Introduction

In 1995, several issues arose which prompted the New England Fishery Management Council (NEFMC) to assess its ability to administer siting proposals for aquaculture and other similar projects in the Exclusive Economic Zone (EEZ). At the request of the Aquaculture Committee Chairman, I prepared a report for the Council entitled "Background Information and Recommendations for New England Fishery Management Council Development of an Aquaculture Policy and Management Strategy" (W.J. Brennan, Sept. 30, 1995).

This report addressed the following topics: the Council's legal authority, responsibilities, and management options related to aquaculture in the EEZ; the Council's relationship to various federal agencies involved with aquaculture; aspects of aquaculture management regulated in adjacent coastal states that may be applicable to the Council's regulatory mechanisms; the Council's role in allowing, prohibiting, or otherwise regulating aquaculture ventures in federal waters; and, criteria to evaluate individual projects.

As many of the federal and state agencies whose programs were covered in the report are participants in this Ocean Aquaculture Conference, I will limit my focus to the issues raised and recommendations made in this report.

I will start, however, with a brief overview of the Council's legal authority and its aquaculture policy to provide a context for my presentation. It is also important to bear in mind the following: first, that no single federal agency has been delegated or statutorily charged
The Act's broad definition of "fishing" encompasses the catching or taking of fish, the harvesting of fish, and any other activity or act incidental to the harvesting or fishing of fish. As harvesting implies the gathering of a crop and an aquaculture facility engages in the "harvesting" of fish from the EEZ, any aquaculture facility located in the EEZ is thus within the purview of the Act, and is subject to management plans developed by the regional councils. That construction is further supported by the Magnuson Fishery Conservation and Management Act (16 U.S.C. 1801 et seq.), which defines "harvest" as including "catching, taking, or harvesting fish . . . in the EEZ.

Any vessel, including a barge, used to support aquaculture activities and facilities is considered a fishing vessel under Magnuson and is subject to regulation beyond documentation and endorsement, at the discretion of a regional fishery management council. Accordingly, structures used to support and anchor net pens for fish aquaculture would also be considered fishing vessels under Magnuson's broad definition, which includes "other craft which is used for building or assisting . . . any activity relating to fishing, including . . . storage. . . ." (16 U.S.C. 1802(11)).

Management Options

The management options available to the NEFMC (prescribed in Sections 300(j), 303(a), and 304(b) of the Magnuson-Miller Act) are relatively limited. The Council can prepare a plan amendment to the proposed aquaculture resource that either exempts or permits activities that are otherwise prohibited, or the Council can prepare an amendment to prohibit the proposed aquaculture activities if it can demonstrate that the project would cause adverse impacts to the fishery resource in light of, or the fishery's management objectives for that species. A plan amendment would address certain obstacles such as minimum fish-size restrictions or other
operations on the use of certain gear types, etc., and thus grant specific exemptions and permissions to undertake the activities proposed by the developer. Each plan amendment, however, must adhere to all Magnuson requirements and, considering the administrative time frame and workload necessary, this approach is unreasonable given the likelihood that additional proposals will be forthcoming requiring subsequent project-specific amendments to the same plan.

A preferred alternative to the above project-specific approach would be an amendment that provides blanket permission or exemption from provisions of an EIP to accommodate aquaculture generally. Development of a framework mechanism would facilitate consideration of individual projects. The framework mechanism would establish the boundaries of project-specific special management zones where necessary and provide the Council with the ability to impose conditions on restrictions deemed necessary to meet the conservation objectives of the FMP in question. The framework mechanism would also provide the Council with the opportunity to receive the necessary public comments concerning the specific project under consideration. This approach would, over the long run, be more time-efficient than a project-specific amendment, particularly if a formalized "application" with parameters for project consideration is established as part of the framework mechanism.

It is not unreasonable to assume, particularly with advances in ocean and aquaculture technology, that projects will eventually be proposed for research or commercial scale aquaculture ventures involving all of the species currently under the New England Council's management. In fact, these are fisheries resources in the EEZ not currently under the Council's management that may be of concern to aquaculturists who have successfully conducted ventures involving these species in coastal waters. The burden on the Council, particularly if special management zones are established, is to determine not only the existing plan and existing new plans could be significant if not overwhelming. Given this scenario, the Council would be far better served by developing one overarching aquaculture FMP that would enable the Council to administer all forms of aquaculture that may be proposed for the EEZ waters.

An aquaculture FMP could greatly reduce the burden on the NEFMC to amend existing FMPs to accommodate projects for various species under its management. This approach would, in essence, "bundle" provisions for exemptions for aquaculture activities that are otherwise prohibited in all existing FMPs and enable the use of a framework mechanism to address individual projects as presented above. However, because of prohibitions inherent in Magnuson, this approach does not appear to be available and statutory amendment may be necessary for the following reasons.

The Act authorizes a council to prepare management plans for "fishing, ... that requires conservation and management" and defines a "fishery" as "one or more stocks of fish which can be treated as a unit for conservation and management" (Section 307(b)(1) and Section 308(1)). Although the "hearth" of fish and wildlife aquaculture is considered to be equivalent to fishing and subjects to council management actions, aquaculture per se is not a "fishery" as defined by Magnuson and, therefore, a council does not appear to have the authority to prepare an aquaculture FMP. Furthermore, as an FMP of this nature would be primarily processed by adults, it would not apply to prohibitions contained in the Magnuson Act.

Many aspects of aquaculture, such as engineering and design of gaging structures and mooring systems, the biological and chemical evaluations of waste discharge, and navigational issues associated with stakeout locations, are technical in nature and fall under the purview of several federal agencies. No entity has thus far been subjected to the range of provisions associated with aquaculture and potential fishery interactions. It has been suggested in this report that issues of predation and competition are central to the aquaculture debate, that the NEFMC has significant expertise in addressing gear conflicts, and, therefore, it has been recog-
thought that the Council should extend its oversight to issues associated with the allocation of space in the EEZ for aquaculture projects proposed within that geographical area.

Section 304(c) of the Magnuson Act provides a council with discretionary authority to designate areas where, and periods when, fishing shall be limited, or shall not be permitted, or shall be permitted only by specified types of fishing vessels or with specified types and quantities of fishing gear. Thus, Special Management Areas (SMAs) have been used often by the New England Council in a variety of management plans, mainly to close areas to protect spawning aggregations of fish, and could certainly be used to afford aquaculture ventures a modicum of excludability. Considering that aquaculture ventures contemplate proprietary, exclusive, or at least preemptive use of public "lands," it is not unreasonable for the Council to discuss whether the use of "rents" or "royalties" are appropriate in the context of aquaculture as opposed to permitting which, under current law (Section 306(c)), cannot exceed the administrative costs incurred in issuing the permits.

Issues

The advent of proposals to undertake aquaculture research and development projects in the U.S. EEZ raises a number of issues, many of which have been addressed at varying degrees at the coastal state level where aquaculture development has been pursued. These issues break along many lines including questions concerning privatization of a public resource and protection of areas that may have historically been utilized by conventional fishing gear: biological questions concerning habitat, genetics, water quality, the use of antibiotics, and whether environmental monitoring is appropriate or necessary; technical questions concerning the design and placement of the structures necessary to support offshore aquaculture activities within navigable waters, means

"to minimize movement of patented products, and interactions with endangered and threatened species; concerns about the complexity of the regulatory process and means to examine the oversight and interfaces of various federal agencies, and, of course, a number of legal questions concerning rights, obligations, protection, and compliance.

That the NEFMC has the legal authority to manage aquaculture in the EEZ appears clear, although it is not compelled to do so. An other federal agencies possess the necessary permitting authorities. The Council does have an obligation to consider matters that may affect fisheries habitat under Section 307(c) of the Magnuson Act and that will be required, in any event, to review proposals to determine whether or not habitat impacts are significant. The Council will also be positioned by developers to amend existing SMAs in permit certain operations, such as the handling of underwater fish, which are otherwise prohibited or restricted.

Beyond its regulatory obligations and its prerogatives to amend existing management plans, however, should the Council opt not to develop an aquaculture-focused management mechanism, it will be relegated to advisory status concerning aquaculture proposals under the Fish and Wildlife Coordination Act, the National Environmental Policy Act, and Magnuson. In this situation, the Council would be disadvantaged in attempting to manage the user conflicts that overshadow all fisheries management activities, leaving this vexing issue to be addressed by other federal agencies that have neither the expertise nor, perhaps more importantly, the forum familiar to the various stakeholders within which the attendant issues can be presented and discussed.

In this context, it is important to recognize that neither the Council nor the Secretary of Commerce has the legal authority to convey, through lease or other vehicle, proprietary rights to the ocean bottom or water column above. From the perspective of an aquaculture firm, the inability to secure exclusive or proprietary...
rights can be a significant deterrent to investment and thus inhibit development. But, as the Council has already experienced, the perception of blame and the "privatization" of a public resource are issues that generate significant controversy, pitting traditional fishermen against aquaculture. The allocation of space is, however, the central issue in the debate over aquaculture in the TPZ, and it is recommended that this debate be moderated by the NMFS, which is the agency in the regime with the necessary expertise, experience, and statutory responsibility to effectively deal with this issue.

The need for the Council to develop an aquaculture policy and management strategy for EEZ-based aquaculture projects is underscored by the guarantees that allocations of space will be renewed each time such a project is proposed. Thus EEZ-based aquaculture is a component of the New England fisheries for which the Council has management responsibility. Furthermore, the likelihood that the Council's workload will be increased by such proposals if PMAs are not to be extended in a piecemeal fashion should provide substantial motivation for the Council to address this issue in a strategic fashion.

For the foregoing reasons, it is recommended that the Council, as a first order of business, develop an aquaculture policy that will aid in the development of an aquaculture management strategy. It is also recommended that the Council be circumspect in determining which steps to address in formulating a management strategy, selecting only those that are clearly germane to the Council's fisheries management role. Although this recommendation appears superfluous, a brief reflection upon any past fisheries management debate will confirm that tangential and non-essential issues often interfere with discussion of the matter at hand. The Council has a role in addressing general fisheries interactions including the possible effects of aquaculture on traditional fisheries or management objectives of other plans. The Council is also, in this context, the most appropriate forum for the debate about allocation of space, resource utilization, and cost and benefit comparisons. Furthermore, the Council has a statutory responsibility to comment on potential fisheries-related impacts of projects proposed in federal waters. It is urged here, however, that issues such as genetic interactions, design of surface structures and monitoring systems, water column chemistry and the like are issues that are beyond the scope of the Council's expertise and should be left to those agencies with the statutory responsibility for necessary expertise.

Federal regulation of aquaculture in the marine environment has a relatively short history and appears largely from development in coastal state waters where, because of the overlap of various state requirements, the application and permitting process can be extremely complex. To minimize the complexity, several states have utilized the process of developing a cooperative application and review procedure for aquaculture administration. All of the federal agencies that have aquaculture involvement are authorized to enter into cooperative arrangements with other entities, including the Council, in the discharge of their responsibilities. Should the Council move forward to develop a role in EEZ-based aquaculture, it should do so with a view towards facilitating rather than complicating an already complex process. Thus, the Council should work closely with the states to ensure coordination and consistency in the process of developing a cooperative application and review procedure for aquaculture in Federal waters and the state waters.

The Council can help facilitate the process by positioning itself as the point of contact for potential aquaculture developers, providing information and federal permit application materials at a central location similar to the cooperative application and review procedures utilized by some state and federal agencies. The Council's ready involvement with individual project development will enable coordination and recommendation.
Reactions of cod (Gadus morhua) in submerged net-gens

W. Hunting Howell
Department of Zoology
University of New Hampshire
Durham

Over the last 10 years, landings from the North Atlantic haddock fishery have declined by almost 50 percent, from a peak of nearly 500 million pounds in 1980 to only 250 million pounds in 1992. The severity of these declines can be illustrated by U.S.-cod landings, which decreased by 20% between 1991 (55,400 metric tons) and 1992 (94,400 metric tons) (Adams, 1993). In response to these alarming declines, the New England Fishery Management Council recommended severe restrictions on fishing effort and closures on certain fishing grounds. While these regulations will hopefully allow the resource to rebuild, they will, by definition, cause landings to decline in the years ahead. At the same time that landings have been falling, the demand for seafood has increased. In the United States, per capita consumption has increased by 24% over the past 10 years, and the per capita consumption is projected to be 28 pounds by the year 2000. Thus we face a situation of increasing demand coupled with decreasing supply.

The most promising alternative for meeting the increased demand for fresh fish is through aquaculture. One of the most promising candidate species for commercial aquaculture in the Northeast U.S. is cod (Gadus morhua). Although cod have been successfully cultured in Norway (for both stock enhancement and for harvest) for many years, efforts by Blenkins (1991), there have been no attempts to rear cod to market size in the U.S. The major impediments to the development of a successful cod aquaculture industry in New England include lack of information on broodstock management, larval rearing, systems, diets for larvae and juveniles.
tiles, and appropriate grow-out systems. All of these issues are being addressed in federally funded research projects. In one of these projects, we are designing and testing net-pen systems that could be used to grow cod to market size. Because net-pen areas are heavily used (e.g., salmon farming and fishing, lobstering, etc.), our working premise is that any ocean-based grow-out systems would have to be located offshore. The often harsher conditions in this environment dictate that the net-pens be engineered substantially differently from those commonly used in more protected, inshore areas. As is clear from the papers presented in this conference, there are a number of offshore surface- based and submerged net-pen systems either available, or being developed. The work we are doing seems to develop small, inexpensive submerged net-pens that could be used to grow groundfish species.

In this paper I will briefly describe some of the biological issues associated with growing cod in submerged net-pens, and then provide some preliminary results from a research project that relates to those issues.

**Biological Issues:**

In considering the viability of submerged net-pen systems, it is important to understand the biological consequences of the fish changing depth as the net-pen is raised and lowered. Obviously, changes in depth result in 1) changes in hydrostatic pressure (one atm per 10 meters); 2) changes in water temperature (generally increase with depth), and 3) changes in light levels that may be important to visual feeders. In general, 1 and 3 are most significant, and their impact will be dependent on the rate of change in depth.

**A. Hydrostatic pressure**

Cod, like most, but not all bony fishes, have a swim bladder (internal gas-filled bladder) that has a number of functions. In cod it is used primarily for the maintenance of neutral buoyancy, for sound reception, and for sound production. Volume of the bladder changes inversely with hydrostatic pressure according to Boyle's law, so the fish has to keep adjusting the volume of its swim bladder as it moves up and down so as to maintain neutral buoyancy. The cod swim bladder is of the physogastric type. Emphysema (over inflation) of the swim bladder occurs as the fish ascends, and is accompanied by removing the gas from the bladder into the blood stream, using a structure called the airlf, which is simply a bed of capillaries. Emphysema occurs as the fish descends, and is accompanied by secreting gas into the bladder from the blood stream in a complex physiological process.

Understanding the physiological rates of inflation and deflation of the bladder is critical to the appropriate operation of a submerged net-pen. If the pen is raised too rapidly, the fish may not be able to remove the gas quickly enough, and this could result in internal organ damage or swim bladder rupture. Conversely, if the pen is lowered too rapidly, the fish may lose buoyancy if it cannot inflate the bladder rapidly enough. Harland Jones and Schönfeld told us in Bulkley and Tyler 1978, have reported on the rates that cod can fill and empty their bladders at different temperatures. If the fish change depth and therefore hydrostatic pressure at these rates, then the fish remain neutrally buoyant (i.e., it adjusts its bladder volume to the depth it occupies). As they descend, cod are capable of absorbing gas at a rate equivalent to a descent of 0.2 m/min at 0°C, and this increases to about 1.3 m/min at 15°C. After a descent of one arm (from the surface to 10 meters), volume is restored in 95 hrs at 0°C and in about 10 hrs at 15°C. As they ascend, cod are capable of expanding gas at a rate equivalent to an ascent of 2.4 m/min as they traveled from 10 to the surface, and the swim bladder is fully adapted after four hrs.

These rates are remarkably slow relative to the rates one might wish to use in raising and lowering a submerged net-pen in a commercial aquaculture operation. For example, raising a submerged pen from
10 meters to the surface should, according to these physiological adaptation rates, be fine; over the course of two hours, the fish would adapt to this change in water volume and thereby avoid stress. Since most submersible pens are likely to be considerably deeper than 10 meters, the time to raise the pens could extend over several hours, thereby making their operation very time-consuming and therefore expensive. My point is that the idea that fish are able to adjust to changing depths is critical, and must be considered in any attempts to evaluate the suitability and operation of submersible pen systems.

B. Water temperature

In New England coastal waters, bottom temperatures are usually cooler than surface temperatures over much of the year. Thus, fish reared up and down in a submersible pen system would presumably experience temperature changes. What effect would this have on the fish? Results from a recent study by Claveau et al. (1995) shed some light on this subject. These researchers have conducted a large number of trials in which they can study the physiology and behavior of fish under different experimental conditions. The tank is 10.4 m high and 4.1 m in diameter, and they are able to induce temperature stress via adding different temperature water through ports at different depths. The fish are able to adapt to different depths to avoid blinding their depth selection behavior. In a recent experiment they worked with adult cod that had been acclimated to 5°C. Some of these were equipped with sensor transmitters that sent continuous information to a computer about the depth of the fish (pen-bottom transducer) and its heart rate. They also recorded heart rate and oxygen consumption of the fish at different temperatures, in a control tank. Using these facilities and a variety of methods, they were able to study the physiology and behavior of free-swimming cod at different temperatures. Their results have a bearing on whether submersible net pens, since fish in such systems would also experience temperature changes. Claveau et al. (1995) found that cod were capable of surviving temperature changes, but tended to avoid temperatures they were not acclimated to, thus maintaining a physiological status quo. 3) Sub and daily temperature changes (several degrees over several days) resulted in increases in swimming activity, heart rate and oxygen consumption. 4) Acclimation of fish to normal swimming activity levels after a 2°C temperature change could take up to three or four days, and at least temperature changes (1°C over 30 minutes) affected their physiology. For example, a rise from 5°C to 7°C resulted in a 3.5% increase in heart rate and a 2.8% decline in O2 consumption. Similarly, a fall from 5°C to 2.5°C resulted in a 20% decline in heart rate and a 16% drop in O2 consumption. These results suggest that there are some very real physiological consequences associated with even small temperature changes such as fish would experience in a submersible net-pen system, and as with hydrostatic pressure, these should be carefully considered as one evaluates the suitability and the operation of submersible systems.

Preliminary Experiment

To conduct preliminary experiments on the reactions of cod in a submersible net pen, a small (3 m3) experimental pen was built of 0.25 x 0.5 cm polyvinyl chloride pipe. A weight was suspended on a line below the pen, providing negative buoyancy. Fish were put into the pen at the top perimeter of the pen and the pen remained approximately 5 m high at the bottom. When submerged, the fish always remained in an upward direction, suggesting that the fish were not in the surface. Since the pen was submerged, the entire system was attached to a large floating stack with a line having sufficient slack to allow the pen to be raised to the surface. Raising and lowering of the pen was done via a line from the pen to a surface.
About 50 juvenile cod were caught in a trawl net in January 1985 by a local commercial fisherman. They were kept alive on board the vessel in seawater tanks and returned to the URI Coastal Marine Laboratory (CML) where they were placed in a 2500 liter round tank supplied with flowing, ambient temperature and salinity seawater. Mean length and wet weight of the fish were 26.9 cm total length (TL) and 225 grams (Fig. 1). Fish were maintained at CML through August 1985 and were fed a diet of dried frozen herring and squid everyday.

![Figure 1: Growth of cod Elode and Atlantic cod at CML and at laboratory site.](image)

The experimental net pen was deployed in August 1985 at a site near the Isles of Shoals, N.H. Water depth in the site was about 30 m. At this time, half of the fish from the Laboratory were moved into the experimental pen. As a second net-pen that could have been kept at the site in 1983, control fish were available. Half of the fish were released at the Laboratory to serve as a pseudo-control for growth and survival comparisons. Mean length and wet weight of the fish at time of stocking was 27.6 cm TL and 386.6 g (Fig. 1). When submersed, the pen was located about 2.5 meters below the surface. From August through October (8 weeks) the experimental pen was raised twice to three times per week, and the fish were fed ad libitum, dried frozen herring. The case of one and a half days varied, but each operation generally took about 10 minutes. Average time at the surface was 5–10 minutes.

In October 1985, a random sample of both Laboratory fish and experimental net pen fish were weighed and measured. fish in both locations had grown in both length and weight. Those held in the laboratory tank had a mean total length of 41.7 cm, and a mean wet weight of 953.9 g. Those held in the net pen had a mean total length of 41.8 cm, and a mean wet weight of 859.5 g (Fig. 1). There was no significant difference (Analysis of Variance, Ftest) between the fish in the laboratory and those in the net pen in either length or weight. No mortality was observed in either the net pen or the laboratory tank. It is concluded from this limited experiment that the cod in the net pen, which were raised and lowered at a rate much faster than would have allowed them to adopt their swim bladder volumes, were not adversely affected, at least in terms of their growth. On several occasions a few fish (25) were observed to be floating upside down when the net pen was brought to the surface. It was clear that their swim bladders were over-inflated due to rapid decompression, but results of the study indicate they recovered and continued to grow. Unfortunately, we did not recover the fish due to an accident that caused us to lose the net pen so it was unable to determine if the swim bladders of some or all of the fish had ruptured.

A similar study using two different submerged net pen designs and a larger number of fish is currently in progress. We will have an adequate control in surface net pen, but we are keeping better records of temperature with a data logger attached to each net pen, and we will be observing the behavior of the fish in the pen periodically using a remotely operated vehicle (ROV). We will measure growth and survival at the end of this experiment, and observe a representative sample of the fish to determine if their swim bladders have ruptured.
Much more study needs to be done to fully evaluate the sustainability of oyster culture in submersible net pens, but this very preliminary research suggests that growth and survival of the fish is acceptable.

Literature Cited:


A fish farm pilot-project in Madeira Archipelago, Northeastern Atlantic - 1. The offshore option

C. A. P. Andrade
Direcção Regional de Pesca, Governo Regional da Madeira, 9000 Funchal, Portugal

The Regional Government of Madeira has decided to promote the development of the oyster culture in submersible net pens. This has led to the development of a pilot project at Funchal, which is scheduled to be completed in the next few years.

Introduction

The archipelago of Madeira is a group of small volcanic islands situated in the northeastern Atlantic (Fig. 1). It is part of Portugal, but governed autonomously. Madeira is the larger island, where most of the population and economic activities are concentrated.

In response to falling catches of demersal fish and to lower the pressure on the local stocks, the Regional Government of Madeira has decided to evaluate the potential of the island for marine aquaculture and consequently to present a strategy for the development of the industry.

The choice of farming system

Bear in mind the long-term development of an aquaculture industry, a model was elaborated to allow for decision-making by analyzing the most important factors that influence the development of aquaculture according to FAO (1983) and the most suitable areas used for rearing different species (following Moline, 1980) - Fig. 2.
The physical-geographical conditions are determined by the geographical situation and geomorphology of the island. From a central protrusion of high mountains, the landscape slopes sharply to sea level, often ending in cliffs or sand-filled coves. The tourism and housing sectors compete strongly for available coastal land. There is no space at an affordable cost for the installation of land-based aquaculture systems.

The absence of a continental shelf and sheltered bays contribute to a high-energy marine environment, especially on the north coast. Even on the south coast, the prevailing wind has a significant wave height, resulting in a low return period of 4.5 meters (SEAWORK, 1992). The exposure conditions make it difficult to develop intertidal or subtidal culture techniques and fish cage culture is limited to offshore systems.

The coastal waters have certain characteristics with constant salinity (36.5-37.0 %), and a high concentration of dissolved oxygen levels (about 7.5 mg/l). Monthly average surface water temperatures range from 17.0 to 23.0°C. These are considered excellent conditions for the growth of most Mediterranean species used for aquaculture. The water is considered "clean" and free of pollutants, but also low productivity (DEN, 1992). The use of larvae at long-line culture of bivalves is therefore out of the question.

Capital and operating costs of offshore fish farming are high and leave no space for trial and error. It is a business-oriented activity, novel to the region, therefore appropriate technology must be imported. Commercial ventures could benefit from the already existing foodstuff manufacturing and the experience facilities for fish food processing.

The offshore pilot project

Acting upon the need for planning, the Regional Fisheries Directorate presented a strategy to develop marine aquaculture in Madeira (Ambriz, 1995):

1. Production plans were drawn to allocate financial resources within the regional development plans (FEDAR, 1994) and European Union funds (ERDF, 1994) with measures to ensure the investments' priority was given to commercial fish farming of high-value species using offshore systems.

2. The creation of an experimental centre to carry out trials and to evaluate the potential of local species for aquaculture, with assistance services (at conception phase).

3. Finally, the presentation of a pilot project using offshore cages to produce galliotid fish species, species common in the area, in order to test the bioclimatic and economical feasibility of this culture system in Madeira and to demonstrate its viability to local investors. The facilities consist of four polyethylene nursery cages (about 1,000 m³ each) and a 1,000 m³ farm cage for growing age 1. The farm was installed by November 1995 and is expected to produce 100 tonnes of fish per year. Within three years the fish farm will be transferred to the private sector.

Conclusions

A model selected offshore fish farming aquaculture as the culture system best suited to the local physical and environmental conditions of Madeira Island. The long-term sustainable development of this sector was planned with a strategy based on financial incentives for the installation of commercial ventures, the implementation of extension services, and finally, the establishment of feasibility demonstrations projects using offshore cages.
References


DLR (1994) Decreto Legislativo Regional Nº 21/94/M.


A fish farm pilot-project in Madeira Archipelago, Northeastern Atlantic –
II. Environment Impact Assessment

C. A. P. Andrade
Direcção Regional da Pescas, Governo Regional da
Madeira, 9300 Funchal, Portugal

A mass-balance model is used to assess the potential environment impact in the cultivation of an offshore fish
farm in Madeira Island. Based on the spatial extent and
the temporal series of the mass-balance model the fish farm
should have no significant impact on the surrounding
biomass of the area.

Introduction
The localization of an offshore fish farm has to
satisfy site requirements, minimize environmental ef-
fects and integrate with other economical and recrea-
tional activities.
The south coast of Madeira presents more suitable
sea conditions for the installation of cage structures for
fish farming. The proposed site for the installation
of the government funded pilot-project in Baía da
Abra at 200 m off the peninsula coast, away from the
principal navigation routes of the local ports and other
human activities.
This presentation deals with the use of a model to
quantify the deposition of wastes under the cages in
order to evaluate the local environment impact of the
fish farm.

Estimate of benthic deposition
The farm facilities, the nursery cages and the em-
growing cages are situated respectively at 22 m and 30
m depth of water.
According to hydrographic surveys the circulation
patterns of the site are mainly influenced by the
greenwich northern winds and the easterly winds of the
ocean currents. Mean current speed estimated using

Matt

Cage shape

Cage size

Cage depth

Figure 1. Decision-making model to evaluate the best performing
culture systems as between Madeira according waste factors that
influence aquaculture development (IAC, 1982) and the different
repositories (Madeira, 1979).
dungue from 10 m (5, 10 meters depth) were low varying between 0.314 to 0.635 mm/s in calm weather.

Total currents are only significant (0.35 m/s) at low and high spring tides (Kerestor Hidrografica, 1979)

The type of substrate is very coarse sand (0.1 mm) and gravel (0.2 mm) suggests the occurrence of fairly strong periodic currents. As expected in these type of bottom there is a slight cover of bentonic fauna in poor abundance and diversity, the only significant population is a fauna of grass eel

**Conclusions**: 100 m west of the site.

As the production capacity of the farm is expected to be of 100 tonnes of fish per year, it is vital to quantify the local environmental impacts. Using a “mass balance” approach as used by Blatchly, Galdu, Mekina, Kustu & Zdansky, 1985), the annual waste loadings were estimated (see Fig. 1).

The dissolved nitrogen waste resulting from excretion are approximately 4.5 tonnes. As the site is open and the water of the area well mixed it is believed that the dissolved nitrogen wastes will not have a significant impact in the generally oligotrophic waters of the bay.

The particulate wastes produced consists of waste feeds and faecal material, with a total year production of about 50 tonnes. Most of this waste is from the big pen cage, where a large part of the production cycle takes place.

To evaluate the impact of these wastes it is necessary to calculate the loading per unit area. Assuming a constant value for the current, as 0.1 m/s, the dispersion of wastes can be estimated by calculating the horizontal distance (D) travelled by the settling particles.

\[
D = \frac{0.1 \times \Delta t}{V}
\]

where \( \Delta t \) is the depth of the water column below cages (30 m), \( V \) is the current velocity, \( \Delta t \) is the settling velocity of wastes (0.04 m/s for the fines and 0.02 m/s for the feed, following Green & Headley, 1987).

**Table 1**: An estimate of waste loadings from the offshore farming following a “mass balance” approach.
The distance travelled will be 25 m for the feed and 75 m for the faces. Considering an even distribution of waste around the cage, the feed wastes will be dispersed over an area of 1,063 m² and the faces over 177 m².

Thus the amount of carbon loaded per unit area resulting from feed waste will be around 5.6 kglm² in a 25 m radius. The faces material will disperse the waste of 2.2 kglm² in a maximum radius of 75 m.

The significance of the waste loadings

The estimated carbon losses from both feed and waste in the area directly beneath the cage is of 7.8 kglm². This is considered to be a high level of carbon loading for submerged farms in northern Europe according to Owens & Bradbury (1987).

In the more open waters of the Mediterranean sea, Black, Hamburger & MacDougall (1994) reported no major impact of the fish farms on the bentho. These authors suggested the wastes were substantially digested by storm events and helped by the deep water current. For the Bay de Alba, it is believed the combined effects of storm disturbance, strong spring tide and occasional wind-generated currents as confirmed by the sedimentation will contribute to avoiding the accumulation of organic material on the sea bed. Furthermore, the higher temperatures of the sea water from Mazara will accelerate the breakdown of the organic compounds.

At the moment there are no regulations concerning the discharge of effluent cages to prevent impacts on the benthic environment. A monitoring programme has been designed for this particular project in order to control the physical-biological effects of the waste on the sediment beneath the cages. Monitoring includes periodic, percent organic carbon, and free and total sulphate and chloride changes on benthic infaunal communities following Rees, Moore, Pearson, Ellett, Sperrey, Perry & Johnson, 1980 and Eleftheriou & Holme, 1984.

**Dispersal of particles**

\[ \text{Disp} = \frac{d}{\text{D}} \times \frac{\text{V}}{\text{Z}} \]

\( \text{D} \) = horizontal distance monitored by particle
\( d \) = depth of water column (m)
\( \text{V} \) = current velocity (mean horizontal, in m/s)
\( \text{Z} \) = settling velocity of infauna (m/day)

**Feed**

- D = 25 m
- A = 177 m²

**Faces**

- D = 75 m
- A = 1.063 m²

**Real loading**

\( \text{Loading per unit area} = \text{waste (kg/m²) \times area (m²)} \)

Feed: 5.6 kg/m²
Faces: 2.2 kg/m²

Figure 2: Enlarged view showing location of cages,\( \text{K}_{\text{aw}}, \) and the loading area of the particle waste.
Conclusions

The waste loadings from the offshore fish farms in Baia de Alva, Madeira were estimated with a mass-balance model and produced a considerable amount of waste. It is believed the waste characteristics of the site will contribute greatly for the dispersal of wastes and avoid their impact on the ecosystem.

The results of continuous monitoring will contribute to improved management, minimizing any impact of the fish farms and ultimately, to define regulations on the control of wastes and safeguards regarding the environmental impact of cage fish farms on the local ecosystems.

References


MAINE AQUACULTURE INNOVATION CENTER
Submersible Hullnut Cage Project:
Interim Report

Thomas Chase
Washington County Technical College
Falmouth, Maine

INITIAL IDEA

In the fall of 1990, phase II of the North Atlantic Aquaculture Inc.'s Hullnut Project was prepared with two goals: to investigate grow-out technology and to assess grow-out rates of Atlantic salmon. Working with Dr. Ken Whitehead and director Robert H. Cook of St. Andrews' Biological Research Station and the staff of the University of Maine's Fisheries and Aquaculture Research Group (FAURG), a submersible hulnut cage was chosen for trial. This was funded by the Maine Aquaculture Innovation Center (MAIC) (see Appendix A). The rationale for selecting this technology was the nature of the habitat. They are basically a deep water horizon fish and a hulnut cage would help simulate their habitat, reducing ambient light, and the effects of wave action on feeding behavior.

At this point, aquaculture coordinator George Kopaloff, whose protein was funded by MAIC, Sea Grant, Washington County Technical College (WCTC), Ooquay 90 Opportunity Zone, and the University of Maine Cooperative Extension Service, developed a submersible design in steel, based on the limiting factors: containment volume and construction cost. Initially, the overall dimensions were 24 ft x 24 ft x 12 ft; the unit area was thought to be important, thus a steel of 0.25 in. x 3 in x 3 in was chosen for the frame, based on strength and cost. Once the frame and construction were completed, a six-panel net would be lightly stretched within it. The net was to be 12 ft deep and sink to the bottom, which in turn would...
next on a bottom of fine gravel to the inside bottom of the frame. The above construction with gravel and mud on it was to simulate a natural bottom for the fish.

Construction of the cage was begun in March 1991 by twenty students from WCTC's welding technology class. The basic frame was completed by the end of March and subsequent purchase of major components (collapsible bags, nets, chains, etc.) was completed by April 1991.

In April, Mr. Kapinos assigned work for the private sector. At the same time, the private company providing a site and funding for the project began to fall. Their commitment caused us to re-evaluate the project. However, we continued to invest in equipment to complete the project. In May, the project was put on hold due to funding issues.

During the summer of 1991, the cage was cut down and re-worked to its present configuration. The cage was then completed and assembled. In consultation with the Biological Station, which was supplying the fish, a target date of August 1991 was set for the project.

By May 1992, the pen was completed and launched by the MTC's 65-ton Marine Traveller from the school's pier onto Foxmassagadie Towing Service's barge. The barge was towed to the TFF landing site, where the pen was released. It soon met with unexpected difficulty and before being positioned. The next day, a diver repositioned the air bags and the pen was lowered to a nearby beach at a high water. Repairs and adjustments to the inflation system were made during low water, the pen refloated, lowered to position and submerged according to plan.

During this process, it became apparent that additional modifications to the cage were needed. The cage's weight was adequate to keep it on station once submerged. This was determined to be an advantage in the final design. The cage was moved later, with fish in it, closer to the salmon pens. Feeding the haddock became easier.

On July 17, 1992, Dr. Walcomb delivered 40 adult haddock to the pen. The divers checked the condition of the fish before being fed. Weights and measurements were taken on Oct. 29, 1992.

The feed system consisted of 78,000 reinforced two-inch I.D. plastic hoses connected to a live-water section of 22,000 cubic feet located at the inside top of the pen. Originally, the hose was then, then that the pen was released to a nearby town of TFF. Whole and cuttlefish were pumped by a 215 hp two-inch pump with 40% air. Feeding occurs every other day at a current rate of 15% per feeding. The feed has been partially provided by RJ Peacock Cannery, where the storage freezer is located.

The material left over from the design changes are stored and available at the MTC campus. The initial design was taken apart so that a complete rectangular frame is available with enough steel left to convert it to...
SUMMARY OF OBJECTIVES TO DATE
The following will examine research plan objectives as stated in the initial proposal.

1 & 2. DESIGN AND CONSTRUCTION
These have been covered in the preceding narrative.

3. PHYSICAL EVALUATION OF CAGE PERFORMANCE
   A. The feed delivery system works well with whole or cut herring, but needs to disegrate pelleted food.
   B. Observations of the fish is difficult. Watching the fish in the net indicate how much to feed them. It is very difficult to get accurate feed conversion data. During the first quarter it was found that too much feed was pumped down to the animal feedbatch data is inaccurate. Determining the daily health of the fish is also difficult. This is being done by divers, which is time consuming and costly methods. Video surveillance would be prohibitively expensive and give only limited viewing.
   C. There is a potential safety problem while the cage is handled. To measure the fish, workers have to enter a tight-lawed cage with a single entrance which exit hatch is in the netting. After observing the cage descend, it is evident that if either buoyancy bag developed a major leak with workers inside, they would go to the bottom in 15 to 30 seconds and probably be trapped. During trials, safety was provided by having a dive unit in each side of the cage before putting workers inside. On a production scale that would not be efficient. One solution would be to modify an existing solution cage rigged with winches to raise and lower the habitat pen with the floating cage providing the buoyancy. This approach could become more cost effective with broodstock seaworthy pens.
   D. On the whole, a self-sustaining, portable pen does not seem to be the most economical way to raise haddock. Woodsmen from the Harbour D'Escare floating pen system to indicate haddock do not require a true bottom. They do prefer dim light but this can be provided without sinking the pen forty feet. Without abandoning the submarine concept floating pens, wees, and lobster pounds should be considered.

4. BIOLOGICAL EVALUATION
The data shown in this report is for the first quarter (March-April) and is not shown in comparison to data of the benthic in the floating cage experiment of the same time period. Data was unavailable for another data comparison, but is included here first quarter results (see Appendix D) were looked at if the bottom cage haddock, fish kept their own against surface cage fish. This data, even when confirmed, must take into account the difference between feeds and the inherent inability to observe feeding in the benthic cage. (The floating pen uses a mixture of fresh herring and some moist pelleted feed."

More definitive data should be available from Dr. Wood by the end of the first year cycle. 1973.

There are some observations that can be made now:

1. Haddock are very valuable fish. They are literally "black skinned" and not liable to wounds, as are salmon. This is important in the reduction of disease and morts.
2. Halibut are delicate and even seem curious when workers are around. Again, this is in contrast to salmon, which can panic and become either off feed very easily.

3. Initial data indicate a feed conversion ratio within the range of salmon.

These three factors suggest that halibut technology should be pursued further.

MAIC
Submersible
Halibut Cage Project
supported by
Travis Island Fisheries
&
Washington County Technical College

Interim Report

Open Ocean Aquaculture:
BRIDGESTONE HI-SEAS Fish Cage

Jorgo Cunzescoen
ARVA TRADE LTD.
Spryfield
N-5429 Uragwage

I am here to tell you about the BRIDGESTONE HI-SEAS fish cage. My presentation will not be about an idea or a concept. It will be dealing with a system at an actual planning, design, or development stage. And I will not be telling you about a fish cage system presently being tested and proposed for commercial application.

My presentation is about the most successful offshore fish cage in the world. Since it was introduced in 1980, it has outperformed all other offshore fish cage systems. It has an unparallelled and enviable track record. And it is daily proving the commercial viability of offshore fish farming.

History
BRIDGESTONE CORPORATION is a Japanese company best known as one of the world's largest manufacturers of tires. The company also produces a wide range of other products, mostly from rubber, and is a world leader in the manufacture and supply of marine hose for the offshore industry.

Japan, of course, is one of the world's largest aquaculture nations with an annual production of about 1.5 million mt of fish, shellfish, and seaweed. At the same time the country is small and there are few offshore sites for fish farming. Fish farms in Japan are, therefore, often placed close together in confined areas, resulting in some cases in severe environmental damage and loss of fish. It was not by accident, therefore, that the first offshore fish cage was developed in Japan. But in fact that is not exactly how it happened.
In 1974, some tuna fishermen in Japan approached BRIDGESTONE to ask if it was possible to make an enclosure to keep and transport live fish. The schools of tuna were migrating away from the Japanese coast and it was getting more difficult to bring them fresh to market. The idea of the fishermen was to use a large holding pen which could be towed behind the purse-seiners out to sea. The pen would be transferred from the catching nets to the pen, which would then be towed back to shore where the fish could be kept live until harvest.

This then is what BRIDGESTONE set out to do, and consequently the frame-cage was designed to withstand the enormous stress of offshore weather conditions as well as the strain of being towed at speed behind ships over long distances.

It was during the development phase that BRIDGESTONE realized that its invention could also be used as an alternative to the existing fish cage in use in Japan. The further development of the frame-cage and nets was, therefore, adapted also to include this other intended use.

**Design**

Conventional fish cages thus far were almost all made from rigid materials: polyethylene, wood, steel, aluminium, and various others. With their extensive expertise in rubber technology for marine application, the engineers at BRIDGESTONE believed that rubber fish cages would provide a viable alternative. Research continued to determine if the flexibility of rubber could be applied to make an open-ocean fish cage. The frame would need necessary flexibility to withstand the forces of wave action in stormy weather conditions, yet at the same time it must retain sufficient rigidity to maintain its general overall shape. Also, it must have enough reserve buoyancy to support its structure.

A whole series of tests was made and various combinations of flexible rubber hose were considered and tested before scale models were made. These were then tested, and different types and sizes of nets were used and data gathered on drag forces, etc.

The results were analyzed and correlated as a prototype full-scale fish cage which was then field-tested for a full two years before the BRIDGESTONE HUR/SAS fish cage system was perfected and marketing and selling commenced.

During the field testing and many times since HUR/SAS cages have been built by full-updeps, with wave heights up to 11m without damage to the frame, nets, moorings, or fish.

The first HUR/SAS fish cage was supplied to a fish farmer in Japan in 1983 and the first cage into Europe to a fish farmer in Ireland in the summer of 1984. In the 12 years since, more than 100 units have been sold and are now being successfully used for farming of several different species of fish in many countries. For the last few years, many cages have been sold to fish farmers, especially in Australia. They use the cages just as the Japanese tuna fishermen in 1974 had envisaged. Next month another enlarged 16-m hexagonal unit will be installed off the coast of Spain.

**Design Philosophy**

The fundamental design philosophy behind BRIDGESTONE's cages is that the frame has but one function and that is to keep the shape of the net. The structure is not intended to carry the net or hold soldiers or service facilities, nor to act as a working platform. We believe that it is more practical to have service facilities on boats or other floating structures which are separate from the cage frames, and which can be brought back to shore when needed.

**Shapes and sizes**

HUR/SAS fish cages are mostly square, hexagonal or octagonal in shape. Standard side lengths are 16m or 20m, although other lengths are made to order.
Each side consists of one flexible rubber hose string and two steel center joints. The sides are held together using four bolts only, and there are no hinges or moving parts. The whole of the wave action is absorbed in the flexible rubber hose sections. Such sumps choose support the jamb pot and handrails, while fans give the center joints equal buoyancy so that the rubber hose sections. The bulks and products of nets are hung on the front collar of the stanchion, and are connected in side and oblique collar to the left of their own height with the help of purse-seine boots. Where necessary a roll-net is used for head deterrence.

There is a clear tendency for the HI-SEAS fish cage to get bigger, and in the beginning, a few 30-m hexagonal cages were built later the 40 m hexagonal became the norm, and later still the 50 m hexagonal cage has become the most popular. Some Japanese fishermen prefer the 100 m square cage as for the Mediterranean, we have supplied nets of six square 16 m cages.

The biggest single unit we have supplied, and as far as I know the biggest cage in use anywhere, is a 30 M hexagonal cage supplied into India, is 762 M in circumference and has a surface area of almost 20,000 M².

The nets have also progressed in size. In the beginning most were at least 50 m deep. The new ones are 150 m or even 200 m deep. One fish farmer in Norway uses a 200 m deep net made of our 15 m non-woven nets. Total volume is about 25,000 m³ and in 1995 he harvested 18.8 t of salmonids from that one cage.

Although the first HI-SEAS fish cages were now 2 to 3 years old, there has been no need for major design changes. The basic system has proved to be satisfactory for its intended purpose and only minor changes have been made to the center joints, sump housings, handrails and the corner flanges, mostly in accommodation aspects, from our many users for ease of operation.

Nets

The nets used in HI-SEAS fish cages are unique in their design and very different from standard nets. The basic intent is to build a net that is able to withstand the same environmental forces as the cage collar and which, at the same time, protect the fish during such extreme conditions. Consequently, the nets have been designed to be as robust and wave action as possible in the top section. They are made with a flat line that has enough buoyancy to carry the weight of the net, even when fished. Also below the flat line the lacing has been incorporated which allows for elasticity and flexibility. Below the lacing is a strong portion of chain net with the mesh on the diamond so that the net can stretch horizontally and vertically. Only then below the hanging net, is the standard square mesh fish net. From the same point the jump net extends on the stack up to the stanchions.

The effect of this special design is that when a wave rolls through a HI-SEAS fish cage, the cage collar will ride the wave. The net inside the collar will benefit from the breakwater effect of the frame, and in addition the flat line on the net will also ride the wave. The lacing and the diamond mesh below the flat line will stretch vertically in front of the wave and horizontally behind it. The result is that the actual fish net, below the hanging net, and further down the sides and into the bottom panel, will be much less affected by the wave motion on the surface than in the case of a conventional cage and net.

The benefits to the fish are obvious. Such a net design and operating conditions of course mean different ways of working on the nets. For that reason we have from the beginning put much effort into monitoring and developing the nets. We have chosen to work with five representative net manufacturers and continuously assist them and our many users in further developing and improving our nets.
Mooring

HI-SEAS fish cages are moored either individually or jointly by using mooring ropes from each corner, connected to anchors on the seabed. The anchors can be concrete or steel, depending on stemmed conditions.

It is our firm belief that the successful fish cage system requires harmony between the four aspects of frame, collar, nets, moorings, and the site location. Therefore, in each case, before installation, site data is gathered and evaluated in Japan where engineers at BRIDGESTONE will calculate the forces that apply before making recommendations for size and type of cage, nets, and mooring system. Detailed materials are given to each user with specifications and drawings of all components, recommendations for nets and moorings, as well as specifications for installation, use, and maintenance. All components from sub-suppliers are thoroughly checked and in most cases BRIDGESTONE will install the representatives will supervise to perform all installation work.

After installation, representatives from BRIDGESTONE will visit the site to make sure that the cages are being used to their full potential.

Day-to-day management

When we first introduced the HI-SEAS cages to the industry, some of the daily chores proved difficult as there were few references and data in the way of industry experience. With such large cages, in an often hostile environment, some, however, handling and servicing is carried out. Regular day-to-day operations, such as transport, feeding, net changing, grading, disease treatment, harvesting, predator control, etc, are handled safely. Some of these operations need to be performed daily and almost without regard to the weather conditions. Such as feeding and monitoring. Others, such as net changing and harvesting, can be scheduled to coincide with favorable conditions.

In most countries our cages are used on growing fish farms near their juveniles in smaller cages
cheaper than they were 10 years ago, and very competitive with other so-called offshore cage systems even the better steel cage systems on the market.

For growing of salmon or other fish in exposed locations, we recommend the use of our hexagonal or octagonal cages. A 16 m octo-cage with a 20-m deep net has a total volume of about 52,000 m³ and a daily 400 m³ per year production capacity.

The investment cost for such a unit is:

<table>
<thead>
<tr>
<th>16 m octo-cage/frame complete</th>
<th>USS 140,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-m deep net</td>
<td>- 10,000</td>
</tr>
<tr>
<td>Set of moorings, complete</td>
<td>- 15,000</td>
</tr>
<tr>
<td>Total cost</td>
<td>USS 215,000</td>
</tr>
</tbody>
</table>

Cost per M³: USS 172.00
Cost per M³: USS 3.00

Prices are c.i.f. North American main ports, East or West coast, and for reference only.

Maintenance costs for HI-SEAS cages are very low. Major parts, such as rubber hose, strings or steel anchor joints are almost never in the need of replacement. While minor work is required such as a few shackles, covers, or fangs to be replaced, and they cost between $ 15. and $ 300. each. As far as the oldest cages are from 1985 and they are still in use. What the life expectancy is, is not yet clear, but given proper care and maintenance, probably another quite a few years.

A few of the oldest cages have been overstayed. Last year brought back the first cage sold in Norway in 1985, a 16 m hexagonal unit, and gave it a complete overhaul, only the rubber hoses and the steel anchor joints were used again. The joints were sand blasted and revarnished and all shackles, fangs, covers, bolts, and nuts were replaced with new ones. Total cost came to about USS 25,000.

A few cages have been sold second-hand over the years and they have fetched remarkably good prices.

Most have been bought by farmers who already have HI-SEAS cages.

In the Faroe Islands there are 32 HI-SEAS cages in use as the market has been to expanding that the local insurance company, which measures through the market, already in 1989 reduced the premium paid by owners of HI-SEAS cages by 10% compared to what they charge for insuring other types of fish cages, even those used in lagoon sites only.

**Future Developments**

We do not foresee major changes in the BROADSTONE cages in the future, but we are constantly improving and perfecting the systems with the help of our many users.

We do expect further developments in the management of fish farms in exposed locations. Service vessels and platforms, floating systems and especially monitoring systems for biomass control will become even more efficient and hence the visibility in offshore sites will improve further.

There will be much more farming of fish in exposed locations in the future. The technology for viable commercial fish farming offshore is already available and in the case of the BROADSTONE HI-SEAS fish cages, well proven.

While most fish farmers may consider the move away from sheltered indoor locations only as a last resort and as an absolute drawback, the users of our cages will tell you otherwise. Moving offshore will improve the living conditions for the fish considerably and thereby better your return.