Practical development of offshore mariculture systems: The Irish experience

Christensen I.

in

Muir J. (ed.), Basurco B. (ed.).
Mediterranean offshore mariculture

Zaragoza : CIHEAM
Options Méditerranéennes : Série B. Etudes et Recherches; n. 30

2000
pages 91-103

Practical development of offshore mariculture systems: The Irish experience

I. Christensen
I.C. TRAWL Ltd, West Pier, Howth, Co., Dublin, Ireland

SUMMARY – This paper describes the evolution of cage farming in Ireland, especially the development of an offshore fish farming sector where some 50% of the 14,500 t of salmon (in 1997) are produced. Aspects of cage evolution are discussed, from early wooden cages and the progression to steel, the progression from steel to plastic and then to offshore cages such as Bridgestone and Farmocean. The paper attempts to describe how the industry had to take the technology and modify it to suit the environmental needs of offshore Ireland, pointing out what was successful and what failed. Finally the future needs and potential for progress for offshore cage farming in Ireland are addressed.

Key words: Offshore, aquaculture, cages, Ireland, salmon.

***RESUME –** "Développement pratique des systèmes de mariculture offshore : L'expérience irlandaise". Cet article décrit l'évolution de l'aquaculture en cages en Irlande, en particulier le développement d'un secteur de pisciculture "offshore" où 50% du total de 14 500 t (en 1997) est produit. Des aspects de l'évolution des cages sont discutés, depuis les premières cages en bois, la progression vers l'acier, la progression de l'acier au plastique, et puis les cages offshore comme le Bridgestone et Farmocean. Cet article veut expliquer comment l'industrie a repris la technologie et l'a modifiée pour s'ajuster aux besoins environnementaux des sites offshore en Irlande, et décrire les réussites et les échecs. Finalement les besoins futurs et le potentiel pour le progrès en aquaculture offshore en Irlande sont présentés.*

***Mots-clés :** Offshore, aquaculture, cages, Irlande saumon.*

Introduction

This paper follows the evolution of cage farming in Ireland, especially the development of an offshore sector where in 1997 some 50% of the annual production of 14,500 tons of salmon are produced from offshore cages. It reviews briefly several aspects of the cage evolution in Ireland, from the use of early wooden cages and the progression to steel, followed by the progression from steel to plastic and then subsequently to offshore cages such as Bridgestone and Farmocean. The paper attempts to describe how the industry had to take the technology and modify it to suit the environmental needs of offshore Ireland, pointing out what was successful and what has failed. Finally the future needs and potential for progress for offshore cage farming in Ireland are addressed.

Aquaculture, according to Wilkins (1989) predates Christianity and was probably developed in China. Commercial exploitation of both salmonid and shellfish farming in the Northern Hemispheres dates from the 1850's when almost all the technical innovations, ranging from artificial hatching to sea cage cultivation, were first introduced or attempted. According to Wilkins (1989, op. cit.), the commercially operated salmon hatchery commenced in Galway in 1850 and the first attempt to grow salmon in sea cages was undertaken in Co. Dublin in 1854. In many ways Ireland has a long involvement with aquaculture development activities.

History and evolution of cage farming in Ireland

The successful development of salmonid farming occurred in Norway over 100 years after the first attempts, and so too, these techniques were the starting point for successful salmon farming in Ireland. This technology was taken and adapted to suit Irish near-shore conditions and went further in pioneering the use of offshore cages in Europe, again a case of adapting Japanese technology to suit Irish conditions. A review of the history of how this proceeded over many years may be useful to other countries that are attempting to do the same. These adaptations also show that one should never stand still in utilization of technology and never be afraid to improve or modify. Though acceptance of modifications by some companies has, in the past, caused some delays and problems, this has changed over the years.

Start of salmon and trout farming

The first experiments were carried out in the west of Ireland in 1975 by the then Electricity Supply Board using a single cage of the EWOS/Tess "wigwam" variety, and feeding minced raw fish with binder and vitamin supplement. These experiments were taken a step further reasonably quickly and by the early 1980's several companies were beginning to farm salmonids (Joyce, 1988). Bradan Mara produced the first 100 t in 1983 in the west of Ireland. The graph of production in Fig. 1 gives a feel for the expansion of the industry over that time.

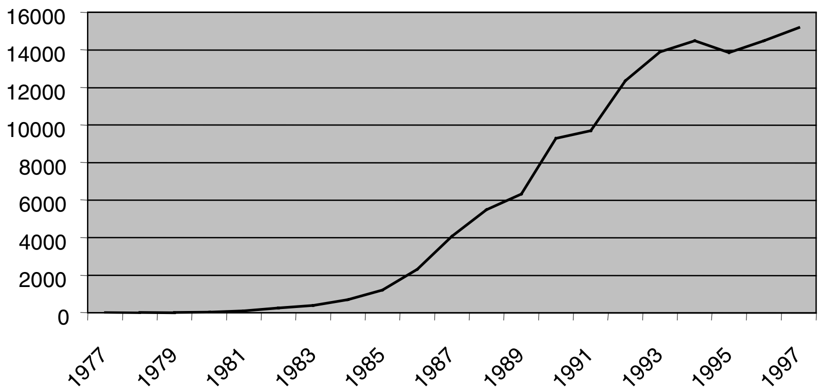

Fig. 1. Irish salmon production (t) 1977-1997.

First cages

As noted, the first trial cages used were Tess "Wigwam" type used with rainbow trout in sheltered bays in the west of Ireland in 1979. These were quickly followed by Sterner type and wooden cages based on the Kames design. The Tess cage essentially used fibreglass poles set through dhan buoys (i.e., buoys used for marker poles, made with a central hole), joined at the top in a wigwam fashion to support the net. The Sterner cage was based on the use of a square configuration horizontal tubular steel frame with vertical legs attached into similar dhan buoys. Though they were relatively cheap and simple, neither the Tess nor the Sterner design were decked, and so had to be serviced from a boat. They were also relatively light, and not very robust. The wooden cage system began as a square Kames type with 5-6 meter sides, with timber frames, deckway and handrail, polystyrene floats and galvanized steel corner brackets. The size of this cage type was usually dictated by the length of timber available.

The Tess cages gave people a start in cage farming and an understanding of how to grow fish, how to change nets and all the problems and techniques involved for cage farmers. This was entirely new technology to Ireland at the time. This and the Sterner cage type represented the first experience of cage farming. The wooden cages were more substantial (but more expensive) and allowed routine husbandry directly from the cage.

Problems and reasons for change

As with cage farming everywhere, problems started to arise. The actual management of the cages such as net changing, keeping out birds and other predators, started to become a problem. The lack of training of personnel was also a constraint. It also became very obvious that some sites were more exposed to weather than the cages could withstand.

Problems started to arise with the strength of the poles on both the Tess and Sterner cages and soon damage was occurring, leading to some losses of fish. It was also becoming a problem to efficiently feed the fish and trials began on how to put autofeeders on such cages. This problem took a long time to solve, because feeders that were suspended from floating buoys in the cage caused problems with scaling on the fish, which also resulted in losses.

It was also apparent that the lack of walkways on the Tess and Sterner cages was a major drawback. The wooden cage evolved in a fashion that is now well known (Beveridge, 1996), in that walkways were added to the structures, making the working of the cage much easier. Husbandry activities such as feeding fish, putting on auto feeders, changing nets, hanging predator nets, storing food and general observation and fish handling all became simpler and more feasible as routine operations. The main drawback was that as the few sheltered sites were taken up, and more exposed sites were used, wooden cages began to show structural problems at the corner brackets. This led to the design of different corner brackets usually containing more steel and with better structural design. These cages lasted for many years in different forms and served the industry very well. Such wooden cages were also widely used in Scotland and elsewhere, and indeed are still used in many freshwater operations, typically raising smolts.

However, it became apparent in Ireland that if the industry was to be expanded, cages capable of withstanding more exposed conditions had to be used. Steel cages were beginning to be used in Norway, and Ireland followed suit.

Second generation cages

Turmec Engineering, a company that made steel structures for harvesting peat for the Irish Turf Board, started to design a steel cage in the early 80s, producing its first working prototypes in 1984-5. Full production began in 1986 and 4400 of the now well known Wavemaster cages have now been manufactured and sold for use in Ireland and world-wide.

The design concept was, however, different from most wooden cages which had normally been built as separate units and then moored together. The new steel cages used a common walkway in the centre yet maintaining individual cage units, all forming part of the group. This was usually based on a group of 4, which could be developed in further multiples of 4. Later designs made it possible to have groups of 6 and 10, etc. Using this modular concept, it was possible to keep down the cost of cage space, and also to devise moorings that worked as an integral part of the cage group. Unlike the wooden cages which started with individual moorings and evolved into various group configurations, steel cages systems started with the premise of whole group mooring. This could save on mooring costs and enable more exposed sites to be developed. The questions posed at that time were whether it was possible to make structural steel units that would withstand the various winds and waves of the site and to design and work nets that would work well with fish in such conditions.

There was some concern about these engineering and biological issues because of experience with a wooden cage design that was supposed to be able to withstand more exposed sites. The Topper cages were originally designed and manufactured in the USA, then made under licence in Ireland. They were designed and made along the group module system, like the early steel cages but instead of using hinges between main walkway and cage deck assemblies, used wooden buffers. The whole cage system was then tensed using a wire tensioning system. The tension in the total system had to be correct to keep the shape of the cages and thus ensure their integrity. The mooring system also had to be exact in order to assist with keeping the exact shape. It proved to be very difficult to keep all these factors exactly correct or indeed have them correct at the beginning when the cages were laid. In Ireland these cages failed in winter gales with the loss of fish. This showed that when there was excessive movement in the nets, fish were lost due to scaling. Some Norwegian timber cages also suffered a similar fate on trials in the more exposed sites of the west of Ireland.

Wavemaster steel cages

These became the most common cage in use in Ireland for semi exposed and more exposed sites. As they were manufactured in Ireland, it was relatively easy for the manufacturers to take into account suggestions from fish farmers for modifications and improvements. This process of continuous improvement was one of the reasons for the success of this cage type. The cages started out in 12 x 12 m configurations, which was quickly expanded to 15 x 15 m and then a 20 x 20 m cage was built for more exposed sites. In addition, the manufacturer always had a potential site assessed for its exposure prior to considering whether the Wavemaster cages would be able to withstand wind and wave conditions of the site. This was also a sensible approach to supplying and servicing the needs of the industry. Many of the early cage builders simply did not evaluate sites where cages were to be placed, nor did they have a follow-up service or maintenance arrangement. Many did not incorporate farmers' modifications into new versions of the cage design nor did they offer maintenance contracts. These were essential parameters in developing a successful cage manufacturing and service business. Wavemaster continue to supply steel and plastic cages to the industry world-wide.

Undertun cages

Several farms tried these steel cages from Norway with some success in the initial phases. Typically 15 x 15 m or larger, the steel deck on these cages was held above the water using variable buoyancy vertical steel floats in the form of large inverted cones on the corners and at strategic positions below the walkway. These generally well in semi exposed sites but eventually suffered from damage around the floats, and the cages were normally replaced with other types.

Plastic cages

The early plastic cages were brought in from Norway, with some also from Denmark, and were used for sorting fish and grading cages. These were circular in form with plastic handrails and were individually moored or attached to a mooring bridle. It became obvious that even though they did not have good walkways, and handrails were weak in early designs, they could withstand semi-exposed conditions, and the cost per m^3 was much less than for steel cages. Thus plastic cages became fairly common in use as a normal grower cage and remain so to this day. These cages started as small circles of 40 m circumference (~12.5 m dia) and now are at 100 m circumference (~32 m dia). Both Norwegian and Irish plastic cages are used.

First offshore cages

Bridgestones

The first Bridgestone cage was brought into Ireland and Europe in 1984. This was part of an evaluation programme devised by Emerald Fisheries and udaras Na Gaeltachta – a development agency on the West Coast of Ireland. It was placed in a reasonably open sea site at Kilkieran Bay. After two years and some learning on how exactly to work the cage it proved to be a dramatic success. Between 1984 and 1997, 157 units were sold world-wide with Ireland accounting for 54 of them (35%) – the largest individual number anywhere in the world outside Japan.

The Bridgestone cages started out as hexagons with 8-m sides. These then progressed to 16-m sides, and then to octagons with 16 and 20-m sides. With standard 15-m nets, the corresponding volumes and carrying capacities were as follows (Table 1).

Table 1. Cage dimensions and net volumes

Bridgestone cage type	Side length (surface area m^3)	Net volume (m^3) at 15 meters	Est. carrying capacity of salmon (t) at 15 kg/m^3
Hexagon	16 (665)	9,975	150
	20 (1039)	15,585	230
Octagon	16 (1236)	18,750	278
	20 (1931)	28,965	434

Farmocean

The first Farmocean cages were purchased in Ireland in 1986/7, the first such cages to be tried outside of Sweden. This adjustable buoyancy octagonal steel umbrella design was developed for independent operation in highly exposed conditions, with a top mounted automatic feeder designed to operate for several days without the need for access (see also Scott and Muir, this volume). The volume of early cages was ~3500 m^3. The company involved purchased two cages and installed the first in a very exposed site. However, problems were encountered during trials with cages empty of fish, including:

(i) Problems in hanging the net, and great difficulties in changing it.

(ii) Boarding the cage in any heavy sea was also hazardous.

(iii) Any driftwood could cause problems with net integrity; because of the configuration of the cage, with net panels exposed at the surface, there were incidences when driftwood penetrated the upper net region when the cage was in the semi-submerged (ballasted) position.

There were eventually structural problems with some of the welding on the cages' main pontoons, which were repaired by Farmocean, but the break up of one of the cages lead to loss of confidence in its use at that site. With one cage broken up, the other was withdrawn from the trial and taken ashore. These cages may well have been resistant at another less exposed site. Ten 16-metre Bridgestone cages were eventually used in this site.

Bradan Feasa – Aran Islands

This was a barge-type vessel fabricated in Bergen and essentially held 16 cage units of 15 x 15 m within it. A single unit resembling an oil tanker but without a bottom hull, it was fully fitted out with accommodation modules, food stores and power generation. The concept of central food distribution is now quite common, but from barges which are separate from the cages, thus avoiding the problems with net scaling of the fish and damage to the net structures from the hull of the barge. The site of the operation was a totally open sea site and subject to very heavy swell at particular points of the wind.

The vessel/cage was very difficult to operate. Part of the problem may very well have been that it was moored fore and aft which meant that the seas would break across the vessel at times and wash fish out through the top nets. If the structure had been on a free mooring this may have been avoided.

This system was on trial for 3 years in Ireland and was sold to a project in France. It is reported to have broken up.

Large plastic circles

With the success of the smaller plastic cages, various companies started to construct larger circles. Going to 70 metres in circumference was a challenge. It meant several things:

(i) Putting in stronger flotation rings – basically using larger diameter pipe.

(ii) Devising some arrangement that would allow the handrails to maintain some vertical integrity without making the walkway and handrail pipe circles too stiff.

To date, these cages are reasonably successful in moderately exposed sites using a variety of handrails from plastic to steel. However, they have not really been tested alongside the exposure that the Bridgestone/Dunlop cage can withstand.

Dunlop hexagons and squares

With the success of the Bridgestone cage, several other manufacturers commenced manufacture of offshore rubber-based cages. Amongst those were Fishtechnik and Dunlop Aquaculture. It was basically felt that those who made hoses for the oil industry could put corners on them thus creating the essential elements of a high seas cage. Bridgestone patented the use of hose in making fish cages and patented their corners. This did not eventually stop companies like Dunlop producing a rival product. Dunlop was open to feedback from farmers on potential modifications and improvements and incorporated these fairly rapidly. They also developed a square cage configuration, allowing complete modules to be constructed, saving on the use of floats and on mooring systems. Bridgestone were initially very conservative and reluctant to take on any suggestions of modifications either to cages, mooring fixtures or net configuration. For example, they held the view for several years that 20 t concrete blocks were the only method for anchoring the cages; only after demonstrations using plough anchors such as Seaboard, did they agree to make such changes.

Dunlop began trials with a cage in Scotland in 1988 with 29-30 m diameter cages, about the same size as a 10-metre hexagonal Bridgestone. The Northern Salmon Company in County Armagh used one of the first Dunlop cages in Ireland. It continues to use these cages, as do several other companies in Ireland. The Salmara company developed, with Dunlop, the use of square 15 m cages and these have worked well in various locations.

What became clear with the development of offshore cages was that farmers in Ireland had to modify many cage functions to make them more suitable for Irish offshore conditions. For example, anchors were used to moor Bridgestone cages instead of concrete blocks. In one case, the structure was redesigned to hold up the bird net which was accepted by Bridgestone. The Bridgestone corner floats were also redesigned; these are now in common use. They were originally made of Styrofoam and wrapped in PVC sheet. These were changed to a specially designed polyethylene float. The nets were totally redesigned. It was also demonstrated that Bridgestone cages could be towed with fish in them over several miles without any losses. This was also carried out by some Tuna operators in Australia who tow the cages over hundreds of miles with live tuna.

The offshore scenario

Advantages of offshore aquaculture

In practical terms, offshore operation means using sites where wave heights can be from 5 to 7 metres, with 1-3 knot currents. Depending on location, there may also be refraction of waves from headlands which can give a confused sea state and short wavelengths. Before deciding on the type of offshore cages and equipment the farmer should use a wave study prediction model for the site intended. This is now generally done in most cage sites in Ireland.

Site availability

In the mid eighties when the salmon industry in Ireland was undergoing rapid change, it became very evident that there would be a shortage of sites for any serious expansion of the industry. This left the only option to go further offshore which, in itself, was pioneering in terms of technology and management of such operations. There was little hard data on the cost benefit of such a move and indeed the quality of the fish that could be reared at such sites. Many other factors also influenced the decision to go offshore such as:

Better water exchange

There was no doubt that water exchange would be better than in near shore sites. Ireland was to the forefront of environmental monitoring and had carried out environmental impact assessments since the early eighties. Many of the very inshore sites that were used in the early development of the industry were giving problems and benthic accumulations were becoming evident. These inshore sites would have had poor water exchanges with bottom currents lower than 10 cm/sec. This was not desirable from a stock or site health point of view.

Less user conflicts

During that period there was also a concerted effort by some local residents of the coastal area to object to the development of cage farming. This was complicated by the attempt by the Government to introduce a rod licence for angling in areas where there was no charge traditionally for angling. This lead to a major move by angling associations objecting to fish farming in an effort to remove any proposals for rod licences. In assembling their case, the anglers harnessed all persons, who for one reason or another did not want to see cage-farming in progress. Many objectors were those with holiday homes and retired individuals who had plenty of time and influence to orchestrate objections. These fears included worries about escapees and genetic pollution, and more recently the possible association of cage farming with declining sea trout populations in certain areas. All these factors motivated the industry to go further offshore, where it was thought that many of the traditional objections would not be levelled.

Maintenance

There was uncertainty about maintenance in the offshore cage situation. In hindsight, to date, maintenance has been of a larger nature and carried out at specific times, rather than the small and continuous maintenance in the inshore cage scenario. Given that the cages were larger, the anchors larger, all gear and equipment had to be more robust to start with. It followed that to service such gear and equipment, better boats and equipment were necessary. Moorings were hauled and replaced every two-three years. Maintenance on shore was then carried out and the mooring re-laid in a sequence.

Increased tonnages

The industry assumed that increased biomass per cubic metre would be possible in offshore locations. However, it has kept more or less the same, though there was generally better water exchange. Though cost per m^3 of cage could be cheaper than inshore cages, overall capital costs were dramatically higher and the boats and equipment were considerably more expensive to operate on exposed sites. However, EU funding has helped offshore farms in the eighties and early nineties.

Better quality fish

It was postulated that the quality of the salmon from offshore cages would be dramatically better because of the space and deeper nets for the fish. Though there was no clear-cut evidence for this, fish reared in offshore locations could be received in a better light and the offshore location message could be used as a proactive marketing tool.

Disadvantages

Higher capital costs

The higher capital costs are a major factor in the ability of a company to develop an offshore site. A Bridgestone cage of 16 m octagon with 20 m net will cost $215,000, giving a cost of $8.63/m^3 or $172.00/m^2. In cost per volume this is relatively competitive but the initial high investment cost can be a problem. However, Joyce (1988), using typical Irish salmon production scenarios demonstrated that overall financial benefits for offshore systems could exceed those for conventional systems over a longer time period.

Larger service costs

The services cost for larger cages and offshore sites are considerably increased over those for smaller cage types. Key factors include:

(i) Larger service vessels.

(ii) A larger shore base, with access deeper water jetty to accommodate such larger service vessels.

(iii) Larger net washing facilities to deal with larger nets, increasing from those able to take 500 m^2 of net. The weight of these machines themselves has increased from 900 kg to 2.5 t.

(iv) Larger winch capacities to take nets ashore and afloat.

(v) The need to be able to transport large quantities of fish.

Essentially, everything had to be scaled up to deal with the movement to offshore farming.

More trained personnel

Personnel generally have to be more skilled in offshore seamanship because of the higher risks and dangers that can present themselves in an exposed site:

(i) Some personnel get seasick which is a factor in some offshore locations.

(ii) Skills for boat operation have to be at a much higher level and require certification in some cases.

(iii) General seamanship has to be at a higher level for net changing, fish dosing and general cage operation, deployment and harvesting, especially in poor weather.

(iv) In early days of offshore farming, there were accidents due to inexperience, e.g., Broken limbs, etc.

Current challenges

Different equipment for net changing

One of the major operations involved in dealing with large cages is the problem of net changing. Many operations try to put in smolts and keep the same net until the harvest up to 15-18 months later, or leave the nets in for 12 months if cages are used offshore for the spring to autumn period and are fallowed in winter. This is hazardous as fouling causes severe problems with a net in hot summers even if it is anti-fouled, as significant loss of oxygen can arise. This can mean that a net may have to be changed once and maybe twice in the period of April to September/October. Nets become very heavy and unwieldy when fouled, apart from the obvious lack of water exchange and can result in an increase of ectoparasites such as sea lice. Dosing cages that are fouled is a dangerous task and loss of fish can result from an inexperienced farmer attempting this. Any condition such as dirty nets that cause fish stress because of low water exchange is undesirable.

In dealing with such nets, a farm will have to have or be able to hire a boat that can handle nets of up to 5 to 6 t in when fouled. In Ireland, for example, on board cranes with a capacity up to 1 t at 16 m were in use.

All previous work experience is now on a large scale

Everything the smaller farmer used to do is now done on a large scale for offshore farming:

(i) Feeding fish can be done by hand but is slow and efficient. This is normally carried out using an air or water-based feed cannon. Daily feed quantities are significantly greater (see next).

(ii) Net changing – as already mentioned.

(iii) Setting and adjusting moorings becomes a large job (see later).

(iv) Maintenance and diving, the latter at depths which offer small working times at the bottom of the 20-m net. Work can be up to 30-35 m deep and is not the same as bounce diving in small cages. Thus full diving safety procedures have to be observed.

(v) Vessels and their operation.

(vi) Harvesting.

(vii) Smolt input.

Different mooring problems

Mooring a large group of Bridgestone cages is very different to a smaller group of plastic cages or a group of 15 m steel cages. The job requires using up to 750-kg plough anchors if the sediment is suitable. The industry uses a 2-inch stud link ground chain with up to 50-mm-braided rope. If concrete blocks were in use these could require up to 10 t units, but it is generally felt that anchors are as good as blocks and easier to lay and move on most suitable bottom types.

Feeding issues

Significant amounts of feed are needed in these large cages. A cage with 300-400 t of salmon could require around 3 t per day. For 10 cages, 30 t of food per day has to be fed automatically. The use of feed cannons is more common in Ireland at present. Akva type feeders are in use in more sheltered locations, and in Scotland barge feeders are being used in partially exposed locations.

Stock assessment and mortality checks

The problem of correctly assessing fish stock has not been overcome. It is also important to obtain sample weights to assess correct feed input for the size of fish at the temperature concerned. However, it is very difficult to get accurate random samples from such large cages. Samples tend to be taken when fish are feeding. However, this is not always a true reflection of the population as larger fish can be first up to feed if the population is mixed in size. The new computer based feed monitoring systems used in tandem with feeding barges would be very useful in the offshore cage scenario. However, determining mortality rates in larger cages can also be a problem if these are in significant numbers. An easy mort sock yet to be devised for operation with large cages. Small mortalities are probably insignificant to the large population but in the early Bridgestone operations there were many problems with stock inventory, with cages known to be short of stock by up to 30% without any known explanation. Some of the factors involved were:

(i) Corrections in the overage supplied by the hatchery. Overage is where an agreed % is supplied by the hatchery when delivering smolts to make up for counting errors (could be + 5%).

(ii) Small net tears.

(iii) Loss of fish through the top net in violent storms.

(iv) Inadequate bird nets.

(v) Seal attacks.

(vi) Minor thefts.

Video monitoring is now becoming more prevalent in assessment. Simrad have developed a unit to monitor progress of the fish and assess biomass. Aquasmart have developed a system to assess pellet wastage under the net so that feeding can be computer adjusted to the needs of the fish. They have now joined with an automatic feeder supplier in providing a more complete feeding and monitoring solution. This has still to be tested in very exposed conditions but is a positive step.

Insurance

It was a new experience in Europe to insure Bridgestone cages. While underwriting continues to be a higher rate compared to inshore cages, this is related to times when fish are at risk during a storm of several days where a small net tear can cause a lot of damage. Risk may also be increased as cage servicing may be prevented because of the weather. Equipment risk for cages such as the Bridgestone are less costly than for plastics and steels. However stock insurance would be more expensive. Service boats have also improved and this helps access. In summary, equipment insurance appears to be less expensive and stock insurance is more expensive. The latter is related to the risk history and with the fact that there is a larger amount of stock in one net.

Disease and other treatments

Treatment of fish can be trickier in large cages. This particularly so when all the population may not be suffering from a malady at the same time or to the same extent. To get a particular antibiotic dose into all the fish can require vigilance. It is important to make sure that all the fish are getting the treatment and not just the dominant fish. Treatment for such large cages is of course expensive, and bath treatments, e.g., against sea lice are much more difficult. This is usually carried out with a 1-2 m deep collar, at slack tide where possible. For Nuvan (organophosphorus) treatments the net was hauled up to half way, then Nuvan applied in solution using a portable pump for the required treatment time. This was a precarious operation at the best of times. An infeed treatment for sea lice would be greatly advantageous.

Dangers for staff-safety

The issue of safety working large cages needs much more attention than the operation of smaller cages. As mentioned before, the skills and training required are different from those in inshore locations. The seamanship required to be a good offshore operator is high and becomes a factor when operating feeding and managing the cages in poor weather. Weather and access to cages is a major factor when assessing offshore potential of any site, and down time on feeding will be a major deciding factor in the viability. On poor sites one can loose a months feeding over the winter months especially in a bad winter, which is a significant in loss of weight gain. Offshore feeding stations may alleviate this, but they are still in the development stage.

Key modifications for Irish cage systems

Most of the experience in Ireland has been with off-the-shelf supply in offshore Bridgestone cages. However, these and other systems have had to be modified to meet local conditions, and to improve their general functionality.

Change of Bridgestone design

The original design for mooring Bridgestones was that as devised in Japan. No variations were allowed in the early days because Bridgestone contended that it would invalidate the warranty of the cages if the anchoring arrangements were changed. They now accept that it is possible to use mooring anchors instead of blocks.

Net hanging – Corner weights

Because of tidal and wind conditions, net weights in many cases had to be changed to carry 25-50 kg on the corners. This was the only way the integrity of the net could be kept, in currents of up to 1 knot and more. This also meant that the net itself, especially the downropes, had to be altered and strengthened to take this weight.

Net types

The history of the evolution of the net types and net twine weights used is an interesting example of adaptation to the environment needed to grow fish safely. This took a lot of work and indeed pressure on Bridgestone to agree to alter the specification of the net for Ireland. Much of the needed alteration was discussed at a meeting of the "Bridgestone Users Group" set up to effect change in net design and specification. The situation regarding the Bridgestone nets (see Table 2) was as follows:

(i) Nets originally supplied in 1984 were of 25 size mesh and twine strength of 210/24. This was tested for one season and discovered to be too light for the exposed conditions, suffering net tears. Its use was essentially discontinued.

(ii) The industry then progressed to 210/48 followed by 210/60.

(iii) Commonly by 1990 they were using 210/90. In addition larger mesh sizes were used, especially for larger fish in winter conditions.

(iv) The common practice is now for 210/72 for smolts and for growers.

Table 2. Evolution of twine specifications

Year	Strength of twine
1985	210/20
1986	210/30
1990	210/48
1992	210/90
1996	210/300

In summary, the alterations that had to be carried out over those years were to redesign the corners, the number of down ropes, the location of the down ropes, the size of rope on the down rope, the strengthening of the bottom panels, the inclusion of safety stitching on certain seams.

Bird nets

Birds are a major cause of fish mortality, especially in the early days of smolt introduction. Much difficulty was encountered with the standard Bridgestone bird nets and new arrangements had to be incorporated to deal with the problem.

Net changing

Crane size

Crane size had had to increase dramatically from small size of 1 ton at 2-3 meters to 1 ton at 16 meters. This is designed so that the crane can at least go someway to the centre of large nets to pick up the centre, thus allowing the fish to spill out of the old net into the newly attached net.

Weight and washing

The weight of nets has created heavy lifting operations, often in difficult seas. This has huge safety implications and has to be dealt with on this basis. A 10 m deep dry net from a 16 m hexagon Bridgestone would weigh ~1 t. When heavily fouled it could weigh approx. 4 t. These factors make the washing and handling of nets a complicated issue. Indeed the material that comes off the nets on washing has to be dealt with carefully. It can cause smells if left on the shore and if the washing is carried out on shore, a discharge licence may be required in UK and Ireland. Such a licence is not required in the UK if the net is washed at sea.

Turmec Engineering, being in contact with farmers and realizing that the Bridgestone market was developing, could see the problems in washing nets on the ground, with high pressure hoses. The traditional way of hanging nets off poles was also difficult. They therefore designed and tested the "Bridgestone Net Washing Machine", a very large and much strengthened version of the traditional net washer.

The logistics of antifouling nets and drying nets has also to be considered. To treat a 10 m deep x 16 m hexagon net for a Bridgestone takes 600 litres of antifouling. This also takes 310 days to dry sufficiently to handle properly.

Grading, harvesting and starvation

Grading fish also proves to be very difficult, as smaller cages are required for smaller grades or for storing harvest fish on starve. These also have to be robust enough for offshore use. One of the difficulties with offshore cages is that all the fish have to be put on starve even to allow a portion of the cage to be harvested. The only other alternative is to remove a portion of stock into a harvesting cage if a suitably strong unit can be set up. Significant growth could be lost, if harvesting was delayed due to bad weather, which coupled with normal starvation periods could reduce weight gain.

Service vessels

The size and specification of the service vessels had to be upgraded as more cages came into use. Such aspects as strengthening decks to carry large quantities of food and harvested fish were essential. Crane capacity was also critical for many operations such as laying moorings, net changing and harvesting. Some companies hired vessels for critical tasks but there can be problems with availability of suitable vessels locally. Critically, in poor weather, access to the cages in safety was impossible without a good vessel

Site security

The issue of security of cages has always to be considered. Radar surveillance is generally necessary. There were no obvious and reported thefts from large cages in Ireland, but in certain cases it was important to have surveillance in case of malicious damage attempts.

Navigation

Offshore sites have to be marked according to International navigation rules. This usually involves marking out the site with lighted navigational markers as well as having radar reflectors on each cage. Cages such as Farmocean have a large Radar echo and from that point of view were easily visible at night and during the day. There were no major accidents but in one instance a trawler towing a pelagic trawl went through the middle of a group of 10 Bridgestones. The only damage was to a cage handrail and some damage to the trawl net. If cages are located many problems can be avoided.

Conclusions and future trends

Production from offshore cages in Ireland amounts to about 50% of the current level of salmonid production, that is more than 7000 t. In general, the quality of the product from these cages is excellent, but problems do have to be overcome. Some of these problems, such as losing feeding time in the winter because of bad weather or poor boat facilities, continue to affect production costs and efficiency. On the positive side the environmental problems associated with offshore cages are very much diminished because of the higher water exchange and better flushing. This is of course assisted by storm action, which tends to keep the benthos in a relatively healthy state. In addition, one company in Clare Island, Co. Mayo is producing an "organic salmon" product because of open sea sites, in which they claim not to have to treat for diseases. The product, "Natura Salmon" commands a higher price.

Development from this stage will be towards more automation and perhaps to even more offshore sites. Several things may happen. Though development may occur slowly, more remote sites will be opened up but this will require platforms that are more or less self sufficient. Feeding and staff accommodation modules will be required, or the farm will be controlled from a shore base by telemetry, where feeding and routine operations are monitored with minimal human presence. An interactive platform and farm might then be developed, somewhat like the Marino 21 project in Japan, in which a tension leg platform forms the centre command unit attached to and feeding a service unit and cages. All onboard services will be at the base platform. The next step may be to include a processing plant. However, the costs of remote control and processing ashore may well be more economical and indeed more socially acceptable than having all activities at sea.

The cost of production will be a major determining factor in how the industry will develop offshore. The other alternative is to have submersible cage units with only the feed barge at the surface. Several groups world-wide have been experimenting with submersible cages. While trials have taken place with Trident cages in Canada, Ocean Spar in Washington, Tension Leg in Sicily and SADCO (Russia) to mention just a few, no major developments have so far occurred with submersible cages, and most are still in the developmental/early commercial stage. Further development in Ireland may take place with a concept using a Spar Buoy Service Module together with existing offshore cages such as Dunlop and Bridgestone systems. The use of Ocean Spar systems is also being actively discussed, with plans for installing a large system in the W of Ireland. Clearly, Ireland's offshore cage culture sector will continue to push the technical and managerial boundaries.

References

Beveridge, M.C.M.B. (1996). *Cage Aquaculture,* 2nd edn. Fishing News Books, Oxford, ISBN 0-85238-235-9, p. 346.

Joyce, J. (1988). Meeting the Atlantic challenge: How Ireland leads the world in offshore technology. *Aquaculture Ireland,* May/June 1988: 4-8.

Wilkins, N.P. (1989). *Ponds, Passes and Parcs: Aquaculture in Victorian Ireland.* Glendale Press, Dublin, p. 352.