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Offshore cage systems – A practical overview

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SUMMARY – A range of cage systems is now potentially available for offshore mariculture in the Mediterranean, though not all of these may prove to be effective in the intended environmental conditions and production regimes. The cost of installation and operation is also very critical. This paper provides an overview of the systems which are currently available, and based in particular on the authors' experience in developing and operating offshore projects, describes the relative advantages and disadvantages of each system. Finally, it provides a brief commentary on some of the critical design and operational factors which need to be addressed in the current generation of cage systems, to improve their effectiveness in the increasingly demanding production conditions of the marine aquaculture sector.

Key words: Cage culture, mariculture, offshore, cage design.

RESUME – *"Systèmes de cages en offshore : Révision pratique". Une gamme de systèmes de cages flottantes est maintenant disponible pour le secteur de la mariculture "offshore" de la région méditerranéenne, mais tous ne se révéleront peut-être pas performants pour les conditions environnementales et les régimes de production anticipés. Le coût d'installation et de gestion est aussi très important. Ce papier présente un sommaire des systèmes qui sont actuellement disponibles, et basé en particulier sur l'expérience des auteurs concernant le développement et la mise en opération de projets "offshore", donne une description des avantages et désavantages de chaque système. Finalement, il apporte un bref commentaire sur quelques facteurs importants de conception et d'opération qui doivent être considérés dans ces systèmes, pour améliorer leur effectivité dans les conditions de production de plus en plus exigeantes qui existent dans le secteur maricole.*

Mots-clés : *Aquaculture en cages, mariculture, offshore, conception des cages.*

Introduction

Cage farming has been practiced at an artisanal level for hundreds of years, originally in freshwater and later in seawater (Beveridge, 1996). However, the development of modern cage systems has only taken place over the past 20-30 years, primarily in line with the development of the salmon farming industry. Such cages were originally designed for sheltered sites in inshore waters, and were constructed initially from wood/polystyrene, poles/buoys, and later from steel and plastic. The current "state of the art" in salmon farming is the large plastic circle cage of 100 m or more in circumference (e.g., the PolarCirkel), giving culture volumes of 10-20,000 m^3 and a capital cost of less than £5/m^3 for an installed cage complete with net and moorings. Such cages are being used in increasingly exposed environments, although are not generally classified as "offshore" cages.

In the last 10-15 years the development of offshore cages has run approximately in parallel with that of inshore cages, and a variety of designs have been tried and tested, though only recently reaching the point of more widespread application. Such designs have originated from a variety of sources, including dedicated research teams, existing cage manufacturers, net manufacturers, naval architects, ship builders, and offshore oil hose manufacturers. Not many have involved specific inputs from fish farmers, and as a result the cage types on offer are generally expensive and may suffer from deficiencies of one kind or another when it comes to holding and managing fish stocks.

Either directly through its own projects, or in association with the commercial production wing of the Institute of Aquaculture, Stirling Aquaculture have first hand experience of operating two types of offshore cage both for salmon and for sea bream and sea bass, notably the Farmocean 3500 and the Dunlop Tempest 2. Through the Institute, Farmocean cages have been used for over 7 years for commercial salmon production in Scotland, and by Stirling Aquaculture for the past 3 years for the farming of 100 t p.a. of sea bream in Madeira, Portugal. Our knowledge of the Dunlop cages comes from having installed a 500 t p.a. offshore farm for bream and bass in Malta (Malta Mariculture Ltd, MML) and managed it for the past 5 years. Most recently, experience of Farmocean, Bridgestone and Dunlop systems in fully offshore conditions has been extended through assisting in the redevelopment of a large offshore cage system at Pachino, SE Sicily[1].

Following a background summary of approaches to offshore cage design, this section describes the different types of offshore farming system presently on offer, their origin and evolution, and their advantages and disadvantages, including comparative costs (see also Lisac and Muir, this volume). It also indicates the current scale of use, and potential for further application.

General approaches to offshore cage design

As with inshore cages, the variety of cage designs has arisen out of attempts to deal with a number of (at times conflicting) design objectives (see also Muir, this volume):

(i) Providing a reasonably stable cage shape, to avoid stressing the stock, and to provide a stable working environment.

(ii) Providing adequate water exchange to satisfy metabolic requirements of stock and remove wastes from the cage area.

(iii) Absorbing or deflecting environmental forces, to maintain the structural soundness of the system.

(iv) Providing an efficient working environment, for routine husbandry, and where equipment and materials (harvested fish, feed, tanks and bins, etc.) can be handled if necessary.

(v) Maintaining position, to provide a secure location, free from navigation hazards, etc.

(vi) Keeping capital and operating costs as low as possible.

A cage system behaves dynamically – forces affecting the cage frame are transferred to the net, to other cage frames and to the mooring system, and the corresponding motion is also transferred. This will affect both the durability of the system, and the acceptability of the system to the stock. Cage elements tend to be designed either as flexible or as rigid structures: cage systems are usually a combination of these. Physically, two major design levels must be considered: (i) the normal, routine and recurrent forces and their effects, typically involving routine wear, fatigue, etc.; and (ii) the unusual, peak or shock forces or loads and their effects, typically breaking loads, etc.

Though a range of classifications can be considered (see e.g., Loverich *et al.,* 1996), the variety of offshore systems currently on offer can most simply be categorized according to the nature of the structure used to support the holding net, as follows (Table 1). This divides the designs into three major operational categories – floating, semisubmersible and submersible, and two mechanical types, flexible and rigid.

Table 1. Offshore cage types

Structure type	Examples
Floating flexible	Dunlop, Bridgestone, Ocean Spar Net Pen, plastic circle types (Corelsa, Aqualine, etc.) Aquasystem
Floating rigid	Pisbarca, Cruive
Semi-submersible flexible	Refa
Semi-submersible rigid	Farmocean, Ocean Spar Sea Station
Submersible rigid	Sadco, Trident, Marine Industries, Sea Trek

[1]The assistance of Bart Vlaminck, Senior Project Officer, Stirling Aquaculture/Production Manager Acqua Azzurra spl, and the support of Dr Zarco Peric, General Manager, Acqua Azzurra spl is gratefully acknowledged.

These cage types are described in more detail in the following outlines, which summarize system characteristics, typical applications, approximate costs – based on £/m^3, and essential advantages and disadvantages.

Floating cages

Floating flexible cages

Rubber hose cages – e.g., Dunlop/Bridgestone

These types utilize rubber hoses originally designed for transferring oil between oil tankers and onshore terminals. The primary commercial systems are those produced by Bridgestone and Dunlop. Table 2 outlines the advantages and disadvantages of these systems.

Table 2. Advantages and disadvantages of rubber hose cages

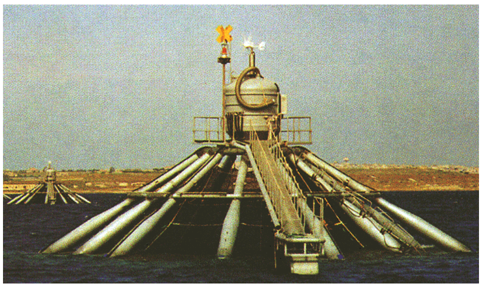
Advantages	Disadvantages
- Highly resilient to wave forces with long service life (>10 years); relatively good impact resistance - Effective and proven net hanging system - Variety of configurations possible - Relatively cheap at higher volumes - Most widely used commercial offshore system	- Stanchions may cause problems – twisting, turning - Relatively expensive at lower volumes - Limited walkway access - Top net and feed systems difficult to place - Large service vessels necessary

The Bridgestone cage was developed in Japan and utilized originally for holding tuna (Gunnarsson, 1988). It is now in widespread use around the world, and is claimed to be the most widely used offshore system, with over 300 units in operation. The cage comes in a variety of configurations using standard hose lengths of 16 or 20 m arranged in squares, hexagons or octagons. The hoses are linked by rigid steel corner joints which also carry additional buoyancy units and access to the hose inflation points. Cage stanchions are simply clamped to the rubber hose at appropriate intervals. Very large cage volumes are possible, and the largest cage so far built is thought to be a Bridgestone in Ireland used for salmon, with a circumference of 160 m and depth of over 20 m (over 40,000 m^3). In the Mediterranean, Bridgestones are in use in Corsica, Cyprus, Italy, and Spain for tuna, sea bass and sea bream. In Ireland and the Faroes, Bridgestones are very popular for salmon farming.

The cage collar is essentially utilized to maintain the shape of the net, and is not designed for working operations, which are all carried out from rafts or boats. The most important feature of the cage is the interface between the collar and the net, as this is where most of the stress is transferred between the two. This is achieved through the use of a float line attached to a section of heavy duty trawl net which joins the main cage net 1-2 m below the waterline, and which carries the weight of the net and acts as a shock absorber. Due to the large holding volumes possible, capital costs per m^3 can be very low, e.g., 16 m octagonal cage of 20 m depth (25,000 m^3) = £5-6/m^3.

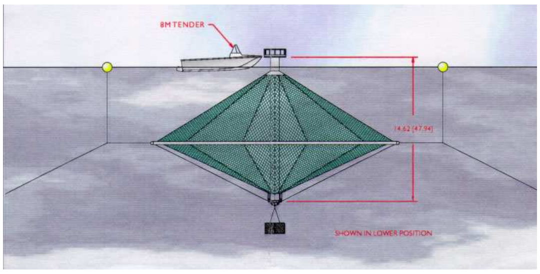
Dunlop cages share broadly the same features of the Bridgestone (Brittain, 1996), although are more commonly found in a square formation linked together in rafts of 4 to 8 cages, especially in the Mediterranean, e.g., the Dunlop Tempest 2. The Tempest 2 (Fig. 1) differs from the Bridgestone in that it carries short walkway sections mounted above the corner joints which facilitate hand feeding and observation. Dunlop also make a large twin hose cage, the Tempest 1, which is available up to 120 m circumference. They also supply a 20 m octagonal single hose cage with 160 m circumference. The Dunlop Tempest 2 is used in Corsica, Italy, Malta and Cyprus typically in 16 m x 16 m square cage format with 2400 m^3 volume, more suitable for bass and bream. However, costs of such smaller systems are relatively high due to the limited volumes enclosed, coming to around £25/m^3 installed for a raft of 6 cages 16 m x 16 m x 10 m deep moored in 40 m of water (e.g., MML).

Tempest 2 fish cage from
Dunlop Aquaculture

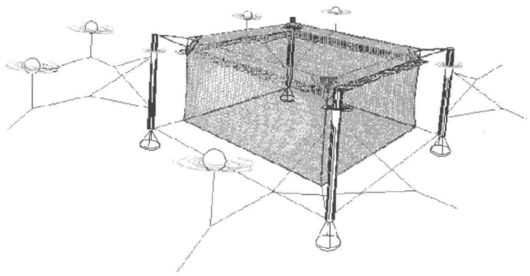


Semi-submersible off-shore system from
Farmocean International AB

Fish farm platform from Marina System Iberica



Sea station from Ocean Spar Technologies, LLC



Sea cage system from
Ocean Spar Technologies, LLC

Refa
tension leg
cage

Cruive off-shore fish farm from
Campbeltown Developments Ltd.

Fig. 1. Different offshore systems.

Hybrid oil hose cages, utilizing second hand hoses, are also in use and are considerably cheaper, but second hand hoses may be difficult to find, and these need to be properly tested, with tube walls and end fittings in good condition. One such farm using this system is P2M in Malta.

Ocean Spar net pen

This system has been developed by Ocean Spar Technologies (Fig. 1), an American firm originally specializing in fishing gear design and manufacture (Loverich and Goudey, 1996). The design is based on the cage net being held in shape by vertical spar buoys at each corner, which are in turn held apart through a tensioned mooring system. A variety of configurations is possible from squares through to polygons of 200 m circumference. In 1996, 5000 m^3 was reported as the largest size tested, but larger installations are being planned. Other Ocean Spar designs may also be used for larger volumes (see later). Cages have been installed in various locations in the USA, and systems and sub-components well tested in a number of locations and species usages. However, it has not been widely installed commercially. Table 3 summarizes comparative features.

Table 3. Comparative advantages of the Ocean Spar net pen system

Advantages	Disadvantages
- Retains 90% of net volume even in strong currents (up to 1.75 m/s)	- Relatively complex mooring system
- Low surface visual impact	- Net changing less straightforward than in bag systems
- Good predation resistance due to taut nets	- Relatively few systems tested commercially
- Relatively simple design	- No walkway access
- Potentially cost effective, especially in larger sizes	- Feeder cannot be installed
- Top net can be attached	- Needs larger service vessels
- Variety of configurations possible, theoretically up to 60,000 m^3	

Floating rigid cages

Floating rigid cages take a quite different design route from that used for floating flexible cages. Rather than attempting to be wave compliant, these aim to be robust enough structurally to withstand wave action, and are generally of large, massive structure, normally of steel construction, with varying degrees of ballasting, sometimes with mass concrete. In addition, most types also attempt to build in a variety of features to facilitate management of the fish, such as feeding systems, harvest cranes, fuel stores and power generation, staff quarters, etc. Some systems are also self-propelling. As a result they are typically the most expensive type of offshore system, although this extra cost has to be weighed up against the additional facilities that would also have to be provided for a floating flexible system. The uptake of such systems commercially has been limited, and some systems have suffered from structural or net failure. Confidence in such systems, whether for technical or economic performance, can therefore be rather uncertain. Examples of such systems are as follows. Table 4 also summarizes comparative advantages of these systems.

Aquasystem 104

A Norwegian design, this ship-like structure 126 m long by 32 m wide was designed to support 12 cage enclosures of 2000 m^3 each and had a claimed production potential of 500 t. At an estimated capital cost of £2.5 million, installed cost would be over £100/m^3. The design would however provide full supporting infrastructure including feeding systems. This cage was first installed in Ireland, but in extreme weather conditions problems were encountered with net failure and the company responsible closed down. The cage was later transferred to Spain.

Table 4. Comparative advantages of floating rigid cages

Advantages	Disadvantages
- Stable working platform for all husbandry and management operations - Potential for integral feeding and harvesting systems; may be used to service other cages - Ship mortgages may be available - Potentially improved operator safety and efficiency - Construction and repair facilities may be developed from conventional shipyards	- Large and heavy structures require good port facilities and/or expensive towing to install - May be susceptible to structural failure in extreme conditions - Large mass may require heavier mooring systems - Relatively high capital cost; steel structures require protection/maintenance - Limited commercial track record

Pisbarca

Built by a Spanish company, Marina System Iberica (Fig. 1), this is a hexagonal steel structure with 7 cages giving a total volume of 10,000 m^3 and a production capacity of around 200 t p.a. It is designed around a hexagonal-plan individual modules, with vertical cylindrical flotation columns and a steel frame deck, on which can be housed various superstructure elements, including lifting gear, stores, accommodation units. The cost is understood to have been around £1.5 million (£150/m^3), but again full support facilities are available, though in some cases, these deck-mounted units have been damaged and subsequently removed. The system has continued to operate, but is commonly extended by surrounding the central system with simpler and lighter cages, with the aim of using the main platform as the service unit for the complete system.

Cruive

The Cruive cage (Fig. 1) has been more recently developed by the Lithgow group in Scotland, shipbuilders and salmon farmers. The system therefore has the potential benefit of both construction and farming knowledge in the design. The standard structure is 45 m x 45 m and offers 4 cages of 20 m x 20 m by 20-25 m deep, with a total volume of 32-40,000 m^3. The structure can be equipped with feed stores, cranes, net handling equipment, etc. Cost per volume is comparatively reasonable due to the large holding volumes. The basic steel structure without cranes, feed stores, etc., but with 20 m deep nets and moorings, costs around £16/m^3. As such this is probably the most economical of the rigid floating systems normally available. However, the system has not so far been tested outside of Scotland, and initial trials suggested that without further technical development, its potential management advantages may not be so clearcut in more exposed locations.

Semi-submersible cages

This group of cage designs can be characterized by their ability to be submerged for periods of time below the higher energy regimes of surface waters. As such they offer the potential advantages of being lighter and simpler structures, as if submerged appropriately during poor sea conditions, they would incur far less exposure and hence physical stress. The reduced movement could also potentially reduce possible damage to stocks, or motion stress. The overall consequence could be simpler, safer and less expensive production systems. However, the deployment of these systems in two modes, surface and sub-surface, and the need to control these effectively and at the right times, adds potential complexity and risk. As with floating systems, there are two structural classes, flexible and rigid, with similar design consequences.

Semi-submersible flexible cages

Refa

The Refa cage (Fig. 1) is a tension leg design in which a positive circular plastic positive buoyancy supporting frame, held below instead of above the net pen, is held in place by vertical mooring ropes.

These mooring ropes stem from concrete blocks on the sea bed which rise to the buoyancy ring, above which the net is kept in suspension by subsurface buoys. An upper conical section gives access from the surface via a traditional plastic cage collar. The cage is available in a variety of sizes up to 10,000 m^3. The design is simple and there are no metal structural components. The upper cone can be removed and the cage raised for harvesting and net changing, etc., utilizing a full size plastic collar brought temporarily to the site. In storms or strong currents, the cage responds automatically, the net being pulled under the water and thus escaping the worst effects. Table 5 summarizes comparative features (see also Lisac, this volume).

Table 5. Comparative advantages of the Refa tension leg cage

Advantages	Disadvantages
- Simple design – automatic response - Relatively cost effective - Small bottom area occupied by moorings - Combines features of conventional operation with storm protection - Volume reduction no greater than 25% in currents/storms	- Feeding should ideally be done subsurface, requiring separate feeding systems, due to limited area on surface - Moorings typically concrete blocks, more difficult to install than conventional anchors

Based on 1996 estimates, the cost for a unit of 4 x 6000 m^3 cages installed with nets would be around £10-14/m^3 (see also Lisac and Muir, this volume). The system has been tested in Norway and Sicily, and cages have also recently been installed in Taiwan.

Semi-submersible rigid cages

These systems are designed with rigid framework elements providing only limited movement or volume change in response to external loads. Normally with steel frame structures, these contain adjustable buoyancy elements to raise or lower the system. With a more rigid structure it may also possible to add service facilities such as feeders, potentially developing self-contained systems. Primary examples of these cage types include the Farmocean cage and the Ocean Spar Sea Station.

Farmocean

The Farmocean cage (Fig. 1) was developed as a result of research in Sweden into offshore farming systems, and the first cage was launched in 1986 (Henriksson, 1996). Over 40 systems have now been installed, mainly in Northern Europe and the Mediterranean. The design of the cage is based on the principle of locating the main volume of the cage well below the surface where it avoids the worst effects of storms. The main structure consists of a hexagonal, conical "umbrella" framework of six steel flotation tubes, connected to a top circular frame, above which is positioned a feeding system with 3 t storage capacity, and associated controls. At the bottom of the frame, the legs are connected to a lower pontoon ring. The feeding system module is connected a floating gangway which gives access to the feeding platform when the cage is submerged; this system is mounted on the top ring so that it rotates, allowing the floating gangway to position itself on the lee side of prevailing sea or current conditions. The net is attached to the inside of the framework; its shape is maintained with a steel sinker tube suspended from the main pontoon ring. Industrial zips are used to allow access inside the cage, and can be used to allow panels to be replaced.

The design is arranged so that the feeder and gangway in the upper part of the system remains above the surface at all times, but that the largest part of the cage's volume is submerged, and exposed surfaces in the upper water column are minimized. The steel umbrella frame can be deballasted by compressed air to bring the main structure, the lower pontoon ring, and the lower net to the surface, for cleaning, maintenance and stock handling. A walkway is mounted over the main pontoon ring to allow for easier access. Sacrificial anodes are attached to lower and upper legs to minimize corrosion. Volumes range from 2500 to 6000 m^3, with 3500 m^3 as the most popular size. Mooring is by means of a fixed 3 point system. Feeding is computer controlled and temperature linked, and allows for several days feeding if access is denied due to bad weather. A wave sensor can shut off the system if conditions become too bad. The cost of the system is relatively high, being over £50/m^3 for the 3500 m^3 cage. Table 6 summarizes key features.

Table 6. Comparative advantages of Farmocean cages

Advantages	Disadvantages
- Now tried and tested over 12 years in a variety of situations and in severe conditions - Proven long service life - Integrated feeding system - Stable holding volume - Good stock performance	- High capital cost - Poor access for harvesting - Difficult to change/clean nets - Limited surface area when submerged for surface feeding - Complex steel structure; needs corrosion protection, regular maintenance

Farmocean systems have now been in operation on some sites with a long record of structural integrity, though in very severe sea conditions, problems have occurred with the floating walkway, twisting of its connection with the top ring, and deformation of the top ring. A number of systems of 8-10 yr age have now been reconditioned and key structural elements appear to have lost little of their weight/potential strength.

Ocean Spar Sea Station

The Sea Station system has also been developed by Ocean Spar Technologies, as a result of their work on the net pen system (Loverich and Gaudey, 1996). In this double cone "flying saucer" formed design a single central steel tube vertical spar provides buoyancy and distributes loads to the net and the circular tubular rim via radiating framing lines. A further version of the design has two tubular rings, vertically separated, to increase the depth and volume of the system. Nets and framing lines use high specification polymer fibres which maximize strength while reducing sectional dimensions and system drag. The tubular steel rim maintains the net's shape and also has ballasting capabilities. This combination provides a very taut net and excellent stability characteristics even in severe weather. In currents of 1 m/s, over 90% of cage volume has been recorded as retained. In severe weather, the cage can be fully submerged by means of varying the buoyancy in the central spar, unlike the Farmocean, some of whose volume remains above surface. A small platform on top of the central spar allows for feeding, access and monitoring. Larger systems could potentially incorporate feeding storage and service controls, but these would have to be fully waterproofed were the system to retain its fully submersible options.

The system is moored at the central spar, allowing either for single point or fixed configurations. Due to the rigidity and stability of the structure, towing is straightforward. Harvesting is also said to be straightforward by means of inverting the bottom conical section of the net. The standard production model has a volume of 3000 m^3, although larger versions with 6-8000 m^3 are said to be planned. Estimated cost based on the 3000 m^3 units is relatively high at between £20 and 30/m^3 installed. Production systems have been tested in the N W Atlantic for flatfish, and a unit has been installed in Cyprus in 1998 (Gace, 1998, pers. comm.). Table 7 outlines the comparative features.

Table 7. Comparative features of the Ocean Spar Sea Station

Advantages	Disadvantages
- Simple format and structure - Semi or fully submersible - Minimal distortion in currents - Integral harvesting capabilities - Easily towed - Simple moorings	- Relatively high capital cost, for currently available volumes - Not yet widely proven in commercial practice; practical design may need to evolve - Efficient feeding and net changing may be difficult

Submersible rigid cages

For true oceanic farming of fish, where wave heights may be considerable, it is may be proposed that the only way to avoid the worst effects of severe surface conditions is by using fully submersible cages, whose normal operating conditions would be at a suitable depth below the more hazardous upper water column. The presence of ice in winter has also led developments in this direction. As required, the systems could be raised to the surface for necessary management functions. These systems could either be unattended by surface units, accessed only when needed, or attached by various systems to conventional vessels. Various designs have been proposed and some pilot scale or commercial systems built, including those by SADCO, Trident and Marine Industries. The Ocean Spar Sea Station, earlier described, could also be operated in this mode; the distinction between semi-submersible and submersible would here be defined primarily on whether surface or submerged modes respectively were the normal operating position. Table 8 summarizes the generic features of comparative advantage.

Table 8. Comparative advantages of submersible systems

Advantages	Disadvantages
- Submersible designs avoid surface debris and ice, and passing vessels - Minimal visual impact - Avoids fully the effects of storms - Structural strength does not need to be as great as a surface structure	- Lack of visibility in normal state - Methods of maintenance and servicing of cages whilst submerged are still in development - Costs relatively high - Relatively complex to operate

SADCO

The SADCO is a Russian design which has evolved since the early 1980s (Bugrov, 1996). Early models of ~100 m^3 in the Caspian and Black Seas (SADCO-100) had successfully withstood severe storms with 12 m waves. The current models (SADCO-500/1200/2000) is based on a ballasted upper steel hexagonal superstructure carrying the net which is kept in shape by a lower sinker tube. The frame also carries a feeder with volume of 1500l (SADCO 50), which can operate underwater. Volumes available are up to 2000 m^3. The cages have been installed in the Caspian, Black and Mediterranean seas, and a commercial unit is currently operating in the SW Italian mainland. The more recent designs are considered to be better built and more reliable, though problems have been noted in efficient feeding in submerged mode (de Gregorio, 1998, pers. comm.). A central-column design with a hexagonal outer ring (SADCO 2500), otherwise similar in concept to the Ocean Spar Sea Station had also been successfully tested at model scale.

Trident

The Trident cage was developed on the East coast of Canada to deal with the particular problems of icing in winter (Willinsky and Huguenin, 1996). The cage is fully submersible, and has a near-spherical (ellipsoid) geodesic format frame made from simple foam-filled tubular frame units of high tensile marine aluminium connected with specially designed structural ties. The net is attached directly to the frame. As with other geodesic structures, this offers structural simplicity, good strength/weight and an efficient volume. Very limited structural deformity under load ensures that the net within is kept taut at all times. The cage has variable buoyancy and in normal use can also be sited with the upper part at the surface, where rotation allows self cleaning of fouling organisms. At 66% vertical submergence, 81% of the volume is below the surface. Sizes available are 1000, 4000 and 5500 m^3, and it is proposed that the design could be scaled up to 10,000 m^3. A telemetry/feeder unit spar buoy system concept has also been developed to operate the systems remotely in open ocean conditions. Performance in test and initial commercial scale production has been claimed to be good, with excellent physical response and good control of fouling. Early problems of corrosion were overcome by selecting grade 6063T6 aluminium. One cage was reported to have withstood wind speeds of 80-120 km/h and breaking waves of >3.5 m, while 2/3 submerged, in conditions which destroyed nearby conventional systems. Structural simplicity suggests that provided materials costs are acceptable, basic system costs could be moderate.

Marine Industries and Investments

The MII cage system was developed in Israel in response to the severe conditions in the eastern Mediterranean (Ben-Efraim, 1996). Brought into pilot scale production at the end of 1993, and first stocked in 1995, it is essentially a submersible rigid steel conventional cage system but with rigid underwater frame to maintain net shape. Clusters of up to 8 cages in one unit are possible, with cage volumes of either 1700 or 3400 m^3. Such clusters can be secured to a simple single point mooring via a service buoy which controls submergence and feeding functions. The system was designed to function in conjunction with an offshore trawler which could provide all infrastructure needs, and could be operated either in semi-submersible or fully submersible modes.

Conclusions

Based on our practical experience, and on surveys of current systems, it can be concluded that none of the offshore cage designs currently on the market, including the Farmocean and Dunlop systems, are fully effective in meeting target objectives. Only a small number of systems has actually reached the stage of adequate proof of performance. Of these, the only extensively proven system capable of limited autonomous operation, the Farmocean, is expensive in terms of initial investment, though Scott *et al.* (1993) suggest that it may be competitive over longer periods of amortization. Though Bugrova (1996) suggests that semi-submersed and submersible cages may be more financially viable than floating systems, the overall performance of most of the systems has yet to be established. At present, most operations therefore tend to focus around the use of rubber hose or Farmocean cages for offshore conditions, while in most severe conditions, even these relatively well tried systems may require modification. This is consistent with our practical conclusion that the installation and operation of any of the current systems must be adapted to the local circumstances and resources of each farm business, requiring continuous innovation and development by the operators and managers. However, the current generation of semi-submersible or submersible designs, using new materials and systematically designed, may if scaled up and tested in practical conditions offer improved and competitive opportunities.

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