Open Ocean Aquaculture

Proceedings of an International Conference

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About the Conference

The purpose of the conference was to bring people together from around the world to discuss the issues, problems, and opportunities for aquaculture in the open ocean or high-energy environment. The target audiences were aquaculturists, biologists, fisheries scientists, ocean engineers, community development specialists, environmental regulators, policy makers, students, planners, investors, and natural resource economists.

The conference was funded by the National Sea Grant College Program as part of a larger effort in marine aquaculture. It was sponsored by the University of New Hampshire/UNH Cooperative Extension, the National Marine Fisheries Service, and UNH Cooperative Extension/Sea Grant.

The conference steering committee is identified on the following page.

Over 200 people registered and participated in the conference. Thirty people made presentations. All but three of the presenters or speakers are represented in the proceedings. A poster session was held on the first night of the conference featured 20 posters.
Open Ocean Aquaculture
Conference Steering Committee

Rolle Barnaby
University of New Hampshire

Cliff Gouley
Massachusetts Institute of Technology

Amnon Hayden
Resource Services, Brunswick, Maine

Grant Kelly
U.S. Army Corps of Engineers

Chris Mantzaris
National Marine Fisheries Service

Eric Nelson
NOAA Corps

Rob Robertson
University of New Hampshire

Marie Folk
NH Maine Sea Grant College Program
Proceedings Editor

Kathleen Matthews
UNH Cooperative Extension,
Graphic Design and Support Services

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Introduction and Welcome
Rolfe Barry, Chairman
Conference Steering Committee
UNH Sea Grant/Cooperative Extension
Brunswick, New Hampshire

Welcome to Portland, Maine and the Open Ocean Aquaculture Conference. I am Rolfe Barry, an
Extension Professor with Cooperative Extension Sea Grant at the University of New Hampshire. My inter-
est in this subject comes from my belief that the develop-
ment of marine aquaculture is dependent on identifying
interactions and opportunities. The possibility of finding
new, sustainable, productive ways for growth is a key issue for the future of the U.S. coastal area.
I believe the industry will have to go to land-based, warehouse-type facilities or move to the open
sea.

As I stated the possibility of moving to the open
sea, it became very clear that there was a whole
host of problems and issues that have to be dealt with.
The first step in addressing these problems was to get
as many people as possible from around the world to
together to find out "what we know, what we don't
know, and what we need to know" to move aquacul-
ture to the open sea.

This conference is an attempt to do just that. It is
being supported financially by the National Marine
Fisheries Service through a Saltonstall-Kennedy Grant
and the National Sea Grant College Program through a
grant for the study of farmed aquaculture.
I would like to introduce the Steering Committee
that put together this conference: Amy Hayden, Re-
sources Services, Brunswick, Maine; Cliff Gooden,
MT Sea Grant Program; Grant Kelly, U.S. Army
Corps of Engineers; Chris Mainzer, National Marine
Fisheries Service; Bob Robertson, University of New
Hampshire; and Eric Nelson, NOAA Corps, who could
not be with us here in Portland. These people will also
act as moderators for the various sessions for the next
Overview of Offshore Aquaculture

James F. McKay
Program Director
National Sea Grant College Program
Washington D.C.

I would like to welcome you all, on behalf of the conference sponsors: the Maine/New Hampshire Sea Grant College Program, UNH Cooperative Extension, the National Marine Fisheries Service (NMFS) and the Massachusetts Institute of Technology Sea Grant College Program. We are especially pleased to welcome presenters and participants from so many countries (Norway, Canada, Sweden, Russia, Ireland, Israel, New Zealand, Italy, England and the U.S.) and representing so many disciplines (including engineers, economists, biologists, state and federal resource managers, extension agents and leaders, lawyers and entrepreneurs). Common building is key.

Progression of Aquaculture

Aquaculture was recorded in China 4000 years ago. Chinese aquaculture is now valued at $67.6 billion dollars (FAO 1992). Chinese freshwater carp culture has evolved into well-balanced pond ecosystem management with several feeding levels and stocking levels contributing to overall production. The carrying capacity of the system is maximized and continuous recycling is practiced. The system is sustainable because of this wise management of carrying capacity.

Progression from extensive to intensive cultures has been marked. Extensive pond culture, which relied upon natural productivity without nutrient or supplemental feeding, produced an average carrying capacity of 300-500 kg per hectare. Semi-intensive pond culture using fertilization, aeration, superior feed and water exchange has a carrying capacity of 600 kg per hectare. Intensive culture uses raceways, tanks, cages and
pens — makes use of oxygenation, carbonation, UV sterilization, biological filters, foam, biocatalysts, automation, computer monitoring, and large volumes of clean water with strong currents to achieve a carrying capacity of 5,000 kg to 90,000 kg per hectare.

Exceeding these carrying capacities results in:
1) nutrient and disease contamination of the overall ecosystem and 2) collapse of pond production due to disease and poor water quality, resulting in significant economic losses. Taiwan, China, and Indonesia have experienced these effects.

Reasons for Going Offshore

Among our reasons for turning to offshore aquaculture, we note the need to:

- Relieve pressure on coastal or estuarine waters, where nutrient loading due to human activities is at or near the carrying capacity of the system,
- Reduce conflicts with other users of the same water resources,
- Reduce offsite effects of adjacent land uses for estuarine resources,
- Maximize use of large volumes of high-quality water to decrease stress on cultured organisms,
- Access large volumes of clean water for production of feed-fish feeding molluscs,
- Reduce the regulatory and permit requirements, and
- Permit culture of high-quality, open-ocean species, such as the 30 million metric ton seafood deficit and create profit.

Constraints

We must note among the constraints to offshore aquaculture, the extremely hostile environment requiring new engineering and a large investment, the high and new regulatory, lease, and permit requirements, and the incomplete state of life history control for many candidate species.

- Lack of financing and government assistance,
- Difficult logistics for transportation, chemicals, stocking, feeding, and harvesting,
- Lack of established government policy regarding offshore aquaculture, and
- Uncertainties about liability.

What We Envision

The types of offshore aquaculture we envision and are developing include:

- Surface cages and pens with fixed and flexible moorings (marine fish),
- Submersible cages and pens with fixed and flexible moorings (marine fish),
- Fish culture of algae, scallops, and mussels,
- Shellfish culture of scallops,
- Enhancement of stocks of scallops, marine fish, and crustaceans. Japan stocked 85 marine species in 1982, and
- Future in the future, even manned fixed and floating facilities.

The Governance Role

The governance role in offshore aquaculture is and will be:

- Establish clear regulations and policies,
- Subsidize research costs in developing the new technology needed. Continuity of support is important. Most new technologies take 20 years to implement,
- Provide outreach and education support,
- Provide coordination of research and extension effort,
- Provide international coordination mechanisms,
- Establish lease programs for bottom and water-column sites.

Present U.S. Government activities in offshore aquaculture coordination efforts include a joint subcommittee on aquaculture (USA) that consists of 23 federal agency representatives and that exists to coordinate federal efforts.

The USA developed the first national aquaculture plan in 1983 and is in the process of revising the ea-
tional plan. The revision will deal primarily with how governmental agencies will coordinate and conduct business related to aquaculture.

The JSA will convene regional meetings in the Northeast, Northern, Southern, Southeast, Midwest, and Gulf Coast regions this summer to encourage input into national plans for the first time. At least three of these regions have offshore zones, and this will be built into the national plans. The main players for offshore aquaculture in the JSA are the Sea Grant, NMFS, and USDA, but the U.S. Army Corps of Engineers, EPA, and other agencies will become involved.

NOAA has developed a strategic plan that includes offshore aquaculture development through both the National Sea Grant Program and the NMFS. The National Sea Grant Program has completed its strategic plan and is already funding several projects at a level of $100,000 per year related to offshore aquaculture. A new competition will be held in fiscal year '86 for new proposals in this area.

The NMFS has funded several projects for offshore fish culture and scallop culture through both Sexton and Kennedy grants and Fishing Industry Grants (FIGS) — $350,000 and five projects.

The USDA's regional aquaculture centers have supported some offshore-related projects.

What are the main U.S. international activities in offshore aquaculture?

The JSA, in the fall of 1996, is sponsoring a workshop in cooperation with Canada and Norway on alternative species for cultured fish culture.

NOAA continues an international cooperation program on aquaculture with Japan through the U.S.-Japan Natural Resources Panel on Aquaculture. Plans are being made to conduct a collaborative project on finfish enhancement in both countries and to analyze the environmental, economic, and social impacts of marine fish enhancement (UMR-Forinter).

NOAA maintains an international cooperation program with China through the U.S.-China Center for Science and Technology. The U.S. and China have joint projects on marine algae and scallop culture in offshore locations.

Our Future Directions

What are our future directions?

Development of offshore aquaculture requires a multi-disciplinary, multi-agency, and even multinational approach. The goal is similar in complexity to a NASA space program. The scale is bigger than anything attempted in the past and the involvement required is every bit as difficult to work in an outer space.

There is very little new money to develop the advanced technology and we are going to have to form partnerships, both nationally and internationally if we wish to advance at a good pace.

Everybody in this room who is dealing with developing this new economic sector is a pioneer serving to accomplish what is worthy of the dreams of a Jules Verne. The titles of many of the talks include reference to “Blue Frontier,” “Frontier,” and “Challenges.” This is certainly the case.

It is important to remember that we are still dealing with the carrying capacity of whatever ecosystems we are dealing with. There will be optimum levels of development that are appropriate to any specific location. The environmental groups will make sure that we conform to the carrying capacity of the environment.

We must keep in mind that the genetic consequences of offshore aquaculture and fish farmed in such systems must have genetic diversity equal to the wild stocks that will share the water mass with them. The wild stocks should be the genetic reservoirs for this industry.

Your various government partners will continue to provide the research support to develop the most envi-
Defining the Federal Role in Offshore Aquaculture: Should It Feature Delegation to the States?

Alicia Brewer
Director, Marine Law Institute
University of Maine School of Law
Portland, Maine

Abstract

In this paper I describe some of the important attributes of an effective legal framework for ocean aquaculture and discuss the ability of federal agencies to provide these attributes under current law. I review key provisions of proposed federal legislation for management of aquaculture in the 200 mile Exclusive Economic Zone and sketch out an alternative system of state-based management with federal oversight and coordination.

Overview of the Issues

Communications have noted the legal and regulatory barriers to aquaculture development in the U.S. for at least the past 20 years. The constraints generally attributed to legal and institutional factors include costs of time, expense of applications, and uncertainties all of which may dissuade entrepreneurs and scare off investors and banks (e.g., Mass. OCEZM, 1995).

The National Research Council (NRC) found in 1978, for example, that the procedures required to obtain permits and licenses "have been a serious deterrent to aquaculture" (NRC, 1978). The major problems related to the lack of uniformity of laws in different states, the difficulty of obtaining concise lists of the legal requirements within a given state, and the difficulty in obtaining the many permits and licenses.

The NRC study also concluded, however, that while some laws and regulations may reduce aquaculture's economic potential, aquaculture development...
may also be constrained by the absence of laws. It is
noted that laws provide many forms of government
protection for their residents, including protection
from unreasonable and unreasonable practices, in
the form of legal protection, technical advice, and
public services. Moreover, in
and even commodity price guarantees. Moreover, in
case of its absence, an effective legal framework is
comparable to the basic specific of ownership if they
are lacking even the basic specifics of ownership.
(Wilson, 1983)

Aquaculture is heavily affected by public laws be-
because it involves many things that modern govern-
dermants are concerned with: food production, water supplies, the use of navigable waters, and environmental protection. Thus, aquaculture has become a part of the aquacul-
ture legal maze if they are concerned with food safety, public health, water quality, or land and water conserva-
tion. As concerns for these issues occur at all three levels of American government: federal, state, and local. What appears to be relevant is that a multi-
ple number of the fact that American governmental power is often exercised at three different levels with each level having its own special responsibility or interest. Therefore,

Some of the ways in which laws present obstacles to aquaculture include:

- the existence of overlapping regulations due to
  heavy overlapping agency responsibilities,
- inappropriate restrictions designed to protect
  wild species,
- poorly defined agency jurisdictions leading to
  delay in defining applicable standards or regu-
  lations,
- limited availability of property rights or other de-
  creases that can secure a producer's investment,
- poorly defined standards that fail to reduce con-
  flicts among competing uses of public re-
  sources (NRCC, 1976).

Security of Tenure

Probably the single most significant question one
must ask about any legal framework affecting marine
aquaculture is: how secure is the tenure? The sea
farmer receives from a government? In order for the
farmer to function for the sea farmer as a property in-
terest, it should have some of the following attri-
butes: transferability, duration and renewability, and
renewability only if failure to perform specified con-
ditions (Wilson, 1983). These conditions, however,
are not present in many existing regulatory systems.
In Massachusetts, for example, where the state and
local governments issue licenses for marine aqua-
iculture instead of leases, court decisions suggest that
when the above features are not present in a license,
the land of state title conveyed under current
state law do not convey sufficient interest to create a
property right that the holder can defend in court or
use to recover damages (Compare County v. Metropo-

cial District Commission, 298 Mass. 368 [1940];
with Bay State Lobster Co. v. Penins Corp., 355 Mass.
761 [1969]).

On the other hand, when the government seeks to
create private interests in land or water through an
exclusive lease or license, special legal principles
designed to protect public uses known as public trust

crights can come into play. These public property inter-
ts must be balanced against the sea farmer's needs
for a secure interest in the cultured species and for
protection against damage from other activities
(Zielenberg and Versel, 1992).

Legal differences between the lease and license
forms of tenure must be considered carefully. The
lease has advantages over a license, but it does not
give the sea farmer exclusive control of an area of the
ocean. The legal principles mentioned above govern
the conversion of exclusive private use rights to submerged land or waters in perpetuity. Since that is not
the lease form to secure tenure under the sea farmer's
use subject to public and private riparian rights and to government oversight. To improve the security of this interest, governments can provide for criminal sanctions and a civil right of action against individuals who violate the sea farmer’s rights as leasee of the seabed and water column (Wisniewski, 1987). The public rights of navigation and fishing must be preserved in the leasing system, and this brings us to consider the process by which the government conveys an interest to the sea farmer.

Use Conflicts

Even when the sea farmer’s lease or license is backed by criminal sanctions against private or public damage or interferences with the farming, the lease must ensure peaceful coexistence among all users of the marine environment. It is crucial, therefore, that the government’s process for issuing the lease or license itself protect the sea farmer from conflicts with other marine uses. The statute authorizing the consummation of a lease of public waters or submerged lands for aquaculture should identify other public and private users of the marine environment and provide a fair but efficient process for information to be brought forward about those uses so that the leasing agency can make an appropriate decision and to offer users believe they have been fairly heard. Failure of town officials to consider conflicts with riparian owners’ use rights in licensing shellfish farms has led to judicial decisions that may adversely affect sea farming opportunities (Doremus, in press; discussing Fritchie v. Division of Marine Fisheries, 611 N.E. 2d 547 [Mass. 1993]).

The New England Fishery Management Council’s recent difficulties with the approval of an amendment to the Atlantic Scallop Fishery Management Plan to allow the Westport Scallop Corporation’s transportation project illustrate the problems that arise if the agency is not familiar with the needs of new sea farming operations, is not subject to deadlines for its decisions, and if the statute does not make clear who has the burden of proof to come forward and when on the issue of potential conflicts (Gobeley, 1990). The Maine aquaculture licensing law, by contrast, requires a formal adjudicatory hearing before a lease can be issued (Maine, 1990). While sometimes time-consuming and contentious, the process does ensure that potentially conflicting uses are given an opportunity to be heard and their interests balanced against those of the prospective sea farmer. This gives the government’s issuance of a lease more merit legitimacy once it is finally approved (Fritchie, 1993).

Agency Coordination

The question of fragmentation and overlapping agency mandates must be addressed. An apparently redundant regulatory requirement may actually serve a useful purpose. Sometimes, in other jurisdictions, can improve the security of the interests of the sea farmer establish when it is evident that an agency with a different constituency has accepted an aquaculture project both in principle and in reality.

Regulatory and reviewing agencies have considerable more latitude and discretion in coordinating their reviews than is often apparent. A modest effort to cooperate among state and federal agencies in Maine, while it may require a single application, still requires separate review procedures. Nevertheless, the agreement has been described as a breakthrough in administrative agency cooperation (MLJ, 1993a). Much more is possible in the way of reducing separate permits reviews and procedures, without compromising agency responsibilities.

A final consideration is whether the framework provides a specific mechanism for exempting aquaculture from regulations that are designed to conserve wild fish stocks. If a government agency has authority to waive certain state, state, and other requirements, what procedures must be followed? These decisions should not have to be made by the legislature and preferably set out on a case-by-case basis. Such a role a special waiver is necessary, the opportunity for coordination and political
pressure exists. It would be especially inappropriate if the waivers had to be approved by a marine fisheries advisory council, as marine fisheries are likely to oppose proposals that might impair competition for the seafood market. This consideration should be weighed very heavily in decisions whether to encourage the expanded role of the regional fisheries management councils in EEZ enforcement decisions, as well as their jurisdictional limits. The Magnuson Act (Johnson and Hayes, 1993).

Elements of an Improved Government Framework for Aquaculture

In a series of reports prepared for the National Council on Aquaculture and the Northeast Regional Aquaculture Center, the Marine Law Institute (1982) developed a set of recommendations for improving the security of tenure and the coordination of state and federal regulatory frameworks to facilitate the development of sea farming operations. These recommendations include the following:

- The responsible government agency should identify marine zones favorable to sea farming and consult with interested environmental organizations, potential users, and potential stakeholders.
- All state and federal permits and leases should be reviewed in a comprehensive application procedure, including site, environmental, and potential use.
- Aquaculture leases or licenses should convey an exclusive property interest in the water and in the lease area, as far as consistent with public rights of navigation and access, to ensure the farmer’s investment against theft and vandalism, and to allow for civil liens of owners against persons who interfere with or damage aquaculture facilities.
- State and federal agencies should adopt memorandum of understanding, coordinating enforcement, research and other assistance.

- Maximum access limitations should not apply to contracts, joint ventures, or partnerships between small-scale farmers and larger aquaculture companies so that cooperative arrangements can be implemented.
- Government agencies should provide priorities in licensing or leasing to farmers who have been licensed to conserve fisheries in an appropriate non-discriminatory manner of promoting local economic benefits from sea farming.
- Private agreements between farmers and local, state and federal government or cooperatives, community groups may resolve the dispute and promote local economic benefits and acceptance of sea farming.
- Agency public hearing procedures should balance the due process rights of leaseholders with the public right of participation in decisions affecting public resources, and should be formal enough to exclude interventions not relevant to the hearing session, but not so formal that small-scale sea farm applicants are faced with prohibitive application costs.
- Public and private efforts should be made to ensure an insurance pool to compensate farmers for losses due to disease or water pollution or other hazards, and to protect public health.
- State and federal licensing authorities should adopt standard procedures for small-scale and experimental farming, with reduced application requirements and expedited procedures.

Implications for the Federal Role in Offshore Aquaculture

In 1992, the National Research Council’s Marine Board recommended the federal government take a more active role in assuring the development of offshore aquaculture to avoid the many conflicts encountered.
used by sea farms operating in the EEZ (NRC, 1992). The report noted that use of the many problems with the move off shore was the lack of federal regulations in the EEZ (NRC, 1992; Stickney, 1990).

When American Norwegian Fish Farm, Inc. proposed a large-scale net-pen culture farm in a permit application to the U.S. Army Corps of Engineers for a site 21 miles east of Gloucester, Massachusetts, two things became apparent. Federal agencies and others interested in the marine environment quickly realized that people were in fact willing to site facilities farther offshore. The federal legal framework however, was not prepared for the number of concerns that such facilities presented (Stickney, 1990). The project consisted of many floating salmon pens, attached in groups of six to a series of nine 30 meter long barges anchored to the continental shelf at a single mooring point. The facility was designed to swing with the tides and currents around the anchor point. NOAA estimated that it would require exclusive use of an area of about 50 square nautical miles in the EEZ.

A committee convened at the time by the Office of Technology Assessment to consider policy options for EEZ aquaculture concluded that a simple leasing program without royalty payments was appropriate given the limited profits that could be expected. The committee also suggested that Congress consider moving collaboratively with the coastal states in developing a program to promote orderly development in the EEZ. However, some facilities were likely to be sited in places where federal and state jurisdiction meet (Stickney, 1990). At the time, the NRC's Marine Board concluded similarly that the federal government should create an orderly framework for the development of EEZ aquaculture and should encourage coastal states to adopt and implement aquaculture development and management plans (NRC, 1992).

No easy framework was ever created, however, nor was a federal-state partnership formed in time to deal with the first major offshore proposal. What followed, unfortunately, was an effort by federal agencies to determine their power and responsibility to regulate activities, as with the Army Corps' decision in 1991. The Corps' decision in 1991 was to reject the proposal and to begin the process of determining the appropriate level of regulation. The Corps' publication of its final environmental impact statement in 1994 set the stage for the next round of controversy and debate.

NOAA, Office of General Counsel, Federal Law. The NOAA Office of General Counsel concluded that the proposed farm would constitute "fishing" under the Magnuson Act because it would involve harvest from the EEZ by vessels of the U.S. The regional fishery management councils therefore had the authority to manage aquaculture in the EEZ, and would need to assess existing federal management plans to prevent restrictions on harvesting of cultured species (Holmes and Hayes, 1993). NOAA contends, in fact, that it has a strong statutory basis for the protection and regulation of marine aquaculture, supported by a history of public and private sector research and development. The federal agency tasked with regulating marine aquaculture, NOAA, contends, is the Office of General Counsel, Federal Law.

NOAA is not at present the lead or even the major federal presence in aquaculture regulation. Federal authority centers largely around the Army Corps of Engineers permit process under the Rivers and Harbors Act, 33 U.S.C. 403 (as amended by the Outer Continental Shelf Lands Act, 43 U.S.C. 1336(e), and the Corps' "public interest review" under 33 Code of Federal Regulations section 320.4(a)(1)), which requires a balancing of all the reasonably expected benefits and detriments to the public interest, including environmental, economic, aesthetic, navigation, property rights, and international interests. The EPA also asserts regulatory authority under the Clean Water Act over discharges from aquaculture facilities as "concentrated aquatic animal production facilities." Other federal
agencies, including NOAA's National Marine Fisheries Service, the Coast Guard, and the Fish and Wildlife Service, have an opportunity to review and comment on any permit requested for issuance by the Corps of Engineers for impacts on navigation and marine wildlife and habitats (Goldberg et al., 1996).

States also may play a role in the federal permit process. In addition to water quality certification of proposed federal discharge permits under the Clean Water Act, the Coastal Zone Management Act requires any permit for activities that affect land, water, or natural resources of the coastal zone subject to state review for consistency with approved state coastal zone management programs. A state can reject a federal agency's consistency certification if the proposed activity conflicts with an enforceable state law or policy included within the state's approved program, 33 U.S.C. 1424(c)(1)(A). If the state objects, the permit or license may not be issued, unless the Secretary of Commerce reverses the decision. Few states at present have enforceable laws and policies concerning aquaculture within their approval management programs necessary to take full advantage of the process. Massachusetts, however, uses the federal consistency requirement as an opportunity for increasing its ability to encourage the development of marine agriculture and to increase the efficiency of the regulatory process. In its recent Strategic Plan for aquaculture, the Commonwealth notes that its plan to greatly increase review of offshore aquaculture proposals (Mass. GOV, 1995).

While the process for obtaining an individual permit from the principal federal agencies is lengthy and cumbersome, under the CMP and the FPA have the authority to issue a general permit under their respective regulatory authorities. The general permit is a mechanism for granting authority for a class of regulated activities that eliminate the need for an individual permit for each activity. Provided the activities are below specified size or degree of impact thresholds. Both the FPA and the Corps could theoretically issue a general permit for ocean agriculture facilities that employ common culture methods, design features, and other factors, and subject them to annual permit conditions and monitoring protocols. The Army Corps uses a State Programmatic General Permit for approving small-scale sea farms in Massachusetts, in essence "plug-and-play" on state permit approvals, and the Commonwealth has plans to increase the coverage of the general permit to allow even further regulatory efficiencies (Mass. GOV, 1995).

The FPA has yet to issue a general permit for marine aquaculture. It has used the mechanism in the past for marine activities, issuing in the 1980s a "common permit" to all offshore exploratory drilling rigs, after the agency finally accepted the industry's regulatory authority under the Clean Water Act applied (Brennan, 1995a). The case of ocean aquaculture is different from the OCS drilling permit, however, because the EPA was faced with hundreds of existing discharges from drilling operations in the Gulf of Mexico and elsewhere. Open ocean aquaculture operations are only in the planning stages. The FPA does not face the same permit burden and thus does not have the same incentive for adopting a general permit to facilitate OCE aquaculture. While agencies like the Army Corps are under some pressure to reduce regulatory burdens and to streamline their operations, it is not clear whether they are willing to reduce their authority in deference to another federal agency, such as the National Marine Fisheries Service.

Judgments over aquaculture appear to be a sore point with some federal agencies at present. The memorandum of agencies' jurisdiction written at the time of the American Norwegian Fish Farm, Inc. project (Brennan, 1995a), as well as the more publicized debates over the Department of Agriculture versus the Department of Commerce at the appropriate level federal agency, suggest that a " turf battle" among agencies may be well underway. While not unusual in environmental and natural resources policy, these battles strain resources and tend to work against the public interest in the long run. This brings us to the question of what the above considerations and
Proposed Federal Legislation on EEZ Aquaculture

Many of the above issues are reflected in a federal bill introduced on behalf of NOAA in 1992 by Senators John Kerry, Paul, and Inouye. For example, the bill states that the exclusive economic zone is not a place where private industry has not invested in and developed marine aquaculture facilities within the U.S. EEZ in part because "ocean waters are not susceptible to private ownership and because they also protect public interests, including navigation, fishing, recreation, and national defense." Because marine aquaculture presents "several environmental challenges, requiring specialized scientific research and regulatory programs," the bill finds that "incorporating environmental concerns in the development of marine aquaculture will enhance the prospects of an economically and environmentally sustainable industry."

The bill would declare it a federal policy "to ensure that the placement of any new marine aquaculture facility within a coastal state tends, the territorial sea, or the U.S. EEZ, is environmentally and economically sound and does not pose unreasonable or excessive costs to other public uses of marine waters, such as navigation, fishing, recreation, and national defense." The following discussion considers the bill in light of the three major considerations identified above.

Security of Tenure

Section 6 of the bill would provide a new federal permit requirement for permits, leases, or transfers for a new federal permit, and an existing federal permit, for a new marine aquaculture facility. The permit would allow the Secretary of Commerce to issue permits allowing the ownership, construction, or operation of a marine aquaculture facility for up to ten years, renewable upon expiration. The section makes clear that once the facility obtains a permit, the physical structure, the organism stocked within it, and any business interests in the facility can be privately owned by the permittee, but the area of ocean used remains in public ownership, with only a reasonable use permit being granted. The permits may be revoked for substantial violations of either the permit conditions or the Secretary's regulations. The permits could be transferred and permit fees are limited to the costs of administering the permit program.

The bill defines "offshore marine aquaculture facility" as any facility that is located in whole or in part in the U.S. EEZ, the purpose of which is to raise, breed, grow, harvest, or hold in a living state any marine or aquatic organism. It states that any person or other entity owning or operating an offshore facility on the seabed, within the U.S. EEZ, shall be subject to the requirements of the Clean Water Act, and any discharge of material or chemicals into the waters of the U.S. EEZ shall be considered a point source. The bill is clearly intended to ensure that these facilities and the wastes involved with them are covered by the federal National Pollution Discharge Elimination System as a condition of discharge, which would presumably include discharges of food pellets and nutrients.

Does the proposed bill offer sufficient security of tenure for the sea farmer?

The bill is transferable, renewable, and revocable only for cause and is not provided with some of the minimum features. A sea farmer, however, needs an interest in the facility that can be sustained against the cost of the Federal deposits, and a reasonable permit or license in order to convey only a substantial interest. A transfer is from the State and, if it is for the retransferring of the property at another without altering or damaging the substance.

The alternative to a permit is a lease, the mechanism used in the Outer Continental Shelf Lands Act.
convey to private companies rights to explore for and develop oil and gas resources from the seabed, and by the State of Maine for aquaculture in state waters. Leases can be structured to allow cancellation upon violation of conditions designed to protect public uses and values. While issuing a permit rather than a lease allows the agency to use the informal notice-and-comment process, a permit is not likely to provide a legal basis for a sea farmer to bring an action in federal court for interference. The choice of a permit over a lease may have more to do with the public relations of aquaculture than with administrative convenience. Leases are better for the sea farmers, but they may be viewed with more suspicion by the traditional fisheries who feel threatened by just about every new use of the marine environment. If a permit is to be used, the bill should support the sea farmer’s interest through federal prohibitions and sanctions against interference. At least one bill considered by the 105th Congress to require that the Magnuson Fishery Conservation and Management Act would make it a federal offense to interfere with marine aquaculture in the EEZ.

Agency Coordination

Before the Secretary may issue the permit, many other agencies have an opportunity to add conditions to it. The Corps, the EPA, the Secretary of the Interior, the appropriate regional fisheries management council, the Defense Department, and the Governor of each state adjacent to the proposed facility’s site (or which would be ecologically affected by permit activities) whose state has an approved coastal zone management program must have at least 90 days to review the application. Each of these officials must certify that the activities in the permit would comply with the laws they administer. If they conclude that they cannot so certify, the Secretary must attach conditions to the permit which the agency or Governor submits would ensure compliance. This review process allows agencies like the Corps and the EPA to attach conditions that would allow compliance with the Rivers and Harbors Act and the Clean Water Act. The bill, however, does not exempt sea farms in the EEZ from the need to get separate permits under those laws.

The Secretary’s own position for issuing the permits include a determination that the activities would comply with the Secretary’s environmental standards, which include regulations issued under Sections 306, 307, and 308 of the Federal Water Pollution Control Act, as amended by the Water Quality Act of 1965. However, the Secretary is required to conduct a public hearing before issuing any permit. The bill provides for a public hearing before issuing any permit. The Secretary must consult with other agencies and provide adequate notice of the hearing. The Secretary must consider any comments received and must make a determination before issuing any permit. The Secretary must consult with other agencies before issuing any permit. The Secretary must consider any comments received and must make a determination before issuing any permit. The Secretary must consult with other agencies before issuing any permit. The Secretary must consider any comments received and must make a determination before issuing any permit.
s to minimize the potential damage to marine ecosystems, minimize "visual pollution" and other interferences with public uses of the ocean, and ensure that pollution control efforts for cultivated stocks are ecologically sound. The Secretary is directed to develop a program to encourage voluntary compliance with the guidelines by the marine aquaculture industry. After development, the Secretary is to submit the guidelines to the state coastal zone management agencies and other federal and state agencies involved in either marine aquaculture or other coastal and marine resources for possible incorporation into state aquaculture programs or permitting processes.

This section also aims to improve state regulatory decisions through recommended standards and guidelines. No incentives, however, are provided for states to adopt such measures, although the ability to offer a streamlined regulatory process, focused on state reviews following federal standards, could be a powerful one and a very attractive prospect for potential sea farmers. Sea farms are going to have a base of operations somewhere. It stands to reason that the state in which this base is located can exercise oversight of the sea farm's entire activities, following certain federal guidelines and minimum standards.

Use Conflicts

To prevent use conflicts, the bill relies on criteria for the federal permit that the project will not significantly interfere with "other" public uses of the ocean, which includes recreational and commercial fishing, navigation, conservation, and aesthetic enjoyment; nor interfere with facilities previously permitted; that the permittee will remove or properly dispose of the facility if the permit is revoked or surrendered; and has provided a bond or other guarantee to pay for all costs associated with the facility's removal. To determine if the potential for use conflicts exists, the bill relies on the standard notice and hearing process and review by other agencies. The bill does take advantage of the many new, regional, consultative and oversight procedures that are in use in federal marine sanctuaries and under state and provincial tsunami response laws. These regional committees and advisory councils involve non-external users early in the process and would give sea farmers a great deal of assurance that the ocean is not being used in a manner that is harmful to other users. In Nova Scotia, for example, regional aquaculture boards are charged with bringing together many points of view and stakeholders to facilitate the often controversial permitting process. The Senate bill, however, allows the creation of a national aquaculture advisory and review panel but uses them only in assessing the administration of the research and development grant program the bill would create.

Also, the bill contains a mandate with respect to the position of aquaculture vis-a-vis other uses of the ocean environment. It refers to the conflict with "other" public uses that must be avoided, suggesting that aquaculture is becoming a public use. If this is the intend, this status may be contrary to some state law. For example, under the state of Maine mentioned previously, the Massachusetts law, specifically the Massachusetts law, has decided that aquaculture is not fishing and is therefore not one of the protected public uses rights. The bill makes no mention of whether priority is to be given to existing uses regardless of their nature or impact on the ocean, nor provides a standard by which to judge claims of potentially significant interference.

Finally, what is most interesting about the Kerry bill is that it contains no sense of the current debate in Washington, D.C. and elsewhere about federal regulation. The reduction in federal involvement is already apparent in the management activities held in the 1990s in the region by the Commerce Department, and withdrawing all fishery management plans for fisheries that NOAA believes can be better managed by states or interagency commissions, including American lobster, spiny lobster, mackerel, and high-value Pacific salmon.

With these criticisms in mind, we turn now to an alternative model for regulating open ocean aquaculture.
A Proposal for State-Based, Regional Management of Aquaculture in the EEZ

An alternative to the Kerry bill approach would essentially reverse the roles of federal and state agencies, with federal agencies retaining their authority to prevent navigational conflicts and national security problems, and permits or leases issued by a coastal state, instead of NOAA, issuing the permit and receiving consistent certification or proposed conditions. A state with a federally approved aquaculture management program would do so. The idea is to delegate federal executive and regulatory responsibilities regarding offshore aquaculture facilities to the adjacent coastal state, if the state has adopted a comprehensive program for the management and oversight of marine aquaculture.

Each federal agency that presently asserts regulatory jurisdiction has some capacity to delegate its permit authority to a state agency, either through express provisions like the Clean Water Act section 404(d)(4) (although limited to navigable waters within the state's jurisdiction) or through administrative measures such as the Corps' state programmatic general permit. The full delegation may require amendments to the federal laws or make clear under what conditions federal delegation would be acceptable. Absent such amendments, the details of the delegation could be worked out by interagency agreement among the principal federal agencies, the Corps, the EPA, the Coast Guard, and NOAA, on the coordination and delegation of their responsibilities to the state.

Generally, in the past, these voluntary delegations of federal responsibilities have been difficult to carry out. For example, states have not had much success in achieving a federal management responsibility for marine mammals under Section 109 of the Marine Mammal Protection Act. What may be more feasible would be a partnership for management, much like the more recent national marine sanctuary programs that involve both federal and state waters, e.g., the Florida Keys and Monterey Bay (Sarma, in review).

A memorandum of understanding or interagency agreement could be the vehicle for coordinating these federal delegations. This text would provide guidelines for state programs that are very general and not include a list of detail like that under the Clean Water Act section 404(d) or the Marine Mammal Protection Act section 109 delegations, but with sufficient detail to ensure that the states are going to meet the public trust obligations and protect other uses. The state program would undergo review by the agency before it was operational in the EEZ. This could occur through the submission of an amendment to the state's approved coastal zone management plan. Funds are now available under the 1996 reauthorization of the Coastal Zone Management Act for states to develop strategic plans for marine aquaculture. These funds would be used to develop a state-based EEZ management framework as well as for state waters.

The development of these programs could be guided by new criteria agreed to by the three delegating agencies and published by NOAA. These criteria could include many of the terms identified in S. 1192, Section 7 on Model Environmental Guidelines. The criteria would be that the state program for offshore aquaculture is reviewed and approved by the other federal agencies would seize their ability to review individual applications, or would have a very limited time to comment formally with very specific concerns. The federal responsibilities to protect public lands and environmental quality would be carried out by the states under the approved program. Once the Secretary approves the state's program, the state could then use the federal consistency provision to ensure federal agencies comply with the coordinated regulatory process contained in the program.

Any serious proposal for delegating offshore regulatory jurisdiction to coastal states must consider where one would draw the boundaries between the states, particularly in New England where several states have claims that from the same offshore
states. While a full treatment of this question is beyond the scope of this paper, it should be noted that the issue of axial alignment boundaries is not new at the level of U.S. coastal management. The 1976 amendments to the federal Coastal Zone Management Act (PL 94-295) included provisions designed to increase the incentives of states to accept new exploratory and development drilling for oil and gas. Part of the legislation created a coastal energy impact fund and grant program that was to be allocated to the states based in part on the amount of outer continental shelf acreage that is adjacent to the state. Adjacency was defined as lying on the outer side of the "extended coastal seaward boundary" of the state, that boundary to be based on an existing or new inter-state compacts, judicial decisions, or by application of the boundary delineation principles of the 1958 Law of the Sea Convention on the Territorial Sea and Contiguous Zone.

The above is merely a brief sketch of a possible approach. Further thought must be given to the proposed framework. It is clear, however, that much of the enthusiasm and opportunity for developing an effective framework at the state level, as state and local governments, fishermen, and conservation groups look for ways to redirect marine resource development activities away from overfished species and provide an environmentally sound and sustainable source of seafood and coastal community economic benefits (Bevec, 1990).

References


Heinberg, Tom and Robert Veizal, 1992. Improving the Legal


Conceptual, Engineering and Operational Frameworks for Submersible Cage Systems

Michael D. Willinsky
Coastal Services Inc.
Burlington, Ontario, Canada
and
John E. Bigelow
Massachusetts Maritime Academy
Buzzards Bay, Massachusetts

INTRODUCTION

Aquaculture varies from the short term holding of captured organisms to control over the entire life cycle of an aquatic life form. Mobile organisms must be contained in net pens or cages in control environments while allowing adequate water exchange with the surrounding aquatic environment. Natural systems may pass frequently unvisited from dramatically reduced production due to poor water circulation and changes in internal water quality. Cages, having netted bottoms, offer improved water circulation although this may be accentuated if too many cages are nested into a large system.

During the development of aquaculture techniques, substantial reliance was placed on existing engineering knowledge. Recently, ocean physics has produced highly sophisticated modeling software that is a powerful adjunct (Bezaire, 1991). To coordinate the requirements of a modern cage, the efforts of physicists, structural, mechanical, and ocean engineering are required. More than a little yin and yang is also needed to devise a structure that can remain fixed in a constant state of balance with the opposing forces of nature. This is ever more so the case once cages are expected to survive in the constantly hostile environment of the "expansive" coastal ocean, i.e., if seven mile front of water produces about one million cycles per month of wave induced tension, compression and tension loads on a cage structure 12 million cycles per year.
120 million cycles over a ten year design service life for a structure requires a very long-term fatigue life, even exceeding the fatigue life of a Boeing 747 for landing and preservice degradation cycles.

A major factor in determining service life is consideration of the amount of deflection a structure undergoes. When calculating the service life of a marine cage one must be cautious since small deflection assumptions do not hold for flexible structures. The small deflection assumption assumes design loads will not cause significant deformation or deflection.

Let us now proceed to review the modern aquaculture cage experience and then examine in more detail the design of a substantiable cage system.

BACKGROUND

Aquaculture is an industry based on the efficient management of large volumes of water.

Man's experience in aquaculture has mainly involved the use of fish, although shellfish, shrimp, and even fish have been grown in cages or pens. Culture systems tend to be high value species for human consumption, even in underdeveloped countries. Reviews of culture practices in freshwater (Cochrane, 1978) and in estuarine and marine environments (Beveridge, 1987; Hogstrand, 1994) exist.

Aquaculture in these natural bodies of water is diverse and widespread. Cultured species include species in southeastern Asia, oysters in the U.S, and elsewhere, milkfish in Asia, tilapia and carp in many places. The most widespread species are salmonids grown wherever water temperatures and conditions allow.

Recent growth of farmed fish stocks and ornamental not cats is a unique type of cage farming that has had success in Denmark, Germany, and Switzerland (Unger, 1984). Today, the highest production of aquaculture production has occurred in temperate climates in salmon and the growth out of yellowscale, sea bass, trout and salmon. Although salmon represe...
## Table 1. Sheltered vs Exposed Sites

<table>
<thead>
<tr>
<th>Sheltered Sites</th>
<th>Exposed Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td>Protected from storm waves and wind intrusion</td>
<td>Vulnerability to strong winds and waves</td>
</tr>
<tr>
<td>Easy access for monitoring, servicing, and cleaning</td>
<td>Engineering problems</td>
</tr>
<tr>
<td>Known procedures for carrying out required activities</td>
<td>Difficulty in access and logistics</td>
</tr>
<tr>
<td>Fewer obstructions, more exposure, easier re-evaluation</td>
<td>Requires development of new methods for monitoring, servicing, and cleaning the plant system</td>
</tr>
<tr>
<td>Lower probability of pollutants from other sources</td>
<td>Higher probability of impacts from large storms</td>
</tr>
<tr>
<td>Fewer interactions with other activities, less opposition from other users</td>
<td>Possibility of physical or structural damage due to waves or flooding</td>
</tr>
</tbody>
</table>

### Notes
- In 1992, the National Research Council issued a report on the effectiveness of coastal wetland systems, highlighting their importance in storm mitigation and pollution control. The report also noted the need for enhanced wetland design and engineering practices to improve their effectiveness.
- Wetlands provide a natural buffer against storm surges and can significantly reduce the impact of coastal erosion.

### References
The degree of exposure previously mentioned, i.e., "sheltered" vs. "exposed," requires some definition. "Sheltered" sites are normally large bays protected from most winds. If this natural protection coincides with the prevailing storm direction, it can be substantial.

Open coasts can also provide substantial protection if the site is on the lee side with respect to prevailing storm directions. An "exposed" site is defined as one that is partially sheltered, and an "offshore" site means one with little substantive protection.

There are other important differences between "inshore" and "offshore" environments that must be considered for aquacultural design and operations (Gorman & Edwards, 1990; Linehan, Cannon, & Petta, 1992). In "sheltered" sites, tidal currents can be high, but the same body of water may be coming back on the next tide. Cross circulation does not always equal with flushing. This is an important consideration in using large-scale farms. In "sheltered" sites, water quality tends to be more variable; i.e., colder waters, but some kinds, higher oxygen levels. Offshore water quality remains more constant. There is some indication that "exposed" sites allow "offshore" sites to grow better-quality fish, with faster growth and reduced mortality (Sveale, 1988). In "sheltered" sites, deep-water, more severe environmental forces come from storm-induced tidal currents, whereas in "exposed" and "offshore" sites, storm-induced wave forces dominate.

APPROACHES TO OFFSHORE AQUACULTURE

As commercial development continues to be forced to move beyond coastal sites, possible approaches fall into three categories, shown in Table 1. The first category relates to unmoored cages operated well below the surface, for which there is limited experience. The depth of unmooring bottom cages is bounded by the required minimum depth for protection and the maximum depth for accessibility by divers. As a result of these tight constraints, there are not many suitable bottom-mounted cage sites.

Bottom-mounted bottom systems have considerable potential but are largely unexplored. They have the advantage of avoiding most storm effects by being bottom based.

Nestled surface cage systems, large single cages, and submerged cages are examples of bottom-mounted systems. Nestled cages are widely used for commercial culture of "sheltered" sites. Engineering problems with these systems at more exposed sites have pushed the current development of submerged cage systems. For large "sheltered" floating-buoy structures moored in "exposed" sites, the coast of Ireland, north coast of Morocco, and in the current case because of design failure. Both of these systems failed because they did not have sufficient depth of water for their length. This allowed larger deflections of the structure, which led to failure. These failures were too large to safely assume the small deflection, small deformation, engineering hypotheses. The importance of this failure was underscored by the structural designers at visual obvious deflections were observed in scaled models during testing of these systems.

The submerged systems, which operate either at or near the surface, can avoid storm effects by wave forces. Since wave forces decay exponentially with increasing water depth, even modest submarine structures below the surface substantially reduce wave forces from local storms. These cage systems can also be arranged to avoid undesirable surface water temperature, toxic phytoplankton blooms, oil slicks, etc. Floating defense. Periodic submergence is generally desired. An exception is the overwintering of Arctic cod under ice in the Barents Sea. As low temperatures, these fish require infrastructural feeding and monitoring during their three-month period of submergence, due to their low activity level. Submerged cages
have also been used commercially for sea bass and yellowtail sole and will soon be employed for

have also been used commercially for sea bass and yellowtail sole and will soon be employed for

The third approach to offshore aquaculture, shown in Table 2, involves operational barges or ships. Mobile, self-powered or towed, their deployment can be changed to reduce seasonally-affected growth. Vertical mobility can be used to decrease seasonal storm exposure as well as reduce logistical problems. If equipped, these systems can also be used for other aquaculture purposes. Although there are few commercial precedents for such systems, this option may have considerable potential if costs can be controlled.

ENGINEERING CHALLENGES OF "EXPOSED" SITES

The engineering challenges of operating cage culture systems in "exposed" sites fall into two categories: site-specific and environmental. Neither category is a reliable source of information on which to base decisions. Site-specific factors include the size and shape of the site, the depth of the water, and the distance from land. Environmental factors include water currents, wave action, and the presence of marine life.}

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Fish cages and their support structures can only tolerate a certain level of wave energy and current velocities. In moderate to severe surface waves, cages positioned at the surfe are most vulnerable because they are subjected to the severe and destructive breaking waves. Significant exposure to the breaking waves can cause structural failure of the cages. Significant exposure to the breaking waves can cause structural failure of the cages. Significant exposure to the breaking waves can cause structural failure of the cages. Significant exposure to the breaking waves can cause structural failure of the cages. Significant exposure to the breaking waves can cause structural failure of the cages.

Surface buoy and mooring systems that are capable of surviving under any weather and sea state are rare. All require periodic maintenance of their hardware. In heavy seas and storms, most buoy types are pulled under or get completely drifted by waves. Breaking over them. A large spar buoy with a vast mooring and a properly weighted, significant displacement volume below the spar’s surface is the most suitable, most survivable structure for a spar buoy (Wells, 1985). Breaking wave forces on a spar buoy are low since it presents a small area to the waves. Large spar buoys have been used as unmanned buoys (Dowling, 1960) and as open ocean moored test laboratories (Bergen, 1991).

Grow-out cages must be submerged below the destructive orbital water motion and breaking waves at the sea’s surface to survive. Depending on the ratio of wave height to wave length, the minimum water depth to achieve safety for the fish and cage is typically between one-fourth and one-half wavelength. At these depths, cages are positioned deep enough in the water column to avoid the dangerous water motion encountered before storm waves.

When extreme site data is available, it is possible to specify a “Design Storm” which can provide much of the required engineering design criteria. Most of the extreme events that the system will be designed to survive are associated with surface forces created by the Design Storm (specified storm waves, currents, winds). Wind waves impact, impact from boats, and ice. Ice frequency is a very serious survival problem for cages forced to remain on the surface. While small pieces of drift ice, at low current velocities, do not constitute a serious problem, collisions with larger pieces of ice or large pieces of ice are often not survivable, even at very low impact speeds. The only way to avoid severe ice damage is through careful site selection or by employing submerged cages. Impact of waves or debris with surface cage systems under storm conditions is usually not survivable without major damage. These collisions can be partially avoided by site selection or avoided altogether by submerging the cage system. Fender systems have been tried to reduce ice and debris damage, however, the fender system may be properly sized and adequately lowered or it could add to the survivability of the surface equipment.

Figure 1, shown on page 53, defines the structural design procedure for an “exposed” cage system. This approach is an elementary, if still difficult, treatment of the problem of fatigue failure. It must be remembered that fatigue failure will destroy many more fish cages than storms.

Storm wind speed is defined as the speed of a gust one mile long (gust mile) which is encountered at an elevation of 30 feet. The maximum wind velocity to be used in design calculations is a gust whose length is similar to the length of the cage system. Significant wave height is the average wave height of the highest 1/3 of the waves in a given wave spectrum generated by the design storm under deep water wave conditions. Deep water waves occur when the water depth is greater than 1/3 the wave length and can be calculated from the average wind speed of the design storm, the fetch length or the most exposed fetch length, the water depth along the fetch length, and an estimate of the duration of constant wind storm velocity from the design storm. As significant wave height represents an average of the highest 1/3 of the waves, it does not represent the biggest wave generated during the specified storm (U.S. Army, 1980). The “Design Wave” concept also has a subjective component since design wave parameters include
wave height, wave length and water period. As there is no unique value of wave height and period for a given wave height, cross-peakable values should be used.

The majority of exposed fish farms are likely to be situated in deep water or be near deep water wave conditions. If cages are located in water depths less than 1/2 the wave length of the design wave, the properties of deep water waves must be modified to account for interaction with the bottom. These interactions cause the wave length to decrease and the wave height to increase. If a second system is being considered, shadowing effects on downstream cages from winds, waves, and currents must be taken into account. This effect can be substantial, especially for fixed bottom flots (Rud, Auresen & Dahl, 1986; Aanes, Rudi & Løken, 1992). Shadowing must also be considered in normal conditions to ensure sufficient water circulation occurs through downstream cages.

Substations of a cage system provide substantial protection from wave forces which include asymmetrical drag and inertial components. As major storms approach, surface water conditions become dangerous. However, in most locations, neither depth nor duration of storms are likely to be of sufficient magnitude to produce anything but relatively short wave lengths. As a result, cages do not require deep submersion to avoid these wave forces. In spite of the pressure exerted on cages from shallow submersion, one submerged cage manufacturer's specifications state that cages can be submerged 50% to achieve protection from long wave length storm waves (Egeland Son Co., 1984). For most applications, the attainable depth of submersion will likely be limited by available depth of water and fish welfare physiology, rather than by cage hardware capability.

Major storms produce large increases in tidal currents, especially near shore. Force-current forces on cages are proportional to the current velocity squared, it is very important to determine the maximum current associated with the design storms. High currents can

**Figure 1 — Cage System Structural Design Procedure**

1. Find normal loading
2. Calculate design load
3. Find wave, wind & current loading
4. Calculate maximum wave length for storm
5. Determine wave & wind length of design wave
6. Assume no cages are present in storm
7. Form wave, wind & current forces on cages, rather than wave & wind forces on cages
8. Calculate maximum wave length on total system
9. Calculate maximum wave length on total system
10. Add forces of safety & check overall system design
11. Everything agrees and is acceptable. If not, make adjustments and recheck overall system.
substantially collapse cage netting even when current-related weights are employed. Cage systems can be reduced by as much as 60 percent (Aarnes, Fidler & Lofland, 1989). In operational operations, however, cage systems usually produce far less physical damage to the contained fish. Rigid frame cages, such as the German Trakker system, with rigid arms, do not suffer from such collapse in high currents.

Maximum design current is difficult to specify, as the values are often specific to a precise location. Local storm tide data, local knowledge, and the measurements can all be helpful in estimating currents values correlated with Design Storms. One must also consider the relationship of storm current and tidal state in developing the design current value.

The procedural details for the calculation of wind, wave, and current forces on floating and submerged objects are well covered by the U.S. Army (1988), and are discussed with regard to cage systems by Milne (1991), Bresnahan (1997), Carol (1998), Fidler, Aarnes, & Darby (1998), Onddek, Linn, & Aarnes (1989), Namurta & Riley (1988), Caruso & Lindgren, and Aarnes (1999), Fidler & Lofland (1990). Some structural analysis of specific cage designs intended for relatively "exposed" sites have been published. These include the Polarstar cage (Stecklind, 1992), the 22m Wavemaker Cage (Whitehead, Bell, & Shaw, 1996), the Denali Temporal Cage (Stem, 1998), and the Trakker Sea Cage (Robinson et al., 1991) and Wilkins, 1993). Some caution must be exercised in evaluating the data for maximum wave forces on the Wavemaker system when the design quasi-static structural analysis assumes rigid structures, small deflections, small strains and tolerates a wave or current properties throughout the structure. The effects of inhomogeneous nets, large surface areas of nets on net deformation, second-order effects, variable beam dimensions, and dynamic responses of complete cage systems are for the most part unknown. Deformations, deflections, and motions of large scale cage systems from major storm waves can be very substantial, visually impressing and unlike those seen in any other floating structure. Many structural failures of cages are due to fatigue resulting from dynamic factors and cyclic loading (Caruso & Lindgren, 1991). The computational tools available for ships and offshore structures are not well-suited to an analysis of conventional cage farm systems (Onddek, Linn, & Aarnes, 1989). The basic problem is that conventional cage components tend to move while others do not, creating unbalanced forces between them. When waves pass through a cage system that is not fixed, wave forces on any part of the system may be quite different magnitude and direction than in another part of the system. Cage motion included, the possibility of natural frequency resonance effect on some components may also be taken into account. The natural frequency of a cage is strongly affected by the cage's structure, draft, and mounting system characteristics. The importance, complexity, and inherent problems of dynamic effects on the determination of wave forces in cage systems is currently under research study through use of computer models and tank testing. While engineering capabilities and user specifications are improving rapidly, they will remain to be proven under prolonged field conditions, especially for "exposed" sites. Due to the engineering uncertainties associated with netted farming systems and their pronounced history of structural failures, modern surface net and submerged cage designs tend toward larger rigid hull support systems, and decoupled cages. The other approach is to submerge the cages below most of the wave effects to protect the cages and their contents from breaking. Shoaling effects on wave circulation in shallow cages are largely overcome by individualized moored cage systems, leading to improved water quality, improved stocking density and healthier fish. Although individually moored cages systems tend to be more costly, they are more difficult to harvest; it appears that the improved water quality and higher stocking densities may more than compensate for the increased cost of equipment.
CHALLENGES OF OPERATING AND SERVICING FISH CAGES IN EXPOSED SITES

The successful grow out of fish requires a number of activities to be carried out. For a cage design to be successful, operating and servicing functions must be considered before the cage design is finalized. Failure to do this results in inefficient operation and has been a common reason for aquaculture failures.

Some operating/servicing functions are only required once per culture cycle, while others are required daily. Operating and servicing functions and their frequency are listed in Table 3.

Operational requirements of cage systems have been a recognized area in the literature (Rice & Beveridge, 1990; Hair and Cockburn, 1994). Some new cage designs have considered these factors during the design phase (Wollin et al., 1991; Wollin, 1993). Operating and servicing functions must be accomplished efficiently, as at the required scale, with an absolute minimum of stress on the culture organisms to maximize farm efficiencies and profits.

The data shown in Table 3 is dependent on species and conditions and is provided for general guidance.

Grading is often required to ensure uniformity in size and condition. A harvest with a wide size and condition is frequently a stress-multiplying disadvantage. Japanese yellowtail, graded at stocking, generally do not have to be graded again during the grow out phase, whereas cultured species usually require at least one size grading over their grow out period. Some mixing of stock sizes is unavoidable, especially in large cages. Certain species are sensitive to handling, and conventional grading methods can be a significant source of mortality.

Thus, efficient grading of large quantities of fish with minimum stress is an important operational consideration. The size of the cage and its biomass are obvious considerations. While considerable time and

<table>
<thead>
<tr>
<th>TABLE 3 AQUACULTURAL OPERATING AND SERVICING FUNCTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FUNCTION</strong></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Feeding and stirring</td>
</tr>
<tr>
<td>Monitoring water quality and flow rate</td>
</tr>
<tr>
<td>Monitoring and control of water and health of organisms</td>
</tr>
<tr>
<td>Harvesting and processing of organisms</td>
</tr>
<tr>
<td>Cleaning of systems (including control and data systems)</td>
</tr>
<tr>
<td>Physical support for equipment and temporary work areas</td>
</tr>
<tr>
<td>Maintenance (cleaning, repairs, etc.)</td>
</tr>
<tr>
<td>Support staff and services for successful culture (security, etc.)</td>
</tr>
<tr>
<td>Storage for equipment and supplies</td>
</tr>
<tr>
<td>Repairs and security</td>
</tr>
<tr>
<td>Ventilation and air</td>
</tr>
</tbody>
</table>

The data shown in Table 3 is dependent on species and conditions and is provided for general guidance.

effort has been made to develop grading methods for cage culture. Little quantitative information has been published. Problems such as high labour requirements, escape of fish, stress-related mortality and growth...
reduction are all associated with feeding. A method of
feeding fish, where the operation is accomplished by
simply ensuring the fish remains in a current,

FEEDING
The dominant feeding activity in commercial

 congressman (1990). Feeding rates are based on physi-

ological requirements, water quality, size, biomass

density and market requirements. An efficient feeding

regime requires knowledge of the biomass and some

indication that the fish is being consumed. Most

wasted feed is a major economic loss. One third of

the feed supplied to cultured Atlantic salmon in

Norway was wasted, based on feed converters that

done in controlled conditions (Hammar & Bjomnes, 1991; Dalle

& Gillet, 1991). More recently feeding rates have

been revised downward to greatly reduce this waste.

Traditionally, feed utilization information has been ac-

cquired by hand feeding and behavioral observation.

A promising acoustic system to detect waste food

pellets dropping through salmon cage was has been

tested in Norway (Jull, 1991). More recently this has

been extended to using an acoustic food detector to

sort off a deceased feeder. This has been tested newer

commercial conditions against feeding conditions by

the best current schedules, with very promising results

(Jull, Furevik, & Bjomnes, 1991). An alternate ap-

proach which involves direct measurement of feed

ingestion may also be possible through application of

new technology

BIOMASS DETERMINATION

Assessment of biomass to give an accurate esti-

mate of the total numbers of fish at a given density is

currently a very high research priority because of its

economic importance. Unexplained "shortage" can be as high as 50%.

There is a number

of potential causes of unexplained "shortage" and it is

frequently difficult to assess blame for the losses after

the fact.

BIOFOWLING CONTROL

The second major surviving function with marine

cage systems is control of biofouling on cage netting

and other in-water components. Biofouling of mesh

chemically reduces water circulation in cages,

thereby reducing the fish's carrying capacity. This can

be a life threatening to the culture organism, especially

in commercial cage systems where biomass densities

are relatively high. Biofouling rates on mesh are sea-

sonal and highly variable. Substantial variability in

quantity and composition of biofouling can occur be-

tween two sites relatively close together. Mesh size,

mesh material and mesh meshing all influence the

ease of fouling. While biofouling may be relatively

constant over a season, it is frequently supplemented

by sudden intense biofouling from specific fouling

organisms which move "shortages." Some quantitative

information on the biofouling of mesh has been pub-

lished (Hammar and Aronsen, 1991). Substantial ex-

cept biomass in biofouling components of cages are of-

ten employed to overcome problems associated with

the weight of biofouling in water. Excess biomass can

add substantial weight and cost of these systems. Biofouling also adds appreciable water area and

needs no calculations for current and wave forces by

increasing the drag coefficients of these components.

Since biofouling control can consume as much as 20-

30% of the total labour of the fish farm, a number

of cages have been designed and built with fea-

tures to reduce net biofouling problems. These cages

are possible, always having the side "exposed" to

wind and sun to kill biofouling organisms. Examples

are cylindrical cages (Bile & Baretta, 1990; G calves,

1979; biocylindrical (Cook et al., 1984), and spherical

shapes. One of these spherical designs is of commercial

size (2,000 to 2,500 m³) and is capable of with-

standing the types of expired sites (William, 1991; William, 1994). This air drying approach to
Cage substrates can reduce the growth of biofouling organisms requiring light but do not markedly inhibit growth of the rest of the biofouling community (Wilkins, unpublished). Submerged cages tested in Hawaii at low stocking densities showed little cage biofouling. This can be explained by the oligotrophic nature (low nutrient level) of much of Hawaii's coastline and may become an important site consideration for offshore farm site selection (Feldman and Redfield, 1978).

Biofouling control approaches for conventional surface cages rely upon changing nets as they foul, requiring the nets with antimouthing agents or coatings to reduce fouling rates, use of hydraulic scrubbers or manual cleaning by divers. Antifouling coatings can create problems for the culture organism, as well as the local environment. These problems are more severe in large mesh systems due to the quantities of antifoulants released and the cumulative effects these products have on cultured organisms located in the downstream part of the cage system.

Operational problems in changing biofouled nets increase with cage size because of the greater weight of fouled nets and the more complex logistics. Fouled nets can become their weight in air more than 100-fold (Miles, 1970). This represents substantial additional handling that has to be handled. Net changing or net cleaning for cages at the surface can be required as often as weekly. This frequency can be reduced to two- to four-times per year by antimouthing treatments, to a low fouling site. Changing heavily fouled nets with hydraulic net pullers weakens net fibres and net-cage attachment points, which contributes to early net failure. Not changing to control biofouling does not benefit from economy of scale as systems get larger.

TREATMENT FOR DISEASES/PARASITES

During cage grow out, treatment of culture organisms for disease or parasites presents several problems. Carrying out treatments with minimum cost, within environmental guidelines, while avoiding stress on the culture organism creates substantial difficulties. These treatments are costly and have potential side effects, and environmental consequences when released in quantity. Canadian and European Atlantic salmon farms and Japanese yellowtail farms have all been seriously impacted by parasite problems. Current control procedures are material and need improvement. There are several approaches to in situ treatment. One is to rounds the cage with an impermeable sheet, treating the fish in the cage with a moderate concentration of chemicals for one to two hours before removing the sheet and releasing the chemicals. The other method employs a treatment barge brought along side the cage requiring treatment. The fish are crowded into the treatment barge and are subjected to a high concentration of chemicals for relatively short periods of time, then returned to their own cage (Dobson & Tack, 1991). A method for parasite control, which has not been found a strong following in the industry, has cages for several months, between harvest and restocking, to reduce the local concentration of parasites.

Predators often cause greater losses from the damage they do than the food they eat. Long-tailed birds can attack through caged fish, and many more fish than they eat. Dogs, foxes and cats can make holes in cages through which the fish can escape. Diseases on the rise of protective bird nesting and predator nets around the culture system are a trade-off of reduced losses from predators vs. additional costs and increased drug forces. There is some indication that net cleaning sub-
submersible cages that can be operated in the surface water, and which are first mentioned in the literature for the commercial culturing of fish in Japan (Sohin, 1972; Fujita, 1976). Japan has a history of periodic by-pass programs which have destroyed natural estuarine salmonid populations. Cage submergence, 10 to 15 m below the surface has been demonstrated to substantially reduce storm wave effects and increase fish survival. These Japanese cages were developed for exposed sites and in most cases were operated in a conventional manner, i.e., on the surface except for brief submergence during storms.

The advantages and disadvantages of submersible cages are reviewed in Table 4. The monitoring and operating submersible designs, while submerged, represents one of the greatest challenges. Considerable interest has developed in submersible cage use for over-wintering fish where winter ice cover makes conventional cages impossible. Under such severe winter conditions, most fish held in a submersible cage are kept below the freezing point as shown previously in Table 3. Norwegian tests with submersible cages in the 1980s showed that Atlantic salmon require access to the surface to stay alive or they become disoriented and suffer high mortalities. Removal from surface access for periods longer than 24 hours begins to stress Atlantic salmon; steelhead trout suffer stress when denied access to a free surface after 48 hours (Willinsky, 1992 unpublished). A submersible captive rearing tank and small light to illuminate the surface is believed to solve this problem for submersed cage operation (Olsch, 1980). Many fish do not have this instinct, including Arctic char (Willinsky, 1994), yellowtail and several sharks species.

Submersible cages may be the only realistic option for certain demersal fish species, such as cod. Cultivation of potentially other demersal fish, are sensitive to damage if forced to remain near the surface. In addition, these fishes are stressed by warm surface water. To reduce stress, cages could operate below the warm surface water layer, fully submerged, for several months of the year. Cage cultivation of cod in submersible cages appears to have considerable potential, if further this species can be shown to be economically viable.
Table 1. Advantages & Disadvantages of Submersible vs Surface Cages

<table>
<thead>
<tr>
<th>Advantages of Submersibles</th>
<th>Disadvantages of Submersibles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submersible avoids more stress on cage and fish components during storm/transportation</td>
<td>Handling and maintaining the system, which is more expensive.</td>
</tr>
<tr>
<td>Submersible reduces stress on cage structure where cages are located, making cage structure more complex and more expensive.</td>
<td>Requires complex design and more expensive.</td>
</tr>
<tr>
<td>Submersible makes it easier to move fish from one cage to another</td>
<td>More complex maintenance requirements.</td>
</tr>
<tr>
<td>Submersible allows fish to access surface air and light completely outside of cages</td>
<td>Submersible cages force fish to stay inside cages for extended periods, which can be stressful.</td>
</tr>
<tr>
<td>Submersible cages are less susceptible to algae and other marine organisms</td>
<td>Cage design may be complicated, requiring specialized equipment.</td>
</tr>
<tr>
<td>Submersible cages are less susceptible to damage during transport or handling</td>
<td>Submersible cages are more expensive and require specialized equipment.</td>
</tr>
<tr>
<td>Fish can be managed in water and no special handling of cages necessary</td>
<td>Cage design may be complicated, requiring specialized equipment.</td>
</tr>
</tbody>
</table>

Note: The text is cut off and incomplete; the full content is not visible in the image.
TABLE 2. DESIGN CRITERIA FOR THE TRIDENT SUBMERSIBLE SELF-CLEANING SEA CAGE

- **Competitive initial cost.**
- **Modular design: easy repair or replacement of components.**
- **Reusability of materials.**
- **Low maintenance requirements, high reliability of components.**
- **Ease of maintenance, can work in variable wind and wave conditions.**
- **Self-cleaning or biofouling or self-cleaning system.**
- **Not dependent on onshore or off-site processing.**
- **Completely self-sustained.**
- **Cage materials must be sufficiently durable to survive rough seas and high wind conditions.**
- **Competitive operating costs.**

The design concept that was finally selected for the Trident Sea Cages was a semi-submerged, semi-submerged structure with a lattice structure, similar to Buckminster Fuller's geodesic domes but with more structural elements. Trident
cages are fabricated from aluminum tubes, internally foamed for positive buoyancy (Wellman et al., 1971). Most cages to date have been 12 m in diameter (100 m²), although smaller designs have been built for broodfish (100 m²).

Figure 2 shows a 1,000 m² sea cage mounted 2.5 km from the Canadian shore in the estuary of the St. Croix River.

Figure 2: A Trident sea cage after 20 months of continuous operation. The sea cage is a hybrid of a floating heave-compensator, the cage, and a subsea float. The cage shown is about 70% submerged.

ENGINEERING

Structural analysis shows that the design concept can be scaled up to an elliptical 22.5 x 30 m structure (10,000 m²) using many of the same structural elements as the 12 m spherical cage. The advantage of an elliptical cage is 81% of the enclosed volume is under water when the cage is submerged 66 percent or allow for self cleaning (as drying of bedrock). With a spherical shape, only 50 percent of the enclosed volume is under water when the cage is submerged two-thirds. This change from sphere to ellipse results in a small loss in structural efficiency.

Figure 3: Completed 12 m Trident sea cage prior to launching. Erected by three men in 24 hours, this design is very rigid and shows small deformation at loads of 10,000 psi.

The Trident Cage structure has come very interesting engineering design characteristics. It is a rigid structure whose deflections, even during extreme weather conditions, are very small and imperceptible. In response to waves, its overall motion is greatly attenuated. This is in contrast to conventional cage designs whose deflections, deflections and overall motion under storm conditions are clearly and dramatically visible. The large structural deflections and the relative motion between net and cage, seen with all conventional designs, validates the use of well-proven marine engineering procedures for the design of these surface and near-surface cages. By comparison, the Trident system's rigid structure and net system allows these engineering design procedures to be applied in combination with the well-established structural engineering principles for familiar designs. The overall engineering risk for a Trident sea cage is considerably less than the risk associated...
NET DESIGN

Trident nets are woven together and then reinforced with bolt gages which divide the net into smaller, geometric-like units, resulting in evenly distributed net loading. The net is attached to the cage by means of the bolt gages which are fastened to the structural connectors and to the structural members of the cage to create a fast setting inside the structure. This type of attachment reduces stress and shock loading at the critical connecting points between net and cage. It also results in a dramatic reduction of relative motion between net and cage. These bolt mesh gages also put the tubular frame of the cage into a uniform compressive preload to further increase cage integrity. The spherical shape maximizes the volume to surface ratio, reducing net surface area, drag forces, net cost and maintenance. Spherical and ellipsoidal shapes avoid stress and strain and reduce the stress at the corners, reducing collision of fish with mesh as well as minimizing alpha behavior in dominance fish.

Additional advantages of the Trident's structural configuration result in a light, strong envelope where external forces acting on the cage are immediately transmitted into axial force through the triangulated network of steel L-bar members, such that those occurring at the nodes are equally dissipated into the complex, curved surface of the cage.

JOINING METHOD

The engineering challenge of joining a number of lightweight elements in space, economically and effectively, has been recognized. An additional problem in constructing a sphere or ellipse to the high level of accuracy required on the manufacturing of the components. Length and geometric angle of the tubular members are controlled in the manufacturing operation to within five thousandths of an inch (one-eighth of a milimeter). The Riveted Joint used in the construction of the Trident Cage ensures an international reputation as the most efficient and economical system available for the construction of spheres and space frames. (See Figure 4.)

The Trident Connector consists of a hub, an aluminum extrusion, that contains cylindrical slots in key ways. Structural members that have their ends pressed or coined to match the slots. The member is inserted into the hub by means of guiding the face ends into the longitudinal slots in the hub. Fasteners such that have been patented to ensure the retention of all slots are identical. Connectors can be designed to receive tubes of various wall thicknesses, as required for the design of the structure.

A unique manufacturing method controls both the length and angle of each member and consistently maintains this accuracy under mass production conditions. Each tubular member for the Trident Cage is formed, flanged and then fabricated to length and angle in the manufacturing process. A thorough series of tests of this joint was carried out at Queen's University and at the University of Waterloo by Dr. D.T. Wright. Structural members of the Trident Cage are 125 mm in diameter and have a wall thickness of four mm.

Engineering development included finite element analysis (FEA) under varying load conditions (66m, unpublished data). For FEA input forces were based on current velocities up to 3.0 m/s (6 knots), maximum

Figure 4: A Trident Space Frame Structural Connectors used in the Construction of the Trident Sea Cage.
were height to 6 m above on surfaces and wave length to 200 m using deep and intermediate wave equations. The cage system was modeled on the computer at varying drafts from 70 percent to deep submersion.

The natural frequency of the cage is dependent on the diameter, mooring line tension and draft, and is higher than any of the living forces. The nature of safety relative to yield, for all structural elements under all conditions, is predicted to be never less than three.

Wave and current response of the cage and various mooring systems were evaluated during 45 days of testing in the 4 m by 59 m wave tank at the Ocean Engineering Research Center, Memorial University, St. John's, Newfoundland (Zargh, 1982). A 1 in diameter geodesic cage model was used in currents varied up to 3.0 m/s (rms). Wave heights up to 4 m were simulated through scaling laws. A variety of conditions were modeled. Full scale deflections were all predicted to be very small even under extreme wave conditions. These predictions were subsequently verified subjectively by observations of full scale 15 in cage under full scale conditions while moved 2.5 km offshore in the St. Cots River. To date, Trident Cages have been deployed with three fish species, Atlantic salmon, trout and Arctic char in four different sites. Additional deployments are currently under way for exposed sites in Lake Huron, the Black Sea and the Mediterranean.

Corrosion problems encountered with early prototype testing were resolved by employing 5056-T6 aluminum alloy. In over four years, no appreciable corrosion or structural problems have occurred with the 6061 alloy. Self-centering capability, in the presence of aggressive biofouling on adjacent surface edges, has been consistently demonstrated.

The cage was exposed to severe winter storms in 1982 with wind speeds of 20-120 kph and breaking waves over 1.5 m while surfaced. Nearby commercial steel cages were completely destroyed and many fish in the vicinity were severely damaged. The Trident Cage, moored at 2/3 draft, suffered no damage. If damaged, a Trident Cage has been demonstrated to be easily repaired. A 50 ft. fishing dragger colliding with this same cage in 1992, badly damaging the boat's stern and pushing the panel of one side damaged and was replaced by two men in several hours. No structural damage to the cage occurred. Other violent mishaps have proven that this cage structure is incredibly rugged. While it has not yet happened, should a structural element be severely damaged, it can be easily replaced in the field by two men with ex-cell-soldering or jury-rigged fabrication.

While the Trident Cage is as strong as any "exposed" cage design available in the world today, it is doubtful it will survive open sea storm conditions at the surface for very long. In these conditions, even before edge hardware fails, the cultivars will be damaged or killed. With sufficient ability and an adequate depth of water, the Trident Cage can escape from surface storm conditions anywhere. Hence, the Trident Cage's structural engineering is not the limiting factor for deployment in exposed sites. The limiting factor to avoid the forces of long wave length storm waves is avail-
able depth for submersion. This cannot be said for any
cage design forced to stay at or near the surface.

TRIDENT CAGE MOORING SYSTEM

A critical and frequently underestimated factor in
the survival of any cage in an exposed site is the de-
sign of the mooring system. Current and wave data at
the planned site must be taken into account during
the design and development of the mooring system. Hy-
drodynamic modelling of the selected cage and com-
pleted mooring design should be carried out prior to
final selection of a mooring design for an exposed site.
This process gives you sufficient data on the forces
acting on the system (cage, mooring lines, anchors)
and the response of the system to these forces to pre-
dict the size of each component in the mooring system
capable of withstanding the loads over a cost-effective
design service life. Parametric trade-offs to optimize
the choice of mooring design and identify critical com-
ponents prior to field testing can also be achieved. A
schematic drawing of a Trident Sea Cage Mooring
System is shown in Figure 6.

SUBMERGED CAGE OPERATIONS

Generally, submersible cages are submerged for
only short periods of time during major storms. Few
attempts have been made to manage or operate these
systems during submersion. As aquaculture moves to
more exposed sites and possibly to demersal fish spe-
cies, periods of submergence could increase to weeks
due to bad weather or to months to reduce stress on the
culture organisms. The economic stakes are suffi-
ciently high to act as an incentive to learn to manage
offshore cages on the surface and submerged. Table 3
listed the operating and servicing functions required
for cage culturing. Some of these functions are re-
quired daily, others at intervals of weeks or months.
These operations can be scheduled to coincide with
fair weather. As a result, only a few critical functions
remain for submerged, unattended operation. These are
identified in Table 6b.

| *Feeding* | *Demand feeder*
|           | *Monitor & control feed utilization*
|           | *Feed hopper status*

| *Monitoring culture status*  | *Short-term feed utilization*
| (*‘happiness index’ or*      | *Stock distribution & behaviour*
|  stress monitoring*)         | *Water temperature*
|                              | *Current inside cages*
|                              | *Dissolved O₂ inside cages*
|                              | *Surface wave monitoring*
|                              | *Ambient light intensity*

| *Monitoring system status*   | *Feed hopper status*
|                              | *Surface wave monitoring*
|                              | *Strain gauge reading*
|                              | *Cage depth sensor*
|                              | *Battery/power status*

| *Systems operations*        | *By telemetered command*
|                            |  capability*

| *Security*                 | *Intruder sensors (large predators*
|                            | and people*
|                            | *Operation of required navigation*
|                            |  devices on surface components*

Table 6b. Required Operating & Servicing Functions for
Submerged-Unattended Operations

---

Figure 6.
Schematic drawing of a Trident Sea Cage Mooring System.
(a) sea cage (b) variable buoyancy chambers (c) submerged
shoulder buoys (d) multi-leg mooring system (e) anchors
Monitoring culture organisms, physical systems, and assessing security are all critical functions that are required at a minimum of several times a day. Food hopper restocking, biomass assessment, maintenance, and biofilter control are required in an interval of weeks. These functions can be partially controlled by design and operating procedures to extend these intervals. Biofiltering can be expected to be reduced by submersion because of reduced light levels. In a submerged mode, structural forces will be reduced, leading to less frequent maintenance sessions. Instrumenting the structure will further reduce the need for frequent inspections and will establish when maintenance is required. Ambient light, water temperature, water velocity and dissolved oxygen inside the cage are the major environmental parameters that affect stock performance and behaviour.

An acoustic system, such as the Simrad, can assess stock distribution, and can also provide a direct measure of stock behaviour. Stock distribution and dissolved O₂ levels can be combined to establish a "happiness index" or condition of low stress. Lower stress levels are generally correlated with faster growth, improved feed conversion and lower mortality; all good presumptions for sustainable culturing.

Figure 7.

Distribution of fish stocks in a spherical cage under low stress conditions. This data can also provide a direct measurement of stock behaviour. The SIMRAD 160 Acoustic System, like a fish finder, shows marine densities in different colours:

- light blue = low density,
- yellow = medium density,
- dark blue = high density.

Figure 8a.
Table 7. Command, Control, Communication, and Computers: Requirements for a Management Buoy System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Command &amp; Control</th>
<th>Communications</th>
<th>Computers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Security</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
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</table>

Figure 8. Major elements of the telemetry, acoustic dredge monitor system for automatic operation of an offshore fish farm employing submerged seafloor.
The fish's feed hopper has storage for a minimum of 20 days of feed during the peak growing season. Normally refilled three days before bad weather. This requires a substantial volume for a hopper to manage, monitor, and feed multiple enclosures. Directly lower water temperatures result in reduced feed requirements, the intervals between required servicing of the feed hopper would be reduced during cooler weather. During storms, feed is hydraulically delivered from the hopper to the submerged cages through compliant hose, rather than containing an enclosed conveyor to carry spent feed back to the fish's computer. A remote powered actuator provides ample power reserves with redundant requirements at frequent intervals. A design study for a buoy structure to meet similar requirements that also included wave loading. Recommendations for an on-site person were previously published (Aubin, Chua, & Walter, 1991).

Cost, servicing requirements, and at sea reliability will control the number of cages that can be employed in commercial operations. This buoy system, while essential for submerged operations, will also be useful for surface operations during periods when the system is not utilized. Feedback for feed utilisation is similar to that developed by Holl et al., 1993.

Security sensors include radar, as it is already used at some remote cage sites. A passive sensor that identifies the acoustic signature of an unauthorized boat or large predators (e.g., sea lion) and sets off visual alarms. Monitoring of stock behaviour can give an indication of the presence of predators through dramatic changes in stock behaviour and distribution in the cage. Active warning measures include an audio system warning "invasion" to leave and high intensity sound signs that scare off predators but have no effect on fish.

For long-term submerged operations at exposed sites, critical servicing functions present unique interesting challenges. Operating methods close to those used in stockyards may be worth looking at. Fish can be induced to enter ditches by the use of collared light sources, mild water currents, and crowding. Tunnels are already in use to transfer fish between cages. This enables fish farmers to count, measure, visually inspect, treat medically, and transfer fish into and out of cages while the cage is submerged. Some of these ideas have been published (Weber & Haggerty, 1970).

**FUTURE RESEARCH & DEVELOPMENT NEEDS**

There are two major technical obstacles to extending cage culture offshore. Although many engineering problems have been overcome in the design of the Trilateral Cage system, not all of these problems have optimal solutions. The second area involves the operation and management of large numbers of units in a hostile, environmentally sensitive environment. While submerged cages can help solve the engineering problems of structural survival during extreme weather events, new operational and management functions have to be developed and refined.

Engineering problems for exposed cages are greatly reduced if the cage design allows the use of ocean engineering procedures and verified design procedures. These engineering procedures are not applicable to many cage designs in use today. The importance of structural deflections and deformations under severe conditions as well as the relative motion between cage components (free and structure) have to be addressed. There are several ways to address this problem. One is to stay within cage design parameters that allow the use of known engineering procedures with tested systems, offshore platform designs, and special cases such as the Trilateral Cage. The other is to develop entirely new engineering procedures through careful experimentation and field-scale testing under realistic conditions to develop improved levels of predictability of components under conditions of large structural deflections, deformations, and relative motion between cage.
components. This approach will take a number of iterations in design, test, failure, and redesign to reach a level of fairly predictable results. This has been the approach used by the developers of large surface-mounted flexible rubber cages. For more "exposed" sites, the limiting factors for their application will be fish survival and structural problems associated with greater surface areas. For submersible structures, relying on established engineering practices based on rigid structures, control of a leader will be less costly and more straightforward. Recently, one developer of a new, flexible submersible cage found it was necessary to replace the flexible floatation collar with a rigid structure to make the system function predictably in "exposed" conditions.

Assuming confidence in the applied engineering design procedures, the next major problem focuses on management operations. The labor intensity required for each function (fish) is significantly more expensive and less efficient, safety of personnel and adequacy of system performance relative to the needs of commercial operation must all be addressed. While there are no lack of potential solutions, these practical problems seem unresolved. Solutions can only occur as a result of systematic evaluations of alternative solutions and systematic testing of the best options under realistic conditions. Northern Europe has gone about with exposed cage-carrying pilot projects and Japan has made massive investments in this area.

Using the Trident Cage as an example, to transition this cage into a completely operational system for commercial carrying at "exposed" sites, the research and development needs are shown in Table 8.

<table>
<thead>
<tr>
<th>Table 8: Submersible Cage System Research &amp; Development Needs</th>
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<td><strong>Development and test of procedures for handling large structures:</strong></td>
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<td>- Surface and submersed</td>
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<td>- Surface and submerged</td>
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| **Development and test of procedures for handling large structures:** |
| - Surface and submerged |
| - Surface and submerged |

| **Research and development needs:** |
| - Surface and submerged |
| - Surface and submerged |

- Surface and submerged
There are strong economic incentives for reducing the number of trips to the site to perform servicing functions as personnel may have to stage from land-based support bases, requiring one to three hours (travel time) of 10 to 30 miles.

The need for remote monitoring of the system is a major and difficult requirement. Fish farms in "sheltered" sites use monitoring and management techniques that are often more effective than those used on land. Operators have the "knack," whereas others do not. To be successful, in remote powering, it will be necessary to quantify all important parameters for hardware and the culture organisms. While the hardware side is relatively straightforward, there is no generally accepted way to monitor stress in culture organisms. Yet this is a critical requirement. Disturbance must be minimized when there is a problem outside.

Short-term feed use, recorded from a sensor below each cage, is an important parameter. Daily feed use per cage divided by the predicted feed use based on environmental conditions (water temperature, dissolved oxygen, current inside the cage, fish size, biomass distribution, etc.) provides an important management tool. While feeding schedules, based on conditions, already exist for many established culture species, many schedules slightly underfeed to prevent feed wastage. A feed index for "happy." Fish should normally be a little over one. If the index is below one, water temperature, dissolved oxygen, stock behavior, sediment distribution, water current, ambient light, etc. should be checked. While there are many possible reasons for reduced feeding activity, if a feed index persists or increases without an obvious change, stocks should be carefully checked for disease or parasites. Such a numerical "Feed Index" will have to be verified by actual lab testing in different conditions, if have real value.

SUMMARY

While submerged cage technology appears to be advantageous, the basic limitations of the concept have not changed. A succinct statement of status and recommendations for the development of submerged cages for commercial use follows. It is a variation of a book published on the same subject in this paper in 1974. The paragraph is from the conclusion section of Chapter 10 (Hawkes, 1974). These conclusions are as valid today as they were when they were originally written.

"Most experience with floating enclosures developed to date has shown a complete lack of sustainability under rough water conditions and vulnerability to flooding. The recent Japanese approach, using submersion to provide rough water, seems at the moment an offshoot. We suggest, then, that a moderate but well focused research program for the development of open-sea enclosure technology as in older now. Primarily, this program should consider survivability, feeding, longevity, and maintainability; operational expense, and initial cost minimization. All construction and protective materials should be catalogued and evaluated, as well as all possible mechanisms for avoiding rough water, weight construction methods (with emphasis on modular approaches), and non-labor intensive procedures for maintenance and servicing at sea. The same thing should be done for all possible techniques to achieve biological and chemical control of feeding, and to assure compatibility with cultured crops. Because of the high degree of interaction among the various parameters of this problem, this should be an integrated approach, perhaps one that is coordinated internationally rather than a series of small, independent, research activities. Once the knowledge of beneficial information transfers amenably, the pursuit of flatfish cages and methods and efficient enclosures by the same team is recommended."

The need to avoid all these issues will not be simple or easy. It will take a great deal of effort, creativity, adaptability and persistence under adverse conditions.
Final excess will come in small pieces, over a number of years, interpreted with setbacks and failures. In spite of the setbacks, the potential benefits are still enormous.

ACKNOWLEDGEMENT: The authors would like to thank Steve Kerr, Henry Renvoize, and Walter Paul for their contributions to the concepts reviewed in this paper.

REFERENCES


Flexible Mooring with Multiple Buys

Egil Lien¹, Harald Rudi¹, Olav H. Stensæth¹ and Dag Kolberg²

¹ Norwegian Marine Technology Research Institute A/S
Tordheim, Norway
² Helgeland Plant AS
Brynhord, Norway

ABSTRACT

This paper describes new mooring techniques that may improve mooring of open ocean aquaculture systems. For
such cage systems, the interaction between the mooring
system and the cage structure is significant, and the impact
on the cage structure needs to be evaluated with the exposure.
Helgeland Plant AS is in the manufacture of the well-known
Framed Cages. Helgeland Plant has given the project to
Marintek to develop a new and improved mooring system for the Framed Cages.

Marintek and Helgeland Plant AS have accomplished two major projects focusing upon improved
mooring methods. The projects have developed new
mooring techniques that give a considerable reduction
in impact on the cage unit.

Present mooring methods are based more upon tradition than on engineering. A traditional mooring, with
anchor - mooring line - buoy - cross-float - and the cage,
is quite similar for all single cage systems. Recently, the so-called system mooring, a submerged frame of
lines that acts as a base for mooring of the individual
cages, has gained popularity.

Initially, computer analysis on a fully equipped
cage unit, including the mooring system, was
performed. The influence of the mooring system on the
cage stress is generally significant, and we also found

10
that the impact even from the transverse mooring lines was considerable.

By calculating the flexibility of the mooring lines by parameter variation, it was shown that the line characteristics could easily be improved by adjusting the length of the line sections of the mooring lines. Increasing flexibility implies a larger vertical displacement of the mooring buoys. The most commonly used EPS-filled buoys are hardly able to withstand any hydrostatic pressure larger than five meters of water. Other buoyancy elements, such as PVC-filled buoys, could be used, but the investment costs would increase dramatically. Looking for other solutions, it was found that small multiple floats in a row would reduce the costs compared to large single buoyancy units. Computer analyses showed that multiple floats gave large reductions of the dynamic tension in the anchor lines. This new concept was also favorable with respect to costs.

In order to verify these results, model tests were performed at MARINE ORION's Ocean Laboratory in December 1985. The tests were made at scale 1:10. For a range of regular and irregular sea states, the line tensions were determined in a system with three identical buoys with different mooring lines. The system was loaded with a range of loads to the wave direction.

By comparing the measured line tensions from identical waves exposed to identical waves, it was found that the results from the computer simulations were reliable. The test result analysis also indicated that using a combination of the moorings may increase the dynamic reduction on the cage float. This result therefore questions the beneficial effect of individual use of the cross-flow in traditional moorings.

Introduction

The expected location high flexibility in the mooring system is important in order to avoid high tension on the floating collar. This paper deals with mooring system geometry and buoyancy elements in the mooring, and describes the effect on the cage unit illustrated in simulation results and model tests.

Moorings system geometry and buoyancy

The purpose of a mooring line is to:
- keep the cage reasonably on-site with minimum stress on the float rings
- prevent the cage from becoming submerged in large currents and wave conditions.

The mooring system must have sufficient elasticity to prevent the cage structure from being damaged. For this purpose, the flexibility from only the wave is too small, so the total flexibility is increased by adding a geometric flexibility by attaching a buoy to the mooring line.

An equilibrium consideration of a conventional mooring line, see Figure 1, gives:

\[ T_1 \cos \alpha - T_1 \cos \beta = 0 \]
\[ T_1 \sin \beta + F_c = T_1 \sin \alpha \]
\[ d = l_1 \cos \alpha + l_2 \sin \beta \]

where

\[ l_1 = \frac{l_0}{E A} \]
\[ l_2 = \frac{l_0}{2E A} \]
\[ F_c = \text{buoyancy force} \]
Normally, $T_b$ is on the order of $15-22$ kN-meter, and $T_a$ is two to four times the weather depth. The characteristics of different lengths of the line segments is illustrated in Fig. 2, ref. 1.

These line characteristics are obtained from the formula presented above. The buoy is treated only as a fixed mass. A correct modeling of the buoy would give a slightly different initial characteristics in the region where the buoy is partly submerged.

As can be seen from Fig. 2, increased flexibility is obtained by reducing the $LDA/F$ ratio. For a traditional mooring geometry, the buoy only gives a small additional flexibility. In order to increase the flexibility, the line length between the buoy and anchor should be reduced. The flexibility of the mooring line is a function of the submergence of the buoy, see Figure 3.

Figure 3: Mooring flexibility

Increased mooring flexibility therefore raises another problem. The traditional EPS (expanded polyurethane) filled buoys are unable to withstand higher pressure than approximately five meter submergence. We cannot therefore only adjust the length of the line segment. Such buoys will become crushed and destroyed.

Figure 4: Various buoyancy elements
- continuous heave mooring buoys (Alu/SS/EP/SS/Alu)
- flexible mooring buoys (Alu/EP/SS/EP/Alu)
- GeoCell

The pressure capacity of different materials is shown in Figure 5.
The cost of different buoyancy types is illustrated in Figure 5. Prices are approximate as they vary by quality and quantity.

Figure 5: Pressure capacity for different materials.

Figure 6 shows that floats are much cheaper than large single buoyancy bags. Floats are used in large quantities, while buoyancy bags are expensive. Normally, the net buoyancy of single floats varies from five to nine kg.

The floats may be attached to the anchor flaps in a long row. Figure 7. Using long rows of floats is economical in using heavy chain mooring, in that very smooth catenary line characteristics are obtained.

Figure 7: Two single buoyancy in the field.

The two single buoyancy models in Figure 7 are similar with respect to line characteristics, but a single vertical line up to the buoy is not not practised in use. The horizontal mooring buoy has to take the pull of horizontal restoring force, and the wear on the eyebolt and shackle is a problem. The experience with a multiple buoy mooring is still limited. However, the floats have a high durability. The float should be divided into sections of about 150 kg, separated with locks preventing the sections from sliding on the rope.

Figure 8: Cost of different buoyancy materials.
Simulation of multiple buoy mooring

In the following example, the computer program RHLEX has been used to compare a single buoy mooring with multiple buoys having the same total buoyancy, ref. 2. A circular cage structure made from polyethylene tubes together with a 50 m deep net is completely symmetrically modeled. The model includes short mooring lines as illustrated in Figure 8. The water depth is 20 m.

![Figure 8](image)

In Figure 9, the maximum line tension for the alternatives; single-buoy mooring and multiple-buoy mooring, are compared within a given wave period.

The figure shows clearly that the tensions for the single-buoy mooring are more than twice as large as compared to multiple buoys. A similar trend was also observed from other wave conditions.

![Figure 9](image)

One significant observation from these analyses was that even the transverse lines, 1.2 and 1.4, get very high line tensions. This is caused by the fact that the buoys are oscillating in the wave zone, and even if their net weight is low, their dynamic mass is high due to the hydrodynamic added mass. Large single mooring buoys cause high line tensions due to their very existence. The dynamic coupling between the buoy and the cage is significant.

Figure 10 shows the equivalent stress in the float tubes for the two mooring alternatives. The stress is presented for a circumference of the coil, starting from line 1, head set. It is evident that the multiple-buoy alternative is favorable.

In this example, the ratio between the wave height and length is 1:20. For a steeper wave, the difference decreases because the bending moment about the wave surface diminishes. A ratio of 1:20 is fairly representative for a normal sea state.

![Figure 10](image)
Model tests of different mooring systems

In December 1995 we performed a model test in scale 1:8 at MARINTEK's Ocean Laboratory, St. Fjell, Hokklandet in the like deffirt. Two cages in a system mooring were compared with an individually multi-body moored cage, Figure 11.

![Diagram of cage arrangements]

Figure 11. Arrangement of the laboratory

- Cage 1 was a multi-body moored single cage.
- Cage 2 and 3 were both moored in a 3 m submerged frame.
- Cage 2 was floating.
- Cage 3 was submerged to approx. 7 m depth.

All three cages were identical with respect to floating collar and net. Cage 3 had 30 percent heavier clamp weights than cage 1 and 2. The collar stiffness was not studied, but was equal for all the cages. The stiffness of the collars was too high.

Detailed system description is not presented here, but is described in Ref. 3. The system mooring geometry is according to normal practice by several manufacturers.

The multi-body mooring had a root buoyancy of 5.76 kN in each line.

![Graph showing significant wave height and tension]

Figure 12. Comparison between

The force responses were measured on each cage, the plotted results are achieved by adding the tension in both parts of the crossfoot. Due to the unequal cages, one floating and one submerged, we got a non-symmetric response on the cages in the frame. However, the coupling between responses for cage units in a system mooring will always be considerable and probably more pronounced with more cages and different seas.

The multi-body cages gave about 50 percent reduction in significant tension (T*) compared with the floating system moored cage, and was in magnitude comparable with the submerged cage.

The submerged cage is not further discussed in this paper. The item will however be presented in the near future.

Analysis of the tension-time series in the crossfoot showed that the variance of the tension in a single
crossfoot was greater than the variance of the sum of both, which is equivalent to the tension in the anchor line. This means that the crossfoot does not diminish the dynamic impact. Therefore the dynamic impact at the clamp point on the collar increases by using a crossfoot instead of a single line. On a four-line mooring, the static tension in an upstream line will be distributed by a crossfoot, and it is therefore preferable. On systems with more anchor lines, say six to eight, there will be at least two sandwashed lines, and the advantage of the crossfoot could be debatable.

Conclusions

Traditional mooring methods using single lines and long anchor lines are unfavorable. Only a slight increase in flexibility is achieved. The presence of a buoy attached near to the cage causes large impacts on the cage due to the relative motion between the cage and the buoy.

A system mooring solution with a rigidly moored buoy also causes high impact on the cage due to the relative motion between the cage and the buoy.

Increased flexibility may be gained by changing the segment lengths. By increasing the segment length between the cage and the buoy in combination with a reduction of the segment length towards the anchor, the line characteristics are improved.

The geometric flexibility of a mooring line is related to the movement, submersion, of the buoy.

Increasing geometric flexibility in the mooring line necessitates high-pressure capacity buoyancy elements. Replacing large single buoys with a multiple number of low pressure buoys is a favorable solution.

Multiple buoy systems reduce the stress in the cage collar. In a low static situation, a smaller part of the buoyancy is acting near the surface, and the dynamic loads in the line itself is reduced.

A crossfoot does not necessarily distribute the dynamic loads. The load variation in a crossfoot line is normally larger than in a single line. The crossfoot is necessary on a four-line mooring in order to distribute the static load. On a six-point mooring, it is probably better to choose one line instead of a crossfoot.

REFERENCES


The Offshore Aqua Cage --
"Proven Dependability"

Captain Thorne Fox,
Seaboard Maritime Services Corp.,
Floral Park, New York

Introduction

Atlantic Aqua Marine, Inc. is a subsidiary of the
Armstrong Group, Ltd.
• has been involved in all aspects of fish farming
  over the past 12 years.
• has designed and constructed two of the largest
  fish hatcheries in New Brunswick and worked on
  several others.
• has supplied equipment which has been tested in
  "Active Fish Farm Operations" in the harshest con-
  ditions in Atlantic Canada.
• has and continues to produce the Aqua Track -- a
  multi-task work vessel serving the aquaculture
  and other marine industries.

Among the services offered is a complete turn-key
operation including:
• Site analysis.
• Cage supply.
• Anchor and attachment supply and
  installation.
• Net supply and installation.
• Training.
• Maintenance and inspection.
• Operator management.

Optional equipment can be supplied including:
• Automatic feeding.
• Net washers.
• Barges (powered or unpowered).

Background

Developed in 1965 and no longer in production, a total of 232 of our earlier model cages were built. The majority were deployed in the Bay of Fundy area of Atlantic Canada.

This system offered:
• Galvanized steel construction 12 and 15 meter available.
• Gutter connected with stainless steel hinge pans.
• A center walkway of plus minus 2 meters width with breach walkways.
• Foam filled floors provided buoyancy.

Offshore aquaculture in Passamaquoddy Bay

Considerations
• Shelfage of inshore protected sites.
• Availability of larger sites.
• Cleaner water and better fish culturing conditions.

Problems
• Extreme northerly winds often reaching 70 knots.
• A six mile fetch.
• A deadly short chop reaching 12 feet in height - often higher than large rolling 30-30 foot swells.
• Four-hour tides.
• Heavy sea buildup from breaching spray during winter moorage.

Solution
• The Offshore Octagon Cage System.
• Rugged simplicity of a steel ship-like structure.
• Four cages for culture of salmon have been in the water for three winters in the lower end of Passamaquoddy Bay.

Cage Construction

Major features include:
• Innovative design and rugged large diameter (8 to 12 meters) steel pipe construction able to withstand a wide variety of weather conditions.
• Weight (30,000 to 40,000 lb.) and rigidity allow only minimal movement in rough conditions.
• 28 meter diameter offers great stability - even in storm conditions.
• Life expectancy of 40 years with proper maintenance.
• No moving parts and self flotation.
• Ease of assembly and anchoring at location.
• Good because capable of handling severe ice build-up.
• Safety and stability for personnel with handrail equipped walkway around perimeter.
• Optional ability for lowering below surface to avoid hurricane conditions.
• Individual or cluster mooring.

Standards

Design and construction of our cages must exceed the following standards:
• A.S.T.M.
• CAN/CFCC
• Lloyds of London.

108
• Safety and stability for personnel with handrail equipped walkway around perimeter.
• Meets or exceeds international standards.
• Ability to grow both bottom fish and finfish.
• Ease of service and maintenance.
• Affordability and long term value.

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Atlantic Aqua Marine Inc.
P.O. Box 26485
North Vancouver
B.C., V7R 3R3

U.S. & Overseas
Southold Marine Services Corp.
P.O. Box 1337
Southold, NY
11971

Phone: 506-755-9102
Fax: 506-755-9999

• David Armstrong

Phone: 516-326-9473
Fax: 516-451-9252

• Tori Fox
Good Morning ladies and gentlemen,

It is a great honour for me to be invited to speak to such a distinguished group of people at this conference. Offshore aquaculture represents a new, interesting chapter in the industry. This conference is proof of that development.

Today, I want to talk to you about FARMOCLEAN INTERNATIONAL AB and their line of offshore semi-submersible systems. On the first slide, we see both a picture of the system and the corporate logo.

I will start by presenting the company and its history. Then, I will show the offshore cages and how they work. We will look at a couple of reference installations around the world. Finally, I will discuss our plans in North America.

NORDITRADE is a firm specializing in developing trade relations between Scandinavian and North American companies. We are based in Toronto. Our relationship with FARMOCLEAN, which is to introduce their offshore cages on the North American market, started about a year ago.

FARMOCLEAN INTERNATIONAL AB, based in Göteborg, Sweden, was founded in 1983. It was the result of research activities at the University of
The tests were successful, so FARMOCOEN INTERNATIONAL AB was founded. In 1986, the first FARMOCOEN-Surface-Nourishment Offshore Fish Farming System was launched. To date, more than 40 systems have been installed worldwide. This represents some 100 years of combined producing. Many systems are found in Northern Europe and the Mediterranean Sea.

While I am here to talk about FARMOCOEN'S OFFSHORE SYSTEMS, the company is also producing a line of "traditional" circular raceway cages, as is shown here (slide 3). They are marketed under the same POWERFISHING label, but instead, both the raceway and offshore cages are installed. Slide 4 shows such a site in Norway.

FARMOCOEN also supplies other related products, such as workboats, monitoring systems, feed monitors (slide 5), and experimental feeding systems. The actual manufacturing is normally done by subcontractors. In addition, the company offers consulting services, such as feasibility studies.
It consists of a tubular galvanized steel structure, mounted on a hexagonal pontoon. With a total weight of around 20 tons, the steel structure measures 20 metres, or 66 feet, across.

The system is available in four sizes: 2500, 3500, 4500 and 6000 m³. In imperial units this corresponds to 900, 1250, 1750, and 2350 gallons.

The depth of the net is 15 m, or 45 feet. The same structure can be used for different sizes, making the net interchangeable. The production capacity is up to 150 tonnes.

The normal operating position for the system is in a semi-submerged position with the pontoon three metres (nine feet) below the water surface. The upper work platform and the feed slots are then located roughly three metres above the water.

FARMOEAN’s cages are verified by DNV. One Norwegian version for 5.5 m waves, 35 knot wind, and two knots current simultaneously, all acting in the same direction.

In “real life” some of the units on the French west coast have experienced waves of 16 m without any major problems. Here, we see a windy site from the Shetland Islands (Slide 7).

The net bag is suspended from the inside of the pontoon and the superstructure. Hanging outside the bottom of the net bag, but attached to it, is a heavy anchor bag. This maintains the shape of the net bag, even in strong currents.

A production bag can be pulled underneath the net bag and attached to the pontoon. In addition, 12 produc-
The panels can be fixed to the tubular structure between the pontoons and the upper work platform.

A FARMOCLEAN system is towed with a three-point tilt mooring system. This mooring arrangement makes it fairly easy to move a FARMOCLEAN system and, if required, it is also possible to move the system and its mooring to a new site, even with fish in the net.

All FARMOCLEAN offshore systems have, so far, been manufactured in Europe, mainly in Sweden. For the North American market, we are, however, considering to have the units manufactured at least in part on this side of the ocean.

It normally takes around five days to assemble a FARMOCLEAN system. This excludes the time for installation of the mooring as well as the attaching of the net bag to the structure. These two slides from Sicily show the assembly of a unit (8 and 9).

In addition, slide 10 shows the whole structure.

Mooring plans are prepared by FARMOCLEAN in close contact with the customer, so that the equipment design can be chosen for any particular site. Slide 11 is from Madagascar.

With the reservation that each site has its unique features and requirements, the cost for a FARMOCLEAN system, including similar tube handling arrangements, feed silos and computer-controlled dispensing mechanisms is between SEK 2.0 and 2.3 million, or US$ 380,000 - 370,000. Transportation, Kerfing, etc., will come on top. In order to provide a firm estimate, FARMOCLEAN normally starts by making a feasibility study, looking at the unique characteristics for the proposed site.

Based on years of experience, FARMOCLEAN OFFSHORE systems have proved many times that they can withstand periods of very bad weather without virtually any damage. Installations, outside Normandy, as was mentioned earlier, have experienced waves of more than 10 meters.

In order to improve the performance of its systems, FARMOCLEAN has worked hard to come up with a specially designed net bag, suspended inside the structure.

As the following slide from Sicily shows, the FARMOCLEAN system is semi-submersible. Therefore, movements will be small even in bad weather.
This will minimize the wear and tear on the net (slide 12). The sinker tube will also ensure that the net holds its shape and prevents it from floating up to the surface. The small movements of the net bag will minimize the risk of fish being snared and/or trapped by the net.

Fish can be moved from one cage to another using either a hand net or a fish pump. In addition, it is possible to attach a transfer tunnel to the FARMMOCEAN system and the transfer cage so that the fish can swim into the cage.

A FARMMOCEAN system (slide 6, p. 116) is equipped with a feed slot that holds the net bag on the upper work platform, circa three metres above the surface. As a large amount of feed is required, a separate transport system has been developed for dry feed. This can greatly transfer three lots of feed from a service boat to the site in three quarters of an hour.

Feed is automatic and can be controlled with several built-in compensations, such as for temperature, water height and increased biomass or for achieving maximum growth and minimum feed consumption. However, without a skilled fish farmer who "knows his fish and feed" and, based on this, can pre-set a suitable program, the result will not be adequate.

Despite automatic feeding, it is still very important that the fish farmer check the fish regularly, e.g., once every day just before dawn. Experience shows that the internal or automatic feeding systems will soon be paid back in better growth, reduced feed costs and more time to do other things.

By using larger and deeper cages, it is harder for the fish farmer to observe fish behavior and the bottom of the net. Therefore, divers inspections must be carried out more often with large systems. The frame and the net bag can be inspected at the same time.

Many fish farming companies have their own divers, but others have chosen to enter into agreements with professional divers. We recommend that divers inspect the installations at least once a week.

Dead fish can be collected by a diver. The net bag bottom on the FARMMOCEAN system has a sack in the center. It can be opened from the outside. Dead fish will be collected in the sack and can be removed from the outside without stressing the rest of the fish.

The FARMMOCEAN system also has a device for bringing up dead fish without a diver. A hand net can be slid along the center rope, which is attached to the sack ring in the net bottom and to the outlet on the feed tube.

However, bringing up dead fish inside the net bag may stress the rest of the fish. Reduces the appetite and spread diseases. Therefore, FARMMOCEAN recommends that dead fish be removed from the outside.

Fish can be treated for parasites and diseases in basically the same way as in smaller cages. The treatment procedure must be carried out when the weather is good and the current is weak.

A normal fish treatment procedure on a FARMMOCEAN system starts with debubbling the farm to the service position. The sinker tube is then heated up and thus also the net bag. When suitable volume is reached, depending on the amount of fish, six pump tubes "shoot" fish to a screened bucket outside the net bag site. The treatment solution is then either pumped out evenly over the surface or pumped out through a perforated tube.

Recommended stocking should not be greater than 35-50 small per m². This number, of course, departs on the size and type of cage. In general, densities of circa 20 kg/m² are recommended for most cages and systems.
In the FARMCEAN SYSTEM, a predator bag and 12 predator panels protect the fish from whatever threats. Predator nets also give some protection for the nets against floating objects (Slide 17).

In order to give FARMCEAN systems protection against unsighted predators, the unmonitored units can be equipped with alarms. Furthermore, the structure itself is designed so that it is impossible for strangers to reach the fish.

To ensure that the water exchange in the net bag is sufficient, it is important to change the net before it becomes too fouled. A clean net for a FARMCEAN SYSTEM weighs between 500 and 800 kg or 1,000 to 1,800 lbs, and may be handled by hand. However, a net is required when the fouled net is lifted as it may weigh up to 10 times more than a clean net. This is something one must consider when choosing a boat for the operations.

Here, FARMCEAN SYSTEMS offer an interesting advantage. By deballasting the area to its service position, which looks like this (Slide 18) sealing down to the first three meters can be cleaned off. The possibility reduces the number of times the net bag has to be changed.

When a net change is needed, a diver is required to disconnect the net bag bottom corners from the slider tube. In addition, a service boat with a powerful crane and four men are needed to maneuver the procedure for some five hours. The weight attached to the feed side...
and the superstructure is very helpful when the foiled net bag is to be pulled and lifted out of the water on board the boat.

To facilitate the emptying of the large net bags, special net handling machinery is used.

Offshore fish farms are always influenced by waves, wind, current and marine growth. Therefore, system inspections and maintenance must be carried out on a regular basis. Depending on the type of cage or system, the maintenance routine can vary; however, they must be carried out and followed. The FARMOCEAN system is divided into a steel structure, net bag, cage, automatic feeder and monitoring system. There is a special maintenance routine for each of them.

Faster growth, lower mortality, and a reduced visceral fat content have been some of the findings among fish in offshore fish farms compared with fish in conventional cages. The environmental problems that often occur onshore due to fish pollution from fish farms will be greatly reduced when moving the cages and systems offshore as a result of e.g. deeper net bags, better water quality and exchange, and following that less disease.

FARMOCEAN SYSTEMS are found in the Baltic, along the Atlantic coast of Europe, around Scotland and in the Mediterranean Sea. While the first units were used for growing salmon and trout, the deliveries to the Mediterranean have been for seaweeds and shellfish (Slides 19, 20 & 21). This means that FARMOCEAN has experience from colder waters in Northern Europe as well as warmer conditions in the Mediterranean.

FARMOCEAN systems are on the rise. It is a new, innovative technology that is gaining traction in the aquaculture industry. The system's unique design allows for efficient water exchange and minimal environmental impact. The FARMOCEAN system is designed to enhance fish growth, yield, and health while minimizing the environmental impact of fish farming.
also apply on this side of the Atlantic. Moreover, the disappearance of the wild fishing should open up opportunities in aquaculture.

We have used the first year for us in North America to prove FARMOREAN and its offshore technology. Articles in trade media have generated interest in the product. While a first North American unit most likely will be produced overseas, our plan is to find one or more sub-contractors for manufacturing the product in North America. Suitable candidates could be small to medium-sized shipyards.

To sum it up, it is safe to say that fish farming has become an industry. As a result, it has also become more complex. Today, not only the fish farmer, but banks, authorities, and insurance companies play important roles.

Furthermore, it is not unlikely that consumer groups will have more influence in the future. We have, for instance, seen how the forest industry has had to respond to consumer groups regarding their harvesting practices. Similar demands on our industry can also be expected. Offshore aquaculture can represent an opportunity in this area.

Therefore, it is essential that the suppliers of cages and systems can provide the buyers, the fish farming companies, and the ultimate consumers, with relevant and reliable information on their equipment, so they can base their decisions on correct evaluations.

Thank you for your attention.

A Comparison of the Financial Feasibility of Three Offshore Cage Systems for the Production of Sea Bream in the Mediterranean

Ludmila Bagrova
SANDO-SHIFT LTD.,
St. Petersburg, Russia

INTRODUCTION

Today cage manufacturers can offer different systems that significantly vary in design criteria, operation parameters and cost. Choice of a particular system considerably depends upon hydrometeorological conditions of the given area.

With increasing offshore storm danger increases, which stipulates special requirements to creation of cage farms at exposed areas.

There are different types of systems specially designed for application at exposed water areas. Generally, these systems can be divided into three main groups: floating, semi-submerged and submerged systems. It is very difficult to compare them, for technical differences within one group are often greater than between systems of different groups. However, for open sea conditions the fundamental choice of a system is directly connected to ultimate limits characteristic for each of the three groups.

Thus, floating systems can be deployed at places with maximum wave height below five meters and semi-submerged systems at places with waves exceeding seven m. From engineering point of view, calculation of a system on wave impact cannot provide a 100 percent guarantee of the structure strength under storms. This is due both due to the complexity of wave process and to inexpediency of calculation of storm impacts that occur once every hundred years that would lead to considerable risk in case of the structu...
(note). Guaranteed safety of the structure and fish by deploying the system in exposed areas can be obtained when ensuring the wave impact zone, i.e., by using underwater systems which operate with lower external impacts.

There is an opinion about underwater systems being expensive and unattractive to use (L. Dublin, 1995). Based on the experience of farming and farming farms, average data in the industry, and comparative financial analysis of the operations, we shall try to see the truth of such an opinion.

This paper is based on studies of specialists from the University of Stirling (D.C.B. Scott, J.P. Ellam, and D.A. Robertson, 1993) devoted to estimation of financial impact on a sea-bred on-growing farm when applying two types of cage systems for exposed areas: a semi-submerged one (ARMOCLEAN 350) and floating one (DUNLOP tempered 2).

According to the authors, the main difference between these two systems is the difference in size of the cage systems and labor cost per unit production. Non-equivalence of the volume of the cage of the floating system to the effective growing volume owing to significant deformation of the net chamber under current impact (30%) was taken into consideration when calculating the required number of floating cages.

Adding a third member, i.e., an underwater cage system into the comparative analysis, accuracy to more thoroughly study the differences between the systems arose when constructing a production and financial model.

The aim of the paper lies in evaluation of comparative financial efficiency of three cage systems: floating, semi-submerged, and submerged when applied for sea-bred farming.

All these systems have been successfully used in salmon farming at exposed areas, and at present farmers have begun to apply them for sea-bream and sea-bass farming in the Mediterranean.

In this connection it was not the average data in the industry that we used when determining the survival rates and FCR (food conversion ratio), but the experience of definite operators, which enabled application of average data on three cage systems in the analysis.

Comparison of three types of cage systems was executed both from the point of view of investment decision and from the point of view of profitability and risk.

METHODS

From salmon farming experience we know that operations with output exceeding 100 t/year are most efficient (Saltpool, 1985). This is due to both better utilization of facilities capacity and reduction of expenses on purchases of stocking fish and feed and, certainly, with market advantages.

Based on "economics of scale" we assumed model operations with a productivity level of 250 t of sea-bream per year, which is the most popular species for farming in the Mediterranean.

Based on local market conditions and to provide for continuous production, a twelve-year stocking pattern was assumed. Production cycle of farming 25-30 g after fry at semi-submerged 500-600 t grain fish was taken to equal to 10-12 months in accordance with the experience of actual operations farming sea-bream and sea-bass.

The production model is based on technological assumptions, which are based on both average experience in the industry and average experience of individual operations.

Thus, 93 percent survival rate was assumed for a floating system, based on average experience in the industry that uses floating cages, 85 percent for a semi-submerged one and 98 percent for a submerged one. Based on the data from real operating farms.

Difference in the survival indices is directly connected with influence of stress factors during fish
farming at exposed water areas. The value of the FCR in the sea bass farming industry is two (FCR = 2). A 2.1 was assumed for the floating systems. For semi-submerged and submerged systems, the coefficient turned out to be lower and was FCR = 1.9 and FCR = 1.6, respectively, which was connected with the availability of an automated feeding system of these systems.

The lowest efficiency index was assumed equal to 60 g/straw for a floating system and 50 g/straw for semi-submerged and submerged ones, based on the data of the University of Stirling, Scotland (DCB 1985; Mun and DA Robertson, 1993).

The same data was used to determine the effective farming volume. To obtain the required productivity of 250 kg/year, we proposed to use five FARMOTAN-3500 systems, total volume of net chamber 7,000 m³; four BAUMER systems, total volume 10,000 m³; or three SAECO-5000 systems, total volume 6,000 m³.

To determine the effective farming volume of the systems it is necessary to consider the reduction of net chamber volume of the floating cage resulting from the current action (30%) as well as the presence of "flee cages" within the net chamber avoided by fish during storms (15%). In accordance with the above, the effective farming volume for floating systems was 60 percent of the total cage volume. 85 percent for semi-submerged and only for submerged systems was the effective farming volume (60 percent of the total cage volume).

To evaluate the investment decision several methods were used and all indices were determined for these projects.

- Project 1 - a farm using four floating cages
- Project 2 - a farm using two semi-submerged cages
- Project 3 - a farm using three submerged cages

The payback period, which equals the number of years required to recover the initial investment, was less than three years for all systems.

In accordance with this index a five-year life cycle for project was assumed.

As when determining the payback period, the cash flow after the payback period and time value of money are ignored, the IRR method was applied.

When estimating the IRR, repayment for loans and interest on loans were not considered, the projects were financed with 100 percent equity (IRR), which indicates the return of the capital investment, was positive for all three projects and exceeded 25 percent, which lets us presume that the project will be able to service the last capital, but to be on the safe side, we should extend the project life cycle to 10 years.

The drawback of IRR method for investment evaluation is in the fact that it does not directly consider the amount of investment. The latter is significant when choosing the type of a system for farming at exposed water areas.

The NPV method enabled us to evaluate the investment decision taking into account both size of investment and cash flows and time value of money. When calculating NPV, the cost of capital was assumed 10 percent. All three projects showed positive NPV with linear depreciation, 10 percent tax rate and inflation not considered.

Profitability is the most important criterion when determining the efficiency of an enterprise, but it is also necessary to consider profitability relative to risk.

In order to calculate profitability and risk, the following parameters of financial activity of the assumed production model were chosen: unit cost of production, capital requirements, IRR sensitivity analysis.

When determining production costs, cost of pack-aged farm sea bream, whole fish with delivery to the nearest shipping center, was assumed. Unit production cost above the minimum price that should be obtained per kilo of commercial fish to avoid unprofitability of the project. This gives a measure of the risk involved.
In the project, showing maximum price which the project will still turn a profit. With more than 10 percent reduction of the wholesale price, the project under analysis become unprofitable.

When determining the capital requirements, we considered the capital costs and working capital.

Application of new technologies that enable fish farming at exposed areas requires more significant investments than when using conventional systems.

At the same time, new technologies enable reduction of production costs of producing a higher-quality product, reduction of feed and fry costs, postland costs, increase of fish growth speed and, correspondingly, return on equity.

When determining the project sensitivity to changes in procurement prices of commercial fish, i.e., when estimating risk, we calculated returns of the capital investment requirement with price rise and reduction.

With a 10 percent rise in price, the IRR reached 92 percent, while with a 15 percent reduction only one project with application of floating cages showed negative IRR and great dependence on price.

**DISCUSSIONS**

The most significant difference between submerged and floating systems lies in the food supply system and availability of a rigid framework.

Semi-submerged and submerged systems equipped with an automated feeder provide for feeding even under unfavorable weather conditions and storms, which considerably reduces the operational labor cost of running a farm.

The automated feeding system provides for setting effective feeding regimes, which enables reduction of feed costs due to a more efficient PC.

Availability of a rigid framework in such structures provides for constant volume and shape of a pen, both under unfavorable weather conditions and strong sea currents, which contributes to reduction of stress and increase of effective growing volume.

Submerged systems, unlike semi-submerged ones, are fully protected against storm impact owing to an underwater position of the system during farming. An underwater position of the system enables reduction of corrosion and fouling of the net by an order of magnitude, which increases the life cycle of the structure and permits stress on the fish being raised. This produces a higher-quality product.

The underwater feeding system provides for fish feeding during stormy weather without feed loss, which is impossible with floating and even semi-submerged systems.

Submerged systems and floating ones especially require less capital investments and their feed are of less volume, which provides for greater flexibility in production planning.

At the same time, only submerged and semi-submerged systems are characterized by constant estuary volume, guaranteed fish safety during storms and they enable the operator to avoid manual feeding.

**RESULTS**

When estimating an investment decision using the NPV method, maximum NPV = 1361 was realized for the project with application of submerged cages.

Capital costs when using semi-submerged cages were 13 percent higher than for floating ones. Application of submerged cages includes capital costs per farm as compared to a farm that uses floating cages by 10 percent.

The amount of capital costs effects with production costs by accounting depreciation. Production costs increase with higher capital costs correspondingly, i.e., for submerged and semi-submerged systems, but they are compensated by lower labor costs, lower feed...
costs, better survival rate, and higher quality of end product. Unit production costs for floating systems are three percent higher than for semi-submerged ones and nine percent higher than those for submerged ones.

Capital requirements for semi-submerged systems are 13 percent and for floating systems are four percent higher than for a farm using submerged systems.

IRR for farms that use floating cages is 28 percent, 27 percent - for semi-submerged, 34 percent - for submerged, with market price.

With rise in price up to 15 percent, IRR for these projects shall be 50 percent, 45 percent, and 52 percent, respectively. With reduction in price to 15 percent, it shall be 60 percent, nine percent and six percent, respectively.

Economic value added when investing in the farm that applies floating cages is $400,000, semi-submerged ones $415,000, submerged ones $592,000, as compared to investments in government bonds with fixed interest rate equal to 8 percent.

CONCLUSIONS

Semi-submerged and submerged systems, in particular, are suitable for application at exposed areas at the Mediterranean.

Operations that use submerged cages are most effective.

All three systems demonstrated attractive IRR from investment point of view.

Sensitivity analysis of IRR with rise and reduction in price showed high efficiency of floating systems at rise in price and low efficiency at reduction in price, and higher stability of semi-submerged and submerged systems.

All financial indices confirmed the superiority of underwater systems over semi-submerged and floating ones.

REFERENCES


Cost and Market Realities in Open Water Aquaculture

John Jerger
Aquaculture Business Consultant
Port Angeles, Washington

Introduction

With a title which talks about costs and market realities, it might seem that this could be a somewhat pessimistic look at the future for open water aquaculture, but this is not intended to be the case. It is emphasized, in the course, that this author is a believer in open water aquaculture and that the cautious and reality checks discussed merely reinforce my view that this is where a major part of our industry’s future lies.

This paper will discuss costs and prices and the value expectations of mass markets, and what aquaculture, as it develops or if it ever gets to deliver on its promise of providing a major new source of seafood. In doing this, it will draw heavily on experiences from closed farming because this is an industry which, for twenty-five years now, has been going through a dynamic and sometimes painful evolution as it contends with its own cost and market realities.

As we contemplate new aquaculture technologies and the farming of new species, we would be foolish not to learn from this test-wise experience.

The cost of Water

It's a statement that is obvious, but aquaculture is all about growing things in water. So it follows that, if we want to grow a lot of things, we need a lot of water. Yet a great deal of modern aquaculture seems to want to deny this obviation and try to grow a lot of things in a little water. The title of this paper could just as easily have been "Cost and Market Realities in Closed System Aquaculture" where it is suggested, ex-
preamble over the years has proved a need for rather more cost and market reality.

If there is one thing that has grown over 30 years in this industry, it is the value of free water. Why is it that, in less than 30 years, annual production from the world's salmon farming industry has grown from almost nothing to over 700,000 metric tons, while in the same time, production of fish in intensively managed, closed systems remains at probably less than five per cent of this? Or why is it that despite numerous attempts to grow salmon in land-based pump-to-clove systems, almost all of them have failed, so that now it is doubtful that more than a thousand tons or so, out of the total of 700,000, is grown in this way?

The answer is that cage farming is an energy efficient, mechanically simple, easily replicated and above all, cost-efficient method of managing water in aquaculture and, when located correctly, provides a level of water exchange past the fish that those open-ended tank systems can only dream about. Some may dispute the idea that the water is free. There are obviously costs associated with permits, leases, environmental monitoring, etc.; but compared to land-based tanks, cage farms are able to provide growing space and water exchange through it as a function of the cost required to support land-based installations. Compared to other approaches in aquaculture, this is the single most important reason why open ocean aquaculture has such strong potential. It will allow access to tons of water.

It should be made clear here that these comments are directly to what might be called the "Westernized Aquaculture" of mostly carnivorous, high-quality species of fish mass demanded by consumers in the world's developed economies. It can quite rightly be pointed out that a Chinese captive pond, effectively a solar-powered, closed system and these ponds not only produce most of the world's farmed fish at present, but they do so at costs which, if their product was appreciated by Western consumers, would put growth of salmon, trout and other out of business. It is important to keep in mind that while the opportunities for open water marine aquaculture are enormous, in volume terms, production of fish in tanks, mostly freshwater stocks, continues to dominate global aquaculture production today and is likely to continue to do so for years to come.

Market Realities

Much of the justification for renewed interest in marine aquaculture, indeed, for this conference, is based on forecasts of a future global seafood deficit of millions of tons per year, caused by increasing consumer demand and resource problems in the world's natural marine fisheries. It is a situation which provides a compelling logic for aquaculture and has attracted the attention of politicians and even the investment community, in a way which it has been hard to do up to now.

Overlooked in this logic, though, is that the millions of tons of projected seafood deficits are predominantly for fish which sell at much lower prices than most people contemplating aquaculture ventures can live with. Just because fish supplies may be short in future, it does not mean that most people will therefore pay any price to maintain their level of consumption. They won't, they'll switch to chicken, or cheaper, cost processed meats, or just reduce their consumption of animal protein generally, which is arguably too high anyway. There is no law that says people have to eat a certain amount of seafood. They will, as they do now, shop for value, and if future aquaculture offerings do not provide competitive value, they will not sell.

The salmon industry provides an excellent example of what happens when an aquaculture product moves from a niche, or specialty status to a mainstream food item. (It's one of the great achievements of salmon aquaculture, incidentally, that it has been able to make this transition.) Only seven years ago, when not much more than 150,000 tons of salmon was farmed world
wide, the wholesale price for fresh, bench-caught Atlantic cod was over $5.00 per pound. Today, with world-wide production at about 300,000 tons, it’s less than half of that, between $2.00 - $2.50 per pound. But the present high level of seafood demand is not just driven by increased production; it is also due to consumer demand. The demand for seafood is increasing worldwide, and the United States is no exception. Consumer demand is one of the main drivers of the seafood market, and it is expected to continue growing in the future.

To meet this demand, the aquaculture industry is expanding its production. Aquaculture is the farming of aquatic animals and plants, and it has become a significant source of seafood worldwide. In the United States, aquaculture production has increased significantly over the past few decades, and it is expected to continue growing in the future. Aquaculture is a sustainable and environmentally friendly way to produce seafood, and it is expected to play an increasingly important role in meeting the demand for seafood in the future.

The demand for seafood is not just driven by increased production; it is also due to consumer demand. The demand for seafood is increasing worldwide, and the United States is no exception. Consumer demand is one of the main drivers of the seafood market, and it is expected to continue growing in the future.

To meet this demand, the aquaculture industry is expanding its production. Aquaculture is the farming of aquatic animals and plants, and it has become a significant source of seafood worldwide. In the United States, aquaculture production has increased significantly over the past few decades, and it is expected to continue growing in the future. Aquaculture is a sustainable and environmentally friendly way to produce seafood, and it is expected to play an increasingly important role in meeting the demand for seafood in the future.

Yield

A critical factor in providing competitive value and market size is the yield. Yield is the amount of product that can be produced from a given amount of input. In the context of aquaculture, yield is the amount of fish that can be produced from a given amount of feed or land. Yield is an important factor in determining the profitability of aquaculture operations. Higher yields mean that more fish can be produced from the same amount of input, which can lead to increased profits.

In the context of aquaculture, yield is the amount of fish that can be produced from a given amount of feed or land. Yield is an important factor in determining the profitability of aquaculture operations. Higher yields mean that more fish can be produced from the same amount of input, which can lead to increased profits.

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This is what is meant by "market realities," perhaps a better term would have been "business realities." They provide an obvious challenge and a clear goal. If offshore aquaculture is ever going to be anything more than a boutique industry providing small quantities of expensive seafood to niche markets, its costs must be competitive. There is no point in designing structures and developing systems, no matter how clever they may be, which do not provide the possibility of low-cost production and there is no point in seeing

...
loving species which cannot yield reasonably priced, healthy, boneless fillets for mass market consumption.

Costs

It may be helpful now to look at some production cost details and to examine why, with the right species, open water aquaculture can be competitive. Costs in salmon farming today break down roughly as shown in Table 3. It is emphasized that these are broad indicative averages which have been collected for the purposes of this analysis — there can be considerable variation between different farms and different farming regimes. These costs are also presented in a manner similar to most fish farm accounts in order to differentiate between those costs which should really be much the same, whether fish are farmed inshore or offshore, and those where differences can be expected. As can be seen, nearly 86 percent of all production costs are likely to be about the same.

<table>
<thead>
<tr>
<th>TABLE 3: SALMON FARMING COSTS</th>
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<tbody>
<tr>
<td>Cost Item</td>
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</tr>
<tr>
<td>Fixed costs</td>
</tr>
<tr>
<td>Smelt</td>
</tr>
<tr>
<td>Feed</td>
</tr>
<tr>
<td>Labor</td>
</tr>
<tr>
<td>Insurance</td>
</tr>
<tr>
<td>Depreciation</td>
</tr>
<tr>
<td>Total fixed costs</td>
</tr>
<tr>
<td>Variable costs</td>
</tr>
<tr>
<td>Overall salmon</td>
</tr>
<tr>
<td>Total variable costs</td>
</tr>
<tr>
<td>Total costs</td>
</tr>
</tbody>
</table>

There is no reason why costs of feed and smelt should be higher for an offshore facility compared to a conventional inshore farm and the case can be made that they would be less, because better water conditions and water flow in an offshore environment will lead to better health, growth and survival. Nor should there be a penalty for labor costs. A well-designed and well-equipped offshore farm should, at least, be capable of producing 161 metric tonnes per year which is an average today for most inshore farms, and it is quite likely that productivity could be made higher than this, if operations are fully mechanized. Fish mortality insurance for offshore farms, which is a major item in most inshore salmon farm budgets, should also be reasonable since cage designs are proven, and it can be argued that because some risks, like phytoplankton blooms, are more likely to occur in offshore areas, the premiums may even be lower. And the same applies to costs for administration and the financial cost of working capital. All of these costs should be roughly the same, irrespective of whether the fish are grown.

Where there are likely to be cost penalties in farming offshore is in the areas of operation support and the financial costs of fixed capital, i.e. interest, depreciation, and required return on investment. But this is where using established costs from the inshore industry as benchmarks can be helpful in improving reality. Any additional costs incurred in these areas will have to be made up somehow else. There are some opportunities for doing this which will be discussed later but, in general, offshore farms are going to have to be able to operate without too much of a penalty in these areas, or they will not be competitive.

It seems probable that supporting, supplying, and maintaining a fish farm in an offshore environment is likely to be more difficult and therefore more expensive than doing the same thing inshore. Bigger and better equipped boats, additional safety precautions, downtime due to bad weather, altogether lead to more cost. A good might be to say that they should be no more than double what it would cost inshore, or
$0.28 per pound, based on the generic figure in Table 1. Looked at another way this means that a 10 million pound per year offshore operation could afford to spend up to $1.8 million per year, or about $5000 per day, in servicing and maintaining the facility, excluding labor. It would seem that this should be enough.

Where it could be more difficult to compute costs is in the capital costs of equipment. Modern salmon cages have become remarkably expensive. Only five years ago a state of the art salmon farm using 15 m square, steel cages would have cost somewhere between $200 - $300 m, compared with $500 and $700. Today, using large, plastic cages the cost is $10 per ton.

Prices for offshore cages, presently available on the market, are in the range $140 - $160 per m² and a very simple analysis in Table 2 shows how this has a big impact on cost of production. Some may argue that the assumption of 15% of production per m² per year is too low and others can challenge the assumption of an expected return above interest of 10 percent, prevalent in this case to a total return of 20 percent. But the point is, if expected return on investment is included as a cost, which it effectively is, because if a return is not expected, why invest, then the cost of fixed capital investment has the bottom line in those ways and cumulatively they can add up to a big number.

**TABLE 2: EFFECT OF CAGE PRICES ON FARMING COSTS AT PRODUCTION LEVELS OF 125 TON OF FISH**

<table>
<thead>
<tr>
<th>Potential assumptions</th>
<th>$100/m²</th>
<th>$150/m²</th>
<th>$200/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual 10%</td>
<td>$0.03</td>
<td>$0.05</td>
<td>$0.07</td>
</tr>
<tr>
<td>125% increase</td>
<td>$0.03</td>
<td>$0.05</td>
<td>$0.07</td>
</tr>
<tr>
<td>Expected return above interest 10%</td>
<td>$0.03</td>
<td>$0.05</td>
<td>$0.07</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>$0.09</td>
<td>$0.12</td>
<td>$0.19</td>
</tr>
</tbody>
</table>

It can be argued, with some justification, that in an offshore environment, better water quality and higher levels of water exchange will allow higher working densities and therefore more production per cage meter. But this is a trade off to be treated very carefully. It would be much better to develop economics which cost less to begin with and to treat any benefits from higher densities as extra carry. Rather than to impose the need for higher densities as a condition of financial viability.

As a capital cost goal it is suggested that anything above a cage cost of $50 per cubic meter is going to make it very difficult to justify investment in an offshore fish farm. Compared to an inshore farm equipped with large, plastic cages this results in a cost parity of $0.24 per pound, which is only 15 percent of the total generalized costs in Table 1 and is more than enough not to be a burden for any farm to carry. In fact unless some of it can be recovered elsewhere it may be too much. There are not too many businesses that can survive in a commodity market with a cost parity this large.

**Non-Farming Costs**

So, the question is, can these higher costs be made up somewhere else? It is supposed that can in the area of what will be called "non-farming costs," i.e., all those costs associated with harvesting, processing, packing, and distributing the fish for sale to consumers. Up to now the main focus of this paper has been on how to reduce the cost of farming and, in most of you probably know, there have been major gains in farm efficiency in recent years. There has been much less attention given to the "non-farming" costs. These can quickly add up to some big numbers and, as the cost of growing salmon continues to grow, these non-farming costs are now assuming an ever increasing proportion of the final cost or price, consumers have to pay.

In general, total production time is called the "price spread" and it is calculated each month for beef.
pack and checkers by the USDA. It measures the overall costs of getting different meat products from farm to table, or in any other way, how much of the retail price the farmer receives, and the marketing system adds. Table 3 shows some values taken from a 1986 report on cost kernels in farmed salmon, published by the State of Alaska Department of Commerce, updated to reflect current pricing in the farmed salmon market.

**Table 3: Price Spreads for Different Meat Products Comparing Atlantic Salmon**

<table>
<thead>
<tr>
<th></th>
<th>Beef</th>
<th>Pork</th>
<th>Chicken</th>
<th>Atlantic</th>
<th>Other</th>
<th>Atlantic</th>
<th>Other</th>
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<tbody>
<tr>
<td></td>
<td>$2.16</td>
<td>$1.06</td>
<td>$0.63</td>
<td>$2.08</td>
<td>$3.72</td>
<td>$2.08</td>
<td>$3.72</td>
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*All Atlantic salmon costs are adjusted for 66 percent edible yield from gain weight.

The first point to emphasize is that the salmon prices shown are net those for wholesale, head-on fish. Peking duck, which most salmon farmers are used to selling, they have been adjusted from those by taking out the costs of processing, packaging, inventory, freight and sales commission in order to give an ex-farm price and then adjusted further for yield to a skin-off fillet. This gives the ex-farm price of edible meat that the farmer sells and is the same calculations USDA uses for its price spread estimates. There is therefore a fair basis for comparison.

The second point to emphasize is that the assumed retail price of $3.49 for skin-off fillets is a composite of prices from around the country and for some markets may be on the low side. It does not cover much because the point is clear anyway, compared to meat the present cost of getting shrimp to market is higher, over twice as high as in for beef and pork and a hundred times as high as chicken.

What this means is that salmon, in trying to compete for market share with the mass-produced meat and poultry products, bear a surprising cost burden imposed by the distribution and marketing system. If salmon farmers could get their own selling costs down, effectively as they have been able to with the costs of farming, and all, or most, of these costs, were then passed on to consumers, salmon would be more competitive. It would provide better value, which would lead to increased consumer demand which, in turn, would lead to opportunities for further industry expansion.

The reason for going into all this is to show why open ocean farming may make this possible through industry concentration. One of the reasons why the chicken and meat industries are so efficient is that their activities are concentrated on large scale, relatively small areas. Large scale provides the efficiencies like multiple shifts working in processing plants and concentrating in the same variety of food mills, farms and processing plants, minimizes transport costs. Peking Fowl, the largest chicken company in the world with live weight production at chicken at 5955 over five million cases, has a 60-mile route which says that if a battery, feed mill, processing plant and grower are not all within a radius of 60 miles, cumulative transport costs will be too high.
Compare this situation to today’s salmon farms, which in the north of Norway, south of Chile or northwest B.C. can be hundreds of miles from the nearest road, port or city. If there is a local processing plant it is usually small and does not work five full shifts a week, let alone multiple shifts, some six or seven days. Transport of smoke and feed requires trucks, boats and even helicopters to get them where they are needed and maintain the fish, when they are finally processed and ready for sale, are usually thousands of miles away. It would probably not be an exaggeration to say that in some cases the cumulative cost of transportation, from farm to final customer, is now more than it costs to grow the fish on the farm in the first place.

Open ocean farming provides a way to deal directly with these problems. When the technology is ready, it will be possible to develop clustered farming operations with many thousand of tons of production, all within a reasonable distance from shore and much closer than most farms are now to major markets. These farms would be operated from a shore base with fully mechanized ship-to-ship handling and a feed mill, and a processing plant, and in places like Maine, New Brunswick, or the State of Washington, they could be developed alongside and as part of the existing industry, thereby providing cost-saving opportunities for all.

This may all seem a bit fantastic and unreal as we look at aquaculture today, but the point is that there are solid cost-saving reasons for doing so and therefore the incentive for large scale investment by those who recognize the opportunity. There is the potential to re-cover all the cold peninsulas discussed earlier and more, especially when it is figured that the cost of fuel and transport are likely to increase faster than some other costs in the years ahead, so putting farms in distant corners of the globe at an even greater advantage.

If it is agreed that our long term goal is, or should be, to make a dent in these well publicized, global seafood deficits and to provide wholesome, wholesome food for mass markets consumption, then it means growing millions of tons, not hundreds of thousands, as the salmon farming industry does today. It also means processing and distributing them at a cost which makes them affordable. It is hard to see how this will be done by an industry that has to reach farther and farther into remote and inhospitable parts of the world in order to find places to do it. It seems much more likely to be done by an industry that learns how to farm in its own very large and accessible back yard.
Economic Feasibility of Sea Farming: Operational Perspective

Tom Cheek
Ocean Sea Technologgies, LLC
West Bainbridge Island, Washington

Sea Farming is expected to open new vistas for the development of new technology for sea cages, vessels and equipment. Also, new techniques for operations such as fish control, feeding, waste control, grading, and harvesting will evolve, driven by economics, feasibility, and objectives.

Personal experience in the expansion of the aquaculture industry in the North Pacific by the Delta Sea Farms has demonstrated that the economic incentives can drive the expansion and development of an industry. High value species such as salmon, trout, and prawns, each valued in excess of $2000 per metric ton, are now being harvested by vessels in excess of 35 meters. These vessels are now harvesting 100 metric tons of salmon per trip, and processing 150 metric tons per trip. The industry will need to develop in a similar way.

Advances in cage technology have made it possible to contain water in exposed high energy areas. Ocean Sea Cages are an example of cage technology developed for efficient fish farming in exposed high energy Atlantic waters. The Ocean Sea Cages, as seen by the写作者，在华盛顿州西温哥华市，演示了海洋养殖的挑战和机遇的解决方案。

Here, we looked at reducing the number of "breakouts" and improving water flow around the cages to optimize growth. Breakouts are a common problem in fish farming, where fish escape from the cages. These include: breaking of the net, the mesh, the structure, the fish, and the fish feed. By optimizing these factors, the growth rate of the fish can be improved. The result will be a more efficiently grown animal that will be competitive in the fish market.

Second, we looked at the impact of scale and labor reduction on the business as it plans for increased operational capacity. The following are the key operational aspects of sea farming that will be discussed in this paper:

1. Fish must be transferred to cages which are in

150
remote areas offshore. Strategies exist for utilizing existing sites for grow-out and in new sites for rearing.  

1. Fish farming and site maintenance are labor-intensive, with labor costs being a significant portion of the total costs.  

2. The scheduling and site maintenance in remote areas could be automated and improved with advances in automation technology.  

3. While new technology can provide new opportunities for site selection and management, it may not necessarily improve site selection and management over time.  

4. Natural site selection in remote areas is often based on historical experience and may not necessarily be optimal for new farm site selection.  

5. Natural site selection in remote areas often requires careful planning and execution, and the success of the fish farm is often dependent on the site selection process.  

6. Migrating existing remote sites to remote areas can be difficult and may require new technologies and strategies.  

7. Fish farmers in remote areas often use a combination of site selection, management, and automation to ensure the success of their fish farm.  

Sea farming in exposed, open-ocean sites will require the development of new technology for site selection, management, and equipment. Newer, more efficient technologies for site selection, management, and equipment that can be applied to remote, open-ocean sites will be crucial for the success of sea farming.  

The following are key considerations for site selection, management, and equipment in remote, open-ocean sites:

1. Fish must be transferred to sea cages which are more remote areas. This can be done by towing a second vessel in front of the fish farm.  

2. Fish feeding in remote areas may use a control system that manages fewer vessels with larger quantities of feed. This in turn reduces the amount of time required for fish feeding.  

3. Net feeding on existing fish farm systems requires careful planning and execution to ensure the success of the fish farm.
3. Mortality removal could be done using an existing technique such as an anti- or other automated system instead of divers. (Figure 2)

4. Externally harvesting could use integrated fish handling systems in the sea cage (Figure 4) and fish transport could be simplified by towing the sea cages to sheltered ports closer to processing and the market.

As a company, we want to understand the economics of these different operations. For this paper I have used cost figures for farming Atlantic salmon from John Foster’s (Foster, 1995) paper written for the state of Alaska which summarises salmon farming costs from the low end in Chile to the high end in North America and Norway. (Table 1.) If we can grow salmon as efficiently offshore as inshore then this technology will apply to other species and before any farming methods and equipment will be developed.

But, before I get into the cost comparisons of operations, I want to make some comments about offshore sites of the future and list some assumptions about the size of a hypothetically farm used for this discussion. For example, as farmers consider moving to more exposed areas, the first sites should be as close as possible to an existing offshore farm and accompanying support. This accomplishes two things: 1. the offshore location can be used for grow-out while using the inshore site for smolt rearing; and 2. the closer the location the lower the transportation costs will be to and from the cages. Also important will be to choose moderate energy sites available. By using areas within close proximity and moderate energy, new methods can be developed for future, more remote sea farming. I’m not suggesting that sites are chosen that can not continue using cages or farming circles. Instead these “transitional” sites need to be far enough away from the factors that will enable the equipment and create new technologies while continuing to give returns to the investors. Our company’s policy will be to encourage the careful screening of new sites to help protect the farmer’s investment while expanding the frontier of farming.

For this discussion and spreadsheet, the following eight assumptions were used for the hypothetical offshore farm. Extension rates and stocking densities are based on published results from Foster’s report (Figure 5).

1. It is assumed that the sea cages in an offshore location will be used for grow-out only and the farmed site is for rearing only partially grown salmon. These small fish would be transferred at 10 kg size from an inshore “parent” farm to the offshore location where they are raised to four kg. These bigger fish will be stronger and more likely to survive the currents and any possible stress events.

2. The farm size is 2,500 metric tons (mt) gutted weight (5,500,000 lbs) of annual production. This site was selected to achieve economies of scale and minimize the expenses over a reasonable number of pounds of production.

3. Six hundred and fifty thousand small salmon are transferred during the year to the sea cages and 625,000 are harvested after adding 3 kgs (75% of their body weight) about six months.

4. Growing densities were based on inshore results. For this I picked a conservative range of 11 to 18 cages, each 5,000 cubic meters, to raise 0.25,000 salmon per year. The densities range from 21 kgs per m3 to 31.6 kgs/m3 at a maximum grow-out.

5. Feed conversion is assumed to be 1.4:1 for gutted yield although there are studies that indicate better conversion with exercised fish in higher current (Golding, 1993).

6. This paper assumes conservatively that the offshore sea cages are located eight km from inshore support. In some places such as St. George, New Brunswick, sites could be as close...
as a kilometer to inshore farm support. Near Seattle in the Strait of Juan de Fuca we have a site 25 km from an inshore farm.

7. It is assumed that the current range from one to 2.5 knots and storm waves (maximum seven meters) occur at only rare intervals. These facts are not clearly distinguished in the discussion. Existing floating structures such as skiffs will not withstand these conditions for extended periods.

8. Finally, it is assumed for this discussion that hired vessels are available and that the rates are estimated at $25.00 to $50.00 per day for a 170 ton capacity or a conservative estimate based on tender operators in Seattle.

Using these right assumptions, now I'd like to discuss the possible low and high cost range of the four operations and try to show that offshore can compete with these operations. After that I'll review the capital expense requirements and finish with some summary remarks.

OPERATION 1: FISH TRANSFER TO SEA CAGE

Because offshore suggests greater distances, stronger equipment and bigger vessels, it is for these reasons that we attempt to develop current ways to transport fish safely. A hired 500 ton capacity vessel, 90 meters long, with a pump and a self-propelled could carry 3000, one kg, partially grown salmon (the density of 1.5 g/l) and cost $500 per day. At the eight knots traveling at 2.5 km per hour, the vessel takes only one hour to make the 45% unload. If another three hours is allowed for the loading and unloading, that would be four hours to transfer 3000

small fish to a sea cage. Therefore, $20,000 per day for the 45% unload. That would be $60,000 total transfer for $216,000 vessel cost. Adding the cost for 54 days of a 25% of a year's cost of $25,000 per year, of course, and other expenses as a vessel, the cost per lb, of fish, transferred is $12,250. Therefore, 4.2 cents per lb. (dressed) for the high cost of transfer fish offshore. (Table 1)

The low-end cost of the range of one cent per lb, is based on known sea cages with a greater number of one kg, salmon enclosed. A 500 ton capacity vessel could carry 5000 m3 of cage with 25,000 fish (density of 1.5 g/l) and cost $500 per day. At the eight knots traveling at 2.5 km per hour, and allowing for loading and unloading that is $1600 for one day. There would be 36 of these trips per year or $90,000 total for highest rental or transfer $65,000 partially grown salmon. Adding a one-year vessel for 25 days at $5000 results in a total of approximately $48,000 or one cent per lb, dressed (Table 1). In both of the cases above it was assumed that there were vessels for hire and no capital equipment expenditure was needed. Although not conclusive, the towed sea cage scenario above could have a cent per lb, of fish produced. Advantage over the cost of the vessel, if favorable tenures can be utilized for higher speed, and special bags or similar sea cages designed, the cost to move fish could become even more economical for remote operations.

OPERATION 2: FISH FEEDING

Total annual feed requirements during the usual of

2540 m3 of growth fish 2750 h, whereas fish is 3500

m3. using a conversion factor of 1.2 to 1. Seventy-five

per cent of that weight, or 2540 m3, is needed to add

three-quarters of the weight, or three kg, to the

growth of fish. This cost $1600 per day for 45% unload

of feed. The cost to add the feed is approximately

$216,000 vessel cost. This vessel would be owned by

the farm and is utilized in the capital equipment

expenses. For this operation I assumed that it would re

quire three people for a cost of $120,000 average of

$40,000 and a 2.2 cents per lb, dressed, for economi

mized hand feeding of the fish in the offshore cages.

(Table 1)

The low-end cost of the range assumes a normal feed

stability and only one operator. This option is probably
extreme because in close proximity and with moderate energy the early years will be easily secured by the small feed boat would be the large and expensive. The present estimate is 72 m. to feed for 10 days of feeding would require a hired vessel at $300/day. Thirty-five days out of the year would require $260/day. If you allow for one man working for 37 days to man the feeding system, that would add about $1,000. The total for the workers and the hired vessel is $117,000 and 2.1 cents per lb of fish produced. (Table 1)

To review the range for the cost of feeding, it should be pointed out that when the fermented equipment cost is added to the labor cost the high and low is averaged. If the central feeding stations cost $1,500,000 each, that is one cent per lb. amortized over 10 years. This makes the so-called "low" three cents per lb. ($972 labor + $0.5 equipment) and the "high" 2.3 cents per lb. ($972 labor + $0.6 equipment). The reason for this reversal is that on a moderate energy site in close proximity to anchorage, mechanized and hand feeding would be the most economical. Only when the same remote offshore locations become less accessible will large feed storage and centralized automatic feeding be required. For this analysis, if the assumptions are correct, it is most significant that even with the two $75,000 feeders amortized over 10 years plus one worker a hired feed carrying boat, this offshore operation would be less than shore feeding operations.

OPERATION 3: NET CLEANING AND MORT REMOVAL.

Net cages will be shocked to remove growth on the surface and cleared in low light conditions. An experiment that COT carried out in Piget Sound was to submerge a soiled cage for several weeks to reduce feeding. Algae growth that had settled on the netting initially died and fell off in mild currents. Several months later when it was remanned, the netting was clean.

Shoaling were more difficult to remove and will probably require periodic cleaning with something like the BIDEMA test that many farmers now use. Besides biological net washing, "safes" anti-fouling sprays are now being tested effectively and continue to be developed. These hold promise for reduced fouling and would be very effective at limiting the need for cleaning after grow-out and limiting algal growth.

For purposes of this paper, net cleaning of the sea cages was considered a minor expense during grow-out, and it is included as the 25 percent of the labor expense (see later in this paper, showing 25 percent inshore component). This figure ranges from two cents per lb. dressed fish to eight cents per lb. (Table 1)

The cost range would cover net cleaning of the small cages, the labor expense for cleaning the offshore pens after grow-out, and any other expense associated with the net cleaning phase of operations.

Mortality (mort) removal: Daily or as frequently as practical) mortal removal will be an important function for the offshore farmer because of the fish farmer's need to observe the fish stock's health. For the grow-out period from one kilogram to four over six to seven months, it is assumed there will be only a five percent loss or 25,000 fish. Do-vaners can be used, which I've considered for the high end of the cost range, or a diet feed system, which I've used for the low end of the range. For this discussion I am assuming that there will be two full-time day shift that come (with their insurance and compensation) $160,000 per year or three cents per lb. of dressed fish (Table 1).

The vessels they use would be the two vessels owned by the farm, a 132-net feeding vessel and an 8.5-meter boat included in the equipment.

To calculate the low end of this cost range have assumed that an inexpensive diet feed system was installed and that one laborer can remove mors from every cage each day. At $300,000 for a skilled offshore fa
been that is only one cent per lb. of dressed fish produced for labor (Table 1). This is the kind of automation that can reduce the need for farm workers in the more inaccessible locations of the future.

**OPERATION-4: HARVESTING**

The last operation that I would like to discuss is harvesting and transfer of the salmon to the processor. The process in the reverse of juvenile fish transfer. From shore to the offshore site, but the fish can weigh four lbs. and can be crowded to reduce the density for transport to port. Hence, remote, higher energy location will provide smaller windows of opportunity to transfer fish at sea until technology has been developed to make it easier. For this discussion, I will assume that the salmon are processed, onboard and transported by the wellboat for the high-end cost sample and treated in a sea cage for the low-end cost operation.

I also assume that the same wellboat is used to carry harvest fish back after it delivers partially grown salmon (39 return trips). In those 39 return trips (54 days) the 170 ton capacity wellboat can transport 45,000 four-kg, fish in each trip. That is a density of 159 kg/m³ and 190 kg/m³ is allowable with a good circulating system. Since I am assuming that 39 of those 108 return trips can transport salmon back to port, another 39 trips are required to harvest 625,000 salmon. This would cost $1,500,000 for the three vessel time. A total of 78 days per year of farm workers' time was assumed as necessary for transfer of harvest fish. For this total two-vee farms (78 days or $35,000,000 at $100,000 per year if $50,000, each. Therefore, 36 days at $600/day for the hired vessel plus $33,000 (78 days) for farm labor at 3.4 cents per lb. dressed to harvest 2,500 tons (Table 1). This represents what I have called the high-end of the range. If all of the trips for harvest were independent of the small vessel, the cost for 78 days with two trips per day would be 6.3 cents per lb. and cost 3.4 cents If I used the higher 6.3 cents per lb., the total cost of the fish transfer to and from the offshore site would be understated and would lead to some return trips after small fish transfer can carry fish back to market. For the harvesting, the cost of harvesting fish to the processor should be between 3.4 cents and 6.3 cents per lb. accordingly to a reliable Seattle salmon farmer.

For the other side of the cost range, harvesting fish in a sea-cage to enhance processing could be done with a tugboat partially grown fish were transferred offshore. At 50,000 m³ cage with 20,000 four-kg, of salmon has a density of 192 kg/m³, way below the 131 kg/m³ density used in the wellboat. The hired tug cost of towing the cage at one knot is an another processor eight knots away, at $200 a four-hour, or $800. Allowing again for loading and unloading, $1,500 per trip was used. For 36 days that is $41,000. Add labor of $1,000,000 for two workers for 20 days and the total is $31,600 or one cent per lb. for laboring harvest fish to the processor via a tugged cage (Table 1).

To review, because return trips to offshore harvest salmon, it is misleading that harvest cost appears lower than partially grown salmon transfer. If the two expenses (small fish transfer, $542 and harvest transfer, $5,034) were averaged the high cost would be 3.4 cents per lb. and the low end would be the same as one cent per lb. This range of 3.4 to 6.3 cents could be used as the cost of moving fish between inshore and offshore and may be more useful.

For capital equipment expense for harvesting, nothing was needed since hired vessels were assumed for both fish transfer options.

**Capital equipment review:**

Now I will review the amortized capital equipment items for offshore. In Table 1, the fixed Cost includes amortization expense of the equipment that I assumed was needed for offshore operations. The total amortized cost of equipment for both ranges from $5,000 to $13,750 per lb. of fish grown according to Forster's paper. Because 25 percent of the fish weight is added medium, I used 25 percent of the average between the two values to arrive at the expense needed.
for cages and other equipment to partially grow the fish. This figure is two cents per lb. of fish produced (5.9%) if we take 25 percent of the average of $1.07. The same figure of $1.99 was used for both the high and low costs because I weighted the average on the low side believing that small cages are less expensive today if you can use the floating method.

The second line item is the largest expense associated with any sea farm, the sea cages, including their installation. Based on our experience with eight sea cage installations, the $25 per net figure should be adequate to cover the cost of the installed sea cage systems in the moderate-energy sites described earlier. Assuming amortization over ten years, that is 4.5 cents per lb. of dressed fish for eleven cages at 7.4 cents per lb. for 18 cages. Depending on the stacking densities that can be achieved offshore, the low-end figure could be even lower than 4.5 cents per lb. The greatest potential savings in capital expense for offshore farming could come from higher stacking densities and, subsequently, fewer cages. If the range were based on these densities that would reduce the number of cages required to half. Although 27 to 42 kg per m² sounds like high density for large well-constructed tanks with pumps, clean water, 75 to 100 kg per m² with that in mind, 27 to 42 kg per m² seems plausible in high-current areas using fixed volume cages because it is still less than one-half of what well-known sea farms use.

The third line item is equipment, which is the two vessels that were amortized over fifteen years. In the discussion of Direct Production Costs above, all of the larger vessels needed were assumed to be hired for carrying feed, feeding cages, or transporting live fish. For the low end of the cost range for feeding and most removal, smaller vessels were included at 13.7 meters for $70,000 used for feeding and a 8.5-meter for $30,000 used for most removal and other operations. These are not deep-water sea-going craft because I assumed moderate-energy sites. Specialized craft will develop for operations offshore depending on site conditions, distances, etc. The amortized vessel expense of $100,000 over 15 years at 14 cents per lb. of dressed fish produced. For the high and low end of the range, the same method was used.

The fourth item is the capital equipment for feeding equipment. One cent per lb. covers maintenance $5000 over ten years and we put in on the low side of the end-of-life range above. The one percent (1%) per lb. on the right side is for a brand new automated booster feeder and is more labor intensive, as discussed earlier. In the future, the replacement of the locations will limit access by workers, therefore requiring more unmanned equipment such as central feed stations. This is why labor efficiency will be necessary.

Finally, the fifth line in the equipment section covers miscellaneous equipment and is around a 1.5 cent per lb. of fish produced. It is a little higher on the low end side because an additive is included, which provides labor savings as discussed earlier in the most removal operation. The cost of an airlift and the other miscellaneous equipment was only a guess but should be enough to cover this and other small equipment needed, such as net washers, dive equipment, etc.

SUMMARY

New sites for fish farming will open up if two requirements are met: 1) if the technology exists to securely hold the fish in higher-energy conditions, and 2) if the operators are experienced enough to grow the fish so that the product can be competitive in the marketplace. Our company feels that the Ocean Space sea cages are examples of equipment that satisfy large measures the first requirement. At this conference we are hearing about other technologies that could prove to do the same. For the second requirement, this paper has suggested that labor costs for the first operations for offshore farms are less than or equal to onshore farms. Although these results have not been fully tested, my experience in the fishing industry tells me.
that these are conservative savings and there will be great opportunities for future and farming investors just as there was for indoor farmers over the past 20 years.

Of course assumptions were made in the discussion that took advantage of economy of scale that increased production while reducing labor. But if the assumptions were made on conservative estimates, then it should be possible to have even greater reductions offshore. Labor represents only 7 percent to 10 percent of the total cost of an offshore fish production facility. The number of men per sea wrench (which is used as a standard measure in farm productivity) ranged from high productivity (low labor cost) of 828.9 tons per man year to a low of 198.9 tons per man year for the offshore scenario in this discussion. These figures assume a high cost for a sea farm of $30,000 per year because of their more specialized, utilizing skills. If you had an average annual labor cost of $30,000 the range goes to 195 to 58 men per man year. In Norway, productivity levels are from 152.3 to 58.4 tons per man year and this may not include small and/or feed transfer costs or harvest costs. Yet it may well be between the low and high ends of my analysis. One hundred and ninety-five metric tons per man year or better is probably achievable in remote locations using automation and tower sea cages. Only experience will show if these figures are possible, but this should challenge us to search for more productive methods and equipment.

Our company believes that improvements in technology and efficiency will make it possible to move into those higher energy locations and open up vast new areas of cod. As I’ve emphasized above, every attempt should be made to make this a “safe” transition by using moderate energy areas first for growth and then moving to the more difficult, remote sites with these new-found skills and equipment. I believe a good case will be made for offshore costs being driven even lower by the efficient use of labor and equipment in areas closest to farming support and infra-structure, i.e. processing, good labor force, markets in big cities, etc.

Regarding land vessels, the sea farming industry will find economical sea-going craft for hire (or sale) from industries such as fishing and oil. These vessels and the land-farming crews that go with them will be well suited for some of the operational tasks. Also, because the fishing industry is on the decline, these used and “piped down” vessels will be more economical than new vessels, especially during the transition to more distant offshore sites. Other equipment needed such as feeding machines or which vessels are being developed by the indoor farmers, and that same technology will apply to offshore farms. As with any manufactured item, if the quantity produced increase, the cost of producing them goes down as manufacturers try to increase market share and profit.

Firstly, I’d like to finish on a “what if” note. The costs of ice cages for offshore operations represent the largest portion of capital so there will be pressure to find ways to reduce the $85 to $107 per lb. associated cage cost. The present savings will come if densities can be increased in high-current areas with stable cage volumes. Most fish farmers are skeptical of increasing these densities because these experiences are limited to indoor, generally low-energy sites and the cages usually floating cages have higher losses to reduce in even moderate currents, badly stressing the fish. With a stable growing volume, a properly designed cage is like a tank farm or well boat with clean water being exchanged often. At O’s site in the Strait of Juan de Fuca, 5000 m³ of water in the cage was completely changed an average every 42 seconds, all day long. Also, if weight gain (feed conversion) is enhanced in higher current by exercise (游泳, 30%), future growth will be another benefit. Therefore, if cage densities can be doubled the capital expense for the cages goes from a range of $2,360,000 to $4,500,000 down to a range of $1,250,000 to $2,500,000. Add to that an amortization that is based on a cage life of ten years and more, and the invest-
ment per lb. of fish raised is quite reasonable— at least more attractive to investors.

Combined cost savings from operational methods and automation should make it possible for future sea farmers to easily compete with fish grown inshore. If it is determined that better water exchange, stable passing volumes, better temperature control, good dissolved oxygen, exercising fish, and higher water quality results in a more efficiently grown animal, then open ocean sea farming will attract investors to grow fish that can compete with other fish and meat products. I think that all of us here believe it warrants further investigation and investment.

References


Figure 1. Central Feeding, 20,000 m² Sea Farm Layout
## Potential Cost Ranges of Farmed Salmon for Inshore and Offshore

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<td>OFFSHORE</td>
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<tr>
<td>Amortized for inshore equipment</td>
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<tr>
<td>Total fixed production costs (offshore)</td>
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<tr>
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### Total Fixed Production Costs

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</thead>
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<td>$0.00</td>
<td>$0.00</td>
</tr>
</tbody>
</table>
Figure 5. Key Assumptions for Hypothetical Sea Farm

- Cages are used for grow-out only
- Annual production is 2,500 metric tons, gilled weight
- 625,000 fish are harvested from 650,000 post-smolts
- Approximately eleven to eighteen 5,600 m³ cages are needed to raise 625,000 salmon
- Feed conversion rate (FCR) is 1.4:1 for gilled yield
- Cages are located approximately eight kilometers offshore
- Current range from one to two knots and storm waves are a maximum of seven meters
- Nitrogen sources are readily available and economical
Market Trends for Farmed Salmon and Implications for Offshore Culture

James L. Anderson
Department of Environmental and Natural Resource Economics,
University of Rhode Island
Kingston, Rhode Island

Abstract

The following are essential points conveyed in this presentation:

1. The current outlook and situation for aquaculture in the Northeast (Sea-Quest, Anderson, and Janzen, 1996) was reviewed, noting that the largest aquaculture sector in this region is the pen-raised salmon and steelhead trout industry in Maine, which harvested approximately 10,000 MT and was valued at nearly $53 million in 1995.

2. Several examples of price trends for aquacultured products were provided. In particular, price for farmed salmon has declined considerably over the past several years, and price pressure is expected to continue (see Figure 1).

3. Economic principles indicate that as long as marginal revenue exceeds marginal cost in a competitive industry, production will continue to increase, and price will tend to be driven lower. This is particularly true with salmon aquaculture, where marginal cost generally declines with improvements in feeds, salmon stock, and management efficiency.

4. Implications for open-sea aquaculture are that expected costs should be lower than costs associated with existing types of operations.
5. Evaluation of several crisis and economic risks associated with open ocean aquaculture demands greater attention than is generally found in many business plans. These areas of concern include: fish transport, feed, and personnel costs; site selection; site monitoring; and regulatory costs. Furthermore, it is unreasonable to expect that moving aquaculture operations offshore will substantially reduce regulatory constraints.

Figure 1. U.S. Imports of White Atlantic, Chilean, and Ohio Salmon and Real U.S. Wholesale Atlantic Prices

Literature Cited


Dartmouth, MA. In cooperation with the USDA, Office of Aquaculture. 78 pp.


Upper Bay Publications, various years. Seabird Price-Current, Torres River, NH.
Open-Ocean Culture of Sea Scallops Off New England

Clifford A. Goodale
MIT Sea Grant College Program
Cambridge, Massachusetts

and

Rudolph J. Srokowski
Commissioner of the Sea
East Falmouth, Massachusetts

Abstract

A near-shore pilot site for the experimental culture of the sea scallop Placopecten magellanicus has been established in the T/L Exclusive Economic Zone (EEZ) south of Martha's Vineyard, Massachusetts. The goal of the project is the demonstration of sustainable production practices for the New England sea scallop industry and the promotion of economic growth. In the project, a variety of methods of culture and an innovative culture method are being evaluated both biologically and economically.

The experimental site is the second in the U.S. to be selected for a project from the Army Corps of Engineers for appraisal open in the EEZ. With the first project to have been initiated in the area of the EEZ for aquaculture purposes, it is the first site to have been designated a near-shore site for evaluation of potential for use as a site for commercial-scale culture. It is the second site to be designated as a near-shore site for experimental-scale culture.

The purpose of this project is to determine the best method for sea scallop culture in the EEZ and to provide information on the potential for successful sea scallop culture in the area. The project will focus on the development of a culture system that is cost-effective and environmentally acceptable. The project will also assess the potential for successful sea scallop culture in the area and the potential for successful sea scallop culture in the area. The project will also assess the potential for successful sea scallop culture in the area and the potential for successful sea scallop culture in the area. The project will also assess the potential for successful sea scallop culture in the area and the potential for successful sea scallop culture in the area. The project will also assess the potential for successful sea scallop culture in the area and the potential for successful sea scallop culture in the area. 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seventy percent of Japan's scallop harvest is cultured. The harvest is now stable from year to year and is an order of magnitude larger than the previous wild harvest history. There are over 1000 scallop harvesting farms in the Mutsu Bay region alone and many other regions also produce cultured scallops.

Since the 1970s, countries in other parts of the world have begun scallop culture operations based on the Japanese model (Kida, 1979; Paul et al., 1981; Royce, 1986; Withers and Cahill, 1986). Scallop culture operations depend on obtaining a large supply of spat, commonly called seed. Two sources of seed are hatched and spat-collecting devices. Hatched larvae are usually released from the wild population and spawned there in captivity. Scallop spat is easily induced to spawn by raising the water temperature (Graffy and Loehr, 1972; Consoli et al., 1973; Hsu et al., 1975; Nakada et al., 1980). There are variations in the rearing techniques, with different levels of difficulty, depending on the species of scallop. In Japan, commercial growers have found that collection from natural production is the most economical approach to generating seed (Chiba et al., 1991).

Scallop spat, if placed directly on the bottom, suffers high mortality. Therefore most culture operations hold the scallops in an intermediate culture phase until the scallops are about (20-30 mm) in size. The most common method of holding utilizes strings of specially designed non-attached ropes or submerged long lines. Hauling the scallops in these nets, up and off the bottom, reduces predation and provides better feeding conditions, enhancing growth.

Final culture, or grow-out, can be conducted at a commercial scale using suspended culture or bottom culture (see Chapter 4). The most common form of suspended culture utilizes a lantern net. This cylindrical cage of netting has about ten compartments stacked one on top of another with a specific separation of scallops placed in each. Scallop larvae are periodically added and the lantern net is lowered to the bottom. Another form of suspended culture is in hanging, where the scallops are tied to a string by means of a hook drilled in the hinge, or ear, of the shell. A third method involves growing scallops to a hinging age (Copp, 1985). All three methods tend to be very labor-intensive.

The least expensive method of growing is bottom culture, where scallops are released onto appropriate bottom to grow to market size (Proctor, et al., 1980). In some cases, the bottom is planted with preferential species such as eelgrass and eelgrass to reduce losses. Upon reaching market size the scallops are harvested by divers or divers.

Re-Engineering the New Bedford Scallop Industry

The giant sea scallop, Placopecten magellanicus, is the mainstay of the New Bedford fishing industry. Declining resources of this species has recently led New Bedford to position as the leading U.S. fishing port in landed value. The industry and fishery managers have had to come to grips with the problems associated with over-access fisheries. As with groundfishing, a strict days-at-sea program has been imposed to allow scallop stocks to rebuild.

Some participants in the New Bedford sea scallop industry believe that increasing natural productivity is a better solution than scaling back effort. From that point of view, the Westport Scallop Project has been initiated to apply to New England the scallop culture techniques that have been proven in other parts of the world. The project is a collaboration of scalloping interests and a science and technical support base as listed in Table 1.

Cliff Craven, MIT Center for Culture Engineering Research
Rolf Emlen, Emerson College
Rolf Emlen, Spiny Lobster Group
Erik Evers, Woods Hole Oceanographic Institution
Gary Lomont, Oceanic Spat Technologies, LLC
Ken Raff, University of New Hampshire
Peter Shaffer, Conservation Law Foundation
Roxanna Smiley, U. S. Fish and Wildlife Service
H. M. Swain, Oceanic Spat Technologies, LLC

Table 1. Westport Scallop Project technical and science support.
The project is supported by a Sustainable Fisheries grant and focuses on the technology needed to culture scallops and the development of an industry infrastructure to support such a change in production methods. In order to “jump-start” the demonstration of the all-important initial stages of production, the project focuses on the grow-out. We will use small scallops that are normally taken as bycatch in the commercial scallop fishery. These harvested scallops are typically 4 to 6 cm in shell length and are considered too small to attack profitably. The eventual hatchery development and wild spats collection are being addressed by other funded projects.

Grow-out Methods

The project will evaluate several approaches to fin-fish grow-out. The first will be direct bottom seeding. This method is the simplest and requires the least change from current production methods. The biology behind this approach is based on the biology of the animal and the nature of its reproduction. Mature scallops each generate millions of planktonic eggs. These tiny drifting larvae feed on microplankton until they reach a stage of development that requires a surface on which to settle. This settled spat then begins to form its shell and assume its role as a filter feeder.

During these early life stages, the sea scallop is prey to many other animals suffering tremendous levels of mortality. When and where conditions are favorable for their survival, extremely dense populations of young scallops can exist. Fishermen call these areas “spat flats.” However, due to fishing pressure, competition for food, and predation, these flats seldom turn into a history of adult, harvestable scallops. By redispersing these challenged juveniles, the Westport Scallops Project aims to capture this lost productivity and develop a sustainable grow-out paradigm for the scallop fishery.

In addition to bottom seeding, some small scallops will be placed in bottom cages which, as shown in Figure 1, look like conventional lobster traps without end. Placed on the bottom, these cages will protect the scallops from predation and allow easy monitoring and 100 percent mortality. As shown in Figure 2, these bottom cages will be rigged and handled in a towing operation.

A third grow-out method will be a suspended culture where the benefits of greater plankton availability higher in the water column should offer more rapid growth. In order to fully exploit the involvement of commercial scallop vessels (15 to 30 m long), we have developed a system called super-liftmanets, which, by their size (24 cm diameter x 4 m high), better match the lifting and survival capacity of these sturdy vessels.

These suspended grow-out units are viewed in Figure 3. The vertical location of the cage will be one of the important variables in our experiments.

Site Selection and Permitting

Site selection will be an important issue as the success of a large-scale scallop farming. The site is even more important in an experimental effort due to the importance of monitoring and evaluatiog experimental control. A site was selected close to New Bedford and Woods Hole, Massachusetts, to minimize logistical costs but that was exposed to full ocean conditions. We also sought an area that was typical of commercial bottom and did not have summer temperatures that exceeded 18°C. We also needed a site that had some scallop productivity but not enough to cause our seeding efforts. To broaden the impact of our project, we wanted our site to be in federal waters. Finally, we sought a location with minimum conflicts with other fishing and maritime activities. NMFS data on fishing activity combined with some advice from local fishermen helped identify the location shown in Figure 4.
Aquaculture in the U.S. EEZ is a popular discussion topic but as of 1996, it is not yet a reality. For this reason, obtaining the necessary permits for our project has taken on national significance. The U.S. Army Corps of Engineers (COE) has authority under Section 10, Rivers and Harbors Act of 1899. This Act relates to activities affecting U.S. navigable waters, and the COE scrutinizes the placement and adequacy of aquaculture structures and operations.

In addition to these concerns of safety and adequacy, the COE application goes through a public review process and is forwarded to other federal agencies for their review. Table 2 lists these agencies and their role in the permit process.

The COE permit process is a mature regulatory function and its application to aquaculture operations has been tested by states, which have been requesting permits for decades. The COE application for our project is the result of months of careful planning and consideration of the potential environmental impacts. Our proposed site was selected based on its suitability for the project and the existing infrastructure. The site was chosen to ensure the successful implementation of our project and to minimize the potential negative impacts on the local environment.

The authority of the NEFMC would have been less clear had we not expended a significant amount of time and resources in developing the necessary permits and garnering support from the local community. The NEFMC has provided valuable guidance and input, and we are grateful for their ongoing support.

However, under current legislation, the management councils are the only entities able to deal with the conflicts associated with the use of federal waters. Any attempts to proceed with our project might have met with resistance (Biemann, 1995). In spite of the relevancy, aquaculture is an area of regulation in which the NEFMC, not any of the other seven regional councils, have experience.

We first approached the NEFMC in August 1994. The subsequent two years revealed the inadequacy of the council process for dealing with aquaculture applications. In Table 3, a schedule of events and milestones is revealed, all related to reviewing the Council's requirements. The two-year duration of this process is not a measure of opposition to our project. Indeed, all parties on our project have been nearly unanimous in favor of our request. The delay is simply the result of the complex nature of the project.

Table 3. A schedule of events and milestones in the NEFMC process.

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
<th>Description</th>
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<td>Project Proposal</td>
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<tr>
<td>Initial Review</td>
<td>1995</td>
<td>Completed with no objections</td>
</tr>
<tr>
<td>Interim Decision</td>
<td>1996</td>
<td>Approved with some conditions</td>
</tr>
<tr>
<td>Final Decision</td>
<td>1997</td>
<td>Approved with all conditions completed</td>
</tr>
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</table>

EEZ User Conflicts

The nature of the Council's role in the future of EEZ aquaculture is the topic of considerable discussion. In an analysis of the Council's responsibilities and
opportunities with respect to GEZ aquaculture. A neutral stance was recommended since the Council would be the arbiter of the unavoidable conflict over user conflicts (Bocian, 1995).

The-Westport Sealing Project was viewed favorably by the Council due to its broad industry base and its short-term (18 month) duration. The Council members opposed our arguments with respect to the appropriateness of our site selection. The objections that were voiced at Council meetings, committee meetings, and the January 1996 public hearing in Woods Hole were generally dismissed as not-in-my-backyard rhetoric.

<table>
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<th>Event Description</th>
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<td>Apply to Council for site closure</td>
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</tr>
<tr>
<td>Presentation to full Council</td>
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</tr>
<tr>
<td>Presentation to Scallop Committee</td>
<td>Oct. 1994</td>
</tr>
<tr>
<td>Presentation to Interagency Committee</td>
<td>Nov. 1994</td>
</tr>
<tr>
<td>Council vote</td>
<td>Dec. 1994</td>
</tr>
<tr>
<td>Submit Amendment 6 Draft</td>
<td>Feb. 1995</td>
</tr>
<tr>
<td>Presentation to Aquaculture Committee</td>
<td>June 1995</td>
</tr>
<tr>
<td>Council vote Amendment 6</td>
<td>Dec. 1993</td>
</tr>
<tr>
<td>Council vote</td>
<td>Feb. 1996</td>
</tr>
<tr>
<td>Industry meeting, Martha’s Vineyard, Mass.</td>
<td>April 1996</td>
</tr>
<tr>
<td>Industry meeting, New Bedford, Mass.</td>
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</tr>
<tr>
<td>Council vote of site relocation</td>
<td>April 1996</td>
</tr>
<tr>
<td>Presentation to Scallop Committee</td>
<td>May 1992</td>
</tr>
<tr>
<td>Council vote site relocation</td>
<td>June 1996</td>
</tr>
<tr>
<td>Scrimmage Fish Reg. comments closed</td>
<td>July 1996</td>
</tr>
<tr>
<td>Estimated closure of site</td>
<td>Sept. 1996</td>
</tr>
</tbody>
</table>

Table 3: Events associated with the NEFSC aquaculture process.

The best available data on the spatial distribution of commercial fish catch is compiled by NMFS from vessel landing reports. This information is based on blocks of 10 minute latitude by 10 minute longitude, an area of about 300 sq. km. The annual landings reported for the block in which our site was located were significantly less catch than the blocks nearby. However, this NMFS data is too coarse to allow identification of local "hot spots." As we came closer to having our site become a reality, specific information was made available to us revealing an abnormally level of fishing through the middle of it.

Our amendment specifically prohibits trawling, gillnetting, and non-project dredging within the site boundaries. This evidence of high-trawling effort indicated that our location was not optimal from a minimum-user-conflict standpoint. Therefore, we organized meetings on Martha’s Vineyard and in New Bedford to discuss with fishermen how we might adjust the site location to reduce our impact on their operations. These meetings also confirmed interest in moving our experiment eight kilometers to the west. This new site meets all the requirements of the project regarding depth, temperature, and bottom types (see Figure 4).

The move has been approved by the OEB; however, the Council and NMFS were concerned that users of concern over the new site might not have been aired at the original public hearing. A second public hearing was held and, with no objections aired, the Council approved the process was resumed, but with a two-week setback.

The lesson learned from this experience is that the current OEB and NEFSC aquaculture review processes do not adequately identify commercial fishing user-conflicts. The detailed interview strategies of commercial fishermen may yield "trade secrets." That information is not found in any public data base nor will it be disclosed during initial public hearings or comments. Only when a project becomes reality will the specific basis for opposition emerge.
References:


Naidu, K.S., E. Mauzr, P. Claydon, and J. M. Grant. 1993. Cultures of the scallops: Phase one, initial growth opportunities and conditions. In Region A of the Canadian Aquaculture


Figure 2. Bottom Cages rigged as in a laboratory operation.

Figure 3. Suspended "super-lateen" growth units.
Open Ocean Aquaculture: From Ireland to the Future

Joe McElwee
Manager,
Muirghéal Teo
Galway, Ireland

The real first commercial salmonid cage farm in Ireland was established circa 1976 in an inshore bay in Connemara, Co. Galway, using square wooden cages. From there, technological advances, a better understanding of salmon biology and feeding requirements, not to mention legislation, environmental pressures/concerns, and the availability of sites, cage farming has developed from close inshore small wooden cages to offshore sturdy, strong, capable, flexible cage farms able to withstand the severest weather conditions and currents and yet still produce excellent quality fish in a reasonable time period. Without a doubt in a short time, fish farming has made huge leaps and bounds and offshore cages are an integral part of most marine farms in Ireland these days. Whilst a variety of different types of cages and materials have been tested and used, varying from plastic to steel, submerging or floating, the type and size can really be dependent upon the site location, currents, winds, number of fish, but more importantly — upon costs.

It costs a lot of money to buy, service, and maintain an offshore cage farm, with equipment being specialised and accordingly quite expensive. The running costs of an offshore farm can be daunting by comparison to those of an inshore facility. Strict budget controls will need to be applied and adhered to, as the price of salmon does fluctuate regularly and costs can rapidly climb in relation to market price. Also due to the nature of the sea, an offshore farm will receive quite horrendous treatment from currents, wave action and winds. The ancillary equipment therefore needed,

Figure 4. Original and concensus site locations.
from amber to mackerel, will need to be of the strongest quality attainable (or affordable).

As mentioned, there is a variety of cage types available for offshore farming. The type to use is always a choice for the potential buyer, but there are a few major points to consider before deciding upon which system one will use. Firstly, there is the cost of the cage, parts, etc., and of course its actual design capability. What types of wind strength will it stand up to and how durable will it secure at? The cost, whilst a major factor, must be balanced in relation to calculated site location and the amount of fish to be cultured. Will the numbers of fish give a realistic profit at the end of the day? Don't forget the running costs of the equipment and auxiliary costs, i.e., net washers, antifoulants and heats, food, repairs, maintenance, etc.

Establishing an offshore cage facility is far:

(a) Better growing conditions, i.e., deep water, fast-flowing currents, and good water exchange. These produce healthier, faster-growing fish.

(b) Environmental friendliness, out of sight — out of mind. No eye-watering problems or pollution-related incidents, and subsequently, little opposition from the powerful environmental lobby.

(c) Maintenance: once assembled, having occasional and routine maintenance programmes, there is little need to spend much time repairing those types of cages.

(d) Prefix: More space equals more fish equals more money.

Due to the size of these cages, far more fish can be cultured than at an onshore site. This always adds profit margins for those willing to go offshore.

While these offshore cage systems have proven their worth in many commercial areas in Ireland, we must ask: what is involved in establishing, maintaining, and running one of these cage systems, and most importantly, are they viable elsewhere?

Well, like in current licensing laws, a lack of suitable inshore sites and severe environmental and political pressures, i.e., the industry in Ireland has had to move to deeper waters, out of view of public eyes and environmental lobbyists, and due to price fluctuations, grew bigger quantities of salmon. This has resulted in the decision to develop offshore sites in accessible areas where employers and infrastructure are available. Certain government agencies operating in peripheral locations died, and other agencies for aquaculture and these have been used. But in some areas, quite suitable offshore sites, there has been no great and available. Typically, some farms started from inshore offshore sites, and others were developed near them, dependent upon push, push to move and push for profit.

So how do we start an offshore site? There are some serious decisions to be made before a few cages are assembled, towed out, and moored in a position somewhere out to sea.

These include:
- location — navigational rights, fisherman's rights
- tidal conditions, water depth, quality
- bottom type — mud, peat, shifting sands
- wave direction and type
- height
- accessibility — sea and land infrastructure, ports, roads, etc., land base
- staff qualifications, experience, availability
- disease status — any natural stock/fishes in area
- grant aid — available, tax breaks or incentives
- site potential, further development, etc., etc., etc.
- health and safety rules and regulations — dangerous place to work.
Those having been considered, the financial costs must be studied:

- How much will the desired cages cost?
- How much will the cage equipment and nets cost? (ropes, chains, etc.)
- How much will the ancillary equipment cost (bricks, buckets, etc.)
- Staff costs?
- Licensing fees?
- Suction costs (provided they are not self-supplied)?
- Feed costs?
- Medication/vaccines?
- Maintenance/repairs?

Running costs in general - these have to be carefully detailed, assessed and estimated for the whole growing cycle of the proposed stock.

**Performance:**

How do offshore cages perform in the ambient conditions expected of them? Each cage system must be sturdy, durable, flexible, non-constricting, sturdy, workable, and produce with confidence, fish of a superior quality and size. So what makes a good offshore cage? Besides the actual design, the earring system (ropes, chains, and layout) is of paramount importance. How the cages are moved will ultimately determine their survival against the elements. As each type of cage system may have its own manufacturer's guidelines, advice a specific type of earring lay-out, the most practical will be determined by:

- Sediment type
- Previous experience
- Weather conditions, on average
- Cost analysis and affordability

**Equipment used:**

Many variations of earring systems have been used, and the one most favoured by myself is the three-tier concrete eyed grooving block, two-inch link-studged chains, 15-tonne sawed hoses, 2.5 inch rope rings and 21 mm double-beaded 250 killer rope. Each cage is monitored by two blocks per corner and where adjacent, connected at two separate corners to the adjoining cages 30-60 m away by surface ropes.

**Disease/Treatment:**

Due to the sheer working area of an offshore cage, for instance, 2500 m monitoring the stocks can be difficult, but it can be done. Regular vigilance of swimming and feeding behaviour will alert a good manager/biologist to pending problems. Treatment or disposal can only be done via one of two methods.

The first is local - in the feed. This, whilst probably the reliable method, does have its drawbacks in cages of this size, in that it's difficult to answer the following questions:

(a) Are all fish getting food plus medication?
(b) Is the dominant factor preventing some from feeding?
(c) Are the stocks actually feeding in the initial phase and thus receiving antibiotics?
(d) Is the antibiotic compatible with mixing in the feed?
(e) Are large amounts of antibiotics toxic?

The other way to be successful in this method is to have the early warning of problematic fish. It is the responsibility of the manager/biologist to respond. Remember early diagnosis means early treatment before the problem escalates and is physically and medically untreatable. Another point to remember is the cost of
treatments. An antibiotic treatment in food feed for 10 days to a number of cases is very expensive. One wants to be certain results are being achieved. This does not mean that constant vigilance and knowledge and experience of the stock are necessary.

The second method is bath treatments. This is an arduous task, involving much labour. The tanks must be emptied, and if possible a帘hall tank placed all around and watered. This is a difficult task, and the fish approach to some cases have just been to raise the net on a fish net to 6-10 ft. The tank, place a lamp around the sides, and then spray the chemical into the cage, hoping that contact with the crowded fish will achieve results.

As can be imagined, this is not a good method of treatments, as:
(a) it produces high levels of stress;
(b) the water volume in calculations and decision factors may be incorrect;
(c) it is expensive with both labour and chemicals;
(d) the treatment may not be effective;
(e) it is hard to monitor the results; and
(f) the levels drop quickly and oxygenation systems have to be used.

Accordingly, in my view the best way to prevent or treat any tropical diseases really will be in the ability of the farm personnel to spot the problem at an early stage and treat before the situation really develops.

A good rule I go by in — what you see on the surface, double it by five and that is the situation within the stock. Get the problem at the start. This is where contact vigilance by the farm personnel, divers and biologists is of paramount importance.

**Feeding:**

Feeding to these offshore cages can only be effective if all the stock have a chance to receive the pellets being offered. In this respect, the most popular method used to get maximum spread and amount is by air compression systems mounted in barges/boats, or below-water-cannon feeders in boats. Each method is effective and the mechanics are available at reasonable prices from suppliers. Again, vigilance by the feeding crews is essential to assess the states of the stock, and it only takes a short time period for a problem to occur. The use of spill systems is not practical due to the size and depth of the farms. Most feeding, while more controllable in smaller pens, does produce good fish. In the large feeders, the sheer logistics will pose problems, and the size of the cage will allow for more waste. Food conversion ratios (FCR) of 1:1.2 are achievable and this can be monitored among research centres and good feeding practices.

**Diving:**

Again due to the sheer size and depth of these cages, plus the "hostile" environment, diving is or around offshore cages can pose problems. Safety must be the prevailing thought in everyone's mind, most especially the divers. This is not like diving in shallow marine pen facilities, where buoyancy diving occurs.

Depth of up to 50 m will require specific dress/torso and decompression stops. Only experienced, qualified divers should work on offshore sites. Their duties can include routine dives, monitoring black bags, and fish and shellfish. Diving in subaquatic environments requires time, so careful planning is essential.

**Harvesting:**

The harvesting from the offshore site is an expensive essential part of the operation. Riffs, pumps and cranes are needed onsite, with transport and packing facilities at a relative distance on the shore. Most sites offshore have trans-aqua (transports) to move live fish, with Tranzvac (Stabtron) pumps to extract them.
from the cages. On average, 20-30 tonnes per cage per day are usually harvested and if the fish are dead, the bloodsuckers are treated to render it biologically inactive. From the packaging plant, fish are sent to European markets within 24 hours. This allows a completely fresh product to be harvested, packed, and presented to the customer within two working days.

Conclusion:

Salmon farming is a profitable business. We now have the technology, experience, equipment, and ability to develop it further. Although sites, which were not suitable for salmon farming, have increased their potential. We now have to achieve greater efficiency and the means to do so. This means introducing the use of new technology. Now that we have the necessary conditions to achieve offshore cage culture, and it's been tried, tested, and proved in other countries, there is only one step left to be taken. All that's needed is some- one to take the initiative, the means, and the facilities, and use them to their full potential. The future is out there, get it!

About the author/presenter:

Joe McElwee qualified from college in Galway in 1989 within the aquaculture field. Initially having spent time working at local salmon hatcheries, he went to Oregon and spent 9 months working for Oregon State Fisheries at one of their Pacific Salmon Hatcheries. Whilst there, he was also involved in some initial work on Atlantic salmon aquaculture, in its infancy stage at that time.

In 1991, Joe returned to Ireland to take up a management position at En-Nor, one of Ireland's most modern and technological parent hatcheries, producing in excess of 800,000 smolts per year. In 1990, he took up the position of Scientific Officer at the Western Fisheries Board to work on various regulations and control procedures.

In late 1988, Joe was appointed to the Management position of Freshwater Salmon Ltd., a large pumped hydroelectric project producing salmon and trout. Whilst in this position, Joe was involved in the First Salmon Trial in Ireland, and it was a resounding success. In late 1991, Joe was appointed to a management position to run the large Rivercork Marine site in Cork/La. This involved much pioneering work with a new site at Bridge Head. This involved much pioneering work, but the future is there, get it!
Operation Regularity, Exposed Locality
Harald Rønne, Jan V. Asknes, Egil Lien, and Ronald Jorgensen
1 Norwegian Marine Technology Research Institute AS
Trondheim, Norway
2 GITAS
Sandvika, Norway

Abstract

Floating growth of seaweed fish farming will require moorings that are more exposed to wind, current, and waves than the sheltered case of net facilities. When establishing fish farms in exposed waters, one needs to consider the following:

- Survival of the fish and the equipment in heavy weather like an extreme storm.
- Regularity of operation sufficient to maintain safe and economic engineering of the fish farm.

A serious attempt to establish a fish farm in exposed waters was made at Giske in a community in northern Norway in 1992. The water depth below the fish farm was about 40
m., with the depth at the anchor point from bottom at 120
m. The estimated maximum wind speed (100-year return period) was about 24 m/s, current 1.6 m/s, and wave 3.2
m., significant wave height. The net enclosures were mounted in polymer self-riseable masts.

An automatic feeding plant was installed in the form of a point contact, which is a platform with the platform 18 m wide and depth 3.5 m. The dry performance of the platform is programmed for regularity and amount.

The report describes the operation regularly analysis carried out by MAI-NET-AK on the computer with the use of the computer, GITAS. The project was sponsored by the Norwegian Research Council. The analysis is presented the following:

- Optimisation and development of all the operation necessary to meet the fish farm needs.
Introduction

Important requirements for successful fish farming are that:
- the locality offers good growth conditions with respect to water quality, temperature, etc.
- the technical installations are able to withstand the occurring weather.
- the actual combination of environmental, technical installations, equipment, and staff allows safe and profitable operation.

The goal of the project presented in this paper was to develop a method for checking the given technology versus a selected locality, and to see if it was possible to obtain a satisfactory percentage of operation time, hence a high yield. Checking of regularity becomes a critical part in the process. The technical installation consisted of a number of cages and a separate service platform with an automatic handling system. The preprogrammed amount of feed was then distributed through plastic pipes between the platform and the cages, one pipe per cage, as shown in Figure 1.

Figure 1. Layout of cages and service platform
increasingly important as one moves the fish farms out to more exposed waters.

**Locality and technical installation**

The position of the service platforms measured by D-GPS was 67° 03' 710 North and 13° 55' 342 East. The most critical wind direction is from South-West which leaves the fish farm totally unsheltered.

**Description of method**

For a regularity analysis one needs:
- long-term statistics of the weather parameters
- hydrodynamic response or behavior of the technical installation
- operation plan i.e. a list of all activities, the frequency of each activity and the consequence of postponement or cancellation
- available staff i.e. number and skills
- available equipment such as boats, cranes etc.

**Long-term weather statistics**

The long-term weather statistics were acquired by two methods:

1. Measurements of wind, current, and waves on board the service platform for about three months; and with linear analysis and extrapolation in long-term data. These data were used for the regularity analysis presented in Table 2.
2. Calculations based on standard wind statistics from the Norwegian Meteorological Institute (DNMI) at the nearest location, Bodø airport. Regularity analysis using wind and wave data based on these data is given in Table 3.

Wind and waves based on standard meteorological data

The DNMI wind statistics give the distribution of wind force in Bodø (BF) for every 10 degrees based on measurements every 6 hours. Statistics are given as monthly and whole year statistics.

A method for prediction of long-term statistics for wind is suggested by John Aaker, where, using the Weibull distribution and with the Weibull parameters, the distribution function is obtained from the mean value and standard deviation, \( \mu, \sigma \) wind velocity from the standard data.

\[
\mu = \frac{1}{n} \sum U_i \\
\sigma = \left( \frac{1}{n} \sum (U_i - \mu)^2 \right)^{1/2} \\
k = \frac{\mu}{1 + \frac{\mu}{c}} \\
V_r = \frac{\sigma}{\mu} = \sqrt{\frac{1 + \frac{c}{\mu}}{\mu^2 \left(1 + \frac{c}{\mu}\right)}}
\]

![Figure 2 Vr, c. relation](image)
Once the Weibull parameters are determined, the regularity can be calculated:

\[ P_{x}(X \geq x) = e^{-\frac{x}{c}} \]

\[ P_{y}(X \geq y) = e^{-\frac{y}{c}} \]

\[ F_{x}(X) \] gives the cumulative distribution of \( X \) (in our case \( X = U_{w} \)).

\[ P_{y}(X \geq y) \] is the probability for \( X \) to exceed the value \( y \). Multiplying by 100 gives the probability in \%.

Wind is measured by DNMI every six hours, i.e. four times a day. The return period \( R \) calculated in years can be calculated by the formula:

\[ N = 4 \cdot 365 = 1460 \text{ obs/year} \]

The return period is found by:

\[ R = \frac{N}{P_{y}(X \geq y)} \]

With these, when the distribution is known, we can find the expected value \( E(X) \) for a given \( R \) by:

\[ E(X) = A \ln NR \]

Local wind-generated waves are dominating on most fish-farm locations. A number of methods have been published for estimation of waves, based on wind velocity and fetch length. We have chosen the following formula, given by Raimo:

\[ H_{0} = 5.112 \cdot 10^{-2} \cdot U_{w} \cdot F^{0.2} \]

\[ T_{p} = 0.00236 \cdot (U_{w} \cdot F)^{0.3} \]

where \( U_{w} \) is wind velocity in \( \text{m/s} \), \( F \) is fetch length in \( \text{km} \), \( H_{0} \) is significant wave height in \( \text{m} \) and \( T_{p} \) is the wave period (max. peak period).

The fetch length for every 30 degrees is taken from the map. The long-term statistics for waves is derived by combining the above formulations with the wind statistics from DNMI and the fetch lengths.

The method for calculation, based on standard wind statistics (DNMI) at the given location, was programmed in a spreadsheet. For our location, this method gave good correspondence between measured
and observed wind and wave data, which are the most critical parameters for regularity of the factors. An example of disagreement is given in Table 3.

Operation criteria

GIFAS made a list of all activities, frequency of each activity, required time and resources, and a judgment of criticality. This is listed in Table 1.

The GIFAS personnel made plans for carrying out the activities, and they logged deviations from the plan and the cause of deviation. After some months of experience with the plans, the staff of GIFAS and MARINTEK met and tested what was considered realistic weather criteria for the activities.

For each operation, a short description of the actual operation was given. Then the following factors were considered:

Importance of operation

- Frequency of operation
- Duration
- Complexity
- Costs
- Consequence of delay: 1 day, 1 week, 1 month, consequence of stopping the operation

Weather limitations

- Maximum wind, waves, and current dependence on resources, i.e., boat size, crane, number of people
- Agreement with observed deviation from operation plans
- Reason for possible disagreement.

An example:

Net change

Importance

Normally four times in the period April-September

Duration: about five hours

Complexity is relatively high. GIFAS has worked out detailed procedures.

Cost: new rent and man-hour = boat

Consequence of postponement:

- 1 day: no consequences
- 1 week: probably less growth and stress caused by insufficient water exchange
- 1 month: not acceptable

Optimistic: catastrophic

Weather limits

Net change requires supply of a large boat with crane, and access to the site. Unfavorable weather condition is if one can both alongside the cage and carry out the operation. The maximum RH is connected to the vessel motions.

Weather parameters:

- Waves: $H_{max} = 0.3m$
- Wind: fresh breeze (8.0-10.7 m/s)
- Current: $U_{max} = 0.2-0.3 m/s$

Necessary crew: minimum three if experienced, otherwise four or five

- Boat: large equipment crane, lifting device
Calculated regularity

The activities listed in Table 1 were then lumped into daily, weekly, monthly, etc., operations. Then the weather criteria of the different operations types were compared with the long-term weather instances based on the extrapolated rainfall amount data in [10]. The probability or percentage of time of non-

Table 2 Calculated regularity

<table>
<thead>
<tr>
<th>Operation</th>
<th>Frequency</th>
<th>Wind</th>
<th>Current</th>
<th>Wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catching</td>
<td>Daily</td>
<td>20</td>
<td>0.005</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Weekly</td>
<td>8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Monthly</td>
<td>67</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Animal</td>
<td>Daily</td>
<td>20</td>
<td>0.005</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Weekly</td>
<td>8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Monthly</td>
<td>67</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Feeding</td>
<td>Daily</td>
<td>20</td>
<td>0.005</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Weekly</td>
<td>8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Monthly</td>
<td>67</td>
<td>0.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Experienced regularity

The conclusion of the theoretical evaluation was that operation of the fish farm with the given technical installation could be made with satisfactory regularity. Lack of the experience in the design that made operations at satisfactory regularity level impossible. The nature of the problems, however, was significant in that the equipment in very bad weather which in turn affected the operation regularity, especially feeding to a negative way.

The problems regarding technical means and the fact that the project funding did not allow for improvements and modifications of the concept, forced GEA to move the concept with about 200 tons of salmon into sheltered water. The most important reason for
this was damage to the tower on Oct. 7, 1984. The wind speed this day was about 20 m/s and gusts above 30 m/s, and the significant wave height was about three meters. The inspection of the tower this day revealed that the buoys on the anchor line towards the incoming waves were fully submerged and there was no flexibility left. This caused damage especially to the two cages installed on the weather side of the frame mooring. Some of the pillars for the railing broke and parts of the cages close to where the cross-over lines were attached cracked because of the pounding, as there was no flexibility left in the anchor line.

The other problem was that the PEH food pipes broke near the platform side in bad weather. The distance between the platform and the nearest cages was about 100 m. Due to the fact that the cages and the platform had separate moving systems and also different weather-induced effects, the food pipe had to be longer than the distance between them in calm water. GIPAS installed a guiding rope from the platform to the cage frame via a cooler and down to a weight. The guiding rope was connected to the food pipes in order to get suitable height and not to large offsets. This worked out satisfactorily and there were few problems with the food pipes 10 meters out from the platform and two in the cages.

As mentioned, the food pipes broke in bad weather at the outlet through the platform side. GIPAS decided to force the pipes by handling them together with the plastic composite bars to strengthen them and to stop pounding force when they were bent. This system worked well and food pipes were made 10 m/s and significant wave heights up to 1.5 m.

The final conclusion, however, is that the food pipes should be laid out of the platform area where the waves are still and perhaps set from the roof of the dock house. With use of guiding ropes as described above and reinforcement of the pipes from the platform down to the sea level about 10 m out from the platform, the pipes should withstand any weather condition on this site.

In general, it is GIPAS's opinion that relatively small improvements could have made the farm concept able to get through the worst weather conditions expected on this actual site.

The next issue to consider is how to produce salmon of acceptable quality at competitive costs in exposed waters. This requires detailed solutions of the whole farm concept from the sea transfer of smolt to delivering of adults ready for spawning. This project has given us valuable knowledge that should form the foundation to develop such a total concept.

References


### Table 3. Calculation of regularity

|         | 6.67 | 1.50 | 5.67 | 3.25 | 4.00 | 2.25 | 5.75 | 3.25 | 4.00 | 2.25 | 5.75 | 3.25 | 4.00 | 2.25 | 5.75 | 3.25 | 4.00 | 2.25 | 5.75 | 3.25 | 4.00 | 2.25 | 5.75 | 3.25 | 4.00 | 2.25 | 5.75 | 3.25 | 4.00 | 2.25 | 5.75 | 3.25 | 4.00 | 2.25 | 5.75 | 3.25 | 4.00 | 2.25 |
|---------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|         |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |

Insurance & Risk Management for Aquaculture

Scott Simmons, CPCU
MP&N Aquaculture Insurance Services, Portland, Maine

The insurance needs of companies in open ocean aquaculture are unique. Over the last several years, our agency has been developing expertise in this knowledge of the risks and problems faced by aquaculture operators. We have developed special knowledge that allows for programs that reduce the cost of risk for our clients.

**Fish Mortality Insurance**

In aquaculture operations, the fish stock represents the largest asset. Like all businesses, fish are subject to death caused by disease, heat, cold, and predators. Mortality insurance provides protection from the loss of the asset.

Aquaculture mortality insurance is a specialized area of coverage in which few insurance companies currently compete. Limited knowledge and experience with the aquaculture industry leads many insurers to stay away from this high-risk business. As a consequence, rates range from fairly reasonable to downright outrageous — and everywhere in between. Many farmers have gone without coverage because of high premiums or the mistaken belief that insurance is not available. However, banks and investors feel more comfortable when the major risk is minimized by protection assured. Many farmers are now buying mortality insurance in order to attract capital.

**Perils**

The first policy provision to review are the perils insured. What are the "causes of loss" insured. Some examples of fatalities and related perils are predation,
lack of oxygen, virus infection, adverse water temperature, and pollution.

A "named peril" policy pays when loss is due to a peril listed in the policy. One named peril policy on the market covers: mortality caused by: pollution, theft, mold, bacterial or viral disease, starvation, fish kill, natural disaster, and structural failure of equipment. Equipment includes: ponds, nets, feed, liners, plants, and fish. This type of policy provides the utmost in coverage. Most agricultural insurance policies only cover the named peril losses. For instance, most agricultural insurance policies do not cover losses due to pollution, mold, or bacterial or viral disease, but a named peril policy may cover all of these losses. This type of policy is more expensive than the usual agricultural insurance policy, but it provides much more comprehensive coverage.

Deductibles

Most policies include deductibles—the amount paid by the insurer, if any, if the loss is covered. For example, if the deductible on a named peril policy is $250, the insurance pays any covered loss over $250. Most insurance deductibles are not fixed. Deductibles may be a percentage of the loss. A 20 percent deductible means that, if the total of the loss was $100,000, the insurer would provide a payment of $80,000 and the insured would pay the remaining $20,000.

Some farms carry a deductible of 20 percent of the value at risk. So, an operation with $1,000,000 worth of fish would be responsible for paying $200,000 before the insurance carrier would pay a loss.

Another common policy provision is a "franchise clause", which requires, for example, that the loss exceed 80 percent of the value at risk (per cage or per site depending on the policy). If the loss is below the franchise percentage, no insurance would be paid. If the loss is above the franchise percentage, the policy pays 40 percent of the loss. The percentage required can be from 30 to 90.

Valuable Help

Insurance companies can offer a variety of services to their clients, including providing advice and assistance to farmers in areas such as vaccinations and predator prevention. An insurance company's experience can be invaluable. The farmer may have never experienced a major disease problem, but the insurer may have dealt with such a problem many times. Both the insurer and the insured can benefit from a specific, consistent loss-control program.

Cage-Site Marine Coverage

Ocean-based aquaculture has unique property exposures. Equipment located on sea sites are subject to perils of the sea. Equipment to be covered at sea sites include: cages, nets, predator control, feed and feed-handling systems. This equipment should be insured under a special policy. Feed and fish shipped to sea sites can also be insured.

Workers' Compensation Insurance

Aquaculture workers are subject to the hazards of their workplace. Some states treat fish farmers like other agricultural employees and allow for protection under workers' compensation coverage. Some states require workers' compensation coverage. Coverage will vary by state. There are also issues of federal law to consider. Jones Act coverage is needed for vessels under "vessels under navigation."

Hull Protection & Indemnity Coverage

A wide variety of marine vessels are used in aquaculture—from small boats to floating processing operations. Hull insurance policies provide protection for damage to the vessel. Protection and Indemnity coverage provides liability coverage. This policy can provide the coverage needed for vessels under Jones Act.
Challenges to the Offshore Culture of Shellfish

Dorothy L. Leonard
Director of Fisheries
Maryland Department of Natural Resources
Annapolis

Abstract

The recent declines in approved shellfish-growing waters throughout the United States have been paralleled by similar declines in the harvest of wild and natural stocks of oysters. The conditions have declined so significantly, in fact, that continued degradation of water quality in these areas now make them too small to be productive along with continued overharvesting and disease may eventually eliminate the wild harvest of shellfish.

Successful operations in Willapa Bay, Oregon and Folly Beach, South Carolina have recently shown, however, that sustained levels of production can be achieved through the use of aquaculture. But ensuring this success requires access to both high-quality water and a land base. In addition, the exclusive use of parcels of land and water is often required. This model often conflicts with coastal recreational uses such as swimming, boating, fishing, and navigation.

In an effort to avoid these conflicts and find areas of clearer water in which to grow their product, shellfish farmers are moving to offshore waters, employing new techniques in both cage and suspended culture.

Among the greatest successes of offshore aquaculture operations to date have been those in California, where abandoned oil rigs and anchored barges provide adequate habitat for the production of mussels, oysters, and barnacles. The sites are carefully monitored for polutant contamination, and sufficient water samples are taken and tested to meet the guidelines of the National Shellfish Sanitation Program (NSSP). Although
Trends in Australasian Open Water Aquaculture.

Neville W. Thomson
Aquaculture Development Consultant
Marine Production Systems (NZ) Ltd.
Hyde Park, Adelaide
South Australia

Introduction.

New Zealand and Australia have substantial coastal waters with established aquaculture operations in both shellfish and finfish species. The combined efforts in both countries towards establishment of a viable open ocean aquaculture industry is being driven by increasing resource needs, changes in fishing activities, and environmental pressures, species' biological considerations, and more importantly market demand opportunities.

This paper will briefly outline the main Australasian shellfish industry groups and the first group who are making the transition to exposed areas and identify key issues and success stories so far. For all these industries the development of open ocean aquaculture is seen as a logical progression step backed by considerable experience and capital resources.

Industrial aquaculture is developing in both countries with greater scale production units using increasingly larger areas of water space and based around capital-intensive infrastructure, economies of scale in production and low labour inputs. Scale-offshore aquaculture operations in this type of industry environment exhibit high levels of specialisation, automation, and mechanisation in order to be internationally competitive.

Background.

The main Australian species farmed in the marine coastal zones of both countries and their respective production values in US dollars are:
Species | US $ (millions) | Culture type
--- | --- | ---
Scallops | 25 | Bivalve enhancement and eastern culture
Oysters | 55 | Intertidal rack culture and longline culture
Mussels | 92 | Longline culture
Pearl Oysters | 169 | Longline culture
Prawns | 22 | Control culture
Salmon | 73 | Cage farming -- sheltered waters
Bluefin Tuna | 95 | Cage farming in semi-exposed and sheltered water

Total Value approx. 5.15 million US dollars in the 1995-96 period.

There are some remarkable advances being made in the aquaculture industry, particularly within New Zealand and Australia. In general, this is due to a number of factors, including the steady development, growth, and diversification of the aquaculture sector, which includes a wide range of ever-changing regulatory requirements.

In this paper, I will discuss the potential for the Australian aquaculture industry. There are a number of factors that are driving this growth. One of these is the increase in demand for seafood in the global market. This has led to a greater focus on sustainable aquaculture practices, which are essential for the long-term viability of the industry.

In the context of fish farming, the single most important element is the ability of the aquaculture sector to adapt to the changing market conditions. This requires a combination of innovative technology, strong management, and robust infrastructure. The industry has made significant progress in these areas, and there is a strong commitment to further improvement.

So, just how are the future prospects for the aquaculture industry looking? The answer is positive. The industry is well positioned to continue to grow, driven by demand, innovation, and a commitment to sustainability. The future looks bright for a sector that is vital to the global food security and economic prosperity.

The Bluefin Tuna are pursued with existing...
originally from the wild coasts, moved hundreds of miles through the wild ocean, reaching maturity and then being marketed. This process has led to the development of aquaculture techniques and technology for both the Japanese and New Zealand industries. The New Zealand industry, which was established in the 1970s, has been successful in developing a sustainable scallop fishery.

In the New Zealand scallop industry, similar successful transitions are being made in all recognized species. The New Zealand scallop industry has been successful in developing a sustainable scallop fishery, which has been in operation since the 1970s. The industry has been successful in developing a sustainable scallop fishery, which has been in operation since the 1970s. The industry has been successful in developing a sustainable scallop fishery, which has been in operation since the 1970s. The industry has been successful in developing a sustainable scallop fishery, which has been in operation since the 1970s.
exclusive resource access rights and claiming the said high ground through extensive argicultural development have been in place. Agricultural development in all areas and including open oceans must be developed from a long-term environmentally sustainable viewpoint and there must be direct spin-offs to recreational interests from the industry.

New Zealand Greenshell Mussel Culture Perma-continuous and the Longline System

The development in New Zealand of advanced longline cultivation systems including extensive information and mechanization of the culture management processes has improved markedly the potential of both oyster and mussel culture systems for moving into offshore locations. In this section of my paper I wish to address the traditional base of both these industries and then discuss in some detail the longline systems themselves, which in the future may hold the key to development of other species in offshore locations. Both industries exhibit similar characteristics of growth based on market demand, sophisticated technology, capacity for automation, and a transfer of capital resources and technology from established industries. The expansion is logically based on existing infrastructures, expertise, and is supported by a developed industry base.

New Zealand Greenshell Mussel Culture System

The New Zealand Greenshell Mussel Industry in 2000 produced approximately 4,000 tonnes. It now produces nearly 6,000 tonnes of product annually based around two growing areas: the Marlborough Sounds, at the Northern tip of the South Island (4,000 tonnes) and in the Greenshell region (2,000 tonnes) located in the eastern part of the North Island.

The industry growth has been based on 110 metre surface longlines with twin-backbend oyster runs, vertically suspended. The longline system has evolved to six to 20 metres deepening on bottom depth and tidal flow.

The culture system is highly mechanized with contracts specifically now demand at every level of the industry producing cost efficiencies far greater than single farm operators can achieve. For example, anchor handling, whether of concrete or screw type anchors, is done by contractors using a purpose-built vessel in most instances and qualified professional divers where required. The anchors themselves are made by specialist companies supplying solely to the mussel industry.

Recruiting, operations and harvesting are again contracted specialist activities with sophisticated automation included on increasingly larger capacity vessels. For example recruiting contractors can now harvest and round up to 20 tonnes a day using four people. Harvesting vessels are similarly capable of stripping, cleaning, and washing up to 90 tonnes of fresh Greenshell product per hour and have carrying capacities from 72 to 180 tonnes at deck level.

The most recent fleet addition in the Marlborough region is a state of the art 29 metre twin screw aluminium hull with forward wheelhouse, crew of four to five. At present capacity harvesting rate on clean product, holding capacity on deck of 120 tonnes will round to 12 to 13 tonnes fully loaded. This approximately NZ $1.9 million dollars.

The trend in all aspects of this industry has been one of economy of scale, increasing size of operators and capital investment, a reduction in the number of individuals and increasing company ownership due to the significant differences in cost of production between large and small operators.

The technical development of this industry structure has allowed the Greenshell mussel cultivation process to far exceed improvement in longline technology suited to open water culture of molluscs systems, and to a lesser degree, scallops and abalone.

Initial trials using submerged single and double backbend were undertaken to enable a more stable en
Development of Australasian Open Ocean Oyster Culture Industry

This industry has in recent times benefited from many of the spin-off effects of farming technologies developed for the New Zealand mussel industry. The oyster industry, on the other hand, has traditionally been limited to intertidal areas, in estuarine conditions with occasional surface light. The development for use in protected, sheltered bays or food type areas. The increased influence of urban and industrial growth, pressure from recreational users and risk of pollution is encouraging oyster growers to consider open ocean locations as an alternative development area where potential risks and conflicts are reduced.

One of the major factors that are considered for significant industry growth are the factors that can establish an industry possessing considerable resources, knowledge and infrastructure. The step of choice is seen as both logical and legitimate step with the planned utilisation of existing resources such as vessels, experienced people, and engineering capability, thereby reducing associated risk.

For the Australasian oyster industry, the question of economic viability will be based upon defining biologically suitable areas for other (or where natural) cultivation areas, which will prove the growth of both shell and meat conditions to acceptable market levels. The Australasian oyster production is focused directly on the market for the highest quality and marketable oysters. There are two notable trends emerging in developing open ocean areas: firstly, where open water areas are used for the intermediate step of culturing, shell stock prior to being established intertidal areas for crop finishing; and secondly, for large volume producers by using significant levels of automation and mechanisation. Not only do these approaches expand overall production volumes, they also provide specialisation with greater efficiency in the use of optimum growing areas.
The Development of Open Water Oyster Culture Systems

Oyster culture operations in the intertidal area are primarily small intertidal expanse production with low technologies and a minimum of automation or mechanisation. Harvesting, sorting, grading, and juvenile culture operations occur on plot sizes from three to 10 hectares acquired during low tide periods and are subject to on-site harvesting criteria to reduce risk of pollution from land-based activities. Seed supply can either be from wild or hatchery sources.

The development of subtidal oyster culture has seen usage of two different techniques. The older modified Japanese type system involves oyster spat settlement onto shells or discs, which are in turn attached to a continuous multiple dropper rope before attachment to the culture longline and growth through until final harvest. This style of low intensity production management is more suitable for only oyster near cultivation and produces limited quantities of high-priced half-shell product. The more recently favoured submerged tray culture system is an advancement on the traditional intertidal single seed style of culture. This system enhances the opportunity for mechanisation, same day on-site operations, reduced costs of production and any land-harvesting in non-cultivated areas, where rainfall criteria have a minimal impact on shellfish operations.

The tray system is based on the culture of single- seed system in a growing unit consisting of up to 10 one-meter square trays separated by spacers and hung vertically beneath a horizontal mainline. As the water depth and/or the exposure of the farming site increases, the culture unit can be suspended at greater depths beneath the surface to optimise growing conditions, reduce fouling, or in open ocean conditions move away from the high-energy surface wave action in exposed locations.

In high exposure areas with waves to four meters, oyster trays have been successfully deployed to eight meters depth off a dropper backbone without product exhibiting stress or growth. In the design of the dropper backbone system, four critical components have become apparent:

1. Buoyancy must be reduced to the bare minimum to ensure that wave energy-induced lift or ‘bounce’ is minimised. From recent experience this is approximately 30% of the buoy profile exposed. Buoys should go through the sea, not try to ride it.

2. Buoy attachment by means of a dropper rope to a submerged mainline backbone in the first solution, as this enables more wave energy to be subvertedly dissipated at a surface level through horizontal deflection of the potential damaging forces. In addition, with pointed ellipsoidal-shaped buoys (as against the usual types, the action of the body is considerably more gentle.

3. The additional 2.5-meter dropper rope from the submerged mainline to the oyster tray units enabled the unit to move independently of both the mainline and the body. Horizontal forces are further reduced.

4. The single backbone for submerged oyster culture means that buoys are positioned in a parallel alignment to the mainline, thus being on the path of the mainline, greatly reducing the direct lift forces, which cause vertical movement to the mainline itself. The mainline length and the dampening effect of the multiple tray units themselves then complete the effect applied to the mainline to reduce any vertical lift component.

Both the submerged longline system adapted from the net culture industry and the tray unit system have greatly improved the potential of the oyster industry to expand offshore whilst still remaining internationally competitive in the world marketplace.

Summary of Major Trends in Open Water Shellfish Aquaculture

To conclude this paper, I wish to briefly summarise the trends identified from the industry examples above, and which are increasingly apparent:

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Longline Shellfish Culture in Exposed and Drift-ice Environments

John C. Baratchel, Ph.D.
Marine Aquaculture Technical Advisor
Direction générale des pêchères et de l'aquaculture
Ministry of Agriculture, Fisheries and Food
of Quebec
Caspé, Québec, Canada

Abstract

The development of successful grow out techniques and habitat types for marine aquaculture in exposed and drift-ice environments was examined in detail by John C. Baratchel of the Ministry of Agriculture, Fisheries and Food of Quebec. The report details the challenges faced in this environment, including the need for specialized equipment and the impact of ice movement on the culture. The findings suggest that longline culture is a viable option for this type of environment, with the potential to significantly increase shellfish production. The report also highlights the importance of further research to optimize culture techniques and enhance sustainability. The full report can be accessed through the Ministry's website.
next the position and depth of the animal's body. It is also
important to note that the animal's body may be
positioned in various ways, including: 1) lying on its
side, 2) lying on its back, 3) lying on its head, and
4) lying on its stomach. These factors must be
considered when designing the study as they may
affect the animal's behavior and movement.

**Introduction**

Marine aquaculture was initiated on the north
shore of Halifax Bay in the early 1980s. The pre-
ferred technique for raising shellfish is the use of
longline methods. However, the initial longline
methods were inadequate in maintaining a firm
hold in the sediment, which is a pre-requisite for
stationary long-term monitoring. The impetus
for this project was to develop a more effective
method for monitoring longline methods used
to culture shellfish. The objectives of the study
were to improve the efficiency of longline
methods and to determine the feasibility of using
longlines for monitoring shellfish species over
long periods of time.

In the paper, I have discussed the

**Biological and behavioral characteristics of shellfish**

Shellfish species exhibit unique biological and
behavioral characteristics that influence their
response to environmental factors. These factors
include water temperature, salinity, food avail-
ability, and predation pressure. Understanding
these characteristics is crucial for developing
effective management strategies and ensuring
the sustainability of shellfish culture.

**Growth and survival**

The growth and survival of shellfish are
affected by various factors, including water
temperature, salinity, food availability, and
predation. Understanding these factors is
important for optimizing culture conditions and
maximizing growth and survival rates.

**Predation**

Predation is a significant factor that affects
growth and survival of shellfish. Understanding
the predation dynamics is crucial for develop-
ing effective management strategies to
minimize predation impact.

**Conclusion**

The study demonstrated the feasibility of
using longline methods for monitoring shellfish
species over long periods of time. The results
highlight the importance of considering
biological and behavioral characteristics when
designing culture management strategies.

**References**

chers by clapping their valves and directing the flow of expelled water. They live in temperatures up to 18°C, can withstand changes of 10°C within a day (Bonavia et al., 1999), and can tolerate -2°C water in the estuaries of the Magdalen Islands. However, feeding may be interrupted when upwelled, wave-induced movements. These areas may be suspended at least five meters (15 ft) below the surface in exposed environments. Detritus in grow-out areas should be controlled according to normal size of mortality will occur due to a tendency for gapping and lashing of shells between individuals (Hendry, 1997; Clos et al., 1997). The best sediment cover on collectors suspended near bottom, and spat tend to remain attached by byssal threads up to 15-25 mm in collectors, but 80 mm wild animals can also be found attached to rocks and other shells. Scallop may be successfully cultured when suspended at specific stock densities and depths, however, under exposed conditions, submerged longline techniques are required to minimize stress.

Shellfish Aquaculture Development

Throughout most of the world's marine regions, aquaculture development has occurred where shellfish beds near estuaries, semi-enclosed bays, and coastal lagoons are protected from wave and wave activities. To some but a few, some of the most suitable sites are in near-shore channels such as the shelf seas of the Canadian Maritime, Ireland, Chile and Japan, the estuaries of France where there is good culture, or in Indonesia and China where lines are suspended from stakes driven in the sediment in shallow water. The use of substrate and submerged longlines has been established in Japan for decades and is applied in Australia and New Zealand, Chile, and many coastal areas, but in all cases the survival techniques may not readily adaptable without careful consideration of the local environmental conditions.

Expansion of the Industry and User Conflicts

As the aquaculture industry expands, there is a reduction in the number of sites, with the most favorable environmental conditions for shellfish culture. This results in greater distances to harbors, facilities, and demand for access to bays with particular micro-habitats, and in fewer shellfish cultivation areas. As a result, the potential for expansion is further limited by socio-economic factors, such as pressure from recreational and/or commercial users, and the seasonal nature of some shellfish. The seasonal nature of some shellfish may also conflict with tourism, who want to maintain the pristine view and avoid looking at industrial sites. The use of pollution increasingly conflicts with tourism, as the capacity of local sewage treatment plants does not keep up with the demand.

Site Selection in Chaleur Bay, Quebec

There are relatively few socio-economic constraints to the installation of near-shore mariculture facilities in the province of Quebec, compared to other coastal communities. The steep cliffs along the rugged coastline are not as significant to the construction of bays as the estuaries of France where there is good culture, or in Indonesia and China where lines are suspended from stakes driven in the sediment in shallow water. The use of substrate and submerged longlines has been established in Japan for decades and is applied in Australia and New Zealand, Chile, and many coastal areas, but in all cases the survival techniques may not readily adaptable without careful consideration of the local environmental conditions.
herring and mackerel fishing beyond 25 meters depth from August to October. Further, the site located along the north coast of the bay are ideal because the bottom structure is appropriate without deep-sea fishing nor for enforcement by bottom seeding.

Environmental constraints imposed at the site must be carefully considered. The site orientation is important to ensure that lines are orientated parallel to the shoreline and allow the current flow to facilitate operation on the lines from the boat, and (b) minimize the potential effects of drilling marks due to winter.

The technical challenge to open ocean aquaculture in the northwest Gulf of St. Lawrence cannot be undertaken. Currents in winter are present from December to April, and will vary lines down to 20 meters depth. In summer and fall, there is a 10-100 day period of the strong currents, causing excessive swell due to the fetch from SE winds that travel westward from as far as Newfoundland into Chaleur Bay.

What Grow-Out Method to Select?

A measure of financial success in shellfish culture is profit. A producer can attain this by minimizing the risks due to weather, loss of equipment, and increased material costs inherent in the operation. The success of production depends on the species cultured, the preferred culture being mussels or scallops along the northern coast of Chaleur Bay. The producer must select the most appropriate method that is adapted to the biology and behaviour of the species, and require all the necessary knowledge of the site characteristics pertinent to successfully reaching its objectives.

Three Methods for Grow-out

There are different alternatives for growing shellfish, depending on the region and type of environmental characteristics. Cultured mussels or scallops may be seeded and grown on the seabed for bottom culture, suspended from floating rafts for raft culture, or suspended from a mainline that is supported by floats for longline culture.

(1) Bottom culture was not of the question in Chaleur Bay, because of the rapidly changing, well-mixed nearshore and poor sediment characteristics offshore. Furthermore, the only adequate bottom was for the exclusive use of the traditional scallop fishermen.

(2) Raft culture was very risky due to the exposure afforded by the strong coastline topography. It would be difficult to avoid the effects of severe environmental conditions on rafts, such as exposure to wind and waves at autumn and winter drift ice.

(3) Surface longlines could be used for mussel culture during summer, but to reduce boring on mussel, scaling net the longlines should be submerged below a depth of 35 ft. Although this depth may seem to fine growth, mortality of bivalves and scallops due to stress is reduced because the mainline is more suitable. Consequently, the submerged longline technique was selected, because it would be relatively to maintain any type of structure in this region, due to strong winds and waves between May and December, and drifting pack ice between December and April. The lines would be safe and stable at a depth of 35 ft from the surface all year round.

Lastly, to accommodate the traditional lobster and herring fishermen, the longlines had to be installed in a narrow zone between 60 and 120 ft.water depth, up to a far from them and 30 min  by boat to the nearest wharf. With a longline submerged at 35 ft, less surf face damage is required, and damage by passing water or ice is eliminated.

Description of a Submerged Longline

The geometry of a longline depends on the depth of water, the depth of the mainline below the surface (submerged main line depth), and the type of longline, which should be about 300 m in length a functional working tension over a long period of time. A long mainline (>250 m) will tend to break, because of the
loss in tension and the variations in current with depth and distance. The tendency to buckle will also occur with a submerged longline that has too little tension. In all instances, a short line is not economical nor practical.

Structural characteristics of longlines

The surface longline is a static structure, because the tension is maintained by the buoyancy of the surface buoys and does not require any particular geometry, as long as the anchors can hold up against the current and the boat attached to it (Fig. 1).

**Structural characteristics**

- **Static longline (surface structure)**

![Static longline (surface structure)](image)

- **Dynamic longline (submerged structure)**

![Dynamic longline (submerged structure)](image)

The submerged longline, in comparison, is a dynamic geometric structure (Fig. 1). It must be brought up to the surface from a mid-water position, so that the boat can propel itself along its length without degrading the anchors. When the mainline is released, it should retain its original position and depth. The tension of the longline is critical to maintaining both its working efficiency from the surface and its underwater stability, without compromising its flexibility.

The structural tension of the submerged longline and the longline’s capacity to remain flexible in order to maintain its dynamic geometry depends on a series of anchoring points at the extremities, a positive buoyancy provided by large submerged corner buoys, and the angle of the anchor line, which is established from the relationship between the length of the anchor line and the submerged water depth (Fig. 2). These parameters will affect the length of the unused segments of the mainline, that segment between the corner buoy and the extremity of the workable segment of the mainline.

**Rope**. The selection of the appropriate rope strength depends on a combination of potential forces, those imposed by the tidal currents on the equipment of the submerged longline and by the wind forces acting upon the boat that is to be anchored to the mainline. Standard fishing boats are designed to move forward. When they are stationary, they tend to act as a sail and drag the boat against or away from the longline, thus creating excessive tension on the mainline and anchor line. Furthermore, one must account for rope stretch (up to 20 percent, which can be higher). As tension is lost, time should be allowed to re-establish the line tension to optimize the working efficiency from the boat. A slack line that is taken with animals is more difficult to manage.

**Anchors**. The use of either in-line weights, scuba divers, or fishing anchors should be avoided for submerged longlines in exposed environments. Tension is quickly lost following storms or within periods of working on the line. The anchor...
Submerged Longline Geometry: Structure tension on handling flexibility

Fig. 1: Schematic diagram of submerged longline geometry. The components are numbered as follows:

A. Structure tension on handling flexibility
   - Anchor/Buoy
   - Middles
   - Leaders
   - Trace/Line
   - Anchors

B. Anchor/Buoy
   - Submerged float
   - Fixed anchor

C. Middles
   - Middle buoy
   - Middle leader

Preparation of the longline

The assembly of the longline is one of the most important steps in managing an aquaculture operation. The longline is prepared by marking the mainline with loops of six-inch braided line every 75 cm or meter, depending on the grow-out site requirements (Fig. 3). The loops are used to separate the internal parts of the longline, while being fastened to the surface or the line stretches. They are also used to secure the buoys and weights to be added to the mainline and thus avoid slipping at sea. Current anchor blocks are prepared several weeks ahead (Fig. 4). The steps involved in building, hauling, preparing, and installing lines at sea are briefly described below.

Building current anchors

- Current block (6 x 4 x 3") high = 1 cubic yard = 4000 lb. (Fig. 5)
- Transport to the site with equipment and three workers
- Assemble 24 plywood molds and place a plastic sheet on ground plate to seating molds
- Pour one n° of cement into mold and complete eight anchors in one hour (one truckload)
Assembly of mainline and anchor blocks:

**Mainline preparation**
- Cut mainline sections to string length
- Make a knot at N.C. ends of each section
- Insert spliced eyes through the center of the knot
- Pull through center of spliced eyes in parallel fashion

**Current meter retrieval**
- Lift 2 blocks on handle
- Pull current meter
- Pull spliced eyes
- Lift 2 blocks onto handle
- Current meter ready

*Fig. 3: Diagram of procedures and material required for preparation of mainline and anchor block prior to installation of submerged longlines at site.*

1. Secure the two 1.5" poly rope rings into cement to act as loops to lift the longlines
2. Unspa the next two rings and measure the marks to remove 2 more blocks (6 blocks in)

**Leading longlines on board**
- Hoist a leader on deck to remove cement anchor required in stockdale (6 blocks)
- Lead 10 blocks on board when the boat is docked (depends on size and type)
- Depending on the type of purpose, position on deck and use of blocks to offset between trips

**Preparation of longline on board while proceeding to site**
- Spool out the longlines and attach the ends to each of the blocks
- Adjust the longline ratio to the number of blocks
- Attach the longline to the mainline at anchor and a buoy at center of mooring
- Attach marker buoy with marker rope to the first anchor to mark start position at site

**Installation of longline on site**
- (Assume wind conditions or strong tidal currents)
  1. Define the position and drop first anchor
  2. Make sure block falls flat
  3. Run down anchor and parallel to shore as necessary
  4. Tie buoy to center of mainline with one-half inch rope to mark depth of submerging (25 ft)
  5. Release anchor once center buoy sinks to bottom
  6. Speed out longline slowly and position buoy carefully prior to releasing next block
  7. Finish first section of six lines (6 blocks) and start again (as shown on video display)
  8. If you cannot finish a section, let the anchor line hang at the surface for recovery
  9. Return to harbor, reload 10 blocks and return to site (1.5 hour round trip)
  10. May use small boat to pass anchor line when ready to commence down-current (trip #2)
  11. Install up to 50 cement blocks/day. In calm weather - complete job in three days

**Flexibility of submerged longlines**

- An efficient aquaculture operation spends a minimal time maintaining its longlines and gets on with producing shellfish. This suggests a rapid access to sites, quick recovery of the longline, and efficient movement along the mainline to add buoy or harvest product.
- This is achieved by a geometric design that incorporates flexibility and structural tension (Fig. 4)

**A new technique for Chiloe Bay - the submerged longline**

In the fall of 1989, 50 longlines were installed within four days. They were placed between 50 to 140 ft deep water in parallel series of five lines attached to six concrete blocks, each weighing 3400 lbs (7800 lb)
We first experimented with the technique by fitting a nine-foot stern tractor to the ship, with a stern tractor and a stern tractor. The tractor was fitted with a crane that could be lowered, and blocks were loaded onto the ship. Once the crane was lowered onto the blocks, the blocks were lowered into the water, parallel to the surface. At the second block is lowered, the position is maintained, as long as the wind or waves or wind. Otherwise, lowering twenty-four blocks at a time on three to four blocks from a stern tractor is a delicate maneuver. If the blocks are lowered while the ship takes too much time to reposition itself to ensure proper tension, the operation is inefficient and expensive.

A more efficient longline installation method was subsequently developed by fitting a 30-ton stern tractor to each block, with two stern tractors and each block, so that ten minute cement blocks could be deployed on the deck and transported each to the site. An industrial quick-release mechanism allowed one to drop the blocks from the side of the boat. This ensured greater maneuverability in windy conditions, and fewer days spent at sea.

About 60 blocks were loaded per day for a total of three days of work. The longlines were positioned in separated series separated by about 30 km and connected at a single point, using a block and tackle (Fig. 5). The only disadvantage was the use of a quick-release mechanism that did not allow for retrieval of the block, so if a block fell to the side, it was, in theory, a more rigid system would be needed. Because this method only handled the polyester, a 0.7 mm wire, approximately 200 lb. in tension on a 100 ft. line.

- Advantage of submerged longlines

The cost of preparation and installation of twenty-four blocks was a greater initial investment, but in the long run, the cost of conventional methods is much higher.
Managing longlines in exposed and drift-ice environments

Risky situations are serious if the potential risk is not evaluated ahead of time. With regard to longline management, several parameters are noteworthy. A producer should monitor longlines for potential changes in tension during the season, which may be caused by lost or damaged hooks, displaced anchors, severed lines, or loss of productivity, either shelffish or groundfish equipment. When winter conditions are an annual event on a site, the producer should ensure that the longline will not be excessively transverse or will not float near the surface during winter if shelffish are lost. This may result in the longline, floating in the passing ice and being torn apart.

Harvesting in strong winds and freezing conditions is a risky situation, mostly for safety reasons. In strong winds, since the boat is tethered to the longline, it will bounce and toss in the sea, causing potential damage to the lines and shelffish. When harvesting in strong winds or waves, the use of cranes and winches to haul shelffish on deck may also be a safety hazard. These situations should be avoided and the number of lost days should be detected especially in northern regions, before selecting a permanent site. In late fall and early winter, when wind and freezing conditions are most prevalent, the deck of the boat and the equipment may become very slippery. At the least, it becomes difficult to handle busy and equipment manually, thus increasing the risk of accidents, and damaging nets.

The selection of an appropriate ship and its carrying capacity per trip are important elements to consider. The daily operations of offshore sites require travel time and movement of human and material resources, both for maintenance and harvesting. Thus the type of ship (boat) and its working area become factors that may limit productivity or affect its cost.

- Verification of position & depth

The organization of an aquaculture site is another important step in the proper management of an operation. Lines should be parallel to shore in most cases, where currents and winds are moderate to weak, and the distance between longlines varies from equidistant to the depth of the water (Fig. 5). This ensures that the fastest line being worked moves over anchor on the downwind side of the neighboring longline as the boat is moved downstream.

The method used to determine the position of the installed longlines is simple. The use of Loran C, Geostationary Positioning System (GPS), or other satellite positioning systems, and clear reference points are basic tools for locating longlines on a site. This may be unnecessary at a nearshore site with poor bearings. However, it is necessary at a offshore site with good bearings. These systems will never be adequate for deep-sea refrigeration or other housing/reefing methods.

To recover submerged longlines after a winter season, the most practical management tool is without doubt the use of a depth sounder to determine the depth and general quality of the longlines from the boat, thus avoiding the costly use of diving. Doing is rarely safe.
5) unless to correct a specific problem. An experienced manager usually identifies the weaknesses of the rope and the progress of growth of the mussel rocks in the amount of fouling on submerged equipment with a depth sounder.

The upkeep of longlines throughout a growth cycle is relatively easy with the proper equipment and scheduling. If fouling is a major problem, then it will not be simple to clean the submerged corner buoy, because they are not accessible using the techniques described above. The problem should take this into account when designing the line; in either developing a way to access the corner buoys with a long system or change the geometry of the longline. I would recommend the former strategy in ice-covered environments.

![Organization of an aquaculture site](image)

Fig. 5 The orientation of longlines in a field is critical to the efficiency of operation. In this example, the longlines are offset to reduce the risk of damage by passing vessels and tank traffic. Although the ideal system is highly sensitive to changes in the field, the system is designed to allow for easy repositioning and adaptation to changing conditions using a central control house and good geometry provides growth in the aquaculture. Compensation buoys are added for fluctuations in the height of mussel rocks or sea level changes in time.
Dunlop "Tempest" Fish Cages

Dave Britain
Product Manager
Dunlop Oil & Marine Limited
Crewe, Cheshire, England

Historically, marine aquaculture was carried out in small bays and firths that were reasonably sheltered from winds and waves. The nature of these early sites, being sheltered, dictated that rigid cages of wood or steel construction, which were relatively cheap to manufacture, would be suitable.

However, being sheltered in surroundings with little or no current, the result was that the sea bed beneath the cages and surrounding waters became heavily polluted by refuse; seaweed, fish food, and fouling. This resulted in reduced growth rates and pollution of surrounding waters and coasts.

Hence the move to offshore and exposed farming, where there is a greater water exchange, little or no pollution, and virtually disease-free sites. These conditions allow the fish to grow healthier at a faster rate and reduce the use of chemical treatment.

In the first quarter of 1988, as part of a diversification programme, Dunlop Oil & Marine identified agriculture as a growth industry. At that time, with over 25 years of experience in the offshore oil industry, it was immediately recognized that we had the technology to hand to enter this new industry.
Figure 1 shows a super tanker discharging crude oil through Dupont hoses at a single ocean mooring buoy. Terminals such as this are located around the world and handle ships in all weathers. During its 35 plus years in this industry, Dupont has continually been the major supplier of hose to the oil industry and the name is synonymous with quality.

A flexible rubber hose is basically a pressure vessel with steel fittings chemically bonded at each end. Figure 2 is a cross section of a hose and its fittings. The main components include:

- **Lining** - to contain the product
- **Skirts** - rubber compound that gives a smooth transition from the steel fitting to the hose body
- **Main reinforcement** - multiple plies of high strength carbon totally encapsulated in high adhesions rubber compound (in fact, very similar to the construction of a car tire)
- **Bonding wire** - high tensile copper coated wire to provide a mechanical bond for the steel fittings
- **Shoulder plies** - high tensile cord plies to provide durability of the wet end between the rigid steel nipple and flexible hose body
- **Helical wire or filter locks** - to provide crush resistance
- **Holding or hoop plies** - provides strength between rubber layers
- **Cover** - rubber compound that is highly resistant to abrasion, UV, ozone and seawater attack

All new hose types and designs are subjected to fatigue testing in the unique Dupont test rig. Figure 3 shows the Dupont 1-wire hose prototype system undergoing fatigue, tension, and compression testing in the rig. The result is an accelerated fatigue test.

Following the fatigue test, a hose will be pressure tested to destruction and the results compared with those of a hose of the same construction that had not been subjected to the fatigue test.
As well as fatigue testing on full-size boxes, each type is designed using the latest finite element techniques (Figure 4). This allows our engineers the luxury of designing boxes with stresses minimised in all areas.

The prototype Tempest I cage was installed in Loch Lomond, at the west end of Scotland, in December 1988 (Figure 5).

This cage, incorporating two concentric rings of flexible rubber hoses, coped superbly with a very harsh winter with winds of storm velocity on many occasions. As the concept was new, it was necessary to use this as a proving/testing cage only and to determine its feasibility before approaching the market in earnest.

Figure 6 shows the same cage in Loch Lomond shortly after installation. A farm worker (at the left) is manually feeding the fish. The Loch Lomond cage is seen again in Figure 7 with a food sausage being thrown to one of the Codorus units.

Automatic feeding systems were later fitted onto the Loch Lomond cage (Figure 8).

Following this one-year trial, during which the industry was sceptical about this type of cage:

In April 1990 an additional 29-metre Tempest I cage was installed off Oban, again on the west coast of Scotland. Here an automatic slow-feeder system is
used from the supply vessel (Figure 9).

Also in Oban, harvesting is carried out from the supply vessel by means of a fish suction pump (Figure 10). Another Terpesti I cage is in service on the west coast of Ireland. This site is particularly troubled by birds, hence the net to deter predators.

This site is very exposed. The excellent water exchange means that the use of chemical treatment is almost non-existent. This allows the farmer the opportunity of marketing his salmon as "green." The cage is shown with supply vessels in attendance (Figure 11-12).

The method of securing the buoy and spar for supporting the bird net at the Clare Island cage is seen in Figure 13.

Figure 14 shows the walkways, floats and moorings on the Clare Island cage. And Figure 15 shows a two-meter swell going through the same cage. It is interesting to note that at the cage flexes, there are no gaps between the cages and the troughs of the waves. Other more rigid cages do not conform to these in this manner and consequently suffer failures.
In February 1990 at the Lyemont site in the Faroe Islands, we supplied two sixmeter diameter iron post 1 edges (Figure 18). The site is open to the predominant south-westerly winds and in the winter it is quite horrendous.

I visited the site in August 1990, two and a half years after installation, and was informed that virtually no maintenance had been carried out on the edges since installation.

The feeding system for the cages is somewhat unique. All the fish food is stored in three silos at the top of the monorail and delivered to the cages by gravity (Figure 19). The 4-inch plastic pipe that you see coming down the mountain-side enters the water and splits into two 4-inch pipes to service the cages (Figure 18).

Next we see the 'bull bars' (Figure 19). The safety bars on the jumping support structure and give an added safety area for personnel to lean against when working on the cages.

The next cage is a 'Tempeh' cage supplied to the site in Norway in January 1993. This shows the area where two lines of the system are connected, along with floats and a mooring eye. Most cages are slightly different by today's thinking. The top rope is replaced by chains to allow the cages more freedom of movement (Figure 19).
Some six months after the installation of the unique design Tempest 2 cage in Scotland, we commenced watching the Tempest 2 square cages on the west coast of Scotland.

Tempest 2 cages utilise only single-hose sides, something we were very experienced in, so negating the necessity to prove the product with field trials.

This cage is of modular design, which enables the farmer to add additional cages of three sides to a raft system as and when required.

Tempest 2 cages incorporate flexible rubber hoses that are pressurised with air to provide the correct degree of bending stiffness to the cage structure and to make them compliant with the waves.

Rigid steel walkways are fitted to each corner of each cage, along with Teflon worstings, to promote the safety of personnel when working on the cage.

Figure 22 shows a raft of six 15 m² Tempest 2 cages at Inner Hebrides on the west coast of Scotland. This is an exposed site, open to the Atlantic ocean with a fetch of some 3000 miles. Another view of the same raft of cages shows how the raft moorings are anchored, an essential feature when lossing the system to "sea" in the swell following a storm (Figure 23).

At the Intervite.

Feeding is usually carried out from a small barge. This is one of the earlier raft systems and it is possible to see a new design of walkway on one of the "tee" sections. All Tempest 2 cages were now fitted with this type of walkway as standard (Figure 24).

Next you can see personnel from the farms inspecting the warp and takes tests for damage following a spell of bad weather (Figure 25).

Still respecting the nets, it is reasonably easy to walk along the bays in a swell (Figure 26).

On the next page we see six Tempest 2 cages that are installed in a coastal channel off the island of Mull in the Hebrides. This is a fine example of the moorings on the surface in a relatively safe environment.
Underwater Fish-Farming Technology for Open Sea Areas: Review of a 10-Year Experience

Leonid Yu. Bugrov
Laboratory of Underwater Technology of Aquaculture
SADCO-SHELF Ltd.
St. Petersburg, Russia

Abstract

Expansion of the scope of marine aquaculture leads to the inevitable development of exposed (open) water areas, which have better water exchange than coastal areas and are free of strong competition for ownership typical of coastal areas (use conflicts). Increased danger of storms, which precludes merely copying the proven technology of coastal cage farming for open sea applications, serves as a limiting factor when developing such farms. At present, there are storm-proof cages, however a purely engineering approach to solution of the problem of cage safety prevails in their structure, while the biological aspects of fish-farming are not adequately considered. For example, floating cages on flexible (rubber or rope) frames withstand wave impact well thanks to their damping features. In other structures, storm-resistance is provided for by strengthening of the semi-submerged rigid 3D framework. However, fish in such cages are not protected from wave impact. They experience stress and do not feed during storms, which results in loss of growth. Moreover, there is an increased risk due to the fact that fish in these cages constantly remain in the zone most susceptible to drifting ice and different floating rubbish.

More than 15 years ago, first generation submersible cages appeared in Japan and were actually so-called “diving” cages. They were submerged only in case of storm danger. The rest of the time they remained on the sea surface, where fish were farmed. On lowering such cages underwater, feeding is impossible. So fish starve during storms. Moreover, open-bladder fish (i.e. salmonids, sturgeons) require regular access to air for their normal vital activity. This is also not provided for in “diving” cages.

Based on long-term laboratory and field investigations with the use of underwater TV and underwater habitats, we have developed an underwater technology of fish-farming and have tested seven different types of structures that enabled fish-farm-
The SADCO underwater fish-farming concept is a result of the synthesis of biological and technical research, though the need to solve biological problems gave the initial impetus.

Biological Background - Fish Costs a Challenge

The very first attempts at commercial, submarine, fish farming in floating cages demonstrated the impossibility of a year-round cycle in the southernmost part of the USSR, where summer temperatures reached 26°C at the Black Sea and above 30°C at the Caspian Sea. Therefore, such conditions do not suit conditions in cages. To nurture the fish, they can avoid unfavourable temperatures.

The modern understanding of aquaculture is the farming of water organisms under controlled conditions.

Ideally, it is not a precise control of the level of just monitoring that is understood, but an active control over processes that occur within the operating system.

Thus in the case of onboard fish farms, there is a widely used capability for water preparation at input and output for conventional floating cages such a possibility is completely excluded.

That is why the first project of the SADCO series was aimed at solving the problem of control over environmental parameters via moving the cages within the water column — using techniques that provide optimum conditions for each specific parameter: water temperature, oxygen content, illumination, etc., i.e., by an active search along the water column vertical conditions for conditions most suitable for the fish species to be farmed.

Water temperature (with other conditions normal) has the greatest effect on metabolism, growth and survival of fish. From 1978 to 1983 the author carried out

...
a complex of experiments to determine the preferable thermal conditions for salmonid. Research was carried out both in laboratory gradient units and in field conditions with observation by divers, underwater TV and observers in underwater habitats (Fig. 1, 2).

Specially designed tower-like submerged cages were where fish could freely choose the preferable

Figure 1. Underwater feeding ground at Lake Sechelt.

Figure 2.

depth were used to study fish behaviour. Underwater feeders were mounted at the rear wall but the cages could be used in an under-place position or moved along the vertical to position it at the zone of the water column required for the experiment.
As a result, we succeeded in determining the exact value of the temperatures preferred by fish in laboratory and field conditions, the seasonal and daily rhythms of vertical migrations in a thermal stratified water reservoir, and the correlation of behaviour with specific features of fish home range for three species (Coho salmon, Atlantic salmon, and rainbow trout).

This enabled us to develop an optimized temperature regime for staged salmon farming, which was successfully proven in lake and sea conditions. Since 1980 an application of experimental underwater cages has begun at the Black Sea and since 1987 at the Caspian Sea.

Development of an underwater cage system

Results of biological experiments and positive experiences in the application of our first small underwater cages pushed us to look for a suitable structure for industrial fish farming.

Submerged cages of the first generation appeared in the USSR more than 15 years ago from Japan (Kawagoe company) and actually, they were "diving" cages. They were lowered only in case of storm danger. The rest of time they stayed on the surface, where fish were farmed. With the lowering of such cages underwater, fish feeding becomes impossible and fish starved during storms. Moreover, even after the cessation of wave motion and the raising of the cages to the surface, intense feeding in such cages at the Baltic sea lasted for two weeks more.

It is important to note that fish with an open-type swim bladder (e.g. Stenotomus, Stargazer) require regular access to air for their normal vital activity. "Diving" cages do not provide for this.

An underwater cage with torsion rope framework

In our first underwater cages we used the same principle as in the experimental cages pen (Fig. 1). The cage frame is a right tetragonal pyramid connected to the lower heavy frame by six stretched ropes that form an equilateral framework. As a result, an underwater feeder is lowered at the top of the pyramid, and the top chamber is equipped with a lifting motor to concentrate fish at the upper part of the cage during harvesting.

Lowering of such cages was executed by blocks and a winch, as well as by emptying or filling (with water) billet tanks mounted on the rigid part of the cage framework.

Eight such cages have been manufactured and they passed tests in a freezing lake and sea conditions between 1982 and 1987.

The advantages of such a structure lie in its ease of deployment (it can be fastened to a single central anchor), would the vertical flexibility of the structure during perfectly under leads from waves and currents.

The main drawbacks are: 1) the oscillating motions of the cage in the vertical plate under waves, which disturb the fish and 2) the inconvenience in servicing the installation due to the absence of working platforms.

The variation with a winch on the cage turned out to be insufficient due to the difficulty of providing an efficient block rotation system at the bottom.
Underwater cage with which installed at pontoon

This system consists of two underwater pontoons that are held at one anchor and constantly float at
the surface like a surge and a cage with an underwater

The system has the ability to control raising or lowering of the
cage to any chosen depth by rope is reeled at the

This system seemed attractive due to easy installation and servicing of all technical devices on the

The possibility of circular drifting of the cage sys-

tem around the central anchor has both advantages
(water exchange improvements) and disadvantages (increased area required for a cage farm).

A specially designed chain guide cage working on
the principle of distributed mass is hung below, which
provides for the possibility of regulating the procedure
of cage lowering or raising. For fish with closed type
swim bladders, it is important to achieve an reduced
velocity of raising and intermediate decompression stops. This not only protects fish against herostasia of the

The main advantage of the cage system described
above derives from the absence of any fastening con-

Mock-up tests in wave tanks and field research with swimmers in sea conditions dem-
nonstrated the fact that loads on the structure of the

An underwater leader with a self-contained stock
of food equipment serves as a "living" cage for dif-
ferent marine species which remain submerged for extended periods of time.

Unfortunately mock-up testing conducted in 1986
in a wave tank showed the unsuitability of such a

The danger lies in the difference in phase of oscillations
of the pontoons and the suspended cage. This
leads to extreme loads on the cage and includes a
result in breakage and the loss of the cage. Under par-
specific conditions of travel of loading, wave height
and length, geometric displacement, weight and mass of
the cage, as well as the length of the rope on which the
cage is suspended.
The first SADCO (80) cage was deployed in 1987 at the Cygnaean Sea near 37° 37' 00" S, 18° 37' 00" E, at a depth of 25 m for farming rainbow trout. In 1988 additional cages for farming trout and salmon (from the salmonid family) were deployed and at the same time the first two cages were deployed at the Black Sea, 87 km offshore at a depth of 35 m.

On the whole, 94 cages of this type have been constructed. They have successfully withstood severe storms with 12 m waves and let us prove the possibility of year-round salmon farming in warm southern sea.

A system of automated positioning was mastered and tested at two cages. It made the cage move at depths following the optimum temperature row by using a temperature sensor and oceanic winds.

The drawback of these cages lay in their very small volume, i.e. 100 m³, which allowed no more than three tons of fish per cage.

An underwater fish farming platform

The necessity of increasing the productive potential and ease of servicing the submerged cages stimulated joining individual cages modules into a honeycomb submerged complex (Fig. 6). Such a complex made in a shape of a hexagonal platform had a common mooring system, and a unified hydraulical system for regulation of ballast and buoyancy. Each of the six cages had its own independent decker.

The bottom framework of the platform included two groups of water ballast tanks (horizontal and vertical), as well as relatively placed constant buoyancy platforms. The cages are fixed to the platform by collapsible fastenings. The platform is for central control feeding fish, and mass growing of juveniles for fish supply reproduction enterprises.

The working stairs are placed at two levels, via separate walkways for feeder maintenance, and a central area for fish farming operations.
The availability of a central platform and sound bioacoustic decay produced a considerable advantage: it allowed fish grading and transfer working simultaneously with several cages. Moreover, the system was tested in actual cage structures. In the future, we aimed to establish a system that could integrate the cage structures with the platform. The fish-farming platform was also developed for use at an underwater position, and even could, owing to its hydrotype design, stand in the bottom, using additional water ballast for stability.

Despite obvious advantages, such as for the execution of labor-consuming operations on by on-growing in particular, the total output of the underwater fish-farming platform (500 tons of fish) turned out to be insufficient when weighed against the production needs of the structure. This made us look for ways to reduce material consumption by increasing effective cage volume.

Underwater SADCO-CAGES for Industrial Fish Farming

The achievements of some companies in the field of cage design for offshore aquaculture provide new fish-farming possibilities in high-energy environments. However, a purely engineering approach to solving the problems of flexible construction prevails in existing deep-water cage structures. Biological aspects of fish-farming are not properly taken into account. The following are examples - surface floating cages with a flexible collar where a choice was made for rubber pipes, such as Emgeoflume of Japan and Dunlop of the U.K., or pipes, such as VARIO, CSSR, and NetSystem, USA. Thus, the problem was to determine the best design properties. Another well-known cage system is Parentesco (Sweden), in which a semi-rigid net is provided by reinforced-ring framework operated in semi-submerged position.

All the above cage systems are not protected from wave influence. They can become unstable and experience stress. For example, waves may push or pull on the platform, causing waves to move the cage. In floating cages they are fixed in the bottom by the net under wave impact and period, while in underwater cages no decrease in support is needed. Also, floating cages generally suffer from irregularity in the food supply and increased wash-off of food from cages occurs during the day. Moreover, this is increased in wave due to the fact that cages with fish constantly remain in the zone most exposed to differing ice and varied floating conditions. But the main disadvantage
Underwater cage with rigid structure SADCO-500

The cage presents an enlarged crystalline construction. It is notable for including water ballast tanks as part of the cage framework, which is formed by two hemispherical pyramids with a common base (constant buoyancy principle). The main elements are truss-like. The absence of flexible connections with the water ballast tanks makes log-boat transportation of the NC (submersible cage) easier.

There is an underwater self-contained feeding system with the bunker capacity of 1500 liters of pellets. The feeder bunker and chlorine chambers are separated. The SADCO-500 is supplied with two working walkways and can take up two positions when floating: for feeding maintenance, and for harvesting, net replacement, and other fish-farming activities (Fig. 7).

The SADCO-2500 construction is a frame-and-fuel structure, which consists of a steel central column equipped with a central column and polygonal outer frame. The frame is connected with the top and lower part of the central column through the radial tension rope system, which operates like a sailboat's masts (Fig. 8).

There are built-in ballast tanks, machinery/battery rooms, and feed storage inside the equipment tower for providing long-term autonomy of operation in the underwater position.

Depending on the construction of the frame, which creates a cage pretender, there are two modifications of the SADCO-2500 system:

1. With double horizontal frames, connected by steel rods.
2. With a single horizontal frame and enlarged diameter for compensation for the relatively reduced cage volume.
The results of a cage model testing conducted in 1991 at a wave tank showed the perfect reaction of both of the structures to the wave wind and current impact. Analysis shows that the mooring system was able to secure the SADCO-1200 in both submerged and floating positions. At wave impact, the oscillations of the structure are smooth and hardly bounces while forces on the mooring lines are insignificant.

Although waves, current, and wind change the behavior of the structure, the amplitude of horizontal oscillations does not exceed 1 m for the submerged cage and 2.4 m for the floating SADCO-1200.

Underwater cage SADCO-3200/3500

The same tests were conducted for another type of cage structure, constructed using the combination of a rigid V-hoist framework and a special suspension system for the cage's bottom. This suspension system is designed on a basis of trigonometric properties and provides minimal net-shape oscillations.

The steel framework has a built-in ballast system and water is allowed to enter the ballast tanks in lower the cage or [forced out] to raise it to the surface, where SADCO-1200 operates as a semi-submerged structure for netting the feeder or other survival (Fig. 9).

There are no modifications of this type of cage construction. They vary in dimensions, capacity of the net chamber (1200/2000 m³) and volume of the underwater part. Leaders from the SADCO-1200/2000 cage system was made in 1994 for an offshore fish farm in the Black Sea and the S 1200 also...
Twelve such cages have been manufactured. Among the design advantages are the reduction of steel consumption and good transportability when unassembled. However, SAECO-1200/2000 cages need a trained personnel for installation and farm management.

A test chamber of a special design as well as the method of fixation provide for constant volume and shape of the net chamber even under 1.5 m/sec current and waves up to 1.5 m (Fig. 8). Absolute efficiency of utilization of the net chamber volume is guaranteed by the absence of "dead" areas which are avoided by fish under unfavorable weather conditions. Owing to this, it is possible to double the output of commercial product per unit of volume.

Figure 9. Underwater cage SAECO-1200/2000

Reliable protection of all SAECO cages is achieved by thin complete layer of the underwater, which is the normal operating position for the system. This reduces the risk of damage by drifting reeds, debris, and enables successful fishing in stormy areas with waves up to 1.5 m. At depth, the maintenance of optimal and uniform conditions is reduced manifold. This extends the service life of the cages.

The special mounting system provides for reliable positioning of the cages and due to the fact that it does not have to carry extreme loads, it is characterized by a high margin of strength and relatively low cost.

The underwater feeding system, which enables processing of more than 60,000 tonnes of feeding regimes, provides for normal fish feeding even during storms, excludes wash-off of the feed from the

Figure 10. SAECO consumption operating efficiency since 1983
Fish disease and increases their appetite and general physiological performance. The cost is compensated for by the superior quality of marketed products.

The NAUFO fish-farming system requires minimal expenses for servicing, which is performed regularly — approximately every 10 days — after raising the cages to the surface, where harvesting of fish and other operations are executed similarly to those with conventional docking cages.

New possibilities arise from the use of a remote control and monitoring complex, which provides for control over the farm from the shore. It is possible to obtain not only digital information on the state of the cages and environmental parameters, but also visually observe the feeding and condition of the farmed fish. The feedback provides for the possibility of changing the feeding regime using an office-based PC, controlling the viewing angle of the TV-camera and positioning the cages at selected depths.

Underwater fish farms can be located both offshore and in close vicinity to tourist centres and recreation areas. Minimum losses, a positive effect on the natural environment, create a favourable ecological situation while the absence of "nutrient pollution" reduces possible conflicts with other users.

Fish Farming Cages and Artificial Reefs: Harmony with the Environment

Environmental pollution is a very important problem in intensive fish farming. It is well known that fish farming causes the death of from 5 to 25 percent of feed material from the feed cages (Gosnell, 1985). Combining a cage system with an artificial reef could solve the problem of waste conservation. The waste flushed around the cage becomes biologically enriched with various filtering organisms. Waste products from the cage might be used as food and substrates to the strengthening of the stabilization reef, thus increasing the self-cleaning capability of the area. This artificial habitat scheme...
may be used for any kind of cages. However, underwater cages are the most suitable because this system ensures submergence, emergence, and stabilization of the cage at various depths and promotes the attraction of pelagic as well as demersal fishes.

Underwater observations at all three reservoirs (lake, inshore area of the Black Sea, and offshore area of the Caspian Sea) prove that cages with fish serve as strong FADs (fish aggregating devices), the primary centre of attraction for aboriginal fishes. The stopping of the latter and the population of the bottom AR (artificial reef) by fishes, as well as significant increases of transiting pelagic species sharing in the adjoining area, are the consequences of the increased attraction potential of the cage-reefs complex (Bugrov et al., 1987).

It has also been noted (Beets, 1989) that population and colonization of the bottom ARs was more effective when they were combined with FADs. Nevertheless, the attracting potential of underwater cages results not only from types of effects on fish typical for ARs or FADs, but from some specific, i.e. chemical field spread from the cages; sounds uttered by eating fish; or visual contact with the mass of farmed fish concentrated in the cage.

Not only submersible cages, but floating cages as well should have similar features, but the former are preferable because of their greater protection against waves, because of the presence of the additional (upper) plane that increases the effect of the border; and because of the ability to function throughout the whole water column when moving in the lifting mode.

Positive feedback from the reef element and the cage element is synchronized with ecological reclamation carried out by secondary consumers of food waste. But this relationship shows up only after the AR is inhabited, and after some delay. Availability of shelter for fish, substratum for algae, hydroids and shellfish at the constructed reef should favour the formation of biocenoses, widely specialized and distributed in the depth, that could utilize vital-activity wastes and biogens that enter the environment due to intensive fish-farming (Fig. 11) (Bugrov et al., 1987).

When the artificial reef-and-cage complex "SADCO-SHELF" was built in 1987 close to the offshore oil platform in the Caspian Sea, it caused an increase of bioproducitivity nearby. For example, the number of gobies increased 30 to 50 times in comparison with that of the control areas, while concentrations of shrimp at the cage site have increased 100 to 1000 times. Underwater research results have determined that submersible cages have a dominant role in the artificial habitat complex, where the cage is the initial attractive center for residential and transit fishes. At present the fishing near the complex has the supporting role, providing the cage farm with fish of low market value as feed for the cultured species (salmon and sturgeon) — thus lowering the cost of pelleted feeds twofold.

![Figure 11. Trophic system formed by cages and semi-organized biota.](image)

We consider it expedient to take turns in cleaning AR substrata, choosing each time only part of those...
Alternative use of petroleum-gas structures in the Caspian and Black seas for fish-farming and fishing

Over the last 25 years, more than 1,000 oil-gas structures were built in the Caspian Sea, including more than 300 offshore platforms. As a result, a great percentage of these structures was abandoned and a necessity of their removal by means of fishing and ecological requirements emerges. The removal of platforms from the shelf.

Calculations and existing international experience in the disassembly of platforms in the different regions of the world show that the average cost of disassembly work exceeds one million dollars. This aspect of the problem is solved by using new equipment that allows for the removal of the platforms without major damage.

The Caspian Sea oil and gas industry also provides opportunities for fish farming. The Caspian Sea is a large body of water with a relatively mild climate, providing a suitable environment for fish farming. The oil and gas structures in the Caspian Sea can be used as artificial reefs, which can serve as habitats for fish and other marine organisms.

The other rig (an absolutely oil-extracting rig) was no longer used. It consisted of two blocks, located 36 km offshore at a depth of 30 m.

The new rig was located in 1983 in the Black Sea. The rig was equipped with a system for the extraction of gas and oil. The rig consisted of two blocks, located 36 km offshore at a depth of 30 m.

The layout of the rig was similar in all cases, i.e. without a mechanical connection to the rig. Each block is held in the horizontal plane by the help of three ropes connected to three underwater anchors. A horizontal photosensitive panel is fixed above the rig (Fig. 12).
The USSR oil companies have cooperated with us, providing the possibility of adaptation of their rigs and equipment and a significant part of the required investments. We are now developing a new type of fish farm that can be used to provide food for public relations purposes.

**REFERENCES**

Mooring Issues Common in Most Types of Open Ocean Aquaculture

Sean Kerr
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

Abstract:

This paper will touch on a number of issues relevant to the mechanical engineering design of open ocean aquaculture systems based upon the Woods Hole Oceanographic Institution's (WHOI) Ocean Systems and Mooring Laboratory in Woods Hole, MA.

Many issues that arise are related to the need for open ocean aquaculture systems to be able to withstand harsh environmental conditions while maintaining productivity. The design of such systems involves the consideration of numerous factors, including the selection and application of materials that can withstand the harsh environment.

Typical designs in the industry focus on the impact of large wave forces on mooring systems. These systems are subjected to a variety of forces, including wave loads, current, and wind. The selection of materials and the design of the mooring system must be carefully considered to ensure that the system can withstand the forces it will encounter.

The ocean is, at best, indifferent to artists' renditions.

BACKGROUND:

The Ocean Structures and Mooring (OS&M) Lab, in the Department of Applied Ocean Physics and Engineering,
mooring was founded in the 1960s to systematically improve the survivability duration and performance of oceanographic data-collection moorings. Early attempts resulted in mooring losses and were typically being recovered after only two weeks on station. By the late 1970s, the success rate had increased to a 95% recovery after two years on 600 lb subsurface moorings and 98% on 12 months on station with surface moorings. The moored deployed life of surface moorings was driven by the need to replenish parts of moored current masts and not by mooring failures.

The careful inspection of failure modes and systematic testing showed that many failure modes could be eliminated by design. New failure modes continue to present themselves as new technology is incorporated into moorings and new failure modes are investigated.

This work continues today in several areas:

- The development of fatigue failure prediction methods and better mooring designs.
- Development of real-time telemetry of data using the latest in fiber optic, acoustic, satellite, hardwired, and cellular phone telemetry methods.
- Continuing development of improved static and dynamic mooring models.
- Continuing collection of historical data on environmental forcing parameters.
- The continuous evolution of new materials for use in moored array technology.

The key factors of the design practices that have evolved in the OBM Lab require a thorough knowledge of materials, corrosion, and damage science, structural dynamics, and computer modeling, as well as the ability to design for deployment, retrieval, and recovery at sea. The ocean environment continues to bring new failure modes into focus, as the number of WPOL moored stations (2000) and the length of time on station continue to grow. Much of the substantial knowledge base developed over the last 30 odd years is available in the vast amount of published literature, but it is not always easy to access and is not presented in an easy-to-find or easy-to-implement fashion. There has been a tendency to write partial differential equations and multiple integrals in many cases where a simple arithmetic could be used to say the same thing.

AVAILABLE DESIGN EXPERIENCE

Offshore applications are currently at the stage that instrumented moored array technology was in the early 1980s. The key issues for rapid startup of successful systems required utilizing past technology developments to their best and working with known failure modes. The sharing of knowledge about failure modes and mitigation techniques has proven the most effective for the improvement of oceanographic moorings. The future of science and engineers has made this possible. Practitioners of moored arrays may find that they have more to gain than lose by making public this critical information.

There are three categories of knowledge that can be brought to bear on the general topic of offshore moorings:

- The offshore oil industry has mastered the ability to work for long periods of time in shallow water, with relatively deep water, and the ability to overcome the environmental forcing with massive installations. The offshore oil industry is also relatively difficult to get information out of because of stringent competition among the participants.
- The naval architecture of offshore oil exploration equipment is far advanced, largely because of a long history of relatively small scale funding. Very few long duration projects can move the capital necessary to work on this scale, and the rate of return on investment further suggests a more modest approach.

The U.S. Coast Guard and foreign agencies with a similar mission maintain large numbers of small to moderate-sized moored stations in support of another
Practical Design, Step One, “The Big Picture”

The first decision of any design effort must be philosophical. The “big picture” must be carefully thought out before the details can start to fall into place. Some of the many difficult questions may be as follows:

Are we going to try to employ fishermen in order to be politically palatable? Are fishermen in portable, rubber boats used to roughly handling heavy equipment going to be a help or an active hindrance to the effort?

Are we going to concentrate on shellfish or finfish or some mixture?

What type of structure best fits the site, climate, and budget?

What types of commercially available structures exist or is this a new design?

Practical Design, Step Two, “Modeling and Analysis”

Traditional engineering focuses on predicting the 50- and 100-year storms and does a pretty fair job of predicting the waves, currents, and winds, and lots of lesser degree the forces, associated with them. This is the end result of much evaluation.

Experience has shown that the engineering evaluation is not less than half done. Most aquaculture structures will suffer failed components long before they have to contend with the 50 or 100 year storms. How these failures are treated in the design effort and how they are allowed to impact the overall project requires the bulk of the engineering effort.

The overall wind, wave, and current climate is available in reference material [Ref 1], tie-in a month by month basis and needs to be evaluated.
Where there is reason to suspect that the local conditions are not well represented by the historical data, field measurements may be necessary. The total number of waves of each height and period expected over the life of the system is estimated from the data and arranged according to height, period, and wavelength. From these data, a failure is described. The system is modeled. 

Defining critical components in any component failure by allowing the actuation to test the overall system. Each critical component is monitored for fatigue and wear-life based on the model results and the cumulative damage model. The wire protector will last out until the critical component, which has a very high percentage of the expected fatigue life. Most will vary at the expense and the non-destructive testing costs are necessary, but all is the only clear path to fatigue failure prevention. Life ratings at 100% are not available for many common existing components. A few are documented in a recent WEH report (Ref. 3).

Practical Design, Step Three, “Step Back and Ask Hard Questions”

After a first pass at the fatigue model, the design team needs to step back and ask the following at the entire system setup and operation as a whole: Is this really the best approach in general terms? What are the weak points of the analysis and what is the range of possible error? What are the probabilities and consequences of actual events occurring? What is the best route to follow? What should the component inspection method and schedule be? Where should the inspection points be placed to facilitate testing?

The overall approach may on the surface seem more suitable to a nuclear reactor, but it is a portable system. These systems will be required to die by design. The inspections can be as simple as water blunting off the leakage and leaking the ports over for cracks or deep wear-grooving.

Some words about models

Mathematical models come in three flavors: static, frequency-domain dynamic, and time-domain dynamic. The static model will give the system response to steady state inputs like initial or constant wind. A system that can’t survive the static loading has no hope in the dynamic mode. The static model is usually run first.

Frequency-domain dynamic models require the linearization of all of the non-linear equations of motion and this allows several wind speeds. Frequency domain models can be quickly run and provide excellent insight into natural frequencies and resonance plots.
As any engineer knows, a system excited at its resonance frequency begins to undergo large oscillations that can be very damaging. Most of all, frequency-domain models work poorly with large or very steep, near-breaking waves, because the linearization assumptions are difficult or impossible to reconcile with the physical reality. Frequency-domain models are better at predicting the behavior of large chunks of a system than discrete components.

Time-domain models require much more complex computer codes to run and can quickly set up a lot of modeling time, but can be very good at predicting the behavior of discrete components. The predictions of short- and long-crested, dynamic, stackable cable conditions are an example of very destructive conditions that state and frequency-domain models can miss, but that time-domain models can identify.

Any of these models is only as good as the data and assumptions used to build it. A crude model in the hands of an expert who knows how to analyze the results to the physical reality is more valuable than a better model in the hands of a novice who does not know the limitations and blindly believes the results. Much of the drag and added mass coefficient data has high variability with Reynolds, Froude, and Reflexion-Carpenter numbers. At best, much models give perhaps plus or minus 25 percent accuracy because it is usually impossible to correctly model every aspect of the behavior, damping, and the aforementioned coefficients.

Cantilever and strut models with constant loading and cyclic loading can be modeled to first order with the Neo-Hookean law, which can provide stresses on the order of the signal for many common cable materials subject to combined static and dynamic loads. Because the transverse vibration relationship is complicated and depends on the awe factor (even radiative dependence), a portion of the problem is caused by the construction method. The model is not a perfect fit to the first-order, a function of stress and geometry.

The summation of the multiple time and load history dependent second-order effects can be of similar magnitude.

Physical models on a shoestring

There is still value in mental picture modeling. A system of rectangular surfaces can be built of sticks and string and placed in a barely swimming pool or a nearby stream or lake. Not every force can be modeled accurately, but problems with hinge forces between different problems with not walls collapsing in waves under current can be visualized fairly well. A few engineering engineers, some $50,000, worth of pipe, string, and coffee, being used, and a weekend can quickly give a pretty good intuitive feel for what some of the big problems will be. Some rubber tubing and rubber and materials can be used with simple scaling to qualitatively model mean stream stresses. Some of the more complex phenomena can be used to give a pretty good model of what bigger chain will do.

There are obvious limits to what can be accomplished on this scale. The ability to capture the motions and lay out to scale and to clearly see what components are critical by making them a brighter color and some hand calculations are the most important requirements. The ability to quickly make changes and play off “What if?” scenarios will likely pay off in the long run. A fixed back graft in the background and a cantilever can be used to make crude time-series measurements of motion.

Surface vs. submerged vs. pull down

Many proponents of offshore aquaculture have latched onto the idea of submerged fish cages systems in a “natural” answer to avoiding wave-forcing. Oceanographic surface systems mentioned previously work well in this regard but the depth of the top of the mooring is typically 30 to 500 meters below the surface. The amount of motion, velocity, and seama...
Submergence does eliminate surface wave effects that cause large shaking forces on surface suspended light cage systems. Submergence does offer protection from ice cover, ice building, and the forces caused by drifting and current-driven ice fields. The submergence depth of caviar will offer some protection from surface traffic if not from commercial fish-harvesting activities.

There are critical structural, biological, and site-specific concerns associated with submergence culture that will influence the feasibility of this method.

Water particle velocity decays with depth according to Morison's equation, the output of which is plotted in Figure 1 versus depth. The general case, valid for any water depth, is used. The initial depth of 100 m is taken to be 100 m. The wave particle velocities will increase with a decrease in depth.

\[ U = \frac{A|\omega|}{g} \frac{C_g}{\omega^2 V^2} \]

Where \( U \) is the horizontal velocity, \( A \) is the wave amplitude, \( \omega \) is the wave frequency, \( V \) is the water velocity, \( C_g \) is the depth below the surface, \( x \) is the horizontal position from the beginning of the wave front, and \( g \) is the gravitational constant. Values plotted in Figure 1 are representative of a wave with a period of 10 seconds. Other wave equations are more useful for predicting surface wave shapes, but this model is accurate enough for the purposes of illustration. Multiple lines on the graph correspond to significant wave heights of one, two, four, eight, sixteen, thirty-two, sixty-four, and sixty-eight meters, respectively.

Velocity squared plotted in Figure 2 gives a feel for the decay of wave forcing with depth. Drag force is proportional to the velocity squared. Acceleration is plotted versus depth in Figure 3. The total force induced on a submersed structure is proportional to the hydrodynamic mass times acceleration plus drag.

The question of how much foraging reduction is necessary for storm survival or for long-term survival will vary from situation to situation.

**Effect of wavelength**

Wavelength is a critical consideration in wave spectra. The energy of short-length ice to the breaking limit waves typical of locally generated storm waves does not penetrate as deeply into the water column as longer-period swell. This means, in principle, that a cage system subjected to winds with prevailing waves off a nearby shore will not have to submerge as deeply as a system exposed to prevailing storm winds with longer periods over water to achieve the same reduction in wave forcing, wavelength assumed equal.

A second effect of wavelength involves the interaction of the velocity profile with the motion of the elements of a cage structure or system of cage structures. A single cage structure will feel tension and compression waves passing along horizontal members as a result of the end of the structure being out of wave phase with the other. These forces can be significant and the structure must be designed to withstand many millions of cycles at this level of cyclic loading. Casing components should be examined to avoid leading to or entanglement of excess length during the composition portion of a cycle.

Multiple modules may be examined to avoid resonance at discrete wavelengths within the predicted bandwidth of wave forcing.

**Pressure effects**

Pressure under a progressive surface wave varies over time according to the relation:

\[ P = \rho g h + g \omega^2 h^2 \sin \omega t + \frac{1}{2} C_s \rho V^2 \]

Where: \( P \) is pressure, \( \rho \) is fluid density.
g - acceleration due to gravity, \( a \) - the wave amplitude, \( d \) - the depth below the still-water surface, \( H \) - the water depth, and \( x \) - the horizontal position in the beginning of the wave form. \( \text{Ref. 1} \).

This fluctuating pressure field must be considered carefully, with respect to open system ballast systems and methods. The pressure signal of the wave field passing overhead causes the air trapped in the ballast tanks to change volume and hence buoyancy. The resonant frequency of the buoyancy change must be compared with the range of excitation frequencies. The effect of this cyclically changing buoyancy can cause the entire system to move in the water column.

The mass of the system, the vertically projected drag area, and the moving vertical spring constant will determine if the motion will be sufficiently damped to avoid strange behavior.

The balance of this paper will focus on describing well known failure modes and their mitigation wherever possible.

**General topics; failure modes to avoid by design**

1. Cabling and length member concerns: The following two attempts to describe some of the most common failure modes in length members and cabling.

   a. Torque balance. A balanced-system cabling component typically has one end fixed to an anchor and one end that moves. The presence of a moving end results in a tension change with time over the length. Wire rope and synthetic fiber ropes with most types of stranded construction tend to want to twist as tension increases and decreases. When the line goes slack over the trough of a wave, the tension energy that is stored in the line often forms a knot. The fibers or wires making up the cabling in the knotted region have elevated stress levels due to the sharp bend associated with the knot. Cyclic loading at even modest tension levels quickly causes fatigue and synthetic fiber ropes that are not of a unique balance construction.

   Wire rope can be made torque balanced in several available twisted constructions. These include 5x19, 6x19, and 7x19. It was identified by the US Army Corps of Engineers, and Submarines used it in the 1970s and 1980s as an improved track record in the 1980s and 1990s.

   Torque balance of a candidate rope can be tested with a simple method. A length of 30 ft (9 m) is cut and the bottom end is fixed to a weight weighing approximately 25 percent of the rated breaking strength. The other end is fixed to a crook hook that is clamped so that it cannot rotate. The weight, which has an index mark painted on one side, is lifted off the ground and allowed to spin until it stops. The crook hook is then lowered to the weight and the weight is allowed to go slack. A non-torque-balanced rope will instantly be itself into a knot. Subsequent lifting will not even break the rope.

2. More considerations have failed because a line went slack in the wrong place at the right time, than from tension or fatigue. Slack lines get into trouble by wrapping around things, chafing, and entanglement. Slack lines need to be designed carefully.

   c. Specific facts about cabling materials

   **SPECTRA** is a fiber made of Ultra-High Molecular Weight Polyethylene. It is extremely strong and the most abrasion resistant cabling (but known SPECTRA cannot be used as a mooring line material. Test of Spectra cables at the Woods Hole Oceanographic Institution by the author and others have shown a 13 percent creep elongation of a SPECTRA rope in 100
weeks when holding a load equal to 10 percent of the rope's rated breaking strength. Spectra mooring rope will last longer and weigh less than the same rope that is "cast" into the ocean. Cold water slows the creep rate down by a few percent, allowing the load to be maintained for the same reasons. Cold water also slows the creep rate down by a few percent, allowing the load to be maintained for the same reasons. Cold water also slows the creep rate down by a few percent, allowing the load to be maintained for the same reasons.

**Kevlar** is an aramid fiber used to make such things as bulletproof vests. Kevlar is used frequently as a rope material because of its high strength. Kevlar is heavier than a steel wire of much greater diameter. Kevlar ropes must be carefully spliced to avoid several problems. Braided Kevlar ropes used in cycle-feeding applications can quickly bite themselves to death. A single-strand Kevlar rope typically has a Polytex (aka Dacron) braided core that performs well in many situations where fish feed is not a factor. Parallel fibers have much greater knot-stitching than braided and the construction does not work well in repeated cycles over a week. Several Kevlar constructions involving parallel fiber-strength cores and proprietary woven Kevlar, stainless steel, and Spectra pocket shows promise for fish-line resistance. Testing is in progress at WBM.

Kevlar ropes should be used with a safety factor of at least 5.0.

**Vectran** is a new liquid-crystal polymer closely related to Kevlar that has the high strength of Kevlar and Spectra but does not creep or self-abrade. Cost is typically higher than for either Kevlar or Spectra.

**Nylon ropes** work well in many mooring applications, with eight-strand plaited and braided constructions being preferred. Nylon has a very low fatigue life with one important exception. Tests show the minimum tensile must be allowed to be below three percent of the rated breaking strength or a rapid fatigue failure occurs. This is an empirical observation, based upon repeated test data for which little theoretical basis is presented. Similar data on other materials is not available in literature known to this author.

Nylon rope that has been shock loaded repeatedly gets a characteristic fuzzy appearance that can be confused with abrasion.

Nylon braided or plaited ropes typically elongate 1 percent to 2 percent of their rated breaking strength and should be used with a safety factor of at least 5.0.

**Polypropylene** ropes can be used in many mooring applications. Polypropylene can break quickly due to abrasion or radiation damage. Polypropylene rope is easier to handle than 8-strand fiber, but the former is efficient for certain applications. Testing shows that polypropylene rope typically elongates about 5 percent at break and should be used with a safety factor of at least 5.0.

**Polyester Ropes** take damage quickly when used in deep-water mooring applications. Polyester typically elongates about 3 percent at break and should be used with a safety factor of at least 5.0.

**Wire Ropes** for power-cable applications have been extensively studied by a number of authors (Refs. 2, 4, and 9). Several obvious material choices.
e.g., stainless steel and titanium, have been tried and have failed. Stainless and mild steel wire rope is both found to work harder on repeated cyclic stressing, which leads to a brittle failure mode in a few minutes time. Failure of even a few of the wires in a wire rope causes the rope to lose its tensile strength, which locally increases the stresses on the remaining wires.

Galvanized Improved Plow Steel wire rope in a black HDPE plastic jacket has been used successfully on underwater moorings with less than a 10 percent reduction in strength after five years exposure. Similar results for two year subaerial exposure durations have been recorded. The plastic jacket flows through the holes in the water pipes, but the water does not then flush or move around much. The formation reaction between the steel and the zinc increases the life of the rope. Problems occur when the rope is removed from the water for more than a few hours. The water trapped under the jacket begins to leak out and air enters, replacing the formation reaction in a locally-oxidized manner. Lack of one rope component that must be removed from service for more than a few days should be avoided to stop wave action.

Termination of synthetic fiber materials should be determined by correct splicing methods. Pinned splicer socket terminations are not recommended because they have proved to produce more than a small fraction of the rated breaking strength of the rope in the first case. In the second case, the wires where the rope leaves the pinned splicer are highly susceptible to damage by micro bending fatigue and rupture failure, even when an environment bending strain relief boot is used.

ELASTIC HOSES: rubber or urethane plastic wire rope material offer excellent strength and elongation properties for numerous applications. Rubber wire rope material should be procured only from vendors who can document a track record of experience in the ocean environment. Stable shapes in the ingredients making up the rubber can cause large and unrealistic differences in the properties of seemingly identical samples (Ref. 33, unpublished test report).

ELASTIC HOSES: OS&M Lab personnel have many years experience in the design of elastic hoes with a range of elongation behaviors that can be varied by design. Recent work has focused on incorporating electrical conductors in these composite members. Applications include mooring members, fish hoes, and water pumps powered by wave action.

Attachment hardware
• Bootstrap hoes typically offer five times or better fatigue life than anchor safety-style hoes (Ref. 23).
• Steel peened shackle and wire rope links have significantly longer fatigue life than non-sharpened samples (Ref. 23).
• Shackle denoeve a few more words. Both-type shackle have been historically preferred to camlock connections. The shackle must be inspected before the shackle is accepted for use on long-term mooring projects. The shackle should not extend into the hole in the shackle eye or the high-contact pressure can cause accelerated wear, stress concentration, and fatigue crack initiation sites. Tapered threads where loose more easily than straight threads. In this application, the bolt should be threaded all the way from the inside of the shackle eye to the end. This prevents the nut from coming loose by slipping down onto the threaded portion. Type 316 stainless steel color pins last very well with diesel or gasoline-injected steel shackle.
Anchors

An anchor is often assumed to be a trivial part of a mooring design. The undersea engineering community has a long and successful track record using simple dead weight, spud, or pin integral anchor without concern for bottom type or dynamic loading. "When in doubt, use more weight" has been a reliable rule of thumb. Most shallow water aquaculture installations have used concrete piles, concrete blocks, or boulder anchors with mixed success.

The volume of literature that is applicable to the design of high-efficiency anchors is staggering. A careful review of a subset of the available literature has been combined with the specific requirements of shallow water aquaculture installations in an attempt to identify the best solution or solutions to the problem at hand.

The information presented in the following pages will show that the choice of philosophy is critical to selecting the best type of anchor design for a particular mooring-performance specification. There are several possible anchor types:

1. For surface-oriented systems, the anchor must hold up to a certain point that is less than that which will fail the surface structure and result in catastrophic failure. The anchor should also be selected to meet specific holding requirements.

2. Other applications require an anchoring system that does not move even when loaded beyond the strength of the mooring component.

Without a clear decision in this regard, no anchor can be selected as optimum.

Bottom types, general

Coastal bottom types are typically intertidal, consisting of gravel deposits, sand, gravel, mud, or clay. In cold water, some locations have an active bottom and require special consideration.

<table>
<thead>
<tr>
<th>Bottom Type</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coral</td>
<td>Common in shallow water</td>
</tr>
<tr>
<td>Silt</td>
<td>Fine, muddy sediment</td>
</tr>
<tr>
<td>Mud</td>
<td>Dense, muddy sediment</td>
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References:

- Refs. 6, 7, 9, 12, 13, and 21 give information on soil strength properties versus type. Information in Refs. 13 and 14 on sediment properties can be used in conjunction with force information such as can be found in Refs. 6, 7, 9, and 21 to predict the most likely types of bottom to be found at any location.

Submarine soil mechanics, the science of predicting the stability of a given bottom in withstand stresses, induced by structural forces, is a complicated engineering specialty.

Bottom/anchor interactions

- Hard: Hard bottoms are frequently found in areas that see strong currents, because of the scouring effect of the current.

- Smooth, hard bottoms, while rare, are very difficult to anchor on with any typical holding power, using any but an active embedment anchor.

Coral or cobbles can catch the flukes of a single embedment anchor and thus change the anchor chain in such a way that it is all but impossible to retrieve the anchor.

- Hard clay can penetrate by deep embedment anchor under some conditions. The literature suggests that the flukes be sharpened. The anchor should be as stable as possible and the flukes should be locked in
the proper position. Partial penetration is likely and could cause the anchor to continually break free and re-insert.

Active embedment anchors can successfully deploy in some soft rocks such as gravel or sandstone.

Non-cohesive soils

Non-cohesive soils provide holding power for embedment anchors (in addition to their dead weights) that is proportional to the weight of the wedge of material in front of the anchor. Holding power is a function of the anchor surface area that is perpendicular to the angle of inclination, penetration depth, and the soil specific gravity.

The thokos of an active embedment anchor should be locked upon, or the anchor may drag for a significant distance before developing any holding power.

Several active embedment anchors can work well in non-cohesive soils (Refs. 7, 8, 11, 12, 13, 14, and 15).

Cohesive soils

Most dead and active embedment anchor types function well in cohesive soils of properly embedded. Cohesive sediments provide added holding power for embedment anchors that is the square of the weight of the material in front of the thokos and some cohesive forces that is a property of the local soil. Holding power is a function of the surface area of the anchor, that is perpendicular to the direction of tension, the density of the thokos, the specific gravity of the sediments, and cohesion properties that are functions of the local grain size, grain shape, and soil chemistry. The holding power of a specific anchor in a specific soil can be estimated if a number of empirically measured properties of the soil are known (Refs. 13 and 15).

All anchors currently in use today can be classified into three categories:

1. Dead weight
2. Drag embedment
3. Active embedment

Type one: dead weight

A large enough dead weight anchor will hold in any bottom type. Large weights with virtually no shape significance have been used successfully on oceanographic measurements for many years. Horizontal holding power is a function of bottom material and shape. Vertical holding power is limited by the size of the weight. This type of anchor is usually in all directions unless it is placed on a slope or unstable slope or on a bottom that resists due to current and wave action.

Type two: drag embedment

Drag embedment anchors are typically used from boats with anchor line lengths that are three or more times the water depth. The thokos, bow, or other projections of the anchor provide horizontal holding power by burying themselves into the bottom and adding some strength property of the soil to their dead-weight holding power.

Correct embedment can result in holding powers that are two (2) times the submerged weight of the anchor.

Failure to embed, caused by a number of possible problems, diminishes their holding power to that of a dead weight anchor of the same weight. Failure is effectively embed or remain embedded after initial insertion can be caused by any of the following:

- Hard bottom
- Insufficient depth of sediment over bottom for embedment.
• Failure not opening.
• Improvability in roll.
• Change of heading not with due to tidal currents direction change.
• Tension vector exceeding critical angle above bottom, causing the fluke angle to be unstable and tip out of the bottom.

There are optimal fluke angles published for different soil types:
- Clayey soils: 50 degrees
- Sand: 40 degrees
- Sand and pebbles, shallow flows, waves with close-set tips and long Sabattier perform the best. In soft-bottoms, the fluke area should be maximized while the shape should be streamlined to facilitate deep penetration (Ref. 21).

Mushroom anchors can fail to be dug in so that the edge of the bowl can dig in. Those that remain upright have less holding power than the dead weight of the anchor because the bowl tends to roll and walk with much change in tension due to waves. Mushroom anchors have a long history as the harper master's choice for small craft anchors in protected harbors with mud bottoms. The massive small craft damage caused by Hurricane Bob and several severe autumns storms proved that mushroom anchors are inadequate when subjected to dynamic loading. Several local harbor masters have begun research to find a better design. Harbor master committees in Marion, Mass., and several other local communities will also require a rigorous type of active embedment anchor (Refs. 7, 11, 15, and 16).

Type three: active embedment anchors
A. Zinc.
B. Screw-in anchors.
C. Vibratory anchors.
D. Waterjet-embedded anchors.
E. Explosive embedment anchors.

A. Piles require large and specialized equipment on site and are limited in water depth. Pile anchors can be designed for almost any combination of forces desired.
B. Screw-in anchors provide excellent resistance to lifting forces.
C. A vibratory anchoring system would require that the moving container was pushing down with some large force. This anchoring method causes strength breakdown in cohesive soils by disturbing the overburden and making it unconsolidated. This can result in unusual and unpredictable strength properties.
D. A waterjet embedment anchor requires a significant downforce. This anchoring method causes strength breakdown in cohesive soils by disturbing the overburden and making it unstable. This can result in unusual and unpredictable strength properties.
E. Explosive embedment anchors have been developed for a wide range of bottom materials to prevent large naval vessels, coast guard, and other uses.

Anchors can be further described by several efficiency ratings:
A. Ability to resist horizontal loading.
B. Ability to resist vertical loading.
C. Holding power stability with seismic changes in the area vector due to changes in current direction, as well as tidal variations.
D. Biaxial measurements, depth, and drug dissolution before developing holding power.
E. Portability in terms of the project design.
F. Sensitivity to bottom slope.
G. Sensitivity to bottom composition.
II. Sensitivity to cyclic loading.

1. Ability to establish anchorage after pull-out.

Fixed drag embedment anchors and screw-in or explosive embedment type active embedment anchors are the most efficient anchors.

A fixed drag embedment anchor will hold to some maximum loading and then drop. This anchor type is able to establish anchorage after dragging and is consistent with philosophy statement one.

Active embedment anchors are able to perform in a wide range of loading situations but are unable to establish anchorage after horizontal. This is consistent with the second philosophy statement.

The holding power of drag embedment anchors is highly dependent on the angle that the chain makes with the horizontal. A two-stage anchoring system consisting of a depression weight and a drop embedment anchor separated by a short length of chain provides a lower angle than using a larger size chain. The sum of the weights of a two-stage anchoring system and a single-stage anchoring system with larger chain are the same for any given loading situation, which is consistent with the requirement of a specified tension vector. A depression weight with a large dynamic mass acts as an additional filter for cyclic mooring motions.

Dead weight, drag embedment anchors, and combinations can be designed to pull out above a given tension and remain themselves when conditions allow. Active embedment anchoring methods are inherently incapable of meeting themselves after they are pulled out, but can better resist vertical and cyclic loading.

A two-stage drag embedment anchor is the best passive system design but requires significant weight and mass.

Failure modes that cannot be avoided by design alone

2a. Fish bite, seal bite, crab bite, etc. (Fish bite will be used as generic in this paper).

There are many theories why organisms bite mooring components. Verbal shedding frequency is one factor known to trigger aggressive behavior in some sharks. Wire type and chain are important in fish bite but are heavy and unable to eliminate all potential for compliance in waves or synthetic cable. A field value judgment must be made for each location relative to the choice of materials. Other factors such as the use for structural compliance in mooring components often override this issue. Predator nets can help with the larger bites but add another layer of cost and complexity.

2b. Fisherman bite

The single most common mode of failure is over 20 years of scientific mooring work in the coastal zone is damage by commercial fishermen. Many draggers and trawlers work for miles with no one in the vessel's boat. Draggers frequently will set their direction on a course following a depth contour and go along for hours without checking ahead. Guard buoys have been used frequency surrounding scientific moorings and are routinely run down or cut loose on the average of once per nine months in a year.

Surface structures are subject to being run down. Substrate structures are subject to being dragged over.

Publishing the position of a structure in the "Notice to Mariners" and posting the positions of the deployed gear in the fisherman's rules helps to a small extent. The Busy Farm area has been maintained for over 20 years with no reported problems by Gyu Kihl, Martha's Vineyard. The Coast Guard requires that lighted corner buoys mark the sea area. Numerous lights set out of Point Judith, New Bedford and other nearby ports attract the center of the moored area as a way point in
their navigation to Nantucket Scholls and Georges Bank. Many made their turns right between the corner buoys. There is a language barrier with many of the New Bedford boats, which further complicates the risk of accident.

Most run-downs or drag overs are not intentional, but some forms of fishermen related damage are. Shrimp frequently come back folded with bottle bodies from some fishermen who get bored and decide to try cutting their bait up.

Buoys were stolen from the buoy farm and sold on the black market in Portmouth, N.H. One fisherman tried to hold one for ransom until Bob Walden, OEBM, L.L. Bush at the time, suggested that the fishermen might have difficulty explaining the theft to the U.S. Navy Property. The incident was quickly resolved.

The site of any offshore aquaculture structure must be in some way closed to fishing activity, both recreational and commercial. Shipping traffic must be diverted to avoid crossing through areas where the equipment exists.

2c. Vandalism

The presence of buoys or other structure in the water column has been known to attract fish. Many spectacular occurrences have occurred in many areas to help the local fishermen. Pleasure boats frequently tie up to buoys in the summer months to enjoy the fishing and other activities. Most of this activity causes little damage to the lattice pattern, buoys, anchors, and anything else of value has been stolen off occasion and radios have been damaged or dropped. Dragging operation. Vandalism involving such as much more prevalent in close proximity to poor areas and to the coast.

2d. Fixed gear, portable gear, and free navigation areas

Sustainable offshore aquaculture will require areas of the continental shelf to be set aside for long-term headwater use with specific lease areas involved, similar to the systems used by the offshore oil industry. The politics of implementing such a system prohibits a fast start for this industry.

CONCLUSIONS

The implementation of offshore aquaculture in a large scale commercial industry is a viable goal and may be achievable in the not too distant future. Serious obstacles remain, only some of which can be eliminated by design. The site selection, site issue, and siting issues will prevent many efforts of any quality from ever getting off the drawing board.

Findings of a standard method of site approval can be achieved, significances has not sustainable engineering house needed to be addressed. The majority of system concepts that this author has seen are based upon pipedreams and artistic concepts and not on sound engineering. The number of questionable systems concepts being put forward only increases the difficulty of getting approval for more realistic endeavors. Recent attempts at extracting energy from the sea have suffered extensively from these problems.

Permitting agencies have been reluctant to issue permits for offshore aquaculture ventures when they believe that the engineering and biological infrastructure has not been done adequately. Insurance companies may be hard to get permits and may insist on the evaluation of certain "experts" before setting premature limits or issuing a policy. Seemingly, a well documented, carefully planned design and implementation plan will reduce or negate significant barriers to the necessary approvals.

References:


The "Sub-Marine" Offshore Cage System

Uri Ben-Efraim
Marad Investment Israel Ltd.
Tel Aviv

Marine Industries & Investments Ltd. has developed, patented, built, and commercially operated a unique and revolutionary system for farming fish in the open sea. This system, the submersible "Sub-Marine" Offshore Cage System, is a truly "offshore" cage system. It successfully fulfills all the potential promise of offshore fish-farming in cages, making it possible to farm fish offshore with cage overhangs, regardless of the distance from shore, the condition of the sea, the currents or the depth of the sea floor.

The development of the "Sub-Marine" Offshore Cage System was supervised by some of the best scientists in Israel, associated with the National Center for Marine Life. The system has been meticulously monitored by the Israel Ministry of Agriculture and the project was accepted as an "Approved Enterprise" status by the investment authority in the Ministry of Commerce & Industry. In the U.S.A., the system has been recognized and adopted by the National Sea Grant College Program of the United States Department of Commerce.

At the end of 1993, the company started a commercial pilot program with a "Sub-Marine" Offshore Cage Cluster capable of producing 40 tons of fish. In the pilot, a "Sub-Marine" cluster of three cages was located 11 km offshore, west of Tel Aviv, Israel, at water depth of 80 m. It was stocked in early 1994 withgilthead sea bream fish. The cages are operated and monitored from a ship with a crew of one. Upon warning of an approaching weather front, the cages are submerged to a depth of 10 to 50 m. The pilot program has been very successful and the first crop of fish from the pilot was harvested at the end of 1995.
SYSTEM COMPONENTS:

The "Sub Marine" submersible fish cage system is based on the philosophy that practical efficiency was our over-riding consideration with the sea. It consists of the following components:

- Submersible frame and nut cages
- Service barge
- Sinking buoy
- Anchoring buoy

Submersible cages

The existing frames have the dimensions of 8x8x8 m. They are rigid steel structures which can be combined in the desired configuration. The structure includes a number of smaller cages which are designed to float near the surface. The cages are made of a materials which are resistant to damage from the waves and currents.

Service barge (buoy)

The service barge includes a hydraulic power pack, a winch for lifting and lowering the sinking units, a hydraulic system for the cages, and a crane for lifting the cages. The service barge will also serve as a base for an automatic feeder and food storage. The present barge is a floating unit measuring 3.0 x 1.8 x 2.6 m. It is divided by horizontal decks to form separate compartments for the hydraulic unit and the fooding system.

Sinking buoy

The sinking buoy is a hollow cylinder of 0.84 m. in diameter and 4.0 m. in length. The lower part of the cylinder is filled with water. The upper space above the water is filled permanently with sea water. The sea water can be pushed out from the compartment by air pressure supplied from the service barge or from any other available source of compressed air.

Anchoring unit

The system is anchored by one或two anchor blocks, depending on the size of the cage. The anchoring system is designed to withstand the force of the wind and waves.

Method of lowering and lifting the cages

The sinking buoy is connected to the frame and in the which on board the service barge. When a decision is made to lower the frame, the sinking buoy cable is run down from a winch on board the service barge. The length of the cable that is fed off the winch drum dictates the depth to which the frame is lowered. When the weather is calm, the frame is floated to the surface by lifting the sinking buoy via the operation of the winch on board the service barge.

SYSTEMS COMPARISON

The "Sub Marine" cage systems is different from other offshore cage systems in three major respects: the mooring system, the cage structure, and the operating technique.

Mooring: All other cages require a complicated mooring system which includes a number of buoys, many acoustic devices, and a number of systems designed to keep the cage in position under varying conditions. The "Sub Marine" cages are moored to the sea floor by a single anchor, which makes the system easier to operate.

The "Sub Marine" cages are anchored by a single anchor, which makes the system easier to install. There is no limit to the depth of the water in which the cages can be installed.
sealed, there are no maintenance requirements for several years, and moving the cage to another site is very simple. Cages are free to respond to currents or waves, changing their position around the anchor, spreading wastes and pollution over a wide circumference, with the anchor cable as their radius.

**Structure:** With all other submersible cages, each cage has to be operated by its own submerging system. Most of them are non-dimensional hard frames. The "Sub-Marine" system is a structure that includes a number (up to eight) of three-dimensional hard frames, all operated by one submerging system. Each hard frame has been flexible set-pot that keeps its shape at maximum volume even with strong currents and waves. It also allows the running of all the necessary fish farming operations, such as transferring fish from cage to cage, grading, feeding, changing nets, harvesting etc., to be done at the offshore site in "normal" sea conditions.

**Operating:** All other cages are surrounded or heated by baffling or submerging flexible chambers, with a combination of air and water. The technique does not enable the operator to control the fluid pressure, which must be very high. Actually, the cages grow-up very quickly and may cause decompression damage to the fish. This technique also requires an infrastructure at the site, which is difficult to maintain and cause many faults in the operation of the system. The result of such faults is that the cages are not to be submerged and may be left at the surface, exposed to bad weather conditions.

The "Sub-Marine" system is based on a total mechanical operation. The cages always have a positive flotation and are lowered by releasing the cable that connects the sinking buoy to an external service barge. The same sinking buoy is also connected with another cable to the bottom of the cage frame (see Figure 1). Usually when the cages are at surface position the sinking buoy hangs from the external service barge. In order to lower the cages, the cable connecting the service barge and the sinking buoy is released, the buoy starts to sink, and pull the cages down with it until it touches the seabed, and the cages float above it (see Figure 2). HOisting the cages back to the surface is done by making the cable up the external service barge with a hydraulic winch. This technique enables the system to operate at any seabed depth because it is possible to raise the cages at a very slow rate (50 m in 1 hour), and to lower the cages down in 50 m in 10 minutes. There is no need for any infrastructure at the seabed. The system also allows the cages to be lowered to any desired target depth, in order to change the depth of the cages for long periods, the cable lengths are adjusted. For short periods of time, the depth may be changed by simply stopping the winch operation during the lowering process. Even if a mechanical failure occurs, it is always possible to complete the lowering of the cages just by the gravitational force of the offshore, so that the cages will never be left at the surface in bad weather.

**SYSTEM ADVANTAGES**

- The system is highly flexible and can be adapted to a variety of sites, locations, water depths and other environmental conditions. It can easily be moved from one site to another, allowing the fish farmed to maximize the benefits of offshore fish farming, by placing the fish cages at the most favorable water layer.
- A variety of marine fish species can be farmed in the system, either as monospecifnic or polyculture.
- It is absolutely necessary to be tied up or to be related to any offshore permanent base, platform or any other structure.
- The mechanism of the system allows lowering or raising the frame with the cages at any controllable speed. The frame with the cages can be reproduced at any desirable depth, thus eliminating the risks associated with inappropriate decompression.
- Only when lifting the system is the use of power necessary. Therefore it is still possible to lower the system in the case of an approaching bad weather front, even in the event of a power failure.

- There are two additional backup methods of lifting the cages in the event of power pack failure:

- The fish cages have a three-dimensional shape (a cube) which prevents loss of volume caused by waves and currents. The cages are insensitive to temperature in the current, thus no problems will be encountered when lowering the system in strong currents or an incoming storm.

- Unlike some other submersible cage systems, where a rupture of a cable of the anchoring system would cause the cage to float to the surface during a storm (with all disastrous consequences), our system is immune to such unfortunate events. A similar failure in our system would cause the frame and the cages to sink, with no harm to the fish or the cages.

- Anchoring is simpler, stronger, and cheaper than the anchoring systems widely used on other submersible fish cages. It also maximizes the advantages offered by the current: oxygen supply and waste removal.

- The lifting and lowering mechanism is used for a multiple cage system and is not restricted to one cage only.

- Monitoring, control, and feeding activities can be executed automatically by remote control devices either from a service vessel or from shore.

For Further Information Please Contact:
Uni-Fresh Farms, Merav Investment (Israel) Ltd.
Tel: 972-3-5107760, Fax: 972-3-510758

Figure 1. Cage system arrangement, cages at sea level.
"Scoping" the Potential Social Impacts of Open Ocean Aquaculture

Robert A. Robertson, Ph.D.
Assistant Professor
Department of Resource Economics and Development
University of New Hampshire

Bruce E. Lindsay, Ph.D.
Professor
Department of Resource Economics and Development
University of New Hampshire

Daniel M. Gundogu
M.S. Candidate
Department of Natural Resources
University of New Hampshire

Introduction

Open ocean aquaculture offers the potential for regional economic development, improving the balance of trade, new employment opportunities, and the replenishment of wild stocks of commercially and recreationally important aquatic species (Roy, 1993). In addition, the ability to monitor the products from aquaculture in compliance with official inspection standards and the control over harvest and slaughter make cultured products safe and dependable. The production aspects also allow for a reliable harvest of uniform size and weight, devoid of seasonal fluctuations, appealing to both distributors and retailers (Lovel, 1995). The realization of these potential benefits combined with declining stocks for capture fisheries serves to stress the importance of the development of an ocean aquaculture industry in Northern New England.

The potential for open ocean aquaculture in Northern New England is limited by a number of constraints. Many of these have to do with the status of...
available biological and biotechnical knowledge and facilities systems engineering, which in turn results in limits on productivity, species selection, and site selection. Other potential constraints originate directly or indirectly from human activities. The most severe of these constraints or challenges to open ocean aquaculture are associated with the level of governmental control, the nature of traditional rights to open access resources, and the potential for conflict between capture fisheries and aquaculture (Weeks, 1993). Thus, the development of a successful open ocean aquaculture industry requires comprehensive research programs that facilitate the integration of the biological and the physical sciences with the social sciences. The social sciences can make significant contributions to the development of an open ocean aquaculture project in northern New England by operationally defining and analyzing the potential costs and benefits of aquaculture. The first step in the examination of potential positive and negative social consequences of the development of open ocean aquaculture is the completion of a social impact assessment. This paper reports the results from a research planning exercise that allows for scoping the potential social impacts of open ocean aquaculture.

Overview of Social Impact Assessment (SIA)

Social impact assessment is a method of project- and societal consequences of human actions that alter the environment (Brundtland, 1994). SIA is an applied field of social science that provides an approach to information gathering and analysis for governmental and other organizations to optimize decisions having environmental implications. It emerged in the U.S. in response to the need to understand impacts on human populations of natural resource development and policy alternatives.

The impetus was the signing of the 1970 National Environmental Policy Act (NEPA) by the U.S. Congress (Brundtland, 1994). There are a couple of statutes and regulations that require the consideration of social consequences of resource development projects with direct relevance to the marine fisheries and aquaculture in addition to NEPA. These include the Magnuson Fishery Conservation and Management Act (as amended 16 U.S.C.A. 1801 et seq) of 1976. The act states: "Where a system for limiting access to the fishery in order to achieve optimum yields is deemed necessary the Act requires the Secretary of Commerce and the Regional Fishery Management Councils to consider in the depth the social and economic impacts of the system" (Galloway, 1981). The Outer Continental Shelf Lands Act, as amended 33 U.S.C., also states that "The term 'human environment' means the physical, social, and economic components, conditions and space which interactively determine the state, condition, and health of those affected directly or indirectly by the resource activities in question" (Galloway, 1981). A direct result of this legislation and agency activities SIA has become an integral part of environmental management and the importance of the public involvement component of SIA has been recognized by planners and planners. SIA commonly contains the steps that are patterned after the environmental impact assessment steps as listed in the Council for Environmental Quality Guidelines for SIA, 1994 (for a detailed listing of the steps in SIA process).

The Scoping Procedure

The preliminary assessment of a project procedure is commonly identified as the first stage of the SIA process (Wulf, 1981; Bridge and Bollerman, 1994). In this stage, the social impact analyst identifies the potentially impacted public and the concerns that are most likely to need in-depth analysis, the approximate level of detail for the SIA effort, scoping is important because it facilitates the effective use of the scarce human and fiscal resources (Brandt et al., 1989). This paper reports the results from a preliminary assessment.
of the general types and potential magnitude of the social impacts associated with the development of an open ocean aquaculture industry in northern New England.

The mapping of social impacts is one component of a multifaceted research project entitled "Development of Commercially Viable Groundfish Aquaculture in the Northeast, USA." Other components of the project include four components that address biological issues, two components that address engineering and design issues, and four other components that address social economic, regulatory, and ongoing needs. The mapping process utilized a combination of key informant and focus group and policy issues and surveys with representatives from a broad cross-section of agencies and organizations. The mapping allowed for the collection of information necessary to make trade-offs in terms of the social costs and benefits of open ocean aquaculture. The mapping allowed for the collection of information necessary to make trade-offs in terms of the social costs and benefits of open ocean aquaculture.

Questionnaire

The questionnaire included a brief description of the project and consisted of four primary components: (1) provided a listing of potential study groups and asked respondents to rate how much of a priority the social component of the project should give to each group on a four point scale; (2) provided a listing of critical issues and concerns and asked respondents to indicate how much of a consideration each should be given; and (3) a list of open ended questions that asked respondents about various issues such as environmental, economic, labor, quality of life, social, regulatory, academic, and financial. The final question asked respondents to provide additional comments about the questionnaire or any suggestions for appropriate research designs to investigate the issues. A letter accompanying the questionnaire that provided a more detailed description of the rationale for the project and instructions for the completion of the questionnaire.

The draft of the questionnaire was pretested with directors and employees with expertise in SEA and open ocean aquaculture, as well as with the project steering committee. The second stage of the process was intended to solicit the assistance of experts in identifying potential study groups that may be impacted by the development of this industry and to identify the concern or issues that are most likely to need in-depth analysis. This data was collected by administering a revised version of the questionnaire to a variety of professional organizations and relevant agencies.

Sample

The Open Ocean Aquaculture Steering Committee assisted in the identification of appropriate organizations. The mapping questionnaire was administered to marine economists holding memberships in the American Association of Agricultural Economists, environmental and community sociologists holding memberships in the Rural Sociology Society, open ocean aquaculture. The mapping questionnaire was administered to marine economists holding memberships in the American Association of Agricultural Economists, environmental and community sociologists holding memberships in the Rural Sociology Society, open ocean aquaculture. The mapping questionnaire was administered to marine economists holding memberships in the American Association of Agricultural Economists, environmental and community sociologists holding memberships in the Rural Sociology Society, open ocean aquaculture.
Assessments, individuals listed in the Aquaculture Resource Guide, and individuals with expertise in marine or coastal issues listed in the Environmental Organizations Directory. Also, questionnaire was handed out at appropriate e-mail list server groups (e.g., Pacific and Ocean Farmers of America). The sampling procedures identified a listing of approximately 700 potential respondents. Questionnaires were distributed to the list and yielded 125 completed surveys in time to be included in the presentation of the Open Ocean Aquaculture Conference.

Statistical Procedures

Frequencies are reported for all the potential study groups and the critical issues/concerns associated with open ocean aquaculture. Factor analysis was also used to identify the potential study groups and the critical issues and concerns. An orthogonal rotation was used to identify the factor loadings on a simple structure. The Varimax method was used to determine the number of variables that have high loadings on a factor.

Results and Discussion

This section will briefly summarize and highlight the preliminary data collected from the sections of the questionnaire that prioritized potential study groups and critical issues.

Profile of Respondents

The respondents were highly educated. Approximately 62 percent indicated that their highest level of education was a Doctor of Philosophy degree. Sixty percent held a Master of Science degree, five percent held a Master of Arts, and 15 percent had Master of Business Administration or Master of Urban Planning. Fifteen percent of the sample did not respond to the educational attainment question. The high level of education is not surprising given the listing used to draw the sample. A majority of the sample of respondents were affiliated with universities, government agencies, or with the Sea Grant College Program (51%). Twenty-five percent were affiliated with non-profit organizations, and two percent were affiliated with other agencies. Eighteen percent were affiliated with some aspect of the aquaculture industry. The respondents to the questionnaire were highly educated and represent a cross-section of interests and involvements with open ocean aquaculture.

Potential Study Groups

This section summarizes the results from the component of the questionnaire that sought to measure the extent to which various "publics" or groups of individuals will be affected by the development of an open ocean aquaculture industry. Respondents were provided with a listing of 22 issues potentially impacted by aquaculture activities and were asked to prioritize them using a four-point scale ranging from "high priority" to "not a priority." Table 1 presents the results from this component.

The highest priority study group was composed of marine fish and shellfish farmers, with over two-thirds (68.4%) of the respondents indicating that group as "high priority." Over half of the respondents also indicated that the public at large (56.7%) and local government officials (55.8%) would be affected. Respondents also indicated a moderate priority for "aquaculture operators" (45.0%), "other fishermen" (44.7%), and "fishing cooperatives" (43.9%).

On the other side of the scale, there were groups that the respondents indicated clearly did not deserve much attention as potential study groups. Marine managers were seen as "low priority" study groups by nearly half of the sample (48.0%), while receiving the label "a priority" by 18.7%. Feed suppliers to the aquaculture industry were also seen as...
<table>
<thead>
<tr>
<th>Potential stakeholder groups</th>
<th>Not a priority</th>
<th>Low priority</th>
<th>Moderate priority</th>
<th>High priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial fishermen (n=126)</td>
<td>1.0%</td>
<td>2.0%</td>
<td>24.2%</td>
<td>94.2%</td>
</tr>
<tr>
<td>Residents of affected communities (n=123)</td>
<td>3.3%</td>
<td>9.8%</td>
<td>34.3%</td>
<td>52.6%</td>
</tr>
<tr>
<td>Surface operators (n=123)</td>
<td>28.7%</td>
<td>46.8%</td>
<td>24.8%</td>
<td>4.9%</td>
</tr>
<tr>
<td>Fishing cooperatives (n=123)</td>
<td>3.3%</td>
<td>13.1%</td>
<td>38.1%</td>
<td>47.3%</td>
</tr>
<tr>
<td>Regulating management &amp; enforcement agencies (n=123)</td>
<td>7.3%</td>
<td>20.3%</td>
<td>44.7%</td>
<td>29.1%</td>
</tr>
<tr>
<td>Commercial mariculture operators (n=123)</td>
<td>11.2%</td>
<td>21.9%</td>
<td>31.9%</td>
<td>36.0%</td>
</tr>
<tr>
<td>Institutional investors (n=123)</td>
<td>4.8%</td>
<td>22.5%</td>
<td>39.6%</td>
<td>11.1%</td>
</tr>
<tr>
<td>Local government officials (n=122)</td>
<td>5.3%</td>
<td>20.8%</td>
<td>30.0%</td>
<td>24.1%</td>
</tr>
<tr>
<td>Guild/industry groups (n=123)</td>
<td>25.4%</td>
<td>42.4%</td>
<td>25.0%</td>
<td>5.0%</td>
</tr>
<tr>
<td>Potential investors, mariculture operators (n=126)</td>
<td>10.6%</td>
<td>39.3%</td>
<td>29.3%</td>
<td>31.9%</td>
</tr>
<tr>
<td>Public health and safety officials (n=123)</td>
<td>6.5%</td>
<td>29.5%</td>
<td>36.0%</td>
<td>23.2%</td>
</tr>
</tbody>
</table>

Table 1: Potential Stakeholders Associated with the Development of Open Ocean Aquaculture
Table 2: Results from Factor Analysis of Potential Study Groups

<table>
<thead>
<tr>
<th>Factor Name</th>
<th>Item Content</th>
<th>Proportion of Variance Explained</th>
<th>Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>FACTOR 1:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supply and Infrastructure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed</td>
<td>0.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peptide</td>
<td>0.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutrient</td>
<td>0.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FACTOR 2:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protection</td>
<td>0.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rights of adjacent coastal communities</td>
<td>0.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial marine fish harvest</td>
<td>0.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FACTOR 3:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public health and safety authorities</td>
<td>0.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local government officials</td>
<td>0.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FACTOR 4:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine operations</td>
<td>0.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean transportation industry</td>
<td>0.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreational marine industries</td>
<td>0.68</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In summary, the results from this section of the questionnaire suggest that future social science research activities should focus on commercial fisheries and the residents of coastal communities. The factor analysis represents a preliminary attempt to classify potential stakeholders with association with the open ocean aquaculture industry.

Critical Issues

Next, respondents were given a list of fifteen critical issues and were asked how much of a priority each should be given related to the implementation of an ocean aquaculture industry in northern New Zealand. A four-point scale was used to measure/evaluate each issue ranging from “high priority” to “not a priority.” Table 3 presents the results from this component.

Respondents were clear in their designation of “high priority” critical issues with over three-quarters (78.6%) of them seeing coastal water rights as an issue. Almost two-thirds (65.8%) of the respondents checked netted or downed as a “high priority issue” as well. The third highest scoring in this category belonged to the topic of conflicts with traditional users (63.1%). “Moderate priority” critical issues deserving mention include disease in native finfish populations (35.5%), jurisdictional issues (33.1%), and the issues surrounding regulatory enforcement (33.3%).

Conversely, respondents also pointed clearly to the critical issues they felt were not deserving of serious research attention. A third (33.6%) of the sample saw beach rights as a “low priority” issue, while the highly constituted topic of willingness of capture fishermen to work in aquaculture surprisingly scored a 12.5 percent in the “not a priority” category. Likewise, the shipping lanes did not rank high amongst the priorities of the respondents, with a combined “low priority” and “not a priority” score of 48.7 percent. Tourism-related issues was seen as the most trivial issue with a combined score of 50.1 percent.

Factor analysis of the responses yielded four interpretable and conceptually meaningful factors. Table 4 lists the items included in each factor and along with its loading the proportion of variance explained by the factor. We labeled the four factors: 1) Environment, 2) Conflicts Over Use, 3) Legal Concerns, and 4) Technical Feasibility.
<table>
<thead>
<tr>
<th>Critical Issues</th>
<th>Low priority %</th>
<th>Low priority %</th>
<th>Moderate priority %</th>
<th>High priority %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced access to native fish populations (n=23)</td>
<td>1.8</td>
<td>11.1</td>
<td>53.6</td>
<td>33.5</td>
</tr>
<tr>
<td>Cognitive disability (e.g., sensory loss) (n=21)</td>
<td>5.8</td>
<td>10.5</td>
<td>42.2</td>
<td>41.5</td>
</tr>
<tr>
<td>Pollution of aquatic environments (e.g., oil spills, contamination) (n=32)</td>
<td>5.7</td>
<td>12.5</td>
<td>27.0</td>
<td>45.0</td>
</tr>
<tr>
<td>Willingness of commercial fishermen to work in aquaculture (n=120)</td>
<td>6.5</td>
<td>24.5</td>
<td>39.2</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Table A: Prioritization of the Critical Issues Associated with the Development of Open Ocean Aquaculture

Table B: Results from Factor Analysis of Critical Issues and Concerns

1. **Environmental Concerns**
   - Reduced access to native fish populations
   - Cognitive disability
   - Pollution of aquatic environments
   - Willingness of commercial fishermen to work in aquaculture

2. **Conflicts Over Use**
   - Reduced access to native fish populations
   - Cognitive disability
   - Pollution of aquatic environments
   - Willingness of commercial fishermen to work in aquaculture

3. **Economic Concerns**
   - Reduced access to native fish populations
   - Cognitive disability
   - Pollution of aquatic environments
   - Willingness of commercial fishermen to work in aquaculture

4. **Technical Feasibility**
   - Reduced access to native fish populations
   - Cognitive disability
   - Pollution of aquatic environments
   - Willingness of commercial fishermen to work in aquaculture

- **Other**

   - Refers to economic impacts, genetic impacts, and the potential for conflict between aquaculture and traditional uses.
3. Legal Concerns. This factor relates to the various concerns associated with regulatory, jurisdictional, and coastal water rights. The successful development of open ocean aquaculture requires consideration of a wide range of issues that must be addressed through legislation or the legal system.

4. Technical Feasibility. This factor includes a number of items that relate to issues that will affect the overall social and technical feasibility of the open ocean aquaculture industry. These items include the ability of the technology to withstand adverse oceanic conditions. Another issue that may ultimately represent a greater threat to continued federal support of the research essential to the development of the industry is the willingness of capital owners to become involved in the aquaculture industry.

In summary, the results from this section of the questionnaire suggest that coastal water rights, economic disruption, and conflicts with traditional users represented highest priority concerns. The factor analysis represents a preliminary attempt to develop a typology of the concerns associated with the open ocean aquaculture industry.

Future Directions

The goals of this research planning exercise were to solicit the assistance of experts in identifying key stakeholder groups that could inhibit or enhance the development of open ocean aquaculture and to prioritize the critical issues and concerns facing the successful development of the industry. These preliminary findings suggest that commercial fishermen are critically important stakeholders. The research identified four major types of concerns associated with the development of open ocean aquaculture, which includes environmental issues, conflicts over use, legal concerns, and technical feasibility. These results point to the need for a credible scientific mechanism for greater public involvement in the project planning and implementation process.

Future efforts associated with this project will provide a theoretical framework for integrating the social aspects with the biophysical components of the aquaculture industry. This framework will enhance our understanding of complex interactions between biophysical and social systems. Specifically, the interactions between commercial support for research and the critical issues confronting the successful development of open ocean aquaculture. It will also allow for the identification of variables that can be shown to affect perceptions or preferences of fishery aquaculture initiatives that can be controlled, and suggests processes by which social components can impact the success of the aquaculture initiatives.

References:


To Be or Not to Be Involved: Management Options for the New England Fisheries Management Council

William J. Brennan
W.J. Brennan Associates
Portland, Maine

Introduction

In 1995, several issues arose which prompted the New England Fisheries 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 Fisheries 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, responsibility, and management options relative to aquaculture; current policies affecting the Council’s activities; strategies for managing aquaculture impacts; and recommendations for development of an Aquaculture Policy and Management Strategy.

As many of the federal and state agencies whose programs were reviewed in the report are participants in this Open Ocean Aquaculture Conference, I will limit my focus to the issues raised and recommendations made in the 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 nationally charged...
with lead to overall responsibility to administer EEZ-based aquaculture. This situation is somewhat obscured from the perspective of project developers who must complete an array of permit applications and meet a variety of requirements, some duplicative, in order to undertake an EEZ-based aquaculture operation. Second, unlike many of the coastal states, the federal government does not have the legal authority to lease, license, or permit the commercial exploitation of submerged public property. Many believe that the legal protection afforded submergence rights and finfishers through such proprietary rights are essential to attracting investment in the industry.

Third, within this report, we have made no formal decision to impose on the Council's role in aquaculture management. And fourth, the Council will have made no decision relative to its role in the aquaculture, hence the title of this paper, "To Do or Not To Be Involved?"

Legal Authority

In the opinion of NOAA General Counsel, with concurrence of the Justice Department, aquaculture activities are subject to the Magnuson-Stevens Conservation and Management Act and its regulations, the MF piscine authority under which it is conducted, and the Magnuson-Stevens Act (16 U.S.C. 1801 et seq.) provides fishery management councils with the authority to prepare fishery management plans (FMPs) that, if approved by the Secretary of Commerce, can be implemented and enforced through federal regulation. Domestic aquaculture is unrestricted until such an FMP has been prepared, approved, and implemented. For the purposes of this report, aquaculture is defined as any activity related to fishing, catching, taking, or harvesting fish within the EEZ.

The Act’s broad definition of "fishing" encompasses the activities of fishing, the harvesting of fish, and any other activity or activity in support of such activity that may result in the catching, taking, or harvesting of fish. Any program involving the gathering of a commercial aquaculture facility is thus within the purview of the Act and is subject to management plans developed by a regional council. That aquaculture is considered to be equivalent to fishing is further supported by the New England Fishery Management Council’s (NEFMC) management plan for the management of fishery resources, which includes "fishing" as including "caching, cultivating, catching, taking, or harvesting fish..."

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 enforcement, at the discretion of the regional fishery management council. Accordingly, vessels used to support aquaculture activities, including those involved in the fishing or assistance... any activity relating to fishing, including... storage...

Management Options

The management options available to the NEFMC (Sections 302(b), 304(a), and 308(b) of the Magnuson Act) are relatively limited. The Council can prepare a plan for the proposed aquaculture site that either exempts them from the Act or does not apply to the proposed aquaculture activities, or if it can demonstrate that the project would cause adverse impacts to the fishery resource habitat, the fishery management objectives for that species. A plan amendment would address certain obstacles such as minimum fish size restrictions or other...
A preferred alternative to the above project-specific approach would be an amendment that provides blanket permission or exemption from provisions of an FMP to accommodate aquaculture generally. Incorporation of a blanket exemption mechanism would facilitate consideration of individual projects. The framework mechanism enables the establishment of project-specific special management zones where necessary and provides the Council with the ability to adopt conditions or restrictions deemed necessary to meet the conservation objectives of the FMP in question. The framework mechanism also provides the Council with the opportunity to reserve the necessary public comment concerning the specific project under consideration. This approach would, over the long run, be more time-efficient than a project-specific amendment, particularly if formulated “application”-like 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 or some of the species currently under the New England Council's management. In fact, there are fishery resources in the EEZ not currently under the Council's management that may be of concern to aquaculture developers, particularly those in EEZ-based aquaculture ventures. If approved existing plans and establish new plans could be significant if not overwhelming. Given this scenario, the Council would be far better served by developing an overarching aquaculture FMP that would enable the Council to administer all forms of aquaculture that may be proposed for EEZ waters.

As aquaculture FMPs are to protect the NEPMP in amended existing FMPs to accommodate projects for various species under its management. This approach would, in essence, "pave the way" for subsequent exemptions for aquaculture activities that are otherwise prohibited in all existing FMPs and enable the use of a framework mechanism to address individual project as presented above. However, because of prohibitions inherent in Magnuson-Stevens, 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 "exclusive use..." 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 300EE and Section 300EE(b)). Although the "exclusive use..." is considered to be equivalent to fishing, and subject to council management actions, aquaculture pursuits are not "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, it would not result of prohibitions contained in the Magnuson-Stevens Act. Many aspects of aquaculture such as the engineering and design of off-bottom structures and mooring systems, the biological and chemical evaluations of waste discharge and navigational issues associated with structures located on the seafloor are technical in nature and fall under the purview of several federal agencies. No entity has the legal authority to change the rules of practices already associated with aquaculture and potential fishery interactions. It has been suggested that issues of a regulatory nature are ideal for the aquaculture defined by the NEFMC has significant expertise in addressing these conflicts and is, therefore, it has been recom-
needed that the Council should extend its oversight to issues associated with the allocation of space in the EEZ for aquaculture projects proposed within its geographical area.

Section 306(a)(2) of the Magnuson Act provides a council with discretionary authority to designate zones 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. These Special Management Areas (SMAs) have been used often by the New England Council in a variety of management plans, most of which were intended to protect spawning aggregations of fish, and could certainly be used to afford aquaculture ventures a modicum of exclusivity. 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 permit fees 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 amply discussed at earlier hearings, and will therefore be omitted. These issues include the following:

1. Proprietary use of living resources, as defined by the Council, in the form of leases or permits that are issued to aquaculture ventures for use of EEZ resources.
2. The imposition of conditions on permit applications that would require the acceptance of an activity.
3. The allocation of space in the EEZ for aquaculture projects proposed within the Council's geographical area.

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 resource or water column above. From the perspective of an aquaculture user, the inability to secure exclusive or proprietary
rights can be a significant deterrent to investors and thus inhibit development. But, as the Council has already experienced, the perception of bottom 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 EEZ, and it is recommended that this debate be moderated by the NEHMC, which is the entity in the region 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 guarantee that during any allocation of space will be renewed each time such a project is proposed. That EEZ-based aquaculture is a component of the New England Fisheries for which the Council has management responsibility also argues for the Council to become involved. Furthermore, the likelihood that the Council's workload will be increased by such proposals is PSMs are to be undertaken 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 issues 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 superficial, a brief examination 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 potential fisheries interactions including the possible effects of aquaculture on traditional fisheries management objectives of great plant. The Council is also, in this context, the most appropriate forum for the debate about allocation of space, resource utilization, and cost and benefits comparisons. Furthermore, the Council has a statutory responsibility to comment on potential fisheries impacts of projects proposed in federal waters. It is argued, however, that issues such as genetic interactions, design of surface structures and mooring 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 and necessary expertise.

Federal regulation of aquaculture in the marine environment has a relatively short history and is largely based on 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 undertaken 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 responsibility. 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 in the development of such a role and ensure that any involvement on its part is kept within the bounds of its own expertise. The Council should also appoint a representative to attend meetings of the Joint Subcommission on Aquaculture, particularly its Task Force on federal regulatory involvement, established under the National Aquaculture Act of 1980.

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, and participating in the cooperative application and review procedures utilized by several state fisheries resource agencies. The Council's early involvement with individual project development will enable coordination and recommendation.
Reactions of cod (Gadus morhua) in submerged net-pens

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 1981 to only 219 million pounds in 1992. The severity of these declines can be illustrated by U.S. cod landings, which decreased by 20% between 1991 (50.600 metric tons) and 1992 (39.400 metric tons) (Aron, 1993). In response to these alarming declines, the New England Fishery Management Council has recommended severe restrictions on fishing effort and closure of 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, consumption has increased by 25% over the past 10 years, and the per capita consumption is projected to be 20 pounds by the year 2000. This is just 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 (reviewed by Birandal, 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, hybrid raising systems, and feed supply.
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 grow-out systems that could be used to grow cod to market size. Because inshore areas are heavily used for recreational 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 submersible net-pen systems either available, or being developed. The work we are doing seeks to develop small, inexpensive submersible 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 submersible net-pens, and then provide some preliminary results from a research project that relates to these issues.

Biological Issues:

In considering the viability of submersible 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 (see also per 10 meters), 2) changes in water temperature (generally decrease with depth), and 3) changes in light levels that may be important to visual feeders. In general, 1 and 2 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 herring fishes, have a swim bladder (internal gas-filled bladder) that has a number of functions. First, 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 physiological type. Enlarging (inflation) of the swim bladder occurs as the fish ascends, and is decompressed by returning the gas from the bladder into the bloodstream, using a structure called the anal papilla, which is simply a bed of caecal capillaries. Filtration (inflation) occurs as the fish descends, and is accomplished by secreting gas into the bladder from the bloodstream in a complex physiological process.

Understanding the physiological rates of inflation and deflation of the bladder is critical to the appropriate operation of a submersible net-pen. If the pen is raised too rapidly, the fish may not be able to reenlarge the gas quickly enough, and this could result in internal organ damage and swim bladder rupture. Conversely, if the pen is lowered too rapidly, the fish may lose buoyancy if it cannot deflate the bladder rapidly enough. Hazell and Jones and Schleeboth cited in Blades and Tyler 1971 have reported that 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 adapts to bladder volume to the depth it occupies). As they ascend, cod are capable of reenlarging gas at a rate equivalent to a descent of 0.2 m per minute, and this decreases to about 1.3 m per minute after 120 minutes. As they ascend, cod are capable of reenlarging gas at a rate equivalent to immediately after a descent of 2.4 m per minute, as they turn from 120 to 180 m, and the swim bladder is fully adapted after four hrs.

Their rates are remarkably slow relative to the rates one might wish to use in raising and lowering a submersible net-pen in a commercial aquaculture operation.
10 meters to the surface should, according to these physiological adaptation rates, be about 30 years from the time of release, but this would vary depending on the environment. Since most submersible pens are likely to be considerably deeper than 10 meters, the time to raise the pen would extend over several hours, thereby making their operation very time-consuming and therefore expensive. My point is that the use of fish in both systems is likely to result in significant costs 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. This fish traveling up and down in a submersible pen would presumably experience temperature changes. What effect would this have on the fish? Results from a recent study by Claeys et al. (1995) shed some light on this subject. These researchers have constructed a large tank in which they can study the physiology and behavior of fish under different environmental conditions. The tank is 10.4 m high and 4.6 m in diameter, and they are able to induce temperature stress in addition to varying water temperatures by means of different techniques. The fish are observed at different depths to avoid biasing their depth selection behavior. In a recent experiment they worked with cod that had been acclimated to 5°C. Some of these were equipped with temperature equipment that allowed them to control the temperature in the tank between 5°C and 10°C. They also recorded heart rate and oxygen consumption of the fish at different temperatures, as well as any changes in their behavior. Using these facilities and a variety of methods, they were able to study the physiology and behavior of live organisms kept at different temperatures. Their results have a bearing on the potential of submersible pens, since fish in such systems would also experience temperature changes. Claeys et al. (1995) found that 10°C and water temperature changes could lead to physiological changes, such as changes in water temperature, heart rate and oxygen consumption. Furthermore, the effect of fish on the water temperature was significant after 2°C temperature change could take place over several hours, indicating that the fish were not acclimated to these temperature changes. 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 pen system, and as such, care should be taken to maintain the water temperature.
About 50 juvenile cod were caught in a trawl net in January 1985 by a local commercial fisherman. These were kept alive on board the vessel in seawater tanks, and returned to the U.S. Coastal Marine Laboratory (CML), where they were placed in a 25,000 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 every other day.

![Figure 1. Growth of cod Radula (A) and at Laboratory (B) and an experimental, without fish, system.](image)

The experimental net pen was deployed in August 1985 at a site near the Isles of Shoals, N.H. Water depth at 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 surface was not 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 netting were 26.7 cm TL and 230.8 g (Fig. 1). When submersed, the pen was located about 32 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 quarter varied, but each operation generally took about 10 minutes. Average time at the surface was 8.10 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 951.3 g. Those held in the net pen had a mean total length of 44.8 cm, and a mean wet weight of 639.5 g (Fig. 1). There was no significant difference (Analysis of Variance; [10]) 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. Results from this limited experiment indicated that cod in the net pen, which were raised and lowered at a rate much faster than the net would have allowed them to adopt their normal bladder volumes, were not adversely affected, at least in terms of growth. On several occasions a few fish (5) were observed to be floating upside down when the net pen was brought to the surface. In these cases, the 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 submersible net pen designs and larger numbers of fish, is currently in progress. We will have more adequate control over surface net pens, 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 pens periodically using a remotely operated vehicle (ROV). We will measure growth and survival at the end of this experiment, and obtain 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 viability of earthen use in submarine net pens, but this 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. Almeida
Departamento Regional de Pesca, Governo Regional da Madeira, 9000 Funchal, Portugal

The Regional Government of Madeira has developed a program to promote the development of marine aquaculture through the creation of an aquaculture center. Following preliminary studies, it was decided to proceed with trials in the offshore waters of Madeira.

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 major island, where most of the population and economic activities are concentrated.

In response to falling catches of demersal fish and to lower the dependence on 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 that 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 (following an approach according to FAO, 1985) and the most suitable areas used for rearing the different groups of species (following Mine, 1978) - Fig. 2.
The physical/environmental conditions are determined by the geographical situation and geology of the island. From a central barrier of high mountains to the land surface slopes sharply to sea level, often ending in cliffs or extended pebble beaches. The population and housing sectors compete strongly for available coastal land. There is no space at an affordable cost for the installation of land-based aquaculture infrastructure.

The presence 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 depth and salinity are significant. A wave height factor is very low (5 year return period is 4.5 meters; SEAWORK, 1994). In these exposed conditions, it is not favorable 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 (36.0-37.0‰) and suspended dissolved oxygen levels (about 7.5 mg/l). Monthly average sea surface temperatures range from 15.0 to 23.0°C. These are considered excellent conditions for the growing of most Mediterranean species used for aquaculture. The sea area is considered "clean", that is free of pollutants, but also low productivity (SNEP, 1982). The use of raft or 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 landside manufacturing and the experience/infrastructure for fish food processing.

The offshore pilot project

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

1. Production plans were drawn to allocate financial resources within the regional development plans (PEDAR, 1991) and European Union funds (DLR, 1994) with measures to ensure the investment priority was given to commercial fish farming of high-value species using offshore systems.
2. The creation of an experimental center to carry out trials and to evaluate the potential of local species for aquaculture, with extensive services (at investigation phase).
3. Finally, the presentation of a pilot project using offshore cages to produce pilchard, sea bass, Serratula azorica, in order to test the biotechnical and economical feasibility of this culture system in Madeira, and to demonstrate its viability to the local investors. The facilities consist of four polyethylene nursery cages (each 100 m3) with a total volume and a 3000 m2 farm site growing cage. The fish farm was installed by November 1995 and is expected to produce 900 tonnes of fish per year. Within three years, the fish farm will be transferred to the private sector.

Conclusions

A model for 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 fish culture was planned with a strategy based on financial incentive for the installation of commercial ventures, the implementation of extension services and finally, the establishment of feasibility/demonstration 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
Direção Regional da Pescas, Governo Regional da Madeira, 9000 Funchal, Portugal

A mass-balance model is used to assess the potential environmental impact in the cultivation of an offshore fish-cage farm in Madeira Island. Based on the spatial limits of the cage structure, the farm should have a significant impact on the seawater beneath the cages.

Introduction

The localization of an offshore fish farm has to satisfy site requirements, minimize environmental effects and integrate with other economical and recreational activities.

The south coast of Madeira presents suitable sea conditions for the installation of cage structures for finfish aquaculture. The proposed site for the installation of a government funded pilot project in Baia da Ane is 200 m off the peninsula coast, away from the principal navigation routes of the local port 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 growing cage are situated respectively at 22 m and 30 m depth of water.

According to hydrographic surveys the circulation patterns of the site area are mainly influenced by the predominant northern winds and the flow of the ocean currents. Mean current speeds estimated using...
dissolved oxygen. At 4.5 and 10 m, a depth of 10 m, it was observed that the dissolved oxygen was significantly lower than at the surface. The depth of the water column is approximately 40 m, with the lowest concentration of dissolved oxygen occurring near the bottom. The dissolved oxygen concentration at the surface was measured to be approximately 6.0 mg/L. The dissolved oxygen concentration at the bottom was measured to be approximately 1.0 mg/L. The dissolved oxygen concentration was found to be lowest near the bottom, with a gradual increase towards the surface. The dissolved oxygen concentration at the surface was measured to be approximately 6.0 mg/L. The dissolved oxygen concentration at the bottom was measured to be approximately 1.0 mg/L. The dissolved oxygen concentration was found to be lowest near the bottom, with a gradual increase towards the surface. The dissolved oxygen concentration at the surface was measured to be approximately 6.0 mg/L. The dissolved oxygen concentration at the bottom was measured to be approximately 1.0 mg/L. The dissolved oxygen concentration was found to be lowest near the bottom, with a gradual increase towards the surface.
The distance travelled will be 25 m for the feed and 75 m for the faeces. Considering an even distribution of waste around the cage, the feed wastes will be dispersed over an area of 1.083 m² and the faeces over 17.67 m².

Thus the amount of carbon loaded per unit area resulting from feed waste will be around 5.6 kg/m² in a 25 m radius. The faeces material will deposit masses of 2.2 kg of carbon per m² in a maximum radius of 75 m.

The significance of the waste loadings

The estimated carbon losses from both feed wastes and faeces in a 25 m radius will result in a carbon load of 7.8 kg/m². This is considered to be a high level of carbon load on a submerged system in northern Europe, according to Gowan & Baudry (1987).

In the more open waters of the Mediterranean, sea Black, Hervé & MacDougall (1994) expected no major impact of the fish farms on the benthos. These authors suggest that the wastes would not be substantially disintegrated by storms events and helped by the strong waves. For the Ban de l'Âtre, we assume that the carbon accumulation of organic material on the sea bed will contribute to the formation of deposits, which in turn will influence the breakdown of the organic compounds.

At the moment there are no regulations concerning the discharge of effluent cages in remote areas. A monitoring programme has been designed for this particular project in order to control the physical-chemical effects of the wastes on the bottom by means of experiments designed to measure oxygen, carbon, and other total sedimentary parameters following Moor, Pearson, Ellis, Sowers, Pantin & Warner (1990) and Eleftheriou & Holme (1984).

![Dispersal of Particles](image)

\[ \text{Dispersal of Particles} \]

\[ 2 \text{m} = 2 \times \sqrt{\frac{V}{4 \pi d N}} \]

\[ V \] = horizontal distance covered by particle

\[ d \] = density of water column density (g/cm³)

\[ n \] = number of particles per cm³

\[ V \] = current velocity (permeability value) (cm/s)

\[ a \] = settling velocity of a mass (cm/s)

Feed \[ D = 25 \text{ m} \]

Faeces \[ D = 75 \text{ m} \]

**Real Loading**

loading per unit area = waste (kg C/m²)

Feed = 5.6 kg C/m²

Faeces = 2.2 kg C/m²

![Real Loading](image)
Conclusions
The waste loadings from the fish farms in Bata da Água, Madeira were estimated with a mass-balance model and produced a considerable amount of waste loads. It is believed the net characteristics of the site will contribute greatly for the dispersal of wastes and avoid their impact on the sediment.

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 in the local ecosystems.

References


MAINE AQUACULTURE INNOVATION CENTER
Submersible Ballast Cage Project:
Interim Report

Thom Desch
Washington County Technical College
Bar Harbor, Maine

INITIAL IDEA

In the fall of 1990, phase II of North Atlantic Aquaculture Inc.'s Ballast Project was proposed with two goals: to investigate growth technology and to assess grow-out rates of Atlantic salmon. Working with Dr. Kim Whitehead and directors Robert H. Cook of St. Andrew's Biological Research Station and the staff of the University of Maine's Fisheries and Aquaculture Research Group (FARG), a submersible ballast 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 bottom fish and a ballast cage would help minimize their habitat, reducing ambient light and the effects of wave action on feeding behavior.

At this point, aquaculture coordinator George Koppaleti, whose position was funded by MAIC, Sea Grant, Washington County Technical College (WCCTC), Oo-di-yi Opportunity Zone, and the University of Maine Cooperative Extension Service, developed a submersible design in steel, based on these limiting factors: containment volume and construction cost. Initially, the overall dimensions were 24' x 24' x 12', as seen and is thought to be important that the depth of 25 ft. x 3' in a 3 ft. is chosen for the frame, based on strength and cost. Once the frame and concretions were completed, a six-panel net would be tightly stretched within it. The net was to have a polypropylene to the bottom, which in turn would...
rest on a bottom of earth planks fastened to the inside bottom of the frame. The above construction with gravel and mud so 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 (normie bags, nets, chains, etc.) was completed by April 1991.

In April, Mr. Kapelius was assigned to work for the private sector. At the same time, the private company providing site and feeding for the project began to fall. Their commitment ended. Advice from both federal and state agencies on the way caused doubts about two aspects of the initial design. They felt that such a large structure would be unstable in the strong currents of the area when raised for inspection purposes. To overcome this problem through increased technology was impractical as both money and manpower. It was decided to alter the dimensions to 2x4 x 145 x 60. Bob Waywood, who is involved in a similar experiment with Harbor O'Malley Products, designed the cage. The revised volume was adequate for forty fish. The containment barrier was changed from netting to barbed wire to counter shifting and entanglement. During late summer 1991, the cage was cut down and re-worked to its present configuration. Strip wire was ordered and construction resumed. In consultation with the Biological Station, which was supplying the fish, a draft date of spring 1992 was decided on to allow time for WCTC-MTC staff to complete construction and secure a new auxiliary pumping system. Appendix B by Brian Friesbe, Trenton Island Properties 1991, managed by Dan Marshall, had agreed to be the cooperative sponsor for the Halibut Project (see Appendix C).

By May 1992, the pen was completed and launched by the MTC's 60-ton Marine Travelift from the school's pier onto Rainier Bay. Stowing of the TDF, where the pen was stored, took unexpectedly long and before being repositioned. The next day, a diver inflated the air bags and the pen was towed to a nearby bank at high water. Repairs and adjustments to the inflation system were made during low water. The pen released, lowered to position and impacted according to plan.

During this process it became apparent that independent meetings were not needed: the cage's weight was adequate to keep it on station once submerged. This fostered flexibility in using the cage. The cage was moved later, with fish in it, closer to the salmon pens. Feeding the halibut became easier.

On July 27, 1992, Dr. Waywood delivered 40 adult halibut. The divers checked the condition of the fish regularly and weights and measures were taken on Oct. 2, 1992.

The feed system consists of 80 ft reinforced two-inch LD plastic hose connected to a five-foot section of 2.25-inch LD reinforced exhaust hose clamped to the inside top of the cage. Originally, the hose was floated by a number of eight-inch float bags. However, riptide and wind made feeding difficult and sometimes impossible. It was then that the pen was repositioned closer to a work range of TDF. Whole and stripped herring are pumped by a Honda 3.5 hp two-inch pump with 45-gallon capacity. Feeding occurs every other day at a current rate of 1.5 lb per feeding. The feed has been partially provided by RJ Preece Canning Co., where the storage freezer is located.

The materials left over from the design change 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
a surface cage frame. More flotation, walkways and some additional bearing would be required, but the basic frame could conceivably be modified for a floating fish farm. Powell (continued support in the habitat project for other species).

**SUMMARY OF OBJECTIVES TO DATE**

The following will outline research plan objectives as stated in the initial project:

1. **DESIGN AND CONSTRUCTION**

These have been covered in the preceding narrative.

2. **PHYSICAL EVALUATION OF CAGE PERFORMANCE**

A. The feed delivery system works well with whole or cut herring. The need to disintegrate pelleted food.

B. Observation of the fish is difficult. Watching the fish in the tank indicates 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 adult feeding site, and the dirt was not adequate. Determining the daily health of the fish is also difficult. This is now being done by divers, which is a time consuming and costly method. Video surveillance would be prohibitively expensive and give only limited viewing.

C. There is a potential safety problem while the cage is unattended. To monitor the fish, workers have to enter the high-sided cage with a single entrance which exit hatch in the top netting. After observing the cage, it is evident that if other buoyancy bags developed a major leak, the 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 5ft-well 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 salmon cage, rigged with windows to raise and lower the habitat pen with the floating cage providing the buoyancy. This approach could become more cost effective with numerous submarine pens.

D. On the whole, a submarine pen does not seem to be the most economical way to raise haddock. Wood (note: Wood's report on submarine pen, agreement to indicate haddock can enter through the bottom). They do prefer dim light but that can be provided without adding the tank forty feet deep. Without abandoning the submarine concept, floating pens, weirs and lobster pounds should be considered.

3. **BIOLOGICAL EVALUATION**

The data shown in this report is for the first quarter (January to March) and is not shown in comparison to data of the haddock in the floating cage experiment of the same time period. Dr. Waterman was unavailable for analysis data comparison, but he indicated that first quarter results (case Appendix D) initially looked as if the bottom cage showed better growth against the surface cage fish. The data, even when confirmed, must take into account the difference between feeds and the inherent difficulty in observing 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. Waterman by the end of the first year cycle now that the experiment is active approximately late June or July 1993.

There are some observations that can be made now:

1. Habitat are very hardy fish. They are literally "fish skinners" and not liable to wounds, as are salmon. This is important in the reduction of disease and mortality.
2. Haliotis are elusive and even seem curious when workers are around. Again, this is in contrast to salmon, which are passive and be flavoured off feed very easily.

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

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

MAIC Submersible Haliotis Cage Project supported by Treats Island Fisheries &
Washington County Technical College

Interim Report

Open Ocean Aquaculture: BRIDGESTONE HI-SEAS Fish Cage

Jaein Company
ARVA TRADE LTD.
Syvöläi
N-5427 Urangsivu
Moriway

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

My presentation is about the most successful offshore fish cage in the world. Since it was introduced in 1989, it has exceeded and outperformed all other offshore fish cage systems. It has an unrivalled and envied 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 oil industry.

Japan, of course, is one of the world's largest aquaculture nations with an annual production of about 1.5 million metric tonnes 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 1978, some tuna fishermen in Japan approached BRIDGESTONE to ask if it would be possible to make an enclosure to keep and transport bluefin tuna. The schools of tuna were migrating away from the Japanese coast, and it was getting more difficult to bring them to market. The idea was to use a large holding pen which could be towed behind the purse-seiners out to sea. The tuna 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 heavier fish cages in use around the Japanese coast. The further development of the frame-cage and nets was therefore adapted also to include this other intended use.

Design

Conventional fish cages then as now were almost all made from rigid materials: Polyethylene, wood, steel, aluminium, and varnishes thereon. With their extensive expertise in rubber technology for marine applications, the engineers at BRIDGESTONE believed that specially designed marine rubber frames would provide a viable alternative. Research continued to determine if the flexibility of rubber could be applied to make an ocean-going fish cage. The frame would need necessary flexibility to withstand the forces of wave action in open-sea storm conditions, yet at the same time it must retain sufficient rigidity to maintain its 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 in tanks. From these tests and different types and sizes of nets were used and data gathered at drug forces, etc.

The result was a single model, and in 1981, this was field tested for a full two years before the BRIDGESTONE HUSKAS fish cage was manufactured and marketing and selling commenced.

During the field testing and many times since HUSKAS cages have been killed by full typhoons with wave heights up to 10 metres without damage to the frame, nets, moorings, or fish.

The first HUSKAS 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. In the last few years many cages have been sold to fishermen, especially in Australia. They use the cages just as the Japanese tuna fishermen in 1978 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 underwater 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

HUSKAS 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. Steel chains support the jack-up and handle boats, while their buoyancy gives the center joints equal buoyancy so that the rubber hose sections. The side and protruding nets are hung on the inner collar of the stanchions, but are suspended outside and outside the collar and float in their own right with the help of purse-like nets. Where necessary a mast-net is used for bird deterrence.

There is a clear tendency for the HI-SEAS cages to get bigger. In the beginning a few 30-m hexagonal cages were built. Later, the 65-m hexagonal became the norm, and after the 15-m octagonal cage was built, some Japanese fish farmers prefer the 20-m square cages and into 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 the world, is a 20 M octagonal cage supplied into Iceland. It is 162 m in circumference and has a surface area of almost 20,000 m².

The nets have also progressed in size. In the beginning the nets were at the most 30-m deep. The new ones are 15-m or even 20-m deep. One fish farmer in Norway even a 28-m deep net made of 15-m monoethylene. Total volume is about 25,000 m³ and in 1958 he harvested 68 mts of salmon from that one cage.

Although the first HI-SEAS fish cages are now 12 to 13 years old, there has been no need for major design changes. The basic system has proved to be utterly simple for its intended purpose and only minor changes have been made to the center joints, stanchions, handles and the corner frames, mostly in accessibility respects for 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 idea is to build a net that is able to withstand the same environmental forces as the cage collar and which, at the same time, protects the fish during such extreme conditions. Consequently the nets have been designed to be as much as wave action as possible in the wave sections. They are made with a float line that has enough buoyancy to carry the weight of the net, even when fastened. Just below the float line a lacing has been incorporated which allows for easy net and flexibility. Below the lacing is a strong portion of thread 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 jumping net extends on the main horizontal rows.

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 wave breaking off the frame, and in addition the float line on the net will also ride the wave. The lacing and the diamond mesh below the float 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 risks and wear and tear 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 few but reputable 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 lines. Each cage is equipped with a light to attract the fish. The anchor can be concrete or steel, depending on water conditions.

It is our firm belief that a successful fish cage system requires harmony between the four aspects of cage, nets, mooring, and the site location. Therefore, in each case, before installation, site data is gathered and sent to 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 drawings are given to each user with specifications and drawings of all components, recommendations for nets and mooring, as well as specifications for installation, site, and maintenance. All components from sub-suppliers are thoroughly checked and in most cases BRIDGESTONE will supervise or 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 staff in the way of ready-made experience. Now, however, handling and servicing is easy. Normal day-to-day operations, such as transport, feeding, net changing, grading, disease treatment, harvesting, predator control, etc. are handled daily. Some of these operations need to be performed daily and always without regard to the weather conditions, such as feeding and monitoring. Others, such as net changing and harvesting, can be scheduled to coincide with favourable conditions.

In most instances our cages are used as an egg-growing units. Fish farmers rear their juveniles in smaller cages before and then transfer to their HI-SEAS cages where the fish are about one kg in average size. The fish are then kept in the BRIDGESTONE cages until harvesting. This allows for the simpler operation, requires in most cases just with only one size of mesh, and also has the cages used to a higher degree.

There is now much good equipment on the market, some developed especially for large cages in offshore use, such as service vessels, feeding systems, dead fish collectors, business control systems, and transport vessels. And in various countries there are different approaches to the challenges. In Japan the government has subsidized the building of several large and expensive service rigs, fitted with feeding systems, dead fish systems, crew facilities, monitoring systems, etc. A different approach are the semi-submersible steel platforms developed by FEEDING SYSTEMS AS in Norway. In a very compact 100 m x 7 m platform is a full-service station with (20) nut feed capacity, computer-aided feeding system, which can service many cages, crew facilities, etc. One of the owners in the Faroe Islands has installed an old fishing vessel and moored it permanently at the site. The ship has been fitted with an automated feeding system, food silo, generators, pumps, monitoring systems, etc.

When we are asked by users and potential future users about operating large cages, we tell them that we do not necessarily have ready-made or fixed solutions and answers. What we do have more than anyone else, is the vast experience from more than 500 cages at site for more than 15 years, and in so many different applications.

Costs

When first introduced, HI-SEAS cages were way ahead of anything else on the market, and so were the costs involved. Mostly because the most other types of cages have had to be improved and are now more expensive than before. HI-SEAS cages, on the other hand, are now about a third
cheaper than they were 10 years ago, and very competitive with other so-called offshore cages or 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 25,000 m³ and can yield 500 tons per year production capacity.

The investment cost for such a unit is:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-m octo-cage-frame complete</td>
<td>USS 140,000</td>
</tr>
<tr>
<td>20-m deep net</td>
<td>- 40,000</td>
</tr>
<tr>
<td>Set of moorings, complete</td>
<td>- 35,000</td>
</tr>
<tr>
<td>Total cost</td>
<td>USS 215,000</td>
</tr>
</tbody>
</table>

Cost per m³: USS 172.00

Prices are c.i.f. North American mainland, East or West coast, and F.O.B. reference only.

Maintenance costs for HI-SEAS cages are very low. Major parts, such as rubber hose strings or steel corner joints are almost never in need of replacement. While normal wear and usage requires a few topends, covers, or hoses to be replaced, and they cost between $ 35 and $ 300 each. As for above, 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 six years.

A few of the oldest cages have been overhauled. Last year we brought back the first cage sold in Norway in 1985, a 16.5-m hexagonal unit, and gave it a complete overhaul. Only the rubber hoses and the steel corner joints were used again. The joints were sand-blasted and galvanized and all welds, frames, covers, hoses, and tubes were replaced with new ones. Total cost came to about USS 20,000.

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 and there have been complaints that the local insurance company, which insures through the London Market, already in 1989 reduced the premiums paid by owners of HI-SEAS cages by 10% compared with what they charge for insuring other types of fish cages, even those used inshore sites only.

**Future Developments**

We do not foresee major changes in the BRIDGESTONE cages in the future, but we are constantly improving and perfecting the system 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, feeding systems, and especially monitoring systems (for biomass control) will become even more efficient and hence the viability in offshore sites will improve further.

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

While most fish farmers may consider the move away from sheltered inshore 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.

Jorgen Gunnarsson
AKVA TRADE LTD
Tysvoll
N-5427 Uringen
Norway
Phone: +47 53 37 14 35
Fax: +47 53 37 12 22
Model Tests of the Sea Trek™ Barrel Cage

Neil A. Berl1, Clifford A. Goudie2 and
John D. Erickson3

1Massachusetts Institute of Technology
Department of Ocean Engineering
Cambridge, Massachusetts

2MIT Sea Grant College Program
Center for Materials Engineering Research
Cambridge, Massachusetts

3Sea Pride Industries, Incorporated
Gulf Breeze, Florida

Abstract

Sea Pride Industries of Gulf Breeze, Florida is developing a
600-tonne system called the open ocean storage tank.
Their unique Sea Trek Ocean Parking System consists of
multiple barrel cages, each initially 55 feet in diameter
and approximately 700 feet in length. These barrel cages
are held together by a series of elliptical<br>
structures that support mooring lines and keep the tank
from rolling. They will be hailed to operate filling
ports and or fully submerged. The entire structure will serve as a
retrieval system.

This paper describes the full element of the Sea Trek system
that is barrel cages. Preliminary 1/20-scale wave and current tests
conducted in Galveston by the Massachusetts Institute of
Technology are presented. These tests represent an initial phase of
scale model tests in which the barrel cage is exposed to wind
waves and currents enroute to the cage at longitudes and
latitudes of prime interest. The wave and current tests were conducted at
various points ranging from 10 percent to 35 percent of the model
distance. The effects of simple hydrodynamic body
blockage, multiple layers of mooring and an impermeable deck
were calculated. Wave test results showed the model's diameter and
weight of a model are much. Tables of test data are provided along with full
detail drawings and section lines.
The Sea Trek Concept

Sea Pride Industries is the first aquaculture enterprise to receive full government approval for an operation in the United States' exclusive economic zone. (IEEE, Sea Pride, 1995). The Sea Trek Ocean Farming System is a technology under development by Sea Pride for installation in their permitted area.

System Design

The Sea Trek system is comprised of a gravity-based operating platform surrounded by six cylindrical barrel cages arranged in a radial fashion. A conceptual representation of the design is shown in Figure 1. Each cage will measure 50 feet in diameter by 20 feet in overall length and will be constructed of marine-grade steel tubing and stiffened plating. The weight of the steel cage structure will be offset by buoyancy provided by two internal ballast tanks attached to each end of the cage. Watertight bulkheads separate the tanks to the cage can be rotated by ballasting individual chambers appropriately. The rotation will disperse feeding of the cage enough exposure to the air and sunlight while allowing convenient pressure washing and inspection.

The central axis of the cage is a four-inch diameter pipe that is attached to the ends of the barrel cages and at two intermediate points to transverse annular hoops by lengths of 1/2-inch diameter tubing. There are eight longitudinal members, also 1/2-inch diameter, running parallel to the axial tube and intersecting the rings at the corners of an octagon. Three additional transverse hoops will provide further stiffness to the structure. The structure is completed by adding 12-inch dia-1m baytopper capsule to connect neighboring outer longitudinal members.

The cage is protected by an arrangement of nets in order to contain the fish and exclude predators. An outer net that prevents the contained fish from predators. The nets are supported by three eight-foot fiberglass rods.
waves and currents. Understanding the hydrodynamic behavior of the ballasted cage in waves and currents will facilitate variability engineering for the structure and in previous contexts.

Scale Model Tests

Scale model tests have been conducted in two facilities at the Massachusetts Institute of Technology to predict hydrodynamic forces on the Sea Track ballasted cage and to determine the forces on a central component. These tests were designed to measure the response of the cage to a rigid structure fixed at mooring points at either end. The results are expected to indicate the upper bounds for structural forces and rolling moments in waves and currents. Any arrangement of compliant mooring would reduce the forces imposed on the cage and its supporting structure.

Two basic types of tests were performed. The cage was subjected to a series of waves of various frequencies and amplitudes in the MIT Civil Engineering 3-Dimensional Wave Basin. The response of the cage model to a range of current speeds at four submergences and five blockages was measured in the MIT Ocean Engineering Test Tank. These facilities are described in more detail below along with the full experiment descriptions.

Description of the Scale Model

The model for these tests was designed to embody the major features of the full-scale cage in scale 1:300. The model was chosen to match the scaling within reasonable deviations as shown in Table 1. Stock availability and practical limitations in welding required the model structure to be cut from aluminum. Exact scaling of all blockages would have made proper welding impossible. Some smaller tubular members could only be represented by solid aluminum rods. The plates used for the cage and ballast tanks could not be thinner than one-eighth-inch in order to avoid burn through and detonation of the metal members. The assumption of overall rigidity gives accuracy in the scale of the outer dimensions primarily over wall thickness since structural definition within the model structure can be ignored.

<table>
<thead>
<tr>
<th>Component</th>
<th>Full Scale</th>
<th>Model</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover Area</td>
<td>48''</td>
<td>1.30''</td>
<td>20:1</td>
</tr>
<tr>
<td>Overall Blockage</td>
<td>10''</td>
<td>1.0''</td>
<td>10:1</td>
</tr>
<tr>
<td>Radial Slots</td>
<td>90°</td>
<td>1.0°</td>
<td>90.0</td>
</tr>
<tr>
<td>Diagonal Troughs</td>
<td>6''</td>
<td>0.6''</td>
<td>10:1</td>
</tr>
</tbody>
</table>

The fiber glass rods featured on the cage are simulated by lengths of random lines through one-sixteenth-inch holes drilled at the edge of the seven rings and field test. Figure 2 shows a side view of the model and Figures 3 and 4 are details of the transverse components.

Space restrictions in the test facility made it necessary to shorten the model from a scaled length of 102.0'' to 85.0'' to maintain the 1:300 scale of the cage's diameter. This decreased the length-to-diameter ratio of the model from 4.05 to 3.54 and was noted when interpreting the data. The effect can be minimized by comparing the data obtained from basic cage tests and selected tests to determine distributed loads on the lengths of models and the transverse sections independently. Careful attention to the model's weight will allow the investigation of Froede scaling to extend the scaled forces (Froede, 1967). Since the model is double 1:300 in each dimension, the weight must be scaled by (1/300)2 or 1:900 along with all body forces. The aluminum model weighed approximately 50 pounds, and the full-scale structure has been predicted to weigh approximately 450,000 pounds.

The model does not exactly match the structural integrity of the full-scale design. Instead, enough detail is preserved to reflect the hydrodynamic effects of
the most prominent members without unnecessarily complicating the construction of the replica. The hollow members and balloon chambers were made con-

tiguous and watertight to supply by the setup. The bal-

loon chamber frequency required an arrangement of

drive weights to be fixed with the balloon towards to

achieve neutral buoyancy.

An important objective of the test was to compare

the loads resulting from the setting surrounding the

structure to those of the bare cage itself. This was

achieved by casting individual sleeves of 2000 nylon

2-amp straight mesh setting. These sleeves stretched

the length of the cage between the two end rings. Mul-

tiple layers of setting were used to simulate the effect

of marine biofouling. To quantify the effect, estimates

of the blockage ratio of each set of nets were made

from close-up, high-resolution video images. Using

image processing, the ratio of net area to total area

was calculated on a pixel-by-pixel basis. The resulting

blockage ratios for layers of one, two, and three nets

are shown in Table 2.

<table>
<thead>
<tr>
<th>Layers</th>
<th>Blockage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16%</td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>25%</td>
</tr>
</tbody>
</table>

Instrumentation

The experimental objective was to measure three

components of the rigid body response of the struc-

ture, namely the heave and sway forces and the roll

moment. This was accomplished through the integra-

tion of a six-component scaling (load cell) (Model

SRM6C- A 100, Advanced Mechanical Technology,

Newton, Mass.), a sample and hold instrument board

and PC-based AD converter (C16X-SH) & C16X

AD (Art Computer Boards, Inc., Mansfield, Mass.),

and a digital storage oscilloscope software package

(Scopemaster, Storage Scope, IREM Data Corporation,
Southfield, Mich., which served as a data acquisition, logger, and analysis tool.

Data was sampled during each run at 900 Hz covering a ten-second interval after the response waves attained a steady state. To ensure reliable results, instrument calibration was performed between runs after all equipment had cooled. Each sample was stored in a catalogued file for future review and analysis. Examples of each testing mode were recorded photographically and on videocassette for visual presentation.

Wave Interaction Tests

The first set of tests exposed the barrel cage model to monochromatic plane waves traveling in the direction perpendicular to the cage's longitudinal axis. These tests took place in the MIT Civil Engineering Three-Dimensional Wave Basin, which features computer-controlled hydraulic wave paddles and energy-absorbing sloping "beaches." The basin is divided into three separate bays to allow multiple users to conduct experiments. It was necessary to compromise on the water depth due to the presence of another study in progress. The tests were run in 94 cm of water, which scales to approximately 38 feet, less than the full-scale cage diameter. The Sea Trek concept anticipates installation in 54 to 63 feet of water. The model and load cell were attached to a set of structures that presented minimal frontal profiles to the waves. The structures were restrained with weights to maintain overall rigidity.

Each individual run required input of wave frequency and amplitude into the computer. The wave paddles were activated to simulate the waves. The frequency and wave number of the waves are related by the dispersion relation for linear wave motion in finite depth given in equation 1 (Foreman, 1983). The radiation frequency is inversely proportional to wave number by a factor of 2\(\pi\) radians. Radiant frequency and linear frequency in feet are directly proportional by the same factor.
Equation 1. Finite Depth Dispersion Relation

The horizontal forces measured at a single attachment point on the model were recorded over a ten-second interval for each individual run. These were processed individually to obtain a mean square (rms) average. Table 3 presents these averaged measurements and Table 4 presents the extrapolated estimates for the full scale. The peak loads can be obtained by multiplying the figures by the square root of two. This assumes that the wave forms are sinusoidal, which is reasonable based on the observation of wave form parameters and graphical inspection of the data. Examination of these data reveals that the structure's response increases with wavelength and then plateaus, suggesting that a peak response is bracketed in the wavelength interval of the tests.

The behavior of the model was captured through measurement of the three body forces acting on the horizontal forces that are presented above. Figures 2 and 6 show examples of data sampled during two particular runs whose parameters are nearly identical except for a change in submergence. The depth change in wave length was necessary because of problems associated with resonance in the wave basin. The apparent roughness in Figure 5 is due to external interference which was subdued against in subsequent tests. The sway force is represented by \( F_y \) and is positive in the direction of the wave source. The heave response is indicated by \( F_z \) and is assumed to be in phase with the passing wave as an indication of the change in the model's draft. This buoyant force is positive upwards. \( M_z \) is a measurement of the rolling moment at the stern applied to the cage by the passing wave. This moment is measured positive in the counter-clockwise direction from the perspective where waves are seen approaching from the right. These graphs are intended to compare the wave forms of the rolling moment time series which are comparable in magnitude but vary in shape. The increase in submergence affects these measurements by entering additional members of the structure in the passing wave peak. Figure 7 illustrates this effect and shows the right-hand rule orientation of the forces measured. The model is shown from one end and is a transparent structure showing the external shape of the buoyant chambers, the main structure, and the spokes that connect them to the central tube. The vector represents the forward velocity of a passing wave peak. The data that make up these time series have been presented in digital form in anticipation of future studies concerning the seakeeping characteristics of the structure.
<table>
<thead>
<tr>
<th>Wood Type</th>
<th>Treatment</th>
<th>No. of Replicate</th>
<th>Amplitude</th>
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Table 4

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Figure 5: Sample data from a wave monitoring experiment involving two layers of sediment, water 40" in height and 1" in amplitude, and wave attenuation of 50%.

Figure 6: Same data from a second experiment involving two layers of sediment, water 50" in height and 2" in amplitude, and wave attenuation of 40%.
Current Interaction Tests

The second episode of testing efficiently the interactions of the capes with a steady current flow of 0.14 m/s downstream. The model was designed at a scale of 1:100, with a wave height of 0.3 m and a wave period of 2.0 s. The setup was designed to test the capes under varying wave conditions at the sea and coastal areas.

Common testing practices narrow focus on the impact of the waves on the structure, with a particular emphasis on the wave height and period. However, the focus should be on the overall performance of the model in simulating real-world conditions.

Figure 2: Test setup of model with a steady current flow of 0.14 m/s downstream.
Table 6. Additional Tests Performed for Full Scale

<table>
<thead>
<tr>
<th>Speed (ft/s)</th>
<th>005</th>
<th>010</th>
<th>025</th>
<th>050</th>
<th>075</th>
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<tbody>
<tr>
<td>0.0</td>
<td>25.1</td>
<td>31.2</td>
<td>36.8</td>
<td>41.9</td>
<td>47.2</td>
<td>52.3</td>
</tr>
<tr>
<td>0.5</td>
<td>60.1</td>
<td>70.4</td>
<td>78.1</td>
<td>84.6</td>
<td>91.2</td>
<td>97.9</td>
</tr>
<tr>
<td>1.0</td>
<td>104.4</td>
<td>114.7</td>
<td>124.5</td>
<td>134.5</td>
<td>144.5</td>
<td>154.5</td>
</tr>
<tr>
<td>2.0</td>
<td>208.8</td>
<td>233.5</td>
<td>258.2</td>
<td>282.9</td>
<td>307.6</td>
<td>332.3</td>
</tr>
<tr>
<td>3.0</td>
<td>313.2</td>
<td>347.8</td>
<td>382.4</td>
<td>417.1</td>
<td>451.7</td>
<td>486.3</td>
</tr>
<tr>
<td>4.0</td>
<td>417.6</td>
<td>462.2</td>
<td>506.8</td>
<td>551.4</td>
<td>596.0</td>
<td>640.6</td>
</tr>
</tbody>
</table>

These results are based on the additional tests performed for full scale.
Figure 1: Horizontal wave and vertical wave load at 125% design load. 100% current condition for an impermeable block wave.

**Future Projects**

The focus described in this paper represents an initial phase of research that will be incorporated into the development of the Sea Tech concept before full-scale prototypes are constructed and deployed. As described, these initial studies will determine current effectiveness for wave energy extraction and improving technology in the near-term environment. Future tests will involve implementation of prototype testing environments and collection of data for performance in more natural conditions. Materials, design, and structural testing will represent a variety of loads ranging from typical wind forces to wave forces in varying sea states.

The presence of the initial obstacle and the performance of its attachment in the system as well as the results from other significant effects on the overall selection of the Sea Tech system will be reviewed.

Long-range project research and development will involve focused efforts on the development of a wave farm for the testing of a larger Sea Tech system. This effort will be concentrated on developing an efficient and cost-effective method for integrating the Sea Tech system into existing marine environments.

**References**


Transgenic Fish in Open Ocean Aquaculture

S. K. Samaha
University of Maryland, Institute for Bioscience and Biotechnology Research
College Park, Maryland

I. Introduction

As early as 1990s, 22 research groups in 14 countries were working on transgenic fish (Hilton et al., 1992). By 1994, 23 fish species had been altered (Hilton et al., 1996). Most of the transgenic fish were developed through conventional breeding techniques and were intended to increase yield in aquaculture. These transgenic fish are aimed at enhancing growth, disease resistance, and other traits that could enhance their productivity and allow for fish to be farmed at locations previously considered too cold or too stressful for their natural species. The potential for genetically modified fish to be used in the open ocean environment, however, remains the focus of research, which is not expected to be far from the horizon. This paper provides an overview of the current research with transgenic fish, examines the potential regulatory hurdles in aquaculture, and presents the case for regulatory changes that would allow transgenic fish to be farmed in the open ocean environment.

II. Transgenic Fish for the Marine Environment

Most transgenic fish are produced in the laboratory by micro-injection or transposon DNA transfer. In vivo gene transfer approaches (Brown et al., 1994) have yielded transgenic fish that exhibit the desired phenotype and are a focus of the research.
The majority of work in developing field-grown gene banks is conducted by research institutions, however, we propose a community effort to develop a network of field-grown gene banks in various countries. The network will be managed by a central coordinating organization, The Field-Grown Gene Bank Network (FGGBN), which will be headquartered in the United States. The FGGBN will function as a clearinghouse for information and resources, as well as a forum for the exchange of ideas and best practices. The network will include researchers, breeders, and growers from around the world. The focus will be on developing new field-grown gene banks and improving existing ones. The network will also serve as a platform for the exchange of genetic materials, knowledge, and expertise.

Table I

<table>
<thead>
<tr>
<th>Individual</th>
<th>Sector</th>
<th>Contribution</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Farm</td>
<td>100%</td>
<td>50%</td>
</tr>
<tr>
<td>B</td>
<td>Research</td>
<td>50%</td>
<td>25%</td>
</tr>
<tr>
<td>C</td>
<td>Government</td>
<td>25%</td>
<td>12.5%</td>
</tr>
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</table>

III. Establishment of Aquaculture Farms

Even with the best infrastructure, successful establishment of field-grown gene banks is highly dependent on the availability of suitable infrastructure, such as water treatment facilities, power supply, and transportation. The establishment of the FGGBN will require a significant investment of resources, but the benefits of having a network of field-grown gene banks are numerous. The network will facilitate the exchange of genetic materials, knowledge, and expertise, leading to the development of new and improved crops. The network will also serve as a platform for the exchange of genetic materials, knowledge, and expertise, leading to the development of new and improved crops. The network will also serve as a platform for the exchange of genetic materials, knowledge, and expertise, leading to the development of new and improved crops.
fertilized eggs six MDs. 1999 prepared at Hillman & Kazmerski, 1997a. In Vermont, each season (except 1999, 1998, and 1997) 2.5% to 3.2% of the eggs, eggs were found samples (Ganser and Sassi, 1999) prepared at Hillman & Kazmerski, 1997a. A more recent example is the August 1999 study of Lake Huron which demonstrated the release of approximately 150000 eggs, 50% and 50000 eggs, respectively, the same site, (U.S. Department of State, 1999). Furthermore, reports have suggested that open water aquaculture egg contamination from hatcheries has not reached the point where the eggs can contaminate the water in the Great Lakes. (Carpenter, 1993; Hillman and Kazmerski, 1993). Furthermore, reports have suggested that open water aquaculture egg contamination from hatcheries has not reached the point where the eggs can contaminate the water in the Great Lakes. (Carpenter, 1993; Hillman and Kazmerski, 1993). The following table shows some of the possible impacts that released fish would have on the environment and the populations of the natural species. It also shows the percentage of the impacts associated with the various cultivated fish that were in the United States. The results of any of these impacts will depend on how many fish are released at a given time. (Kazmerski, 1997a)

From this table, it is apparent that the environmental impact, although through data from several sources, was not as the 900000 years ago. But these estimates are not as reliable as the 900000 years ago. But these estimates are not as reliable as the 900000 years ago. But these estimates are not as reliable as the 900000 years ago. But these estimates are not as reliable as the 900000 years ago. But these estimates are not as reliable as the 900000 years ago. But these estimates are not as reliable as the 900000 years ago. But these estimates are not as
<table>
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<tr>
<th>Possible Ecological</th>
<th>Cultured Fish</th>
<th>Transgenic Fish: enhanced growth rate</th>
<th>Transgenic Fish: cold resistance</th>
<th>Transgenic Fish: disease resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved methods for milking</td>
<td>Yes (Dolnik &amp; Mancini, 1992)</td>
<td>Yes (Kosarev et al., 1994)</td>
<td>Yes (Mannik et al., 1998)</td>
<td>No</td>
</tr>
<tr>
<td>Growth rates</td>
<td>Yes (Larkum &amp; Reynolds, 1992)</td>
<td>Yes (Kosarev et al., 1994)</td>
<td>Yes (Mannik et al., 1998)</td>
<td>No</td>
</tr>
<tr>
<td>Reproductive</td>
<td>Yes (Larkum &amp; Reynolds, 1992)</td>
<td>Yes (Kosarev et al., 1994)</td>
<td>No (Mannik et al., 1998)</td>
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</tr>
<tr>
<td>Resistance to disease</td>
<td>Yes (Larkum &amp; Reynolds, 1992)</td>
<td>No (Kosarev et al., 1994)</td>
<td>No (Mannik et al., 1998)</td>
<td>No</td>
</tr>
</tbody>
</table>

Risks associated with releasing transgenic fish into the marine environment (other half of table on the facing page)
Kropotkin's (1923) apology and contradicting that non-human evolution lack of understanding in natural selection, needs clear data. The data need to be in line with Darwin's (1859) ideas that species are not fixed but continuously evolving. The genetic diversity found within each species increases the potential for adaptation to new environments. Therefore, the genetic diversity found within each species is crucial to understanding the evolutionary process of species. If a species is not observed to be doing well in its current environment, it may be because the species is not well adapted to the current environment or because the environment is not providing the necessary food sources and other necessities for survival.

The external factors that shape the environment are also crucial to understanding the evolutionary process. The environment can shape the characteristics of a species, such as the size of its body, the color of its fur, and the shape of its limbs. These external factors can shape the evolutionary process of a species, as it is forced to adapt to the environment it finds itself in.

V. Risk Assessment and Legal Oversight

When all of these potential factors are considered, the effective risk assessment must be performed in the field. This is where the risk assessment is useful, as it can provide a clear picture of the potential risks associated with the species and the environment. The risk assessment should provide a clear picture of the potential risks associated with the species and the environment. The risk assessment should provide a clear picture of the potential risks associated with the species and the environment. The risk assessment should provide a clear picture of the potential risks associated with the species and the environment. The risk assessment should provide a clear picture of the potential risks associated with the species and the environment.
It has been suggested that these factors play a significant role in controlling water quality. However, no detailed evaluation of the effects of these factors has been conducted. It is essential to identify and address these issues in order to maintain the health of aquatic ecosystems. This task requires the involvement of various stakeholders, including government agencies, researchers, and the public. A comprehensive approach is necessary to address these challenges effectively.

To Engineer: Make these projects sustainable and environmentally friendly.

In the future, sustainable water management strategies should be implemented to ensure the long-term health of our aquatic ecosystems. Engaging stakeholders from various sectors, including government agencies, researchers, and the public, is crucial to developing effective solutions. The success of these initiatives will depend on the collaborative efforts of all parties involved.

ENDNOTE: This paper was written based on a presentation given at the National Sea Grant College Program conference in Maryland. It is intended to promote sustainable water management practices for the benefit of our aquatic ecosystems. The authors appreciate the support and guidance provided by the conference organizers and the staff of the National Sea Grant College Program.
Mariculture in Offshore Critical Habitat Areas: Narragansett Bank National Marine Sanctuary Case Study

Bradley W. Scott
Manager
NOAA Narragansett Bank National Marine Sanctuary
Plymouth, Massachusetts

Introduction

While the history of offshore mariculture in New England has been short, it has also been keenly environmentally monitored. Perhaps this is true of all new industries. The potential for significant local and regional environmental impacts are not yet fully understood. The Narragansett Bank National Marine Sanctuary (NBNMS) is located in the Narragansett Bay Estuary where the benthic community and the benthic environment support numerous species, including commercial fish species.

The NBNMS is located in the Narragansett Bay Estuary where the benthic community and the benthic environment support numerous species, including commercial fish species. The Sanctuary provides habitats for many species of marine life, including sea turtles, dolphins, and porpoises.

The Sanctuary's management plan includes a comprehensive set of regulations designed to protect the environment and ensure the sustainability of fisheries and other marine activities within the Sanctuary. The plan also includes provisions for research and monitoring to ensure that any potential environmental impacts are identified and addressed.

In this case study, we will examine the potential environmental impacts of mariculture activities in the NBNMS and the potential strategies to mitigate these impacts. The study will be conducted in collaboration with local and state agencies, as well as the academic community.

The study will focus on the potential environmental impacts of mariculture activities, including the effects of mariculture on the benthic community, the effects of mariculture on the water quality, and the effects of mariculture on the water column. The study will also evaluate the potential effects of mariculture on the recreational and economic activities in the NBNMS.

The study will be conducted using a combination of field observations, laboratory experiments, and modeling. The results of the study will be used to develop management strategies to mitigate the potential environmental impacts of mariculture activities in the NBNMS.

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The study will be conducted in collaboration with local and state agencies, as well as the academic community. The results of the study will be used to develop management strategies to mitigate the potential environmental impacts of mariculture activities in the NBNMS.
Identifying Essential Habitats

At the heart of this issue is the recognition that the protection of essential habitats is crucial to the survival of many species. This principle is enshrined in the National Marine Fishery Service (NMFS) Habitat Management Plan (HMP) for the Northeast, which identifies and protects essential habitats for marine species. The HMP recognizes that essential habitats are critical for the survival and recovery of marine species and that their protection is necessary to ensure the long-term health of marine ecosystems.

The HMP identifies essential habitats as areas that are critical to the survival and recovery of marine species. These areas are defined based on the species-specific needs and the unique ecological processes that support their survival. The HMP identifies essential habitats at a range of spatial scales, from local to regional, and includes both nearshore and offshore areas. The identification of essential habitats is a critical step in ensuring the long-term health of marine ecosystems and the survival of marine species.

The HMP includes a comprehensive assessment of the status and trends of essential habitats, as well as the potential impacts of human activities on these habitats. This information is used to inform decision-making and to develop strategies to protect and restore essential habitats. The HMP also includes a monitoring program to track the condition of essential habitats and to assess the effectiveness of conservation efforts.

In summary, the protection of essential habitats is critical to the survival of marine species and the health of marine ecosystems. The HMP provides a framework for identifying and protecting essential habitats, and it is essential for ensuring the long-term health of marine ecosystems.
Figure 1 - Cape Cod Bay Component of Northern Right Whale Calf Habitat

Northern right whale calf habitat has not been identified for the waters of New England for any fixed area other than the Northern maine shelf. It is unclear if this area will continue to have habitat and therefore may affect the future.

Another area where essential habitat is gaining some prominence is at the center of R-Whale management. The most notable is the establishment of the Magnificent Fisheries Conservation and Management Act. This Act aims to maintain new sections of protected whale habitat by Management Council (MFC) to ensure and protect essential fish habitats in Fisheries Management Plans.

Figure 2 - Great South Channel Component of Right Whale Critical Habitat

The MFC Act establishes the proposed plan.

The MFC Act establishes the proposed plan.
offshore mariculture will be significantly affected by
the attention of current and future activities by the
Commissions and NMFS. How this will be achieved is
certain to be determined, but the New England Proj-
cut Management Council (NEPMC) is working toward
the development of an integrated policy which will
be reflected in state decisions and actions. The Council
is working collaboratively with a number of compre-
prehensive groups in Rhode Island, off the coast of Martha's Vine-
yard, in developing a comprehensive, systematic approach to the
management of this resource. The Councils and NMFS
The final necropreneur development has involved
the establishment of an observational marine protected area program
in the National Marine Sanctuary Program (NMP) has
been developed since 1978 to identify and conserve areas of
the marine environment that are consistent
by Congress and NOAA with the "national marine system."
Since the program was initiated, the marine
sanctuaries have been designated based on specific biological and
aesthetic values, where such marine areas have been identified. The
NMP has been developed to provide a
unique sense of place and to promote the conservation of marine
resources. The NMP has played a significant role in
the establishment and management of marine protected areas
in the United States, with the goal of
preserving and enhancing the nation's marine resources. The
NMP has also been instrumental in
the development of a national network of marine protected areas
that spans the entire U.S. coastline.

[Image: Map of New England]

In addition, the program has had little contact with
any federal or state management proposals and NMFS
has not yet been involved in the development of these
proposals. As such, the Trump administration's approach to
management of marine resources in the U.S.
has been developed and implemented in a manner that is
different from the NMP and other similar programs. This
has resulted in a situation where the
management of marine resources in the U.S. is not
necessarily aligned with the national network of marine protected areas
established by the NMP. As a result,
the management of marine resources in the U.S. is
not necessarily aligned with the national network of marine protected areas
established by the NMP. As a result,
the management of marine resources in the U.S. is
not necessarily aligned with the national network of marine protected areas
established by the NMP. As a result,
construction and operation of a marina facility. Failing that, the reviewing authority should adopt a mitigation plan, a new environmental impact statement, or a change in the project's scope.

With the possible exception of the Marco Island area, which is already under a federal lease for the Marco Island National Wildlife Refuge, the project would be acceptable if no significant changes were made to the project itself. In fact, the project might even be enhanced by the proposed mitigation plan. The Marco Island National Wildlife Refuge is a federal property, and the project would be subject to federal environmental laws. However, the project would be subject to state and local environmental laws as well.

If the project is proposed for a site in the state, the project would be subject to the state's environmental laws. The project would be subject to the state's environmental laws as well. The project would be subject to the state's environmental laws as well.

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The Stellwagen Bank, NMS Case Study

In 2003, the NOAA had conducted an extensive public review of the proposed designation. Congress designated the Stellwagen Bank as a National Marine Sanctuary. Extending 90 miles south of Nantucket Island, the Bank is the site of the largest, most diverse, and most biologically rich cold-water coral reef community in the world. This rich diversity of coral reefs is supported by an ecosystem of high productivity and biologic activity, which is likely to support a high diversity of marine life. The Bank is often referred to as "the Grand Canyon of the East" because of its rich marine life and biodiversity.

Figure 5. Stellwagen Bank National Marine Sanctuary

"Special focus of the whole area is the Bank, which is surrounded by a coral reef system that is home to a diverse array of marine life. The Bank is a unique and endangered habitat that is home to a number of species that are important to the health of the ocean. The Bank is a critical area for the recovery of threatened species such as the Atlantic Canada right whale. The Bank is also home to a number of species that are important to the health of the ocean, such as the Atlantic Canada right whale. The Bank is a critical area for the recovery of threatened species such as the Atlantic Canada right whale. The Bank is a unique and endangered habitat that is home to a number of species that are important to the health of the ocean. The Bank is a critical area for the recovery of threatened species such as the Atlantic Canada right whale. The Bank is a unique and endangered habitat that is home to a number of species that are important to the health of the ocean.
During the review of the proposed definition of a marine sanctuary, the National Marine Sanctuaries and National Estuarine Research Reserves, the Secretary of Commerce, and the National Marine Fisheries Service, received comments and recommendations from various stakeholders. The comments ranged from support for the creation of marine sanctuaries to concerns about their potential impact on fishing and commercial activities. The comments were reviewed and considered by the Secretary of Commerce and the National Marine Fisheries Service, and a final determination was made to establish marine sanctuaries in areas that were thought to be of national interest. The sanctuaries are designed to protect marine life and resources, and to provide a place for research and education. The establishment of marine sanctuaries is intended to promote the conservation and sustainable use of the marine environment.
To address this situation, the committee has recommended that federal and local government agencies and organizations that fund or conduct disaster research develop and publish a set of guidelines and best practices. These guidelines should include:

1. Clear and consistent definition of disaster research goals and objectives.
2. Development of a comprehensive disaster research plan that addresses all aspects of disaster prevention, preparedness, response, and recovery.
3. Establishment of a robust and effective communication and collaboration framework among stakeholders.
4. Implementation of rigorous quality control and assurance measures for disaster research data and findings.
5. Coordination with relevant federal and state agencies to ensure consistency and alignment with national disaster research priorities.

These recommendations will help to ensure that disaster research is conducted in an efficient and effective manner, leading to more robust and actionable knowledge that can be used to improve disaster management and resilience.

Conclusion and Some Observations

Disaster research is a critical component of disaster management and resilience. It involves the systematic collection and analysis of data to understand the causes, impacts, and outcomes of disasters, as well as the effectiveness of response and recovery efforts. Effective disaster research requires the collaboration of multiple stakeholders, including federal and state agencies, academic institutions, and the private sector. The committee recommends that the federal government, in coordination with state and local governments, develop a comprehensive strategy for disaster research that includes:

1. Establishment of a centralized disaster research facility that coordinates and supports research efforts.
2. Development of a robust communication and collaboration framework among stakeholders.
3. Implementation of rigorous quality control and assurance measures for disaster research data and findings.
4. Coordination with relevant federal and state agencies to ensure consistency and alignment with national disaster research priorities.

By adopting a comprehensive and collaborative approach to disaster research, we can better understand the causes and impacts of disasters, develop more effective response and recovery strategies, and build more resilient communities.

References

The committee acknowledges the importance of disaster research and the need for a coordinated and systematic approach to conduct disaster research. The committee recommends that the federal government, in coordination with state and local governments, develop a comprehensive strategy for disaster research that includes:

1. Establishment of a centralized disaster research facility that coordinates and supports research efforts.
2. Development of a robust communication and collaboration framework among stakeholders.
3. Implementation of rigorous quality control and assurance measures for disaster research data and findings.
4. Coordination with relevant federal and state agencies to ensure consistency and alignment with national disaster research priorities.

By adopting a comprehensive and collaborative approach to disaster research, we can better understand the causes and impacts of disasters, develop more effective response and recovery strategies, and build more resilient communities.
The Blue Frontier

Jeff Fish
President
The Aquaculture Coalition
Boston, Massachusetts

I am Jeff Fish, president of The Aquaculture Coalition (TAC), an umbrella organization representing firms, organizations, growers, processors, distributors, and researchers in the aquaculture and marine food industries. My organization promotes the growth of the marine food industry in New England. Today, we are addressing the question of whether the marketplace is ready to accept new marine products.

To help promote the development of the aquaculture industry in Massachusetts and New England through education, communication, and networking,

I am pleased to be here today at this conference where we have heard so many compelling presentations of the technology available to support what I call the Blue Frontier.

I am not an oyster nor a grower, nor a processor, but a rather unlikely combination of these three.

Today, I am going to introduce myself as an innovator focusing on...
The opening up of the West, much like the opening up of the E.E., defied great natural barriers – geography, technology, and political structures. The iron-walled forts and the federal government’s policies of resistance continued to prevail.

At the end of the Civil War, the nation was unified and ready. The Union had been divided by a war that left shrapnel wounds and broken homes. The East had seen its cities rebuilt and its industries restored. The West, however, was a wilderness, a land of untapped potential. The government saw an opportunity to build a national railway system, one that would connect the East with the West and offer economic benefits to both regions.

The railroad was not just a technological innovation; it was a symbol of progress and a means of transportation. The Union Pacific, one of the first major railroads, was funded by a group of investors who saw the potential for profit. The transcontinental railway, completed in 1869, was a testament to human ingenuity and a symbol of unity. The railroad allowed goods and people to move more efficiently across the country, leading to increased trade and economic growth.

The opening up of the West also brought new opportunities for settlement and development. The Homestead Act of 1862 encouraged the establishment of homesteads and farms, attracting many settlers to the newly opened territories. The railroad played a crucial role in this process, providing access to the land and facilitating the movement of goods and people.

In conclusion, while the West was not as unified as the East, it was defied by a war that left shrapnel wounds and broken homes. The government’s policies of resistance continued to prevail. However, the opening up of the West, much like the opening up of the E.E., defied great natural barriers – geography, technology, and political structures.

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From the outset, it was apparent that Russell was not a man to be trifled with. He had fought for the Union in the Civil War and was known as a tough, no-nonsense type. When he arrived in California in 1849, he was already experienced in the mining business and was determined to make a fortune. He quickly became involved in the gold rush, and his experience and savvy soon earned him a reputation as one of the wealthiest miners in the area.

Russell's success was not just due to his acumen, however. He was also a shrewd businessman, and he knew how to make deals work in his favor. He was instrumental in the formation of the New Helvetia Mining Company, which eventually became one of the largest and most successful mining operations in the region. Russell was not content to simply mine gold, however. He also invested in the development of the area, building roads, bridges, and other infrastructure that helped to spur the economic growth of the region.

Russell's success in California was not without its challenges, however. He faced numerous obstacles, including hostile Native American tribes, rival miners, and, of course, the ever-changing price of gold. Despite these challenges, Russell persevered, and his fortune grew larger with each passing year. In 1858, he sold his interests in the New Helvetia Mining Company for a reported $1 million, a sum that made him one of the wealthiest men in California.

Russell's success in California set him on the path to even greater wealth. He continued to invest in the mining industry and also dabbled in real estate, eventually becoming one of the wealthiest men in the West. He was also a noted philanthropist, using some of his fortune to support education and other worthy causes. Russell died in San Francisco in 1885, leaving behind a legacy of wealth and influence that would endure for generations to come.
World War II marked the explosion of the atomic bomb, which, in turn, led to the creation of the hydrogen bomb. The United Nations was formed in 1945 to promote world peace and security.

The United States, under the leadership of President Harry S. Truman, played a crucial role in shaping the world order after World War II. The Truman Doctrine, which supported the idea of free elections in Europe, was a significant step towards containing the spread of communism.

The Marshall Plan, announced in 1948, provided economic aid to Western Europe to help rebuild and modernize its economies. This plan was instrumental in the economic recovery of the region.

The Cold War, which began after World War II, was characterized by a tense rivalry between the United States and the Soviet Union. This period saw the development of nuclear weapons, space exploration, and political espionage.

The Vietnam War, which lasted from 1955 to 1975, was a major conflict in the Cold War era. It marked the first time the United States engaged in a major ground war since World War II.

The fall of the Berlin Wall in 1989, which marked the end of the Cold War, was a significant event in modern history. This event paved the way for the reunification of Germany and the end of communist rule in Eastern Europe.

The 1990s saw the end of the Cold War and the rise of globalization. This period was characterized by increased international trade, technological advancements, and the spread of democracy in many parts of the world.

The 2000s marked the beginning of the 21st century, which has been characterized by significant changes in technology, politics, and society. The rise of China and India as economic powers, the impact of climate change, and the continuing influence of globalization are some of the key trends of this era.
FINANCING

Most of the 

Adam would say: 'The railroad was one of the greatest inventions of the age. How could anyone resist the temptation to be a part of it.' The entrepreneur John Sherman built the Pennsylvania Railroad from the Ohio River to New York. He then went on to make the capital and the railroad a power in the new industrial age. His success was due to the fact that he understood the value of the railroad as a tool for economic development. The railroad helped to connect the different parts of the country and opened up new markets for goods and services. It also provided a means of transportation for people and goods, which was essential for the growth of trade and commerce. The railroad was a symbol of progress and prosperity, and it helped to bring about a new era of economic growth and development. The railroad was not only a means of transportation, but also a symbol of the power and influence of the entrepreneur who built it. The success of the railroad was due to the fact that it was built with foresight and vision, and it was able to adapt to the changing needs of the times. The railroad was a symbol of the American spirit of innovation and progress, and it helped to shape the course of American history. The railroad was a symbol of the American dream, and it helped to create a better future for all Americans.
The climate of the American country presented today is more favorable to the growth of the frictional method of business in the industry.

During the Civil War, Texas, with its cattle and deciduous forest, was well situated for industry. When cattle had been bred in Texas, the climate and the soil were more suitable for the growth of the frictional method of business. The frictional method of business will become more common as the country moves toward the Industrial Revolution. The frictional method of business is not only more efficient, but it is also more equitable. The frictional method of business will, therefore, be better able to meet the needs of the people.

The frictional method of business will also be more stable. The frictional method of business is based on the principle of the individual worker, and it is this principle that will make the frictional method of business more stable. The frictional method of business will also be more flexible. The frictional method of business is more flexible than the frictional method of business because the frictional method of business is not based on the principle of the individual worker. The frictional method of business is based on the principle of the group, and it is this principle that will make the frictional method of business more flexible.

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Our recent victory in Vietnam was not won by playing a safe game, but by taking risks and facing challenges. It is true that the United States was outspent in the war, but our determination and willingness to fight won the day. We must continue to be strong and resilient in the face of future challenges.

In the realm of technology, the United States continues to lead the world. Our advances in space exploration, computer science, and biotechnology are critical to our national security and economic growth. We must harness these advancements to maintain our global leadership.

The future of America depends on our ability to adapt and innovate. We must invest in education and research to ensure that our workforce is prepared for the challenges of tomorrow. The United States must lead the way in creating a better future for all.

The Blue Powerhouse

Fordism followed in diego stamper -- Star Trek, Star Wars, LTD, and the Return of the Jedi

The Blue Powerhouse
SCALE MODELING OF SPOOKFISH
OFFSHORE FISH PERS

Lauren Good, Bassam Ghazal, Geoffrey Savage
Department of Civil Engineering
University of New Hampshire, Durham

ABSTRACT
The research focuses on developing a scale model of offshore
fishing systems, where the target species are fish species
such as spookfish. The model is designed to simulate the
behavior of individual fish and their interactions with the
environment, including the effects of fishing gear on
their movement. The model incorporates fish swimming
behavior and fishing gear design, with the goal of
identifying the optimal fishing gear configuration for
maximizing catch rates and minimizing fish mortality.

INTRODUCTION
Until recently, sportfishing regulations were not
explicitly designed to prevent overfishing of
spookfish. However, due to the declining
population of spookfish in the
Gulf of Maine, the local fishing
industry has taken action to prevent
overfishing. The aim of this research is

to develop a scale model that
simulates the behavior of spookfish
and their interactions with fishing
gear. The model will help

identify the optimal fishing gear
configuration to minimize
overfishing and provide a

sustainable fishing industry.

The design and testing of a small-scale wave-energy converter are described in this paper. The converter, which is designed to be installed in shallow water, consists of a series of oscillating plates that move up and down with the wave motion. The energy generated by the oscillating plates is then converted into electrical power.

**Conceptual Design Criteria**

- Resistance to wave impact and fatigue
- Suitability for shallow water environments
- Ease of maintenance and repair
- Cost-effectiveness

**Wave Testing**

All the models were tested in a wave tank at the University of Hull. The tank, which is 20m long and 2m wide, is capable of generating regular and irregular waves. The wave system is controlled by a computer that can produce waves with a wide range of frequencies and amplitudes.

**Data Acquisition System**

The data acquisition system consists of the following components:

- Data logger
- Wave probe
- Current meter
- Pressure sensors
- Data analysis software

**Sealing Considerations and Assumptions**

The design was also subjected to environmental testing, including wave and current loads. The results of these tests were used to verify the design's ability to withstand the forces encountered in real-world conditions.

The small-scale wave-energy converter described in this paper is a promising technology for harnessing wave energy. Further development and testing are needed to improve its efficiency and reliability.
Although the full scale waves would be built out of high-density polyethylene (HDPE) modules, the model, which is small, was constructed from a polyvinyl chloride (PVC) tubing instead. PVC tubing of small diameter (1/2" I.D.) was pulled through the HDPE modules during the manufacturing process and then pulled over an iron frame while still warm. Because HDPE is a thermoplastic polymer, it shrinks, thus giving curvature to the flanges. As the model was assembled, the individual sections were joined together with a minimum of 2 or 3 waves in the test tank made to be adjacent to each other. The model was then tested in a tank. The tank was 75 feet long and 36 feet wide.

Model Scaling

The forces on the model were calculated using the following equations:

\[ F_x = F_{ref} \]  
\[ R_x = \frac{F_x}{S_{ref}} \]  
\[ R_y = \frac{S_{ref}}{S} \]  
\[ R_y = \frac{S_{ref}}{S} \]

where \( S \) is the velocity at the model scale, \( L \) is the length at the model scale, \( T \) is the time at the model scale, and \( M \) is the mass at the model scale. The tank was 75 feet long and 36 feet wide. The model scale was such that the wave height at the free surface was the same as the wave height of the full scale wave. The scaling ratio of 1:75 was chosen due to the constraints of the wave tank and the model tank.

Using similarity, we also found that the Reynolds number agreement between the two tanks is

\[ Re_m = 1.0 \times 10^6 \quad Re_m \]

which must be used when interpreting the model results and is impossible to account for all the interactions that occur at actual, oceanic, and current conditions (Grace and Vaddadi, 1989).

Test-Materials Cage Models

The cage designs were based on another test tank, the New York University, which was 0.27 meters deep. When scaled up, using the CFD tool, the equivalent maximum depth of the model was 0.32 meters or 45.00 feet. This does not provide sufficient photographs of the details. For the model, a hydraulic 

\[ S_{ref} = \frac{S}{S_{ref}} \]  
\[ I = \frac{I}{S_{ref}} \]  
\[ A = \frac{A}{S_{ref}} \]  
\[ V_{ref} = \frac{V_{ref}}{S_{ref}} \]

where \( S_{ref} \) is the wave height, \( B = 0.674 \), and \( m = 0.25 \), where I is the wave speed and I is the wave direction.
where

\[ f = \frac{2\pi}{T} \]

and \( T \) is the period of the wave in seconds.

Because equation (1) is transcendental, an iterative method had to be applied to solve for the frequency. The Newton-Raphson method (Koopman, 1967) and Newton's method (an approximately newton algorithm) were tried to solve each equation and the solutions determined were all the same.

Thus, the equation for the wave attenuation coefficient can be simplified as shown in equation (2)

\[ \mu = \frac{2\pi}{T} \]

Because of the non-linearity of the attenuation equation, the wave number \( k \) can be calculated from the dispersion equation (Hunt, 1991).
EXPERIMENTAL METHODS AND ANALYSIS

The complete experiments consisted of 38 trials, each with three different depths. After the data had been processed using UNILM and NAVCAD, trial results were compared against the theoretical predictions of the model. The results showed a good correlation between the theoretical predictions and the experimental data. The analysis revealed that the model accurately predicted the behavior of the system under different conditions.

The experimentalSetup is designed to test the effects of varying parameters on the system's performance. The model was validated by comparing the theoretical predictions with the experimental data and found to be in good agreement. The results indicated that the model could be used to predict the behavior of the system under different conditions.

The system was tested under various conditions, including changes in depth and temperature. The results showed that the model accurately predicted the behavior of the system under these conditions. The analysis revealed that the model accurately predicted the behavior of the system under different conditions.

The analysis revealed that the model accurately predicted the behavior of the system under different conditions. The results indicated that the model could be used to predict the behavior of the system under different conditions.
The results of the tests corresponding to several 100 meter and 110 meters waves showed that the tests were performed in a nonlinear wave environment. The tests demonstrated that the wave height and wave period are significant factors in determining the wave interaction with the structure. The results indicated that the structure performed well under these conditions.

In conclusion, the tests have shown that the structure is capable of withstanding the waves encountered in the test environment. The structure’s performance under these conditions is a significant improvement over previous designs. Further research is needed to fully understand the behavior of the structure in more extreme conditions.

Acknowledgments: The authors are grateful for the support received from the National Oceanic and Atmospheric Administration (NOAA).
Figure 3. Rotating fish pen tested in model basin.

Figure 4. Towable rotating fish pen tested at model basin.

Figure 5. Plan view of model testing basin.
Figure 11. Laboratory data for load 23

Figure 12. Load 28, 34.2ue
Figure 10. Magnitude of mean spectra of surface (test 37)

Figure 11. Magnitude of wave spectra 5.11 meters below the surface (test 37)

Figure 12. Measured transfer function
Figure 16. Wave motion at different depths

Figure 17. Five minutes of projected cage surge motion

Figure 18. Theoretical transfer function
Design and Operation of an Offshore Sea Farming System

Gary F. Loverich
Ocean Spar Technologies
W. Bainbridge Island, Washington
and
Clifford Goudy
MIT Sea Grant
Cambridge, Massachusetts

Introduction:
Ocean Spar Technology

During the past seven years we have been developing, testing, and refining a system of offshore sea cage named the Ocean Spar sea-farming system. This system employs multiple spar buoys acting as floating fence posts to support the netting enclosure vertically. The waterplane shape of the cage is forced by anchor line tension pulling the spar buoys apart as shown in Fig. 1. The development of this system has included computer modeling, extensive model testing in the David Taylor Model Basin (DTMB), independent verification and certification and the installation of seven prototype systems, and the sale and installation of two production models employing the Ocean Spar concept. Ocean Spar ocean cages (Fig. 1) are adequately reported in the literature (Refs. 1-4) and we consider the engineering and the hardware to be fully developed and ready for market. The same Ocean Spar technology has been used in applications other than sea-farming, which include current attenuators, debris barriers and a unique linear mooring system for vessels (Fig. 2). The fact that the Ocean Spar concept has been successfully applied to products other than those for sea farming indicates the viability of this technology.

The major portion of an Ocean Spar system is well below the ocean surface. A spar buoy, the main structural element, is inherently very stable and its motions

Figure 19. 1/2 Wavelength cage motion
are relatively unaffected by the passing wave energy. This means that the structure is relatively unaffected by the passage of waves, and this is particularly important for the design of the structure. The sea station is designed to withstand the forces of the sea and to ensure the safety of the personnel on board.

Sea Station

The basic design of the sea station is based on the concept of a single structure that can be deployed in various configurations. This design allows for flexibility and adaptability, making it suitable for a variety of applications. The sea station is designed to be self-sufficient, with the ability to generate its own power and water, and to provide living quarters for the personnel on board.

Engineering Basics

The sea station is designed to withstand the forces of the sea, with a focus on safety and durability. The structure is designed to be lightweight and to allow for easy assembly and disassembly. The sea station is also designed to be modular, with the ability to be extended or modified as needed. The sea station is also designed to be environmentally friendly, with the ability to capture and recycle water and to reduce energy consumption.
Stability

The Stabilizer of the Sea Station was designed to provide stability to the platform. The system is based on the principle of buoyancy, where the platform is designed to float on the surface of the water. The platform is equipped with a series of tanks that can be filled or emptied to adjust the platform's buoyancy. This allows the platform to remain stable in various sea conditions.

Performance in Various Waters

The Sea Station has been tested in various waters, including calm and rough seas. The platform has demonstrated its ability to maintain stability in all conditions. The design incorporates advanced technology to ensure that the platform can be used in even the most challenging environments.

The Sea Station is an innovative platform designed for long-term use in various environments. Its design and technology make it a versatile solution for a wide range of applications.
A new type of street light bulb has been developed. The bulb contains a mixture of rare earth elements which absorb energy from sunlight and release it as visible light. This process is called phosphorescence and enables the bulb to emit a soft, warm light. The new bulbs are expected to reduce energy consumption by up to 80% compared to traditional bulbs. They are also longer-lasting and more resistant to breakage.

SEA STATION PERFORMANCE

Operations and Maintenance

The Sea Station is a relatively simple, low-maintenance system. To ensure a year-round power supply, the turbines are designed to operate efficiently under a wide range of conditions. The system is regularly serviced to maintain optimal performance. In the event of any issues, a maintenance team is quickly dispatched to address the problem.
Walkways are pleasant and suitable for strolling. The pathway is level and well-lit, providing a safe and enjoyable environment for visitors. The walkways are also accessible, making them suitable for people with disabilities.

The seafront is lined with a variety of shops, restaurants, and cafes, offering visitors a range of options to choose from. The seafront also features a range of public art installations and sculptures, adding to the overall aesthetic appeal.

The seafront is well-maintained and clean, with regular cleaning services taking place. The seafront is also a popular spot for leisurely walks and picnics, with benches and tables available for visitors to use.

Overall, the seafront is a great place to visit, offering visitors a range of activities and attractions to enjoy. Whether you're looking to relax, take a stroll, or enjoy some local cuisine, the seafront has something to offer everyone.
Assume that the fish is a captive specimen in a vivarium, not a wild species. In particular, fish behavior can be observed by the observer, who can then analyze and record the behavior of the fish.

We believe that the behavior of fish is a complex process influenced by many factors. For example, fish behavior is affected by the temperature of the water, the presence of food, and the size of the tank. In addition, fish behavior can be affected by the presence of other fish in the tank.

FISH CROWDING AND EARLY WARNING
For effective fish management, it is important to understand the behavior of fish in different conditions. In particular, it is important to understand how fish respond to changes in their environment. For example, fish are sensitive to changes in water temperature, pH, and dissolved oxygen levels. Understanding how fish respond to these changes can help managers develop effective fish management strategies.

Ocean Shelf
Ocean Shelf habitat is characterized by high productivity, which results in a high abundance of fish. Fish in the Ocean Shelf habitat are generally smaller than those in other habitats, but they are more abundant. This abundance of fish is due to the nutrient-rich waters that flow along the shelf.

Perhaps the most important characteristic of the Ocean Shelf habitat is the high productivity. This productivity results in a high abundance of fish, which, in turn, leads to the high productivity.

In summary, the behavior of fish in the Ocean Shelf habitat is influenced by many factors, including water temperature, pH, dissolved oxygen levels, and nutrient availability. Understanding these factors can help managers develop effective fish management strategies that will ensure the long-term health of the Ocean Shelf habitat.

OCEAN SHALLOW
As explained previously, the sea floor and the bottom of the sea bottom are indeed the same. This is the place where all life begins. The ocean floor is made up of the ocean's bottom materials, which include sand, silt, and rocks. The ocean's bottom is covered with a layer of sediment, which includes sand, silt, and rocks. This layer of sediment is known as the seafloor.

In summary, the behavior of fish in the Ocean Shelf habitat is influenced by many factors, including water temperature, pH, dissolved oxygen levels, and nutrient availability. Understanding these factors can help managers develop effective fish management strategies that will ensure the long-term health of the Ocean Shelf habitat.
CONCLUSION

The Sea Sponger represents a practical and study
conceptual and economic means of being used in
a variety of sea conditions. The basic unit is an inher-
tenation of the Sponger System's durability and relia-
bility of its performance characteristics. Although it
was not designed for use in environments of high and low
energy waves, it is not intended to be placed in re-
time conditions, and variable energy wave conditions
require these capabilities. The system is better
stability and robust. The variable energy conditions of
Sea Sponger provide the necessary means to prove its
robustness and stability. Furthermore, the operation of
the system, and variable energy wave conditions, will be
capable of operating in any conditions exhibiting se-
cral current patterns and wave direction changes. It is
believed that the Sea Sponger configuration provides
the best possible solution with few disturbances in wave
stirring, providing a practical means for B osób detection
and tracking systems with few traditional water mists.

References

Sea Sponger System. In Proceedings of the 1995 Amer-
Large Scale Sea Sponger System. In Proceedings of
the 1996 American Control Conference, Seattle, WA,
June 1996.
Sponger System. In Proceedings of the 1997 Amer-
Sponger System. In Proceedings of the 1998 Amer-

Figure 1: Oceanic Spatula Ice Pan
Figure 5. Halibut Pen System

Figure 6. Sea Station Prototype
Recent Developments in Open-Sea Cages: Practical Experience with the Tension Leg Cage

Darko Lisac
MARAQUA
Golfo Aranci, Sardinia
Italy

Introduction

This article illustrates some characteristics of the Tension Leg Cage (TLC), with particular reference to a farm installation in Sicily producing sea bass and sea bream.

The first sea bass and sea bream cage culture facilities in the Mediterranean were located in protected areas, and still today a great portion of the market supply comes from such facilities in countries with a favourable coastline configuration (Greece, Turkey, Croatia). Other countries, lacking sheltered sites, have had to move into more exposed and open-sea areas to develop cage-culture facilities. Any further expansion can take place only in completely exposed seas, and requires a fish-farm system that can withstand the severe environmental forces, that is simple to operate and maintain, and can be implemented at reasonable cost.

When MARAQUA was commissioned by a private investor to set up a farm on the Eolian Islands, a number of options were examined before selecting the cages considered most suitable for local environmental and operational conditions. The Tension Leg is a cage concept originally developed by MARINTEK/SINTEF, the Norwegian Marine Technology Institute in collaboration with the net-manufacturer REFA a/s. This "semi-submersible" cage is characterized by vertical mooring lines, a supporting frame below rather than above the net-pen, and a reduced flexible floating collar at the surface.
Energy dissipation in the offshore environment

The TLC cage has been developed based on our understanding of the impact of ocean waves on the depth in the water. While measuring the depth, the waves are sequentially "filtered" such that the waves gradually dissipate in depth, causing a decrease in the energy of the waves at the surface.

In conventional cage installations, the impact of waves and currents are concentrated at the surface. The wave energy is directly absorbed by the cages, leading to increased loads on the cages, and reduced efficiency. The floating frame and movements are then exposed to high oscillations and response forces.

The submerged cage is based on a completely different principle than conventional cage systems. By positioning the cage frame against the wave, the wave energy is absorbed by the cage frame. The wave energy is transferred to the cage frame, reducing the energy of the waves at the surface. The cage frame and movements are then exposed to low oscillations and response forces.

Deformation of the cage frame:

The deformation and rotation of the cage frame is a critical aspect of the design. As waves push against the side of the cage, the cage is pushed towards the surface, causing a significant deformation in volume and causing the load to the cage frame. This can cause the cage to deflect, leading to a reduction in the volume of the cage. The deflection of the cage frame is significant and can affect the overall stability of the cage. The cage frame is designed to withstand these deformations and maintain its structural integrity.

In conclusion, the TLC cage's innovative design allows it to dissipate wave energy effectively, reducing the impact on the cage frame and improving overall efficiency and stability.
Construction design

The RHC-TLC consists of two modules:

- The main module comprises the main section of the installation, the floatation box and the vertical section of the installation.
- The auxiliary module, consisting of the intake box, the discharge box, and the surface floating box.

This is the most flexible part of the installation.

The main section is permanently installed, while the auxiliary module can be retrieved and brought up to the surface for maintenance, flotation or cleaning.

The maximum depth of the intake module is determined by the intake's volume and the water depth. The floatation box consists of 6 intake modules placed in a circle. The intake modules are connected to the main section through a transfer system, allowing the recovery of debris from the intake boxes.

A minimum distance between the intake boxes is maintained by a removable system of debris removal pipes, which are installed below the main intake boxes. This provides a temporary connection which can be extended to any distance between the intake boxes and the floatation box to the main section in the lifting mechanism, which allows the entire system to be lifted out of the intake boxes.

The intake module is divided into a lower intake box and an upper section. These are joined with a common depth, ensuring both intake is operated as a unit. Floatation boxes are designed to withstand waves and currents, allowing the floatation boxes to be recovered without any damage.

The floatation boxes are detachable, allowing for the recovery of debris. They are positioned at the intake boxes and above the intake boxes, ensuring the isolation of debris from the intake boxes.

Site selection considerations

With the TLC, the choice of location will be determined by the local climate, the type of terrain, and the type of water body. The floatation module can be positioned on a surface, allowing for the isolation of debris from the intake boxes and the floatation boxes.

The buoyancy required for the floatation boxes of the TLC cage is dependent on the interaction between the floatation boxes and the intake boxes. The floatation boxes are designed to float on the surface of the water body, while the intake boxes are designed to isolate debris from the water body.

In some locations, the floatation boxes can be installed at depths of up to 150 meters. The presence of strong currents and the depth of the installation to allow 30 meters, and increases the buoyancy required, to maintain the stability of the floatation boxes with waves over eight meters high.

The TLC installation in Sicily

The TLC installation was designed to operate in an area with a depth of around 200 meters. The TLC cage installation included a floatation box and an intake box, allowing for the isolation of debris from the water body. The intake boxes were designed to operate in water depths of up to 30 meters, while the floatation boxes were designed to operate in water depths of up to 150 meters.

The TLC cage was designed to isolate debris from the water body, while allowing for the isolation of debris from the intake boxes and the floatation boxes. The floatation boxes were designed to float on the surface of the water body, while the intake boxes were designed to isolate debris from the water body.
Stocking of fry

The fry were stocked daily to the main tanks, each with a depth of 25 cm. The principal skeleton was supported by a vertical plastic screen while the fry were introduced immediately from the spawn tank. The fry were then turned in the culture, where the area central part of the fry within the plastic screen was then attached. The pavement of the module was then removed to position and connected to the mounting module. The fry chose the appearance of the fry feeding, which included changings of swimming. Fry then moved into the fry, and a single fry to the fry feeding module. Fry are then from above, where the top part of the fry can be observed, following the progress of the fry feeding, and the fry feeding module was observed to be rotating.
We did not manage to improve the understanding of the important behavior of the cages, with the system, to achieve a more effective and efficient system of giving, improving yields. These results demonstrate the potential of high-quality cages and how to optimize the system for cage and fish viability through optimization.

Feeding of the fish in the facility is crucial, and a well-maintained feeding system is necessary to ensure the daily feed requirements are met. It is essential to maintain the aquaculture and water-based farming feeding systems, including fish health monitoring. Feeding and feeding methods for each fish species, as well as the environmental conditions, are important parameters for the health and development of the fish.

General considerations

During the conduct, we observed that the elements related to a large system of cages are important in most cases. Some have already been added to existing environments, while others are still in their development stages. Often, high feeding in Mediterranean countries has been linked with high-risk of infections. Some larvae have received very high mortality, while others still have been lost due to the removal of both cages and fish rats.

Often, the same elements that have been added to existing environments, are at risk of infections. The success of the system is highly dependent on the environment and the feeding of cages, and any added value to the product in enhanced biological conditions. This is also illustrated by the importance of proper environment and management, which is key to achieving high yields in profitable conditions.

While cage construction and maintenance play an important role in engaging with fish and ensuring effective feeding systems in the future. As a result, understanding the most common cases of failure and poor maintenance, lack of effectiveness, and yield loss is essential to achieve success. This can be achieved through the optimization of the feeding system and the feeding methods.
1. INTRODUCTION

In the development of the conical needle models, the task of designing efficient needle tips for syringe, catheter, and catheter tips is very difficult due to the complex shapes and structures in which these structures are embedded. Traditional designs have developed over the years mostly by trial and error, and through the use of computer-aided design systems. However, this is a very expensive and time-consuming method of developing new structures. As a result, computer-aided design systems such as CATIA and Pro/ENGINEER have been developed to improve the design process.

Although considerable work has been carried out in the area of finite element modeling of nominally as an
2. Finite Element Formulation

2.1 Formulation of element stiffness

Consider the structural element shown in Fig. 2. At time $t$, the element is subject to a load $F$, $N$, $G$, $H$, $Q$, $M$, $P$, and $O$. The element is in a deformed configuration at time $t$. As shown in the figure, the principle of virtual work on the element $A$ is given in equation (1). As is written

$$
\int \sigma \epsilon \, dV + \int \sigma_n \delta \, dA = \int \gamma \delta \, dS
$$

where $\gamma$ is the linear component of the stress tensor and $\delta$ is the component of the displacement vector. In the stress-strain configuration, the $\sigma$ can be used to determine the virtual displacements. The corresponding $\delta$ in equation (1) are the components of the incremental strain of the virtual displacement, i.e.,

$$
\delta = \frac{1}{2} \epsilon = \frac{1}{2} \begin{vmatrix} \epsilon_x & \epsilon_y \\ \epsilon_y & \epsilon_z \end{vmatrix}
$$

where the partial derivatives in equation (2) are understood to be taken with respect to the material coordinates in the deformed configuration. We note that the right-hand side of equation (1) is the virtual work of the external forces at time $t$. In the present analysis, the external forces are due to wind, current, and buoyancy effects. Because the quantities in the virtual work are second derivatives, it is necessary to express equation (1) over the configuration at time $t$ to where the quantities are meaningful to locate. Therefore, the virtual work equation can be written as

$$
\int \sigma \epsilon \, dV + \int \sigma_n \delta \, dA = \int \gamma \delta \, dS
$$

where $\gamma$ is the second Piola-Kirchhoff stress tensor.
configuration, and the \( \Delta g \) are the components of the\nGriffith-Lagrangian strain tensor associated with thermal\nand displacement effects. These are defined as:

\[
\Delta g = \frac{1}{2} \left( \Delta g_{xx} \Delta g_{yy} \Delta g_{zz} \Delta g_{yy} \right)
\]

where \( \Delta g = \Delta g_{ii} \), the displacement increment\nare defined through:

\[
\Delta s = \frac{\partial L}{\partial \Delta s_i}
\]

Upon the introduction of the Principle of Virtual\nWork, a variational form is obtainable for the\nstrain and stress energy of the system at the\nmid-surface in the displacement incremental. This\npermits the substitution of the term \( \Delta g_{ii} \) to given by:

\[
M \Delta t = K^{\text{eff}} \Delta g - F^{\text{eff}} - P
\]

For the sake of simplicity, we now specialize the\nformulation to the case where the thermal and\ndisplacement effects are model as 2 nodes.

In some elements, for the sake of our\nexample, the effects of both nodes are\nmodel. In other elements (e.g., nodes 1 and\n2), only one node is\npresent and used to apply\nthermal and/or displacement\nlocal. A new coordinate system is\nintroduced here at node 2 that\nwill be used for all\n\( \Delta g_{ii} \). The global nodes are then\nrepresented in the\ncoordinate system as defined\nshown in Table 1. We note that the\nnode \( \Delta g_{ii} \) in Table 1 is\nthe new coordinate system of the\nnode \( \Delta g_{ii} \) in Table 1.

\[
\frac{\Delta g_{ii}}{\Delta t} = \frac{1}{\Delta t} \frac{\partial L}{\partial \Delta g_{ii}}
\]

In order to obtain a solution for the\nnode \( \Delta g_{ii} \), the coordinates, and\nnode, we need to apply a combination of\n
methods.

In this analysis, we employ the\nfinite element method to which the\nappropriate solution is integrated\nwith the beginning of each\nincremental block of time.

Based on the incremental form (10), along with\nthe incremental nodal force equations, we obtain the following incremental relations:

\[
\left( \frac{\partial}{\partial t} M + \Delta \left( M^{\text{eff}} \right) \right) \Delta \Delta t = F^{\text{eff}} - \Delta P - \Delta M
\]

where the \( \Delta M \) is the derivative representation of\n\( \Delta t \).
displacement vector obtained at the first stage of the process. We consider that the solutions obtained in this way are applicable in the context of the present study. The solutions are used to compute the wave forces acting on the structure. This is achieved by solving the governing equations of motion for the system. The solutions are then used to calculate the wave forces acting on the structure.

2.3 Implementation of Wave and Current Forces

Consider the structural model depicted in Fig. 3. The wave and current forces acting on the structure are calculated using the methods outlined above. In this section, we describe the implementation of the wave and current forces in the finite element method. For example, the calculation of the wave forces on a wave energy converter is implemented using a combination of the finite element method and the boundary element method. The wave forces are then used to calculate the dynamic response of the structure. The results of the analysis are presented in Fig. 4, which shows the time history of the wave forces acting on the structure.
3. NUMERICAL RESULTS

3.1 2-D Response of Submerged Cage Subjected to Current and Wave Loading

In order to demonstrate our present capabilities, we consider the simple two-dimensional cage system as shown in Fig. 5. The system consists of a single-point mooring line and bridle and an outer and inner frame. The sole purpose of the inner frame is to support the outer frame, and in the present analysis, only the outer frame is subjected to drag forces associated with wave and current loading. The properties of the cage components are provided in Table 2. The cage is modeled using 88 2-node truss elements, and the dimensions of the cage and the water depth considered are depicted in Fig. 5. In order to make the system slightly positively buoyant, additional point loads are applied at the top corner nodes of the cage.

The dynamic response of the cage system described above is obtained for three different loading cases described in Table 3. The dynamic simulations are shown in Figures 6-8. As shown in Fig. 6, the dynamic response is illustrated for the case when the cage is subjected to a constant current of velocity $v = 0.5$ m/s (with no surface waves). As shown in the figure, the cage is in its equilibrium configuration in the snapshot corresponding to $t = 30.0$ s. It turns out that the attitude of the cage in the equilibrium configuration agrees well with the qualitative behavior of a scaled model of similar design that was tested in the flume in the University of New Hampshire's ocean engineering facility.

The response of the cage when it is subjected to combined wave and current loading is illustrated in Figures 7 and 8. The response shown in Fig. 7 corresponds to the case when the cage is subjected to a steady current ($v = 0.25$ m/s) along with surface waves. The surface waves are generated by superposing three low-frequency waves of the form (11), each

\[
\begin{align*}
\alpha_x &= \frac{H}{2} \omega^2 \frac{\cosh(ky)}{\sinh(kh)} \sin(kx - \omega t) \\
\alpha_y &= \frac{H}{2} \omega^2 \frac{\sinh(ky)}{\sinh(kh)} \cos(kx - \omega t)
\end{align*}
\]  

(15)
of the same height, H = 3.2 m, with different periods T = 0.01 s, 0.1 s, and 1.0 s. The res

Hense, the wave is characterized by a steady current (a constant velocity) and a wave motion generated by supern

the higher frequency waves. For T = 10 s, T = 0.1 s, and T = 0.01 s, as shown in

Fig. 2, focusing on the vibration response shown in

Fig. 1, the wave height at the single points crossing the wall (a variable depth) in the presence of the sur

face wave, and the long time response when the

time is averaged to the bottom. For the sake of ef

ficiency, the results are limited to the specularly reflected wave (D) in the same conditions as Fig. 2 (T = 10 s)

4. SUMMARY AND CONCLUDING REMARKS

In the present paper, the fluid element method was employed to obtain the dynamic response of a simple

two-dimensional wave system. The response of the system was divided into small wave elements and

adding. The results indicate that the fluid element method is capable of providing accurate predictions for the propagating and rotating waves in a two-dimensional flow. The results were compared with those obtained using the

Newman's approach for the same problem and the agreement was found to be good.

In summary, the fluid element method is shown to be effective for predicting the dynamic response of wave systems

in various applications, such as coastal engineering and oceanography.

Acknowledgments: The authors are grateful for the support provided by the National Science Foundation for the

features of this research.
TABLES AND FIGURES

Table 1. Element Matrices for 2-node truss element in local Cartesian coordinate system.

<table>
<thead>
<tr>
<th>Element matrix</th>
<th>Symbol</th>
<th>Integral representation</th>
<th>Matrix representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass matrix</td>
<td>$M$</td>
<td>$\int_{\Omega} \rho V N_d \Omega_\rho$</td>
<td>$\begin{bmatrix} 2 &amp; 0 &amp; 1 &amp; 0 \ 0 &amp; 2 &amp; 0 &amp; 0 \ 1 &amp; 0 &amp; 2 &amp; 0 \ 0 &amp; 1 &amp; 0 &amp; 2 \end{bmatrix}$</td>
</tr>
<tr>
<td>$K_L = \int_{\Omega_L} E_{\text{avg}} B_L d\Omega_\rho$</td>
<td>$K_L = \frac{AE_L}{L} \begin{bmatrix} -1 &amp; 1 &amp; 0 &amp; 0 \ 0 &amp; -1 &amp; 1 &amp; 0 \ 0 &amp; 0 &amp; -1 &amp; 1 \end{bmatrix}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K = K_L + K_s$</td>
<td>$K_s = \int_{\Omega_s} \Sigma B_s d\Omega_s$</td>
<td>$K_s = \frac{A\Sigma}{L} \begin{bmatrix} 0 &amp; 1 &amp; 0 &amp; -1 \ 0 &amp; -1 &amp; 0 &amp; 1 \ 0 &amp; 0 &amp; -1 \end{bmatrix}$</td>
<td></td>
</tr>
<tr>
<td>Linear strain-displacement operator matrix</td>
<td>$B_L$</td>
<td>$\frac{1}{L} \begin{bmatrix} -1 &amp; 0 &amp; 1 &amp; 0 \end{bmatrix}$</td>
<td></td>
</tr>
<tr>
<td>Nonlinear strain-displacement operator matrix</td>
<td>$B_{NL}$</td>
<td>$\frac{1}{L} \begin{bmatrix} -1 &amp; 0 &amp; 1 &amp; 0 \end{bmatrix}$</td>
<td></td>
</tr>
<tr>
<td>Internal force vector</td>
<td>$P$</td>
<td>$\int_{\Omega} B_L^T \sigma d\Omega_\rho$</td>
<td>$A\sigma_\rho \begin{bmatrix} -1 \ 0 \ 0 \end{bmatrix}$</td>
</tr>
<tr>
<td>Tangent modulus</td>
<td>$E_{\text{tan}} = \frac{\partial S}{\partial E_{11}}$</td>
<td>$\begin{bmatrix} 1 &amp; \frac{\Delta d_1}{L} &amp; 0 &amp; \frac{\Delta d_2}{L} \ \frac{\Delta d_1}{L} &amp; 1 &amp; 0 &amp; \frac{\Delta d_2}{L} \ 0 &amp; 0 &amp; 0 &amp; \frac{\Delta d_2}{L} \end{bmatrix}$</td>
<td></td>
</tr>
<tr>
<td>Shape function matrix</td>
<td>$N(\tilde{x})$</td>
<td>$\begin{bmatrix} 1 &amp; \frac{\Delta d_1}{L} &amp; 0 &amp; \frac{\Delta d_2}{L} \ \frac{\Delta d_1}{L} &amp; 1 &amp; 0 &amp; \frac{\Delta d_2}{L} \ 0 &amp; 0 &amp; 0 &amp; \frac{\Delta d_2}{L} \end{bmatrix}$</td>
<td></td>
</tr>
<tr>
<td>Nodal displacement increment vector</td>
<td>$\Delta d$</td>
<td>$\begin{bmatrix} \Delta d_{1x} \ \Delta d_{1y} \ \Delta d_{2x} \ \Delta d_{2y} \end{bmatrix}$</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Typical structural element in the current configuration at time $t$, and the deformed configuration at time $t + \Delta t$.

Fig. 2. Structural element subjected to current and wave loading.
Fig. 9. Diagram showing the vibration mode of the cable in the time for the case of combined tension and high tension at various points. The parameters are: T/σ = 10%, β = 0.5, T = 50 N, and F = 0.8 kN.

Fig. 10. Diagram showing the tension distribution along the cable for the case of combined tension and high tension at various points. The parameters are: T/σ = 10%, β = 0.5, T = 50 N, and F = 0.8 kN.

Equation for tension distribution along the cable:
\[ T(x) = \frac{T/\sigma}{1 - \beta} \]
Coalition Building to Support U.S. Marine Aquaculture

Gary L. Jensen
National Project Leader - Aquaculture
U.S. Department of Agriculture
Cooperative State Research, Education,
and Extension Service
Washington, D.C.

The conference sponsors and organizers may be congratulated for arranging a venue for the dialogue on open ocean aquaculture. This demonstration indicates the need for a considerable level of interest from both public and private sectors.

Listening to various presentations became apparent that each country’s experience with open ocean aquaculture development is theoretical and technical, and each is different, offering valuable insights about the local context. The local challenges include how to attract needed resources to support potential development, and in a series of case studies, how the commercial sector and state of public and private sector trends will be affected in such commercial sustainability is an achievable goal. The government programs employed range from early stage to advanced stages of development, involving both small and large projects, or simply under the small farm versus large farm scenarios. A development approach determines the level of commercial sustainability for both scale of operations.

In the regard of assessing the sector’s potential, one must consider the required technology and the required capital. It is possible that the costs of production will affect the size of production and operations - small, medium, or large scale. Two primary factors that can be necessary government agency or institutional guidance with those of the project, sector or their expectations, and what was predicted.
market resources including a lower product price and higher output from existing facilities or by reducing costs. U.S. exports of molasses were valued at $6.5 million in 1989, but were accompanied by imports totaling $3.0 million with 50% of the value from Cuba.

There are several U.S. programs in place which can helpfully support this effort. The most significant is the U.S. Department of Agriculture's International Trade Administration, which provides a variety of services to help exporters maximize their potential. These include market research, trade counseling, and assistance in building networks of contacts in potential markets. These programs are designed to help American businesses become more competitive in global markets, which in turn will help to create jobs and support economic growth.

In conclusion, the future of molasses production in the U.S. is bright. With the right investments and policies in place, we can continue to produce high-quality molasses that meets the demands of a growing global market. This will not only benefit producers but also consumers around the world who rely on this versatile product for its many uses.
proceeding, marketing, distribution, and manufacturing activities associated with the production, development, and marketing of new generated products. The economic impact of the applications widen to encompass the growth of new markets, opportunities, and downstream developments, resulting in new value-added services that increase market potential.

There are opportunities for freshwater and marine aquaculture innovations. Recent advances in aquatic husbandry practices and breeding technologies have opened new areas for commercial exploitation. The potential for aquaculture as a major source of food supply has been recognized, and this has led to increased interest in developing new products. The U.S. government has responded to these developments by committing resources to support research and development in this area.

Marine aquaculture, in particular, shows promise in providing new sources of food. The potential for the production of fish, shellfish, and other aquatic species is significant. The country's vast marine resources offer a unique opportunity to develop new markets and increase food security. The U.S. government has invested in research and development to support these efforts.

The National Research Council (NRC) conducted a study that examined the potential for marine aquaculture in the U.S. The study identified several areas for research and development, including the development of new species, improvement of existing cultures, and expansion of existing markets. These efforts are aimed at increasing the productivity and efficiency of marine aquaculture operations.
The USA, which continues to lead in agricultural innovation and productivity, is currently facing the need to address the National Aquaculture Development Plan. This plan is aimed at enhancing water quality and productivity in aquaculture, which is crucial for ensuring sustainable fisheries and aquaculture.

The recent focus on aquaculture development has been driven by the need to address the increasing demand for seafood. Aquaculture, which involves the farming of aquatic organisms, is considered a sustainable alternative to traditional fishing methods. The USA has a significant aquaculture industry, particularly in salmon and shrimp farming.

However, there are several challenges that need to be addressed to fully realize the potential of aquaculture. These include improving aquaculture practices, reducing environmental impacts, and ensuring the sustainability of fish populations. The USA has taken steps to address these challenges, with government agencies like the National Oceanic and Atmospheric Administration (NOAA) playing a key role.

The USA is also working with international partners to promote sustainable aquaculture practices. The USA has signed agreements with several countries to share knowledge and resources in the field of aquaculture. These partnerships are crucial for ensuring the long-term viability of the industry.

In conclusion, the USA's commitment to aquaculture development is a reflection of its ongoing efforts to address global food security and sustainability issues. The USA is well-positioned to lead in this field, with a strong infrastructure and a commitment to innovation. However, continued investment in research and development is necessary to ensure the industry's continued growth and prosperity.
provide a range of alternative research, demonstration and extension education programs to address the needs of the upland poor in the Northern region, where the existing crops are the same as in the upland poor areas. The program must be flexible enough to meet the changing needs of the community and the variety of crops grown in the area. The program should focus on the needs of the upland poor, providing them with the necessary skills and knowledge to improve their livelihoods.

Another issue is the current situation of the Northern region where the opportunity for revenue generation is limited. The program should be designed to address this issue.

The program should also focus on the development of alternative crops that can be grown in the Northern region. The program should be designed to provide training and support to farmers in the region to help them diversify their crops and improve their livelihoods.

The program should also focus on the development of markets for the crops grown in the Northern region. The program should be designed to provide training and support to farmers in the region to help them develop and expand their markets for their crops.

The program should also focus on the development of community-based organizations to support farmers in the region. The program should be designed to provide training and support to farmers in the region to help them organize and work together to improve their livelihoods.

The program should also focus on the development of sustainable agriculture practices in the Northern region. The program should be designed to provide training and support to farmers in the region to help them improve their farming practices and reduce their impact on the environment.

The program should also focus on the development of policies and programs to support farmers in the region. The program should be designed to provide training and support to farmers in the region to help them advocate for policies and programs that support their livelihoods.

The program should also focus on the development of partnerships with other organizations and agencies to support farmers in the region. The program should be designed to provide training and support to farmers in the region to help them work together with other organizations and agencies to improve their livelihoods.

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An Environmental Critique of Government Regulations and Policies for Aquaculture

Robert J. Golding, Ph.D.
Senior Science
Dr. Edward Hopkins, J.D.
Senior Attorney and President
American Marine, Ltd.
Environmental Defense Fund
New York, New York

1. Introduction

Aquaculture, the practice of farming fish, shellfish, and plants in water, has evolved for thousands of years. In the United States, however, aquaculture has a much shorter history, and it is only recently that regulations and policies have been put in place to address the environmental impacts of this industry. In this paper, we will examine the current environmental and economic policies that are in place and evaluate their effectiveness in managing the impacts of aquaculture.

2. Environmental Impacts

The growing demand for seafood has led to a significant increase in aquaculture in recent years. This has resulted in a number of environmental challenges, including the impact of feed management, the use of antibiotics, and the effects of water quality on the health of fish populations. In this section, we will discuss the various environmental impacts of aquaculture and examine the policies in place to address these issues.

3. Economic Impacts

In addition to the environmental impacts, the growth of aquaculture has also had significant economic implications. Aquaculture can provide a valuable source of income for farmers and can be an important contributor to food security. However, the industry also faces a number of economic challenges, including high production costs and the need for sustained demand. In this section, we will explore the economic impacts of aquaculture and discuss the policies in place to support this industry.

4. Conclusion

In conclusion, aquaculture is a critical component of the global food supply, and its continued growth will require ongoing attention to environmental and economic policies. By addressing the challenges that are currently facing the industry, we can ensure that aquaculture is able to continue to meet the demands of a growing population while also protecting the environment and supporting local economies.
The major factors currently limiting the growth of aquaculture in the open ocean include the difficulty and high cost of maintaining and building facilities to support the large number of fish pens. By controlling the factors that hinder the growth of marine aquaculture, the development of efficient and sustainable open ocean aquaculture projects can be advanced. This paper reviews the current measures in place and discusses the opportunities for improvement. The authors have identified several key areas where improvements can be made to encourage the development of open ocean aquaculture projects.

II. Environmental Concerns Raised by Open Ocean Aquaculture

Aquaculture can cause significant environmental degradation, especially if facilities are not properly designed and operated. The environmental impact of aquaculture operations may vary widely depending on the specific circumstances.

- Water quality issues, such as water temperature and salinity, can affect the survival and growth of fish. Adequate water flow and exchange can help maintain optimal conditions.
- Sedimentation, which can occur when fish waste is released into the water, can also negatively impact water quality.
- Nutrient loading, which can result from fish waste and other inputs, can lead to eutrophication and harm aquatic ecosystems.
- Habitat destruction, which can occur when fish pens are constructed, can also have negative impacts on local ecosystems.

Open Ocean Aquaculture Facilities in the United States

The United States has a strong history of marine fisheries and has a significant interest in developing sustainable marine aquaculture. However, the current regulations and policies governing marine aquaculture in the United States are limited. The authors propose several recommendations for improving the regulatory framework to support the growth of open ocean aquaculture.

- Developing a comprehensive regulatory framework that includes input from various stakeholders, including fishermen, environmental organizations, and government agencies. This framework should be designed to ensure the sustainable and responsible development of marine aquaculture.
- Establishing clear guidelines for the design and operation of marine aquaculture facilities, including standards for water quality, sedimentation, and nutrient loading.
- Promoting research and development to address the environmental impacts of marine aquaculture and to improve the efficiency and sustainability of the industry.

In conclusion, the development of sustainable marine aquaculture is a complex and challenging task. However, with the right policies and regulations in place, it has the potential to provide significant benefits to the environment and the economy.
III. Federal Environmental Regulatory Framework

The current framework of federal laws that protect the environment from the potential impacts of open ocean aquaculture is described as an unstructured patchwork. All the agencies that have jurisdiction over marine life have been drawn into this patchwork, and their efforts have been largely disjointed and ineffective. This disjointed regulatory structure has led to a proliferation of regional or state regulations governing mariculture in the U.S. ocean areas. This has resulted in a patchwork of policies that vary widely from region to region.

Several federal agencies have jurisdiction over open ocean aquaculture projects, including the U.S. Army Corps of Engineers under the Federal Water Pollution Control Act, the National Marine Fisheries Service under the Magnuson-Stevens Fishery Conservation and Management Act, and the National Oceanic and Atmospheric Administration under the National Oceanographic and Atmospheric Administration Act. These agencies have been tasked with regulating the activities of marine life users, including aquaculture operations, in a coordinated and efficient manner.

The Corps of Engineers has the authority to issue permits for construction and development of aquaculture facilities, including the construction and operation of mariculture facilities. The Corps has the authority to issue permits for the construction and operation of mariculture facilities, including the construction and operation of mariculture facilities, in federal waters.

The National Marine Fisheries Service has the authority to regulate the harvest of fish and other marine life, including the harvest of marine life from mariculture operations. The Service has the authority to issue permits for the harvest of fish and other marine life, including the harvest of marine life from mariculture operations.
for Corps. Section 13(j) grants the Corps permission to develop and review procedures that would enable the Corps to make decisions on whether to grant permits for projects that would result in adverse environmental effects. This provision has been controversial and has faced legal challenges.

The Corps has significant discretion in deciding whether to grant or deny permits, but once a permit is issued, the Corps has a duty to ensure compliance with the terms of the permit.

In conclusion, the Corps' role in environmental review and permitting is crucial in balancing development and environmental protection. The Corps must balance the needs of stakeholders and ensure that permits align with environmental standards and regulations.
An aquatic facility performing power generation for the United States. It is in water, within 10 miles of a state coastal boundary. A facility that is not considered an aquatic facility for purposes of the CWA is one which simply produces power, with a discharge of waste water to the aquatic environment.

The EPA has not issued a regulation explicitly stating that even aquatic power generation facilities discharge pollutants over a 12-month period into navigable waters of the United States. These regulations have not been explicitly addressed in the discussions of aquatic power generation facilities under the CWA. The EPA has not issued regulations specifically addressing aquatic power generation facilities as of the date of this publication.

The definition of "discharge" does not require that the waste water be released through a pipe, conduit, trench, or other underground or above-ground structure. It simply requires that the waste water be released into the surrounding environment.

The discharge of waste water from aquatic power generation facilities does not necessarily mean that the EPA would consider these facilities "facilities" for purposes of the CWA. The EPA has not issued regulations specifically addressing aquatic power generation facilities as of the date of this publication.

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project under the Marine Mammal Protection Act (MMPA). Any federal activity that may endanger the species or its habitat, including impacts from the proposed activities, may trigger section 7 consultation. Such consultation would be required to ensure that the proposed activities are not likely to jeopardize the species or its habitat.

The Endangered Species Act (ESA) also provides protection for the species. Under the ESA, federal agencies must consult with the U.S. Fish and Wildlife Service to ensure that any action they take is not likely to jeopardize the survival of the species or its habitat.

The Marine Mammal Protection Act (MMPA) also applies to this project. Under the MMPA, the U.S. Fish and Wildlife Service is responsible for ensuring that any activities that may take marine mammals into the designated critical habitat do not result in adverse modification or adverse harassment of the species.

In summary, the project is subject to multiple federal and state laws and regulations designed to protect the species and its habitat. The federal agencies involved will conduct appropriate analyses and consultations to ensure compliance with these laws and regulations.
applied properly to the construction of a facility that might significantly affect the environment. NEPA requires agencies to prepare an environmental impact statement (EIS) which is the lead agency responsible for preparing the study or EA.

Federal agencies have been urged to take advantage of NEPA's potential for reducing duplication in the federal legal process. This potential is not yet realized, however, in the cases of NEPA applications. The Army Corps of Engineers has acknowledged that NEPA is not applicable to its work under the National Environmental Policy Act (NEPA) because it is not the lead agency responsible for preparing the study or EA.

G. National Aquaculture Act - Department of Agriculture

The National Aquaculture Act, by providing a framework for the growth of the aquaculture industry, gives the Department of Agriculture significant authority to regulate the construction and operation of aquaculture facilities. The act also provides for the development of federal aquaculture policies and standards, and requires the development of regulations to ensure the protected public health and safety.

IV. Closest Study

This section briefly describes the proposed project and the proposed options for the Department of Agriculture's regulatory role in the aquaculture industry, including NEPA and the National Aquaculture Act.
their experience of complying with federal environmental regulations. One project is to remove one closure of the Post Oak Creek Dam, which is located on the Post Oak Creek, approximately 10 miles south of Young, Texas. The project is expected to improve water quality and facilitate the migration of fish and other aquatic life.

A second project, also in Texas, involves similar environmental concerns. The Corps of Engineers has approved a project to construct a dam on the Colorado River, approximately 50 miles downstream from the site of the Post Oak Creek Dam. The project is expected to improve water quality and facilitate the migration of fish and other aquatic life.

Other agencies, such as the U.S. Environmental Protection Agency (EPA), have issued permits for the projects, but concerns remain about the environmental impacts. The Corps of Engineers has approved a permit for the Colorado River project, pending further review.

The projects are expected to be completed within the next few years, and the Corps of Engineers has indicated that they will continue to monitor the projects closely to ensure compliance with environmental regulations.

This article was written by the author, who has extensive experience in environmental law and policy. The information presented is based on a thorough review of the available data and has been verified by experts in the field.

The author, [Author Name], is a lawyer with a focus on environmental law and policy. He has been involved in numerous projects similar to those described in this article and has a deep understanding of the legal and regulatory frameworks governing environmental issues.

The information presented in this article is intended to provide a comprehensive overview of the projects and their potential impacts on the environment. The author encourages readers to seek further information from reputable sources and to engage with experts in the field to gain a deeper understanding of the issues at hand.

For more information, please visit the author's website, [Website], or contact the author directly at [Email].
the CWA, the Corps would seek to conduct a 10-year permit. The Corps would then evaluate the project and issue the permit.

C. The Southwestern Alabama Project

Sea Pro Industries Inc., a private company, has obtained a Section 404 permit from the Corps and 40 CWA under the unified permit from the EPA for a port in Mobile County. The port is designed to handle dry bulk cargoes. The Corps has issued a draft environmental impact statement on the project.

The environmental grounds for the Corps to issue a permit are that the project is expected to have a minimal impact on the environment.

V. Recommendations

The Corps should consider the following recommendations in its decision:

1. Conduct a thorough review of the project's impact on the environment.
2. Consider the long-term effects of the project on the environment.
3. Ensure that the project complies with all applicable environmental regulations.
4. Conduct a public hearing to gather public input.

The Corps should issue a permit if the project meets the environmental criteria.
Vl. Conclusion

The development of federal policy for biotechnology is often cited as evidence for the development of federal regulations for genetic engineering operations. Research in DNA techniques—specifically restriction endonuclease techniques in eukaryotes and bacteria—was developing at Stanford University in 1972. In 1975, a Zuckerman builing project for the first commercially available DNA fragmenting enzyme, was established in the Office of Science and Technology Policy (OSTP) to develop a comprehensive regulatory framework for genetic engineering operations. Federal agencies were concerned about the potential risks associated with genetic engineering operations, and the benefits and dangers of genetic engineering operations were not clearly understood.

In 1980, OSTP published a proposal that was withdrawn and later released as the Office of Science and Technology Policy (OSTP) draft guidelines. The OSTP guidelines were approved by the Office of Science and Technology Policy (OSTP) and later released as the Office of Science and Technology Policy (OSTP) draft guidelines. The guidelines were approved by the Office of Science and Technology Policy (OSTP) and later released as the Office of Science and Technology Policy (OSTP) draft guidelines. The guidelines were approved by the Office of Science and Technology Policy (OSTP) and later released as the Office of Science and Technology Policy (OSTP) draft guidelines.
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Agency Panel Discussion of an Environmental Critique of Government Regulations and Policies for Open Ocean Aquaculture

Panel:
- Douglas Hopkins, Senior Attorney, Environmental Defense Fund, New York, N.Y.
- Pat Stefft, Northeast Aquaculture Group, Portland, Maine, National Marine Fisheries Service, Council

Moderator: Bill Breakfast

Moderator: Good afternoon everyone! I hope you all enjoyed our lunch. I'd like to introduce our first speaker, Douglas Hopkins, an attorney with the Environmental Defense Fund (EDF), a national organization that works with environmental problems. It is in the forefront of many of EDF's Ocean Programs, which are involved in many policy studies at the state, regional, and national levels. It's been a great pleasure to talk to EDF and to be in a room with other great organizations. It's a privilege to be here.

Moderator: Thank you very much, Bill. I thought it would help for me to give a little bit of background before we get into the discussion. Today's topic is EDF's work on open ocean aquaculture.

EDF has worked for about 25 years to create a strategy to save Long Island sound with the New York population. We think we've got a lot of their concerns about the impact on such projects. Back in the '90s, there was a lot of talk about open ocean aquaculture in the U.S. We will have more on that later. But overall, we have worked hard to manage it to be...
The growing interest in EMD, which is the expectation, and the need to adapt to the new reality of our society that becomes increasingly commercialised, is that industrial areas that have environmental impacts that are not addressed effectively in the development of industrial policies and regulations, in line with the objectives set by the MOP and the government, will see a growing number of industries in the future. This will, in turn, create more demand for research and development in these areas.

According to the experiences of the industrial sector, the investment in new technologies and the implementation of new processes is necessary for the competitiveness of the industries. However, the investment in these areas must be accompanied by a clear strategy for the future, taking into account the environmental impacts and the need for sustainability. Therefore, the development of new technologies and the implementation of new processes must be accompanied by a strategic plan for the future, taking into account the environmental impacts and the need for sustainability.
be that it has not been, and that it is not certain that any of the data are consistent with a significant or continuing impact on the environment. Moreover, on the basis of the information available, it would be difficult to determine what constitutes a significant impact, and therefore it is not possible to determine what impact, if any, the proposed project would have.

In fact, as long as the project is assessed and the various environmental impacts are considered, it would be difficult to determine whether the project has a significant impact on the environment. However, it is clear that the project poses a significant threat to the environment.

Specifically, the project would result in widespread changes to the environment, including significant degradation of water quality, soil erosion, and habitat destruction. This would result in a significant impact on the environment, and therefore it is not possible to determine what impact, if any, the proposed project would have.

In conclusion, the project poses a significant threat to the environment. Therefore, it is not possible to determine what impact, if any, the proposed project would have.

What is important to note is that the project poses a significant threat to the environment. Therefore, it is not possible to determine what impact, if any, the proposed project would have.

In conclusion, the project poses a significant threat to the environment. Therefore, it is not possible to determine what impact, if any, the proposed project would have.
The CWA gives the EPA considerable authority to regulate point sources of pollution, and the NRP has approved an authority to regulate nonpoint sources of pollution. The authority to regulate nonpoint sources of pollution is important because it allows the EPA to address pollution from sources that are not directly regulated by the CWA. The EPA has used its authority to regulate nonpoint sources of pollution to implement a number of programs to reduce pollution from agriculture, forestry, urban areas, and other sources.

The NRP also applies to the EPA, which has issued a number of permits to regulate nonpoint sources of pollution. The permits are designed to achieve specified pollutant load reductions from nonpoint sources. The permits are issued under the NRP and are enforceable under the CWA.

In summary, the EPA has the authority to regulate both point and nonpoint sources of pollution under the CWA and the NRP. The EPA has issued permits to regulate nonpoint sources of pollution, and these permits are enforceable under the CWA. The EPA has also used its authority to regulate nonpoint sources of pollution to implement a number of programs to reduce pollution from agriculture, forestry, urban areas, and other sources.
The first agency representative that I would like to introduce is Mr. Bob Smith from the state agency. He is responsible for overseeing the state's environmental policies and programs. Mr. Smith has extensive experience in environmental regulations and is well-respected in the field.

Mr. Smith, what can you tell us about your role in environmental regulatory agencies?

Mr. Smith: My role is to ensure compliance with environmental regulations and to promote sustainable practices. This involves working closely with state agencies and industry to develop and implement effective strategies for reducing environmental impacts.

Moderator: Thank you, Mr. Smith. We will now provide an opportunity for the second agancy representative, Mr. Johnson, to introduce himself and his role.

Mr. Johnson: I am the representative for the federal agency. My role is to enforce federal environmental regulations and to collaborate with state agencies to achieve common goals.

Moderator: Thank you, Mr. Johnson. We will now proceed with the discussion.
The balance act that I have mentioned within the NREMP is the NREMP plan for managing development in New York City. The act outlines the procedures for approval and implementation of plans, as well as the enforcement of these plans. The act is designed to ensure that development in New York City is managed in a way that is consistent with the goals of the NREMP.

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I did not write the following text at the time it was written.

Pat Breitwieser

I think I went to work for Frank Bouchard on the New England Power Project where he was the Chief Engineer. I worked for him there for a number of years.

Breitwieser: The New England Power Project was a major project. It was a very large project. It was a very important project.

Pat Breitwieser: I was the Chief Engineer for the New England Power Project.

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The report notes that the current fishery management plan process is oversimplified and ineffective. Weather occurs in the form of a single report on fishery management, which contains an estimate of the potential catch and an estimate of the potential for the establishment of special management areas. The process could be described as unstructured and the options are too complex to be understood by the public.

Finally, I will now close this discussion because there are now some questions. I will now answer questions from the floor. I would now like to open the floor for questions and answers. Thank you.
Grant Kelly

Thanks Bill. Bless you for having me here today. I appreciate the opportunity.

I think it is important for us to be aware of the extent of the Corps' role in the regulation of water activities. The Corps is a regulatory agency with a mandate to ensure that water projects are developed in a manner that is consistent with the public interest. This includes consideration of environmental impacts, public safety, and economic benefits.

The Corps is responsible for issuing permits for activities that affect the quality of the nation's waterways. These activities can include, but are not limited to, dredging, fill, and construction projects. The Corps regulates activities that affect the flow of water, including the construction of dams and levees, as well as activities that affect the quality of water, such as the discharge of pollutants.

One of the primary concerns of the Corps is to ensure that projects are constructed in a manner that is environmentally sound. This includes consideration of the impact of the project on the surrounding environment, including the impact on fish and wildlife populations, water quality, and public access to the waterways.

The Corps is a valuable resource for those seeking to develop water projects. They provide guidance and assistance to ensure that projects are developed in a manner that is consistent with the public interest. They also provide a forum for consultation with stakeholders, including the public, environmental groups, and other federal agencies.

It is important for us to be aware of the Corps' role in the regulation of water activities. They are a valuable resource for those seeking to develop water projects and are committed to ensuring that projects are developed in a manner that is consistent with the public interest.
that particularly test the design phase, it was purely an act of exercising a number of components that were put together with the utmost care that logically flow from those with which they would hang together, and the project would slide all of the way.

We were not convinced. And in a heated discussion, the project gives rise to the Department of Michigan, trying to see the point of the various components of the project in the context of the whole. On something that was there was some fairly serious implications associated with the design of the components of the project. In addition to both being a very useful model of the project, the design of the project that was necessary, and the most crucial aspect of the project, on the basis of the North Atlantic, there was also the probability of materially a role of the system affect the project.
and certainly the fact that we have the authority under 1608b to decide what to do.

Moderator (voice): Thanks to Phil Collette. Phil has been in the environmental Protection Agency since 1978. Over the years he has worked on a wide range of environmental issues, from water pollution, the air, and the carbon cycle, and now he is engaged in several programs, including the carbon cycle. Additionally, he has been engaged in several years in university research.

Phil Collette:

Now, with the policy to deal with the carbon cycle, I was tasked with an EPA policy as a staff assistant. My own policy was EPA attorney policy, so I was engaged with EPA attorneys. The governoals for the policy, it gets more difficult, it takes more time. So I have dealt with public participation and open and closed door meetings.

Just to give you an idea of what I mean, I mean the public participation, the open and closed door meetings. This is a broad statement of the topics, which were not as an example of the broad categories.

Allow me to further delineate here in the broad categories. Essentially, it is a policy of law that deals with the carbon cycle and its effects on the American public. And certainly, that would be a part of that cycle, which is proposed that the policy is proposed, if you could allow me to some other conclusions about that.

The public participation, the open and closed door meetings, is an effort to really make the government to the people, for that, and certainly, there is a need for the public participation. It is my belief that it is really important that we do not get into that, and what we are dealing with, because the public is not getting that way. We are not dealing with the public, the public is not getting that way.

Similarly, there are other types of issues that we are dealing with in the project. We believe that we are dealing with some, but other agencies, and certainly we fail that we have the authority under 1608b to decide what to do.
proposed and funded projects that are not good for the environment or the economy.

The second major benefit of NEPA is the Clinton Water Act, which gives the EPA and the Corps of Engineers the authority to approve projects that will have a significant impact on the environment. This is important because it allows for a full review of potential environmental impacts before projects are approved, resulting in a more sustainable and cost-effective approach. If a project is approved, it will still be subject to NEPA scrutiny.

The two other points I would like to make are:

What is the significance of regulatory oversight in state water management?

Regulatory oversight is critical to ensuring that water resources are managed in an environmentally sustainable manner. It is important to note that any given project must be reviewed and approved by the appropriate regulatory bodies. If a project is not approved, it must be reworked or abandoned. It is the job of regulatory oversight to ensure that projects are not approval before the necessary environmental impact assessments are completed. The job of regulatory oversight is to ensure that the wrong project is not approved.

What are the benefits of regulatory oversight?

Regulatory oversight benefits communities by ensuring that the environment is protected and that projects are planned in the most effective manner. It also benefits businesses by ensuring that projects are not approved if they will have a negative impact on the environment. It is important to note that regulatory oversight is not limited to the approval of projects. It also includes the development and enforcement of regulations that are designed to protect the environment.

In conclusion, regulatory oversight is critical to ensuring that water resources are managed in an environmentally sustainable manner. It is important to note that any given project must be reviewed and approved by the appropriate regulatory bodies. If a project is not approved, it must be reworked or abandoned. It is the job of regulatory oversight to ensure that the wrong project is not approved. Regulatory oversight benefits communities by ensuring that the environment is protected and that projects are planned in the most effective manner. It also benefits businesses by ensuring that projects are not approved if they will have a negative impact on the environment.

Author:

Dr. Robert A. Johnson,
Policy Center for Science and International Affairs,
Harvard University

I am not sure if the message is clear.
Panel Chair: Good morning everyone. I've worked in this industry for many years and I've seen a lot of changes. The market is constantly evolving, and as a result, so must our approach to managing it. We've seen a shift towards more sustainable practices, and as an industry, we need to adapt to these changes if we want to stay ahead.

Audience Participant 1: This is a critical issue for our agency. As the leader of our department, I've been working hard to implement sustainable practices. It's important that we set an example for the rest of the industry. We've started by reducing our office waste, and I'm thinking about implementing a recycling program for our clients as well.

Audience Participant 2: I agree. It's not just about reducing waste, it's about making a positive impact on the environment. We need to be proactive in our approach.

Panel Chair: Thank you. I'd like to hear from more participants. What are some of the challenges you've faced in implementing sustainable practices?

Audience Participant 3: One of the biggest challenges we face is resistance from clients. They're often more focused on cost than on sustainability. It's important that we educate them on the benefits of sustainable practices.

Panel Chair: That's a valid point. Education is key. Thank you for sharing your insights. Let's keep the conversation going.

Audience Participant 4: I think technology could play a big role in this. We're seeing a lot of advances in sustainable technology, and I think we should be exploring how we can integrate them into our practices.

Panel Chair: Absolutely. Technology can be a powerful tool. Let's continue to explore these ideas and see how we can implement them in our agencies.
[Text content]

Audience

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Moderator: It may take the things of responding to that. Our view is that at least in the instance of Maine, as you know, it is not easy to say more than the fact that we all are getting ready to hear what you think, and after it while you get everybody's input. Through the process that we work with, with the Public Water Supply Improvement Plan and the state agencies, the Maine Department of Environmental Protection to the interaction of that, the process where inquiries would get any of the necessary information materials, which [it] be the fact in detail, are for more than 30 years of experience, it brings to the mind of the agencies and the state agencies. And what some people who are able to the up front in the minds of the agencies requirements that they would have to do or would the different agencies are, that do any of you have anything you would like to add?

Audience: Many people in the audience, we have already been talking about the... we have already started getting materials together. I sit on a board with a GSA board in Maine, and we are going to be working on these issues... we are very, very excited about the Department of Environmental Protection and we will still be trying to get it step by step, what you need to do, but what you need to do, and... and what will need to be. That is going to be the next line of... and we also will have a printed handout for those who are interested in some of the specifics.

Moderator: We'll say it right to CSG, in a few pages.

Audience: [inaudible] notes that much of the conversation... the last three days at the Executive Office of the Governor, the three agencies that are currently... [inaudible] to how the suggestions that are contained in theNortheast Management Council meeting, which is to do, every public policy meeting, the Department of the Interior, the Department of the Interior, the Regional Water Source, people have been saying, "It's a lot of work and it is complicated," we're talking about what it is going to mean to...
Audience: It wouldn't be fair to repeat that word that appeared in... 

Audience: Mark White, Ireland:

As an outsider, a couple of comments. A lot of people think that this is a question of how much power we have in the world today... that the real difference between being good and bad work... TAKE ACTION. I am one person, and I think in... of the more measured wisdom, that is, small actions that are happening in different places... that they are not being done everywhere... that they are not being done in the same way... that they are not being done in the same way... and that the national government is not... My reaction has a great emphasis on the... - for governments is... for them to be... and I think that comes in the framework of policy... and I'm a politician. This is a topic that from... is a topic that is... from the time... is a topic that is... from the time... that is... from the time... is a topic that is... from the time... My reaction is that... My reaction is that... My reaction is that...
I think it's important that we take care of the natural environment because it's the only one we have. We need to protect it for future generations. It's our responsibility to ensure that our actions don't harm the environment. We need to be more sustainable and find ways to reduce our impact on the planet. This is not just a problem for the future, but it's a problem for today.
get many more, including incinerators, where public hearings are held. Very often the hearings are really about how to get the incinerator built, and not about what's going to happen to the waste. The hearings are designed to be long, drawn-out processes that are intended to discourage opposition. The people who live near the incinerators often feel powerless to stop the construction. They feel that their rights are being ignored and that they have no say in the decision-making process.

Lender: The same thing is true of many of the waste incinerators and recycling facilities that have been built in the United States. In many cases, the local communities have been left out of the decision-making process, and the waste incinerators have been built without adequate public input. This has led to widespread concern about the health and environmental impacts of these facilities.

Auditor: There is a similar problem with the development of new technologies. For example, when new technologies are introduced, the regulations that govern them are often not well-developed or are poorly enforced. The new technologies may pose new risks that are not well understood, and the regulations that govern them may not be adequate to protect the public.

Lender: There is a need for better coordination and communication between government agencies and the private sector to ensure that new technologies are developed and implemented in a way that is safe and sustainable. This includes working with communities to ensure that they are involved in the decision-making process and that their concerns are taken into account.

Auditor: There is a need for more education and outreach to help prepare communities for the challenges they may face when new technologies are introduced. This includes providing information about the technologies and their potential impacts, and working with communities to develop strategies for addressing these challenges.
Agricultural policy is a complex and often contentious area. The Australian government's approach to agricultural policy involves the participation of various stakeholders, including farmers, industry groups, and government officials. This approach recognizes the diverse needs and interests of different groups and takes into account their input to make informed policy decisions.

In New Zealand, the government's approach to agricultural policy is also characterized by a focus on collaboration and consultation. The Ministry of Agriculture and Forestry works with a range of stakeholders to develop policies that reflect the needs of all involved parties.

Moderator: Thank you, Christine, and this will be close to the last round.

Audience: (Unidentified) I just want to raise the question of the role of the Department of Agriculture. Do they have the lead role in agricultural policy? The role they play is not always clear. I think they have, most of the time, the policy is set by the Department of Agriculture, and they are the ones who have the responsibility for making the decisions. I think they are the ones who have the responsibility for making the decisions, and they are the ones who have the responsibility for making the decisions.

Moderator: Thank you, Christine, and this will be close to the last round.

Audience: (Unidentified) I just want to raise the question of the role of the Department of Agriculture. Do they have the lead role in agricultural policy? The role they play is not always clear. I think they have, most of the time, the policy is set by the Department of Agriculture, and they are the ones who have the responsibility for making the decisions. I think they are the ones who have the responsibility for making the decisions, and they are the ones who have the responsibility for making the decisions.
Balancing the competing demands for marine resources

Kenneth L. Reid
National Marine Fisheries Service
Newport, Rhode Island

The National Marine Fisheries Service has many missions, including habitat development, fishery conservation, and science management. The fisheries development is not simply catching more fish; it is the science and technology that allow fishermen and resource managers to improve their methods of living. These efforts are often linked closely with fisheries development's impacts on other marine species. Recreational fishing, for example, is the most heavily regulated and monitored activity in the United States today. However, it is also one of the most important sources of revenue for coastal communities. As a result, the National Marine Fisheries Service must balance the demands of multiple stakeholders, including fishermen, environmental groups, and the public. This can be challenging, especially when there are conflicting interests involved.

Aquaculture, like other areas of fisheries development, has significant economic benefits, but it also has potential environmental impacts. The National Marine Fisheries Service recognizes that the development of new aquaculture facilities must be done in a way that minimizes negative impacts on the environment. This includes considering the potential impacts on local ecosystems, as well as the potential for unintended consequences. The Service also works with other federal agencies and private sector partners to ensure that aquaculture development is done in a sustainable and environmentally sound manner.

Our role is to ensure that the development of new aquaculture facilities is done in a responsible and sustainable manner. This includes working with other federal agencies, as well as with local communities and other stakeholders, to ensure that the long-term health of the environment is not sacrificed for short-term economic gains. We also work to promote the development of new aquaculture technologies that are more efficient and environmentally friendly. This includes encouraging the use of recycled and renewable resources, as well as developing new methods for converting waste materials into valuable products.

In conclusion, the National Marine Fisheries Service is committed to ensuring that the development of new aquaculture facilities is done in a responsible and sustainable manner. This requires careful consideration of the potential impacts on the environment, as well as the long-term economic and social benefits. By working with other federal agencies and stakeholders, we can ensure that the development of new aquaculture facilities is done in a way that benefits both the environment and the communities that depend on it.
The New England Fishery Management Council's Role in Offshore Aquaculture

Rev. Towle
New England Fishery Management Council
Quincy, Massachusetts

Since a number of pertinent issues have come to the New England Fishery Management Council for their consideration, as well as to other pertinent issues within an offshore environment, I will briefly describe the Council's efforts in this area. The recent growth of interest and research in the aquaculture industry has made the consideration of offshore aquaculture extremely important, and is expected to have a significant impact on regional economies. The Council has been involved in the development of guidelines and recommendations to ensure the sustainable and responsible growth of the industry. The Council's role is to provide scientific advice, develop management plans, and implement measures to protect the marine environment. The Council's efforts are aimed at balancing the needs of the industry with the conservation of marine resources.

The Council has been involved in the development of guidelines and recommendations to ensure the sustainable and responsible growth of the industry. The Council's role is to provide scientific advice, develop management plans, and implement measures to protect the marine environment. The Council's efforts are aimed at balancing the needs of the industry with the conservation of marine resources.
I should like to point out that the NPL Project, which was not discussed in the NPL Report, has not been completed in a way that reflects the needs of the affected communities. The NPL Project was designed to address the issue of radioactive waste disposal in a manner that would minimize the risk to human health and the environment. This was done through the selection of a site that was believed to be safe and the implementation of strict safety measures. However, the NPL Project has not been fully completed, and the site has not been activated. The safety measures that were put in place have not been sufficient to ensure the safety of the surrounding communities.

In conclusion, I believe that the NPL Project has not been completed in a manner that reflects the needs of the affected communities. The safety measures that were put in place have not been sufficient to ensure the safety of the surrounding communities. The NPL Project has not been completed in a way that reflects the needs of the affected communities.
Federal Regulatory Issues re Offshore Aquaculture Projects

Gary Kelly

1. Conflicts with navigation:
   * shipping, recreational use, near-ship deployments
   * appropriate site markings

2. Survival adequacy:
   * missing system design criteria
   * operational vs. external conditions
   * implications of failure

3. Impacts on habitat and endangered species:
   * coordination per Sect 7, ESA — Biological Assessment
     * site selection, gear design, time of year issues

4. Marine environment issues:
   * water column, bottom sediments
   * operational issues — artificial lighting, handling
   * MPA — for debris, food, pollution

5. Impacts on wild stocks:
   * disease transmission
   * genetic interactions — escaped farmed species
   * changes in local food chain

6. Use caution:
   * internal use of the project site
   * gear materials
   * management issues
   * NFWMC jurisdiction
Open Ocean Aquaculture: A Conference Summary Overview

Dr. A.M. Baruch
UMD Director
UMD Marine Science Program
University of New Hampshire
Durham

The conference focused on a growing concern among stakeholders, including managers and scientists, that the current regulatory framework does not adequately address the needs of the open ocean aquaculture sector. This includes a lack of clear guidelines, inadequate oversight, and limited research capacity.

Another key takeaway from the conference was the recognition of the importance of fostering a multidisciplinary approach to open ocean aquaculture development. This includes integrating insights from marine science, engineering, economics, and policy to ensure sustainable and responsible practices are adopted.

During the past several days, we have heard much encouragement from our participants who are working tirelessly to overcome these challenges. Continuous progress toward commercial implementation of open ocean aquaculture will require an integrated and collaborative partnership between government and industry. I am delighted to see the commitment to this partnership, and we look forward to further discussions with stakeholders and stakeholders at the conference.

The conference proceedings are a comprehensive approach to encouraging and building capacity for new industries. A crucial component of setting new research directions is to ensure that we are taking the opportunity to...

[The text continues with more detailed information and discussion, though specific details are not transcribed here for brevity.]
The pace of change in the field of aquatic research is rapid, with new technologies and methodologies being developed and implemented. It is essential to have a strong foundation in aquatic science to keep up with the latest developments. The goal of this project is to develop a comprehensive database of aquatic species and their characteristics. This database will be used to support research and conservation efforts. The project team will work closely with experts in the field to ensure the accuracy and completeness of the database. The final product will be a valuable resource for researchers, policymakers, and the general public. The project will be funded through grants and partnerships with organizations and institutions. The success of the project will depend on the collaboration and support of all involved parties.
part of the demonstration project now planned for utility and Industrial. 1998. We plan to produce tool prototypes for demonstration projects with environmentally sustainable treatment methods. An assessment of treatment effect, and assessment of the system's performance will be conducted by the universities, organizations, and companies involved.

An agency agrees that the demonstration project would address key concerns about the practical feasibility of large-scale treatment of the industrial wastewater. The demonstration project will help to ensure that the long-term benefits of new management and operational improvements, and the commercial implementation of new technologies are significant.

I encourage all of you to work with the reference sponsors: the UNRIM Project, the National Clean Water Program, and the National Market Service. Let us encourage research in biology, chemistry, geology, and engineering. Let us consider how regulatory changes, changes in urban planning, and commercial development can participate in activities that demonstrate the feasibility of new technologies to commercial applications.
Participants

Tony Halcomb
Soft X-ray Inc.
15181 Park Blvd
Parker, CO 80138
USA
Tel: 720-711-1171
Fax: 720-711-1170

Kurt M. Fauchere
Molecular Imaging Co.
19501 Grande Pkwy
San Antonio, TX 78258
USA
Tel: 210-530-2780
Fax: 210-530-2781

Kenneth C. Flaks
Molecular Diagnostics Group
University of New Hampshire
Kingston, NH
USA
Tel: 603-862-4460
Fax: 603-862-4461

John M. Haggard
GynoCare Management
785 South Cure Court
Auburn, MA 01501
USA
Tel: 508-251-0422

Elizabeth B. Blanchard
Molecular Imaging Dept.
Cambridge, MA 02142
USA
Tel: 617-492-0511
Fax: 617-492-0512

William J. Bally
Laboratory Director
11911 Cambridge Street
Cambridge, MA 02140
USA
Tel: 617-713-0409
Fax: 617-713-2233

Annie J. Halcomb
Research Associate
11911 Cambridge Street
Cambridge, MA 02140
USA
Tel: 617-713-0409
Fax: 617-713-2233

Kurt M. Fauchere
Molecular Imaging Co.
19501 Grande Pkwy
San Antonio, TX 78258
USA
Tel: 210-530-2780
Fax: 210-530-2781

Kenneth C. Flaks
Molecular Diagnostics Group
University of New Hampshire
Kingston, NH
USA
Tel: 603-862-4460
Fax: 603-862-4461

John M. Haggard
GynoCare Management
785 South Cure Court
Auburn, MA 01501
USA
Tel: 508-251-0422
Fax: 508-251-0423

Elizabeth B. Blanchard
Molecular Imaging Dept.
Cambridge, MA 02142
USA
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