisaged where the need for the juvenile or smolt site could be eliminated altogether. The implications of this are projected in Fig 3. **(Fig 8.3)**

In this case, the capital cost for the juvenile site has been removed and the juvenile portion of the cost per kilo is reduced because the survival rate is higher and less smolts are required. The cost per smolt is kept the same as in Fig 8.2 as the hatchery will be more efficient with two full cycles per year going through it,despite producing a larger juvenile.

By putting a much larger smolt to sea,with superior genetics for fast growth and low maturation (as discussed in Chapter 6),together with first rate feed control,it would be possible to reduce the growing cycle time from approximately 18 months to 12 months at sea.

Thus only one site would be used,stocked twice a year, with S1 and S1/2. It would be large enough in area to allow effective fallowing in two 'zones',each on an 11 1/2 month production cycle.

Such a strategy would be advantageous from a number of perspectives: assets would be more productive, risk would be reduced,and overhead and labour costs would be lower. In addition,yield per smolt will increase and the smolt cost as a proportion of unit cost will decline, also the assets will be more productive as there will be continuous production.

When these elements are all taken together, it may be seen from the summary table in Fig 8.3 that an extremely competitive projected unit cost of production and a very attractive margin per tonne are achieved.

In summary, it may be seen from the financial projections as set out above that farming marine finfish in semi-offshore conditions with current technology is an economically viable prospect. This will be true only if the right business plan is combined with appropriate choices in terms of site selection,equipment and support infrastructure.

These conclusions regarding scale, growth rate and yield-per-juvenile will hold equally true for other species of farmed marine finfish. The details will vary but the principles will be the same.

It should be acknowledged however that a successful integration of all of the required technology components has not yet been achieved and will require some further development.

Nevertheless, as a prospect it is quite feasible and it could well become a concrete reality in the not too distant future if the necessary collaborative structures are put in place now to iron out the remaining technology wrinkles.

Once this level of operating capability is achieved,farms such as those projected above would in their turn become the development incubators for the more radical technology solutions required for Class 4 site locations.

Assumptions (Fig 8.3)

FCR 1.1:1 12 month grow out cycle - Thus single marine site only.

Reduced smolt input 2.2 m - better survival.

The capital costs for the "smolt" site are removed.

Projected Fixed Capital Costs €M

Production unit	**Unit cost**	**Quantity**	**10,000 t**
Workboat	1.25	2	2.5
Feedbarges	0.9	3	2.7
Cages and moorings	0.6	10	6
Fully equipped shore base	2.5	1	2.5
monitoring/robotics			1.2
Small boats	0.04	5	0.2
Vehicles	0.05	5	0.25
Harvest cages	0.1334	6	0.80
Total			**16.15**

Projected Working Capital €M

Direct Production unit	Unit cost	Quantity	10,000 t
Smolt,millions			1.76
Feed cost, € x tonnes	900	11,000	9.9
Veterinary			0.6
Direct wages			1.2
Operating costs			1.3
Stock insurance			0.6
Selling costs @ €0.45 per kg gutted fish			4.05
Total			**19.41**

Projected Overhead Cost €M	Unit cost	Quantity	10,000 t
Production unit			**10,000 t**
Administration			0.35
General insurance			0.20
Marketing etc			0.06
Total			**0.61**

Summary Table €	Unit Cost	Quantity	10000 t
Production unit			**10,000 t**
Set up cost			16,150,400
Depreciation cost per annum		10%	1,615,040
Depreciation cost per unit tonne		10,000	161.504
Unit tonne cost of production			
Total direct cost		10,000	1,941
Total overhead cost		10,000	61
Total			**2,002**
Sales price per tonne (RWE)			2,970
Total cost of production per unit tonne plus depreciation			2,164
Margin per tonne			**806.50**

Chapter 9

The Vision: A Blueprint for the 'Blue Revolution'

9.1 Introduction

As discussed in Chapters 1 and 2, the case for realising the ultimate vision of offshore finfish farming is compelling. The world's population and world's seafood markets need the fish that will come from these farms. There is no doubt that there will be a market opportunity, and the only way that it can be fully exploited is by developing real offshore finfish farming capability. Although the required production cannot be sourced from elsewhere, the basic driver for development is market demand and this is as it should be.

Over and above this necessary commercial motivation,the major environmental benefits that will also accrue from a successful move offshore have been examined in Chapters 5 and 7,and on their own they justify the necessary effort to make open ocean farming a reality.

As may be seen from the results of the economic analysis in Chapter 8, and from the conclusions reached in the other chapters, the possibility of putting together a profitable and sustainable offshore finfish farm similar to that shown in Chapter 6,Fig 6.10 in a Class 3 location is tantalisingly close.

This report concludes that fish will be healthier and of better quality in an offshore environment and that this new production will be achieved with minimal environmental impact. Thus, offshore finfish farming has the potential to be a truly sustainable form of development.It will bring significant socio-economic benefits to the coastal communities where the fish come ashore, health benefits to consumers and provide a valuable source of high-grade protein to the wider population.

In the case of Ireland,the report has identified at least fifteen Class 3 sites, with new and extra production potential of 150,000 tonnes, valued at almost half a billion Euro per annum,which would generate thousands of additional jobs.

Utilising such Class 3 sites as test beds for technology incubation,it will be possible to develop the extra techniques and equipment required to move further into the deep blue and successfully occupy Class 4 open ocean sites. As with all journeys, this first step is the most important and there is some preparation required before it can be taken.

This game is definitely worth the candle, in Ireland and internationally.

9.2 Getting There

As explained in Chapters 6 and 7,what is required to successfully move marine finfish farming offshore is a careful step-by-step process characterised by high levels of pre-planning,and underpinned by focussed R&D to fill in the technology gaps that have been identified in this report. The traditional "try it and see"type approach will not be adequate.

It is a firm conclusion of this report that it is not possible to move straight to commercially viable operations in Class 4 offshore sites without moving through a developmental phase in perfecting the equipment and techniques required for Class 3 sites (See Fig 6.10 – The Next Step).Achieving this latter objective in an economically sustainable manner is a formidable challenge in its own right,as has been shown by the experience of the promoters reviewed in Chapters 3 and 4.

Valuable lessons must be learnt from past mistakes, and the wasteful and piece-meal approach followed up to now should be exchanged for a better developmental paradigm.

It is recommended that the following should be used as guiding principles:

- **Learn to speak a common language.** Classification systems with international acceptance need to be developed for the description of offshore sites and containment systems.
- **Capture the lessons to be learned.** Once a common nomenclature has been developed,it will be possible to make meaningful inter-comparisons between different locations and equipment types so that vital trial results are not lost through inadequate communications.

- **Spread the developmental costs.** Where possible, when designing new or improved solutions for the offshore situation,the equipment or technique created should have a ready market potential in the existing inshore sector. For example, effective automatic net-cleaning robots and high capacity remote telemetry systems, necessary for the offshore, would also be attractive to the inshore sector and would thus enjoy high sales volume immediately.

- **Start now to educate the regulators and the public.** The key process of generating acceptance of the necessary scale of development of offshore farms (as demonstrated in Chapter 8) will take time. Experience with the development of inshore finfish farming has shown just how prolonged and difficult this can be.

- **Pool knowledge and resources.** Chapters 3 and 4 show the expensive pitfalls that have dogged the development of new technologies for offshore finfish aquaculture. Investment capital is a precious commodity, and its impact should be maximised by an effective means of collaboration amongst offshore finfish developers. For example, promoters who intend to rear different species will not be competing with one another and could freely cooperate on a range of equipment development projects, to solve common problems.

  (An aspirational catalogue of desirable R&D topics in offshore finfish operations is given in Appendix II.)

9.3 The Vehicle For Getting There

Following wide consultation and having carried out the reviews elaborated in Chapters 3 and 4,the author has concluded that there is an urgent need for the establishment of an international body to energise and coordinate the accelerated development of offshore finfish farming. To overcome natural reservations regarding the geographic location of such an organisation and to utilise the opportunities afforded by modern communication systems, it is proposed that this body should exist primarily in the form of a global community operating in a high-tech virtual environment.

There exists considerable expertise in the formation and operation of such organisations, supported by reliable IT platforms. These technologies, married with advanced organisational structures based on the 'Community of Practice' approach,have the potential to revolutionise the development of offshore finfish farming.

The key recommendation of this report is that such an organisation should be founded as rapidly as possible.

It might be titled:

The International Council for Offshore Aquaculture Development (ICOAD).

The mission statement might read as follows:

> ICOAD will promote and facilitate, through all means possible, the development of suitable technologies and methodologies for successful aquaculture operations in the offshore zone. The ultimate aim is the creation of a major offshore aquaculture industry, which produces a significant proportion of the total world fish requirements in an economically and environmentally sustainable manner.

What would ICOAD do?

The ICOAD organisation would become a world-class centre of excellence for offshore aquaculture development and be the international focal point for collaboration.

It is envisaged that ICOAD would develop major international expertise in sourcing the funding and creating the partnerships required to bring forward key offshore technology development programmes. The choke points blocking advances, identified in Chapters 6 and 7 and further elaborated in Appendix II,would be prioritised and R&D programmes initiated to yield solutions.

ICOAD, if formed,will become the central communications node for international cooperation and information dissemination and its creation will accelerate the process of developing large-scale offshore aquaculture. Members of ICOAD will have a major advantage over non-members with regard to offshore aquaculture development in terms of gaining access to financial and knowledge capital.It is envisaged that ICOAD will have membership from both governmental and private organisations. It will function on a two tier basis, with some members accessing information and attending events while others actively participate in multi-company R&D projects, which reflect their interests and are facilitated by ICOAD.

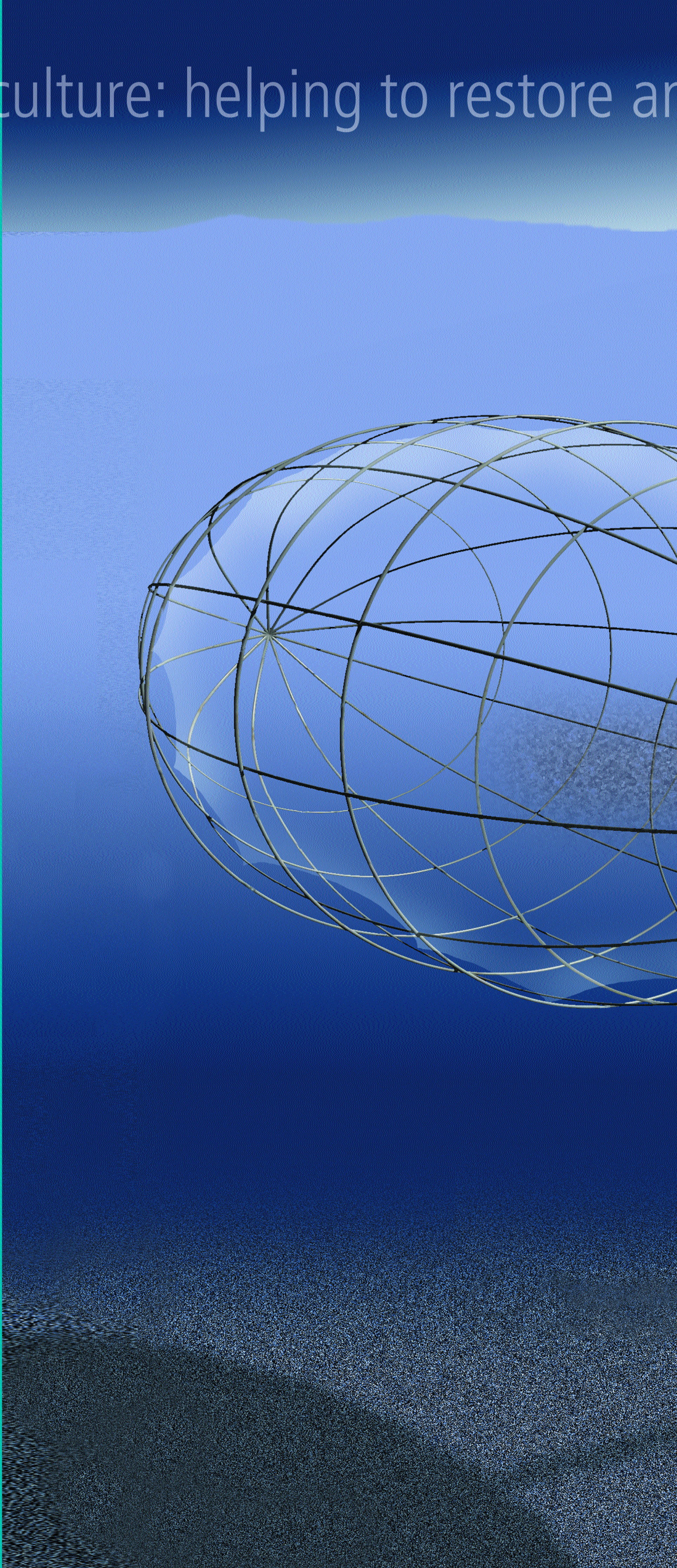
Detailed proposals for the formation of ICOAD will be presented to the delegates at the 'Farming the Deep Blue' conference in October 2004. These proposals have been developed by leading experts in the field of building Virtual Communities from the University of Limerick,Ireland.

The successful formation and operation of ICOAD would,over time, lead to true open ocean finfish farming,leading the way in the evolution of the 'Blue Revolution'.

An artist's impression and a detailed explanation of what such an operation might comprise is presented as the author's vision of the future in Fig 9.1.It is captioned:

Offshore aquaculture: helping to restore and sustain the ocean's bounty.

Illustration: Frank O'Reilly

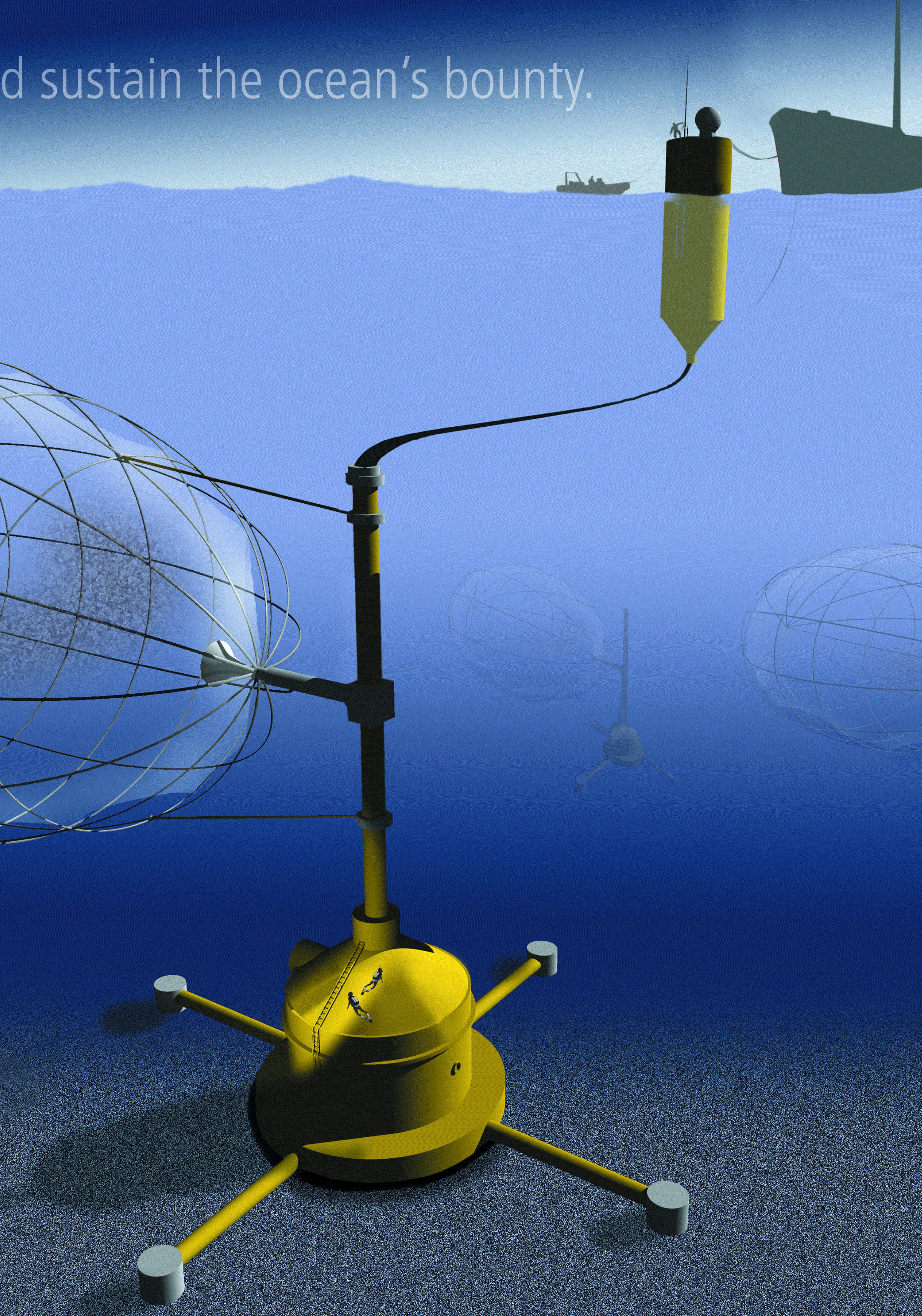


FUTURE FARM

One scenario for ocean farms of the future is total submersion of not just the cage but the feed storage and distribution system as well. The concept illustrated shows a 'Blimp' cage with a capacity of 1,000 tonnes of fish,connected to a feed store mounted on top of concrete anchors on the seabed. The stores are refilled by pumping from a visiting feed supply ship that moors to a surface buoy.

The surface buoy contains electricity generation systems, which supply power to feeding,monitoring and control systems. It also contains data processing and transmission hardware, which facilitates remote operation of the entire system from land.

To harvest, the cage is disconnected,floated to the surface and towed to an inshore location where the fish are removed as required.An alternative scenario would be to have feed supply pipes radiating out from the feed store along the seabed to an array of additional 'Blimps'.


d sustain the ocean's bounty.

Appendix I

Health benefits of fish as human food

Throughout the world fish is increasingly perceived as a healthy food option,and this perception is backed up by numerous research findings and health reports. It is now an accepted medical fact that eating fish is good,if not essential,for both brain and body.

In the case of the brain,Omega-3 fats - EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid) - are integral components of the myelin sheath around neurons and are essential ingredients in the synthesis of prostaglandins, which are extremely active hormone-like substances. In the brain, prostaglandins regulate the release and performance of neurotransmitters, and low levels are known to be associated with various conditions, including depression and schizophrenia.

It is this involvement of Omega-3 fats in the basic physiology of the brain that accounts for the growing evidence of their ability to improve learning and alleviate behavioural problems, attention deficit disorder, depression and schizophrenia.

A diet rich in Omega-3 fats has also been shown to improve children's performances in IQ tests. In addition, a recent study of over 1,000 elderly people at Tufts University, USA,has shown that candidates whose diets were rich in DHA were 48% less likely to develop Alzheimer's disease compared with those whose diets were low in DHA.'These dramatic results show how older adults can play a significant role in their own neurological health by increasing their intake of fish,fish oil,and especially DHA,' stated Ernst Schaefer, a senior scientist and director of the Lipid Metabolism Laboratory at Tufts. (**Intrafish News 17/11/03**)

The benefits to the human body of eating fish are many, and one of the most topical is their role in breast cancer prevention.In a fascinating study into the health and longevity of Okinawans, entitled The Okinawa Way, the author notes: 'Three populations – Okinawans, Japanese, and Inuit – that consume fish at least three times per week have a much lower breast cancer risk. This fact has been confirmed in a range of studies. The connecting thread here may be fish oil, which is rich in Omega-3 fatty acids and appears to be active in breast cancer prevention' .

Eating fish is also important in the prevention of heart disease. Again in The Okinawa Way, the author states: 'There has been a wealth of evidence to support eating Omega-3 foods including fatty fish like salmon, tuna, and mackerel. The initial observations of very low death from heart attacks in Inuit (Eskimo) populations – despite a diet high in total fish consumption – led to research that demonstrated the blood thinning qualities of Omega–3 fatty acids. These fatty acids were obtained mostly from saltwater fish'.

Finally, the author concludes: 'This is all to say that if you're a meat eater, make the switch to fish and keep your arteries clean. Fish is one of the most heart-healthy foods you can eat. The Omega-3 fats in fish acts as a platelet inhibitor and keeps them from forming clots in the coronary arteries and elsewhere. That's actually why Omega-3 fats are present in coldwater or saltwater fish. They keep the blood thin and flowing freely, like anti-freeze for your car in the winter'.

This type of information on the health benefits of eating fish is compelling and is no longer confined to the pages of medical journals and obscure self-improvement publications. It is found in the magazines and newspapers that ordinary people are reading on a daily basis. For instance, an edition of Now magazine published earlier this year cited Hollywood's latest craze:the 'Perricone diet',which 'pledges to reduce wrinkles and improve facial sagging'. The magazine explains that the diet was 'devised by US dermatologist Dr Nicholas Perricone (and that) the key is eating fish three times a day in order to benefit from essential fatty acids that stimulate nerve function and 'plump out' skin. Wild coldwater fish such as salmon, mackerel, and trout have the highest levels. At the same time, Dr Perricone says that protein rich fish are crucial in keeping facial lines at bay.'

Over the past decade, the effect of global advertising on the health benefits of eating oil-rich fish has lead to a dramatic increase in its consumption,especially amongst populations not traditionally associated with a high seafood diet.

Appendix II

Aspirational Catalogue of Desirable R&D Topics in Offshore Finfish Operations

1. Standards

1a. Development of an internationally-agreed classification system for aquaculture cage sites, based on wave height,length and period. It may also be necessary to include aspects relating to current speed in this system

1b. Development of an internationally-agreed standard based on design and construction techniques for aquaculture equipment. An important objective of this standard should be that equipment is graded according to what type of site it is suitable for, by using the site classification system arising from Project 1a above

2. Environment

2a. Establishment of a detailed catalogue of the stresses and strains to which moored and towed equipment is subjected to under various conditions of wave, current and wind. This is essential in order to inform proper design,which would be carried out through desk-study, modelling,tank-tests and empirical work such as load measurement on aquaculture equipment in situ.

2b. Monitoring of benthic and water quality impacts of large-scale offshore operations

2c. Development of sonar systems capable of detecting reductions in cage fish biomass arising from escapes.

3. Which fish species?

3a. Review Atlantic and Mediterranean fish species in terms of quality, yield and suitability as new candidates for finfish farming.

3b. Development of culture methodology for species selected under 3a.above.

4. Cages

4a. Assessment of the performance of existing conventional floating cage systems in offshore sites, and identification of where the problems arise.

4b. Using data from Projects 2a and 4a,develop more appropriate floating cage designs.

4c. Assess the performance of novel cage systems in offshore sites, and identify directions for further development.

4d. Using data from Projects 2a and 4c,develop successful novel cage designs.

4e. Design and develop submersible cage systems.

4f. Design and develop suitable mooring systems.

5. Feeding systems

5a. Assess the performance of existing feeding systems in offshore sites and identify directions for further development.

5b. Based on data from Projects 2a and 5a,develop feeding systems suitable for offshore use.

5c. Develop suitable pipe systems that will deliver feed from permanently moored feed barges to submerged and floating fish cages.

6. Monitoring and Control

6a. Assess the methods of wireless data transmission systems currently in use in offshore aquaculture and in other marine applications, and identify options for further development or direct application.

6b. Based on data from Project 6a,test various data transmission systems on existing offshore farms.

6c. Based on data from Projects 6a and 6b, test wireless data transmission systems for the remote operation of:

- feeding system control
- subsurface video monitoring of the fish and equipment
- sonar monitoring of fish and feed consumption
- equipment monitoring systems, such as load meters and mooring lines and bilge-water levels in feed barges

- net integrity monitoring systems
- low impact probes attached to a small sample of the fish monitoring critical physiological parameters such as heart rate, blood-oxygen levels or levels of the stress-indicating hormone, cortisol
- in-cage probes monitoring critical water quality parameters such as oxygen levels, ammonia levels, turbidity and temperature. Data from these probes would be combined with that collected from state-sponsored ocean monitoring buoys to give a comprehensive picture of unfolding environmental events
- security systems based on radar and video cameras
- data processing and a systems control package that integrates all of the above systems

7. Housekeeping

7a. Commission a study on possible anti-fouling strategies in order to determine likely technologies for offshore aquaculture use. The oil and shipping industries are particularly knowledgeable in this regard

7b. Develop net-fouling prevention methods and net-cleaning systems. These might include new net construction materials and techniques plus remotely-operated,robotic cleaning systems

7c. Promote the incorporation of mortality collection systems into all cage design options

7d. Develop mortality collection robots and ROVs. There may be some overlap here with development of net-cleaning robots

7e. Promote the inclusion of a passive fish grading system as a design criterion for all offshore cage types

8. General finfish farming issues

There are many issues regarding RTDI that are not exclusive to the offshore zone but are critical to the success of finfish aquaculture regardless of where it is carried out.It is debatable whether these should be on the agenda of the proposed Institute but the most important ones include the following:

8a. Replacement of fishmeals and fish oils as constituents in fish feed.

8b. Development of commercially viable sterile fish strains in order to both address early maturation problems in aquaculture and to mitigate genetic impacts of escapees on wild fish.

8c. Promote the commercial availability of increased ranges of fish vaccines and fish medications

8d. Development of breeding programmes that select for factors such as: fish growth,disease resistance, late maturation and finish quality

8e. Development of predictive methods that forecast jellyfish and algae blooms

Industry involvement in research and development

Research and development in offshore aquaculture must be grounded in commercial reality. This would be best achieved through strong industry participation in the proposed offshore institute so that practitioners have a significant input into prioritising and selecting projects. New technologies should be piloted in an offshore environment as soon as practicable so that unforeseen problems can be resolved by the time a product becomes commercially available.

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