DESIGN CONCEPTS FOR INTEGRATION OF OPEN OCEAN AQUACULTURE AND OSPREY™ TECHNOLOGY

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ABSTRACT

A unique opportunity exists to develop a multi-benefit, commercial ocean enterprise off the coast of New England, with potential sites reaching from Nantucket, Massachusetts, to Eastport, Maine. This enterprise could generate electric power, provide a base for installation of open ocean aquaculture facilities, help revitalize depleted fisheries, recycle discarded materials, and enhance economic development in several coastal industries, including shipbuilding and tourism. The concept is centered on the Ocean Swell Powered Renewable Energy (OSPREY) technology device developed by Applied Research & Technology (ART) of Inverness, Scotland. The OSPREY is a hybrid wind/wave energy generation system wherein wave energy is harnessed by means of an oscillating water column within a collector chamber anchored to the ocean floor by large, permanently installed ballast tanks. The OSPREY forms the central element in a multi-use ocean structure. Successful establishment of aquaculture facilities in the high energy environment off the New England coast will require solutions to a number of engineering challenges including structural integrity, security, operability, maintainability, and affordable design. The concept of design integration of aquaculture net pens into the OSPREY provides the opportunity to meet a number of these challenges in a cost-effective manner. Concepts for integration of submersible and floating net pen structures and their operation into the OSPREY technology must be advanced, potential sites must be studied, and benefits to the aquaculture industry determined.

INTRODUCTION

The purpose for this paper is to present and discuss ideas for an existing technology which may provide a viable technical and commercial partner for offshore aquaculture facilities in the future. It is clear, from research conducted by the present authors and many others, that the establishment of a viable offshore aquaculture industry in the Northeast United States will require meeting numerous technical and economic challenges.

An offshore location for aquaculture facilities will require structural design for survivability in the severe weather, which is prevalent during the fall and winter seasons in these areas. Large, wind-driven waves and strong currents are common in these latitudes, even relatively close to the coastline. Permanently moored net pen structures must be designed to maintain structural integrity and net integrity in conditions approaching sea state seven (perhaps higher sea state during hurricane season), and currents up to 3 to 4 knots.

The offshore aquaculture facilities must be designed to provide for logistic support from shoreside facilities through the use of service vessels. The service vessels must be able to come alongside, dock, and offload personnel, supplies, and equipment. Furthermore, products will be

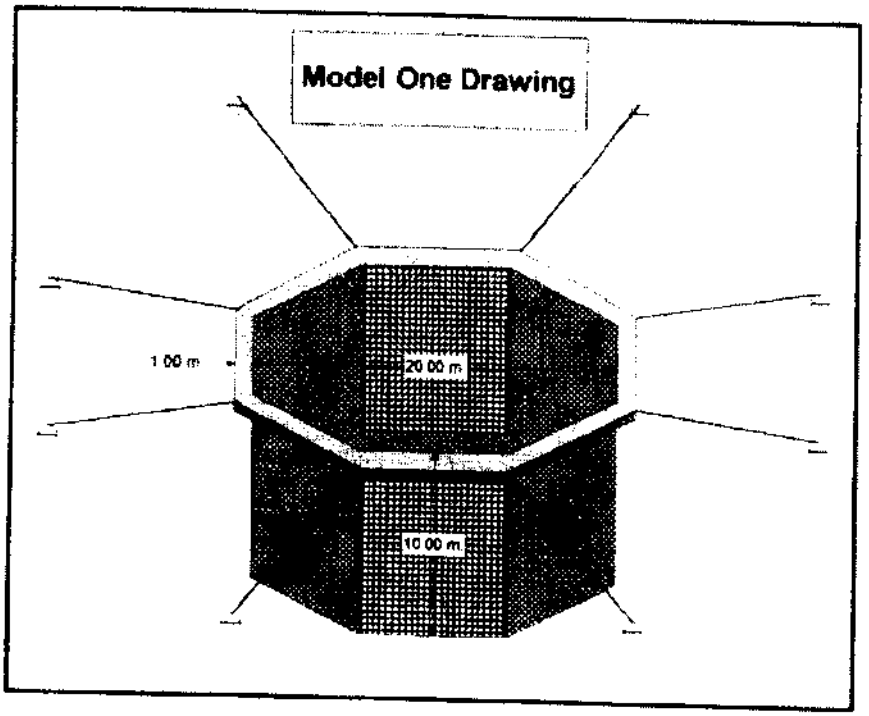


Figure 1. Modular floating net pen.

harvested and delivered to shoreside facilities for processing by the same service vessels. The aquaculture facility must provide for effective harvesting and net handling.

One of the major concerns voiced by the operator community has been associated with security of such offshore facilities. These structures will represent potentially large capital investment in net pen structures and finfish stock. Access to these facilities will be limited and/or impossible during extended periods of bad weather. This is in contrast to the existing operating conditions inshore, where daily access and visual inspection are possible during all weather conditions. Potential security concerns include accidental collisions by commercial shipping and offshore fishing vessels, intrusion by marine mammals, human intrusion, and detection of structural degradation.

The economic challenges associated with establishment of a viable offshore aquaculture industry are substantial. The market conditions for finfish products in the United States are extremely competitive today. As finfish aquaculture expands in developing countries, market competitiveness is expected to increase. The cost for purchase, maintenance, and operation of offshore facilities will be higher than such costs for today's inshore facilities. These trends are clearly in conflict. Future offshore aquaculture operators will be required to explore new and novel techniques for reducing cost and increasing productivity in order to remain competitive.

Several net pen architectures are currently in use or are under consideration for offshore facilities. Figures 1 through 4 illustrate floating, modular net pens, two types of individual floating net pens, and a submersible net pen concept advanced by the Ocean Engineering Department at the University of New Hampshire. Each of these architectures provides relative advantages and disadvantages. Each meets the projected requirements with varying degrees of success.

Notional Technical Requirements

In order to visualize the potential advantages to integration of aquaculture net pens with OSPREY™ technology, it is useful to review specific notional engineering technical requirements for offshore aquaculture. It is expected that these

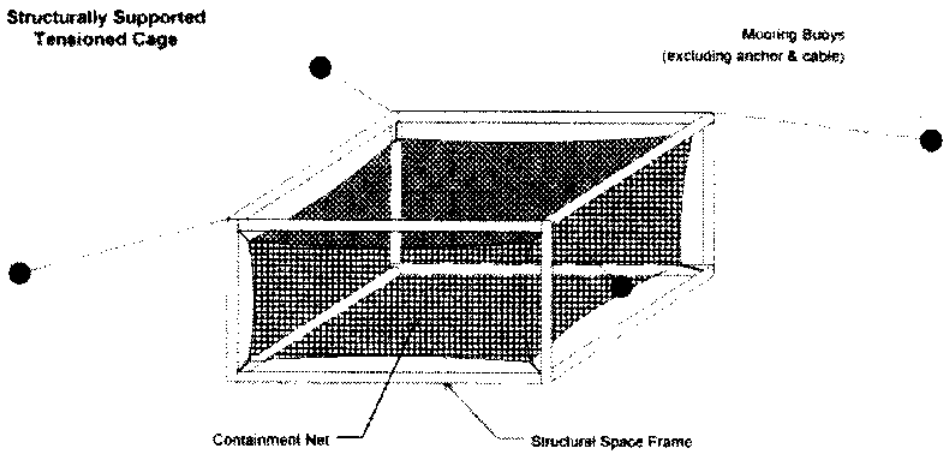


Figure 2. Individual rigid floating net pen.

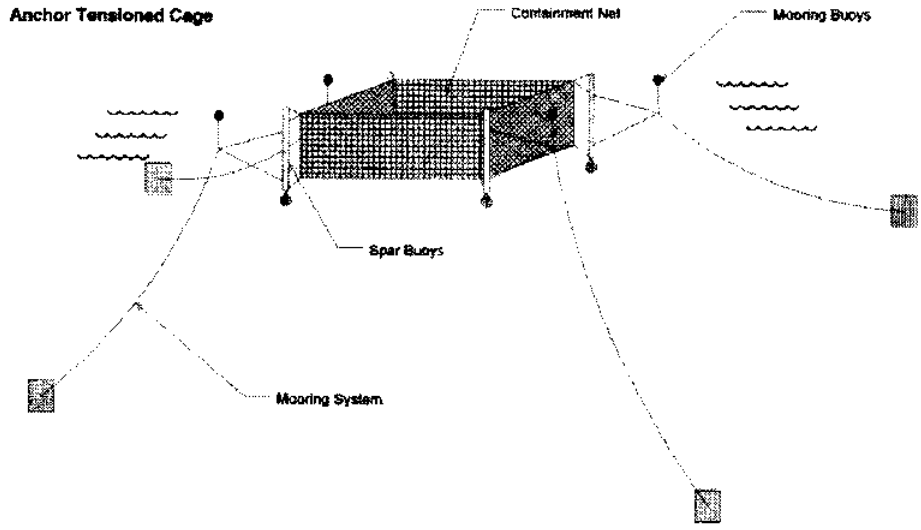


Figure 3. Individual flexible floating net pen.

facilities must meet the following operational and technical requirements:

- The facility must have the capability for independent operation without human intervention for extended periods. These periods would be primarily due to weather conditions. This operational need is distinct from today's practice of daily human intervention which is, in most cases, continuous during daylight hours.
- The structure must retain integrity during periods of severe weather. As described earlier, these periods would be primarily during the fall and winter seasons. However, brief periods of severe weather may occur during spring and summer seasons as well.
- The facility must provide a stable platform for personnel to perform operation and maintenance tasks during periods of occupation. Walkways and enclosures are

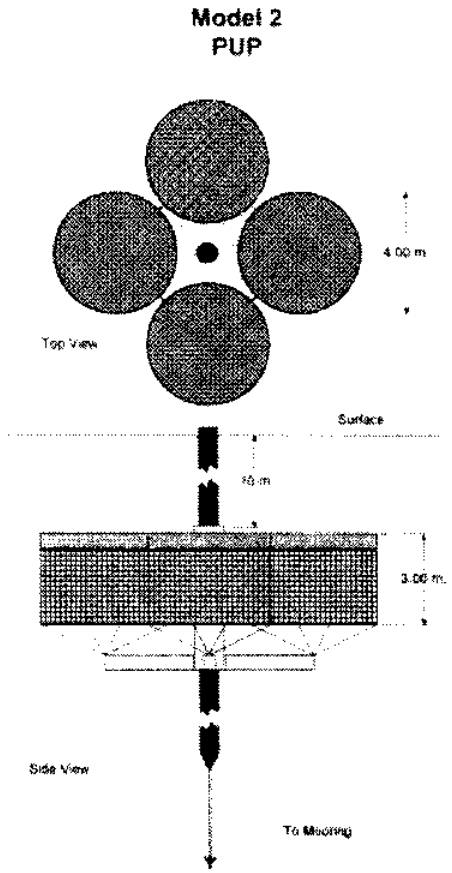


Figure 4. Pull-up pen (PUP), submersible net pen.

needed. Personnel safety must be ensured. Also, stability of the platform may be an issue for certain species of finfish envisioned for offshore culture.

- Provision for alongside operations by service vessels is required. This consists of features for tie-up, fending, loading and unloading of cargo and personnel, and conduct of net handling operations. Successful performance of these evolutions in open water will require careful engineering design and careful planning at time of execution.
- The facility must include sheltered storage space for feed, tools, spare parts, lines, nets, and other miscellaneous equipment.
- The facility should provide habitability space for short overnight visits by personnel during periods of settled weather and high activity aboard.
- The facility must provide sheltered spaces with suitable environment for electrical and electronic equipment. Such equipment may include sensors and monitoring equipment for intrusion detection and alarming, net containment breach, structural failure, weather conditions, automated feeding equipment, navigational aids, telemetry electronics, actuators for surfacing and submerging of submersible net pens, materials handling equipment such as cranes and hoists, electricity generation, and others.
- The facility must provide security monitoring and alarming. Security includes human intrusion, predation, structural integrity, and net containment integrity.
- The facility must provide an on-board electrical power source for sensors, monitoring equipment, processors, navigational aids, telemetry electronics, materials handling, automated feeding, and actuators.

Through consideration of the operation and maintenance of a future offshore aquaculture facility, it becomes clear that the design of such a facility must be very carefully considered, with participation by experienced operators along with mechanical, electrical, ocean engineers, and marine biologists. A successful design will require an interdisciplinary approach by a dedicated design team.

In considering a relatively mature technology for electrical power generation using wave energy, known commercially as **O**cean **S**well **P**owered **R**enewable **E**nerg**Y** (OSPREY™), it became clear to the authors that an opportunity for strong synergy between renewable power generation and aquaculture off the New England coast exists. Design of an aquaculture facility for integration with an OSPREY™ array offers the potential to satisfy many if not all of the engineering technical requirements for aquaculture described above. In addition, business arrangements may be feasible between the aquaculture operator and the power generation commercial entity (such as lease) which greatly reduce the cost of operation and maintenance of the aquaculture facility. In the next section, we provide a brief overview of the OSPREY™ system and notional concepts for

integration of net pen designs. The reader is encouraged to consider the potential advantages for structural integrity, protection from wave action, housing, storage, and electrical power which may accrue from such integrated design.

OSPREY™ system description and concepts for integration with aquaculture net pen designs

The concept of utilizing ocean wave action as an oscillating water column for energy generation is an accepted technology and is utilized in numerous applications around the globe. Most of these installations are based upon coastal geology and therefore offer poor replicability on a general scale. The ability to fabricate such a device into a deployable configuration would have far-reaching impact on renewable ocean energy utilization and sustainable-yield aquaculture development. This proven technology was realized through the development of OSPREY by Applied Research &Technology of Inverness, Scotland. The OSPREY unit is fabricated of a closed rear bulkhead catamaran design. Each unit would consist of 800 tons of steel or concrete and is estimated to cost $5 million US to build, including an NEG Micon 1-Mw wind generator. Figures 5 through 7 depict OSPREY units in various settings.

Each unit will be constructed in a local shipyard and launched, towed or thrusted to the deployment site where it is scuttled and ballasted to the bottom, then interconnected to the grid via submarine cable. Each unit will be designed for local wave resource optimization. When deployed, each unit will displace in excess of 8000 tons. This formidable structure, when deployed in arrays of five to ten units, will be able to enhance the wave capture resource and the aquaculture resource yield can be increased substantially.

LIMPET (Locally Installed Marine-Powered Energy Transformer) coastal harbor deployment unit

Where practicable, structures could be deployed along coastal harbors, improving harbor defense against ocean wave action while generating clean renewable energy. We have identified our oceans as an important new frontier; we will need a platform to develop our coastal marine technologies and OSPREY is ideal. An

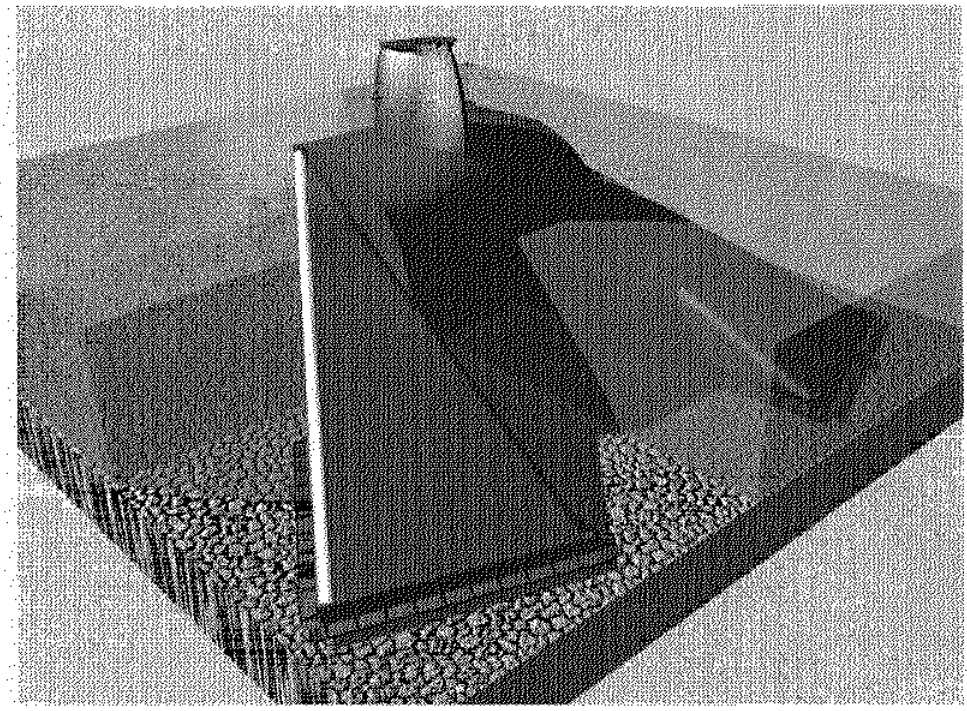


Figure 5. Dimensional 3-D drawing of OSPREY.

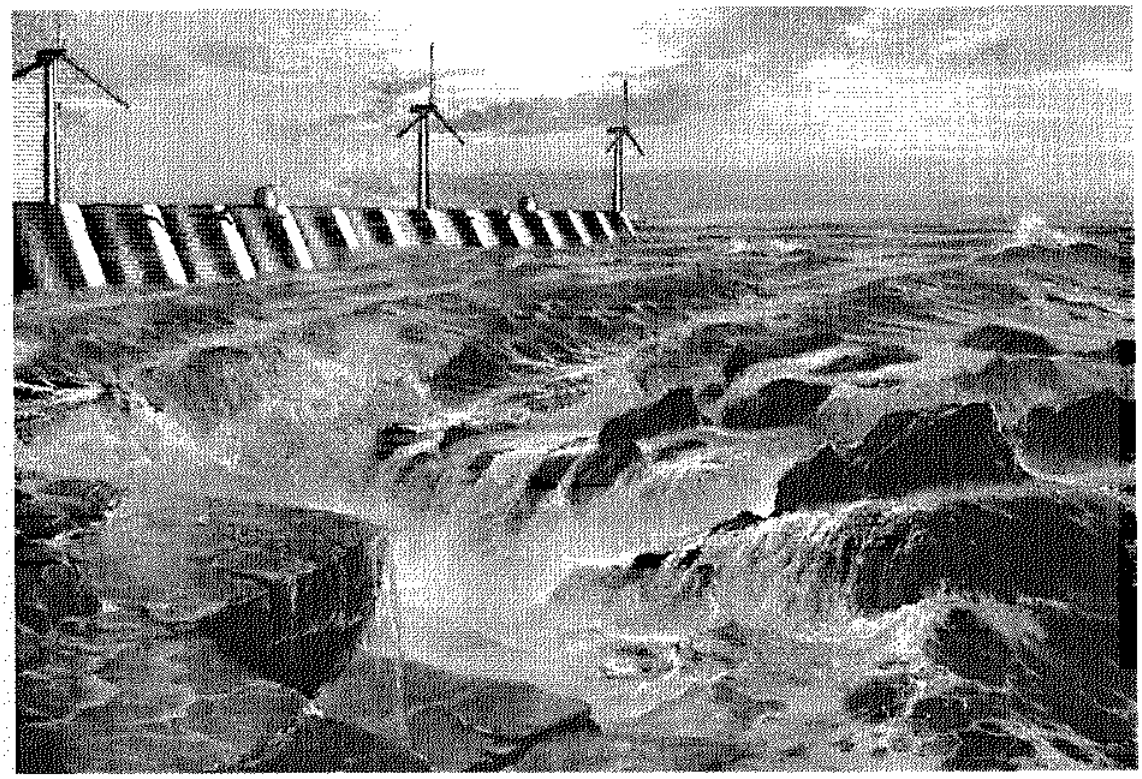


Figure 6. Rocky coastal harbor unit.

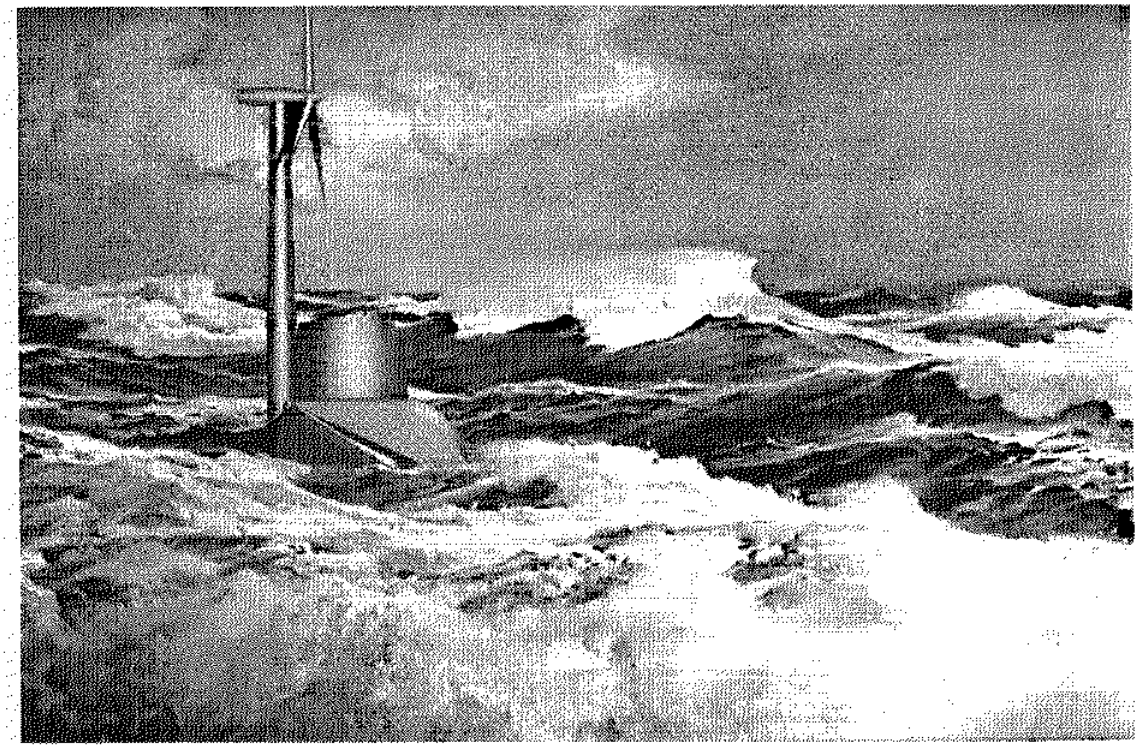


Figure 7. Ocean energy unit in storm conditions.

array of ten OSPREY could provide offshore research opportunities for a better understanding of our coastal ocean resources. The structure could provide sheltered facilities for the support of ocean ranching as suggested in the open ocean cage culture section of this paper. The structure would perform well as a structure for meteorological arrays, remotely operated vehicle (ROV) deployment, aquaculture, and cage culture as well as offshore laboratory deployment.

Each site will determine structure design

The variability of the ocean wave resource makes the specific design of the wave capture chamber and ancillary design criteria such as those outlined previously very site-specific. It is therefore necessary to understand the resource from a regional coastal perspective with energetic resource sites given a priority development focus. Coastal resources, demand characteristics, and demographics will determine the final economic potential of each deployment opportunity.

The authors believe that the overall economic resource represented in the development of regional OSPREY centers will be substantial. The aquaculture community is in general agreement that offshore cage culture will become an important component of the future for sustainable-yield aquaculture development. The OSPREY unit presents the opportunity for a myriad of marine technology applications as well. A detailed ocean energy resource assessment should be conducted. This study will determine the wave resource potential and unit design criteria for a pre-designated area, ideally, from Florida, USA, through Newfoundland, Canada.

Recommendations for future work

Future offshore aquaculture facilities must be designed to meet challenging engineering and technical requirements. Potential for meeting these requirements may be substantially improved through integration of these facilities into the design of OSPREY™ offshore power generation structures. The OSPREY™ technology is relatively mature and commercially available. Potential exists for attractive commercial arrangements between the aquaculture operators and the power generation business entity which may increase the cost competitiveness of finfish culture. Furthermore, the integration of aquaculture structures into the OSPREY™ design could probably be accomplished with minimal impact to the OSPREY™ mission.

The first step must be to fully evaluate the potential market demand for commercial power generation with the OSPREY™ system off the Northeast coast of the United States. It must be shown that OSPREY™ can generate power at significant levels at a competitive cost with fossil or nuclear sources. It should be noted that with the on-going deregulation of the power generation industry in the Northeast, several states are considering mandatory use of renewable energy sources at a percentage of the total energy usage. It must be shown that OSPREY™ can compete with wind and hydropower sources.

A systems engineering study is required to integrate net pen concepts with the OSPREY™ structure. Concepts for aquaculture mechanical and electrical systems, aquaculture primary structure for alternative architectures, and concepts for operation of both the OSPREY™ system and the associated aquaculture facility must be developed and evaluated. An important element of this systems engineering effort must be cost estimates for acquisition, construction, and operation of the integrated facility.

A final element of this early work must be the examination of the range of commercial arrangements which may be possible between the aquaculture operators and energy generation operator. The objective of this systems engineering effort will be to establish the technical and commercial feasibility of the integration of aquaculture with OSPREY™ power generation for sites off the Northeast coast of the United States.

WATER QUALITY GUIDELINES FOR AQUACULTURE: AN EXAMPLE IN JAPAN

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ABSTRACT

The basis for setting up water quality criteria (WQC) for the protection of aquatic living resources set by the Japan Fisheries Resource Conservation Association (JFRCA) is that good water quality is needed to provide for the healthy growth of fish and shellfish and to maintain their high economic values. Eleven parameters are established to maintain optimal conditions. The parameters are dissolved oxygen (DO), chemical oxygen demand (COD), pH, suspended particulate matter (SPM), total phosphorus (TP), total nitrogen (TN), amount of coliform bacteria, *Escherichia coli*, petroleum hydrocarbons, temperature, toxic chemicals, and sediments.

INTRODUCTION

In the 1960s, water pollution was an epidemic in Japan and many fears concerning contamination of fish and shellfish were widespread. In response to those public concerns, in 1965, the Japan Fisheries Resource Conservation Association (JFRCA) had established Water Quality Criteria (WQC) for the Protection of Aquatic Living Resources. The WQC have been revised several times, and a major revision was made in 1995 (JFRCA 1995) reflecting the renewal of the Environmental Quality Standards for Water Pollution (EQSWP) set by the Environment Agency of Japan (EAJ). These WQC in the marine environment are presented and the strategy for determining WQC values is discussed in this report.

Basis for Water Quality Criteria

The ideal situation in a good marine environment for fish and shellfish often is one without any anthropogenic perturbation. But, that is almost impossible and it is not practical to set WQC based on no human impact. Therefore, we need to seek a way to reconcile human activities with preservation of a good marine environment. Under these circumstances, good water quality is the water condition which produces normal and safe-to-eat fish. Harvested fish also need to be economically high in value so that fishermen can earn enough money for a living. These basic ideas should also be applicable to aquaculture. Human impacts are actually larger in aquaculture as it is normally operated in semi-enclosed waters where water quality tends to get worse even without anthropogenic perturbation.

Items Related to Living Environment

Eleven items are listed in Table 1. These were made by reviewing existing data and also considering the environmental quality legislation (Environmental Quality Standards and its related legislation) issued by EAJ. Each item is discussed below.

Dissolved oxygen (DO)

Normal environmental water contains oxygen close to its saturation depending on temperature and salinity. But the concentration may fluctuate significantly in a short period of time and it is difficult to maintain at a steady level. Only a few studies have been reported for DO requirements for saltwater fish. An excellent review by Davis (1975) indicates that an oxygen saturation level less than 60% may induce physiological changes in some marine species such as pile perch, dogfish, and dragonet. Saunders (1963) even reported that any reduction in ambient

Table 1. Water Quality Criteria for the protection of aquatic living resources: items related to living environment (by JFRCA).

Items	Concentration
Dissolved Oxygen	6 mg/L
COD, Open waters	1 mg/L
Coastal waters	2 mg/L
pH	7.8 - 8.4
SPM	2 mg/L
TP, Open waters	0.03 mg/L
Coastal waters	0.05 mg/L
Nearshore waters	0.09 mg/L
TN, Open waters	0.3 mg/L
Coastal waters	0.6 mg/L
Nearshore waters	1.0 mg/L
Escherichia coli (MPN/100 mL)	1000
n-Hexane extracts	<D.L.
n-Hexane extracts in sediment	0.1% (dry)
sediment COD	20 mg/g (dry)
Sediment sulfide	0.2 mg/g (dry)

oxygen level produces a rise in ventilatory water flow in Atlantic cod.

For common Japanese commercial fish such as jack mackerel, sandfish, yellowtail, black seabream, red seabream, stingfish and puffer, the incipient lethal level of DO ranges from 0.2 to 1.5 ml/L (JFRCA 1989). Chiba (1983) reported, based on his laboratory studies, that the 60% oxygen saturation level is necessary for the healthy growth of silver bream. Field surveys of benthic organisms in the Seto Inland Sea by Imabayashi (1983) show that a decrease in DO causes a decrease in the species diversity. Moreover, the number of benthic organisms exponentially decreases with decreasing DO and below the DO concentration 2 ml/L their survival becomes very low. Similar studies in Omura Bay by Mori et al. (1973) indicate that benthic organisms such as goby, shrimp, and crab can apparently swim away from low oxygen waters (< 3 ml/L). By considering all these facts, JFRCA judged the critical concentration level to induce a physiological change in saltwater fish to be 3.0 ml/L (= 4.3 mg/L). Considered as a safe factor, JFRCA recommends 6 mg/L as WQC.

Chemical oxygen demand (COD)

The COD is an amount of oxygen molecules equivalent to organic matter consumed by oxidizing chemical reagents. There are several methods for the determination of COD. Japanese Industrial Standards (JIS) has listed three methods (Japanese Industrial Standard 1993). Among them, the dichromate reflex method is most widely used for COD (COD_{Mn}). But, this method is interfered by chloride ion and suffers reproducibility. Since the chloride ion is the major component of seawater, this method is not suited for seawater analysis. The recommended procedure is alkaline oxidation using potassium permanganate (COD_{OH}).

The COD is considered an indicator of eutrophication. A high load of nutrients and organic matter from land disrupts the material cyclings in coastal environments and produces nutrient-rich conditions and eutrophication (Fig. 1). The target value of COD_{OH} is not an anthropogenic perturbation level. In the marine environment, reported values of COD during a pre-highly industrialized period in Japan between 1931 and 1940 are less than 1 mg/L. However, some coastal species such as mullet, sea bass, and sardine are known to be caught in higher COD waters (Satomi 1985). Therefore, JFRCA recommends 1 mg/L as WQC for open waters and 2 mg/L for coastal waters.

pH

An event of acid rain leads the public to an increasing awareness of a pH change in aquatic environments, especially in the freshwater system. A suitable pH range for organisms is 6.5 - 8.5. A pH change may induce a physiological disturbance. It may also promote a higher toxic effect of chemicals dissolved in water to aquatic organisms. However, in the marine environment, the effect of acid rain is minimal due to the buffering capacity of seawater. JFRCA recommends natural levels

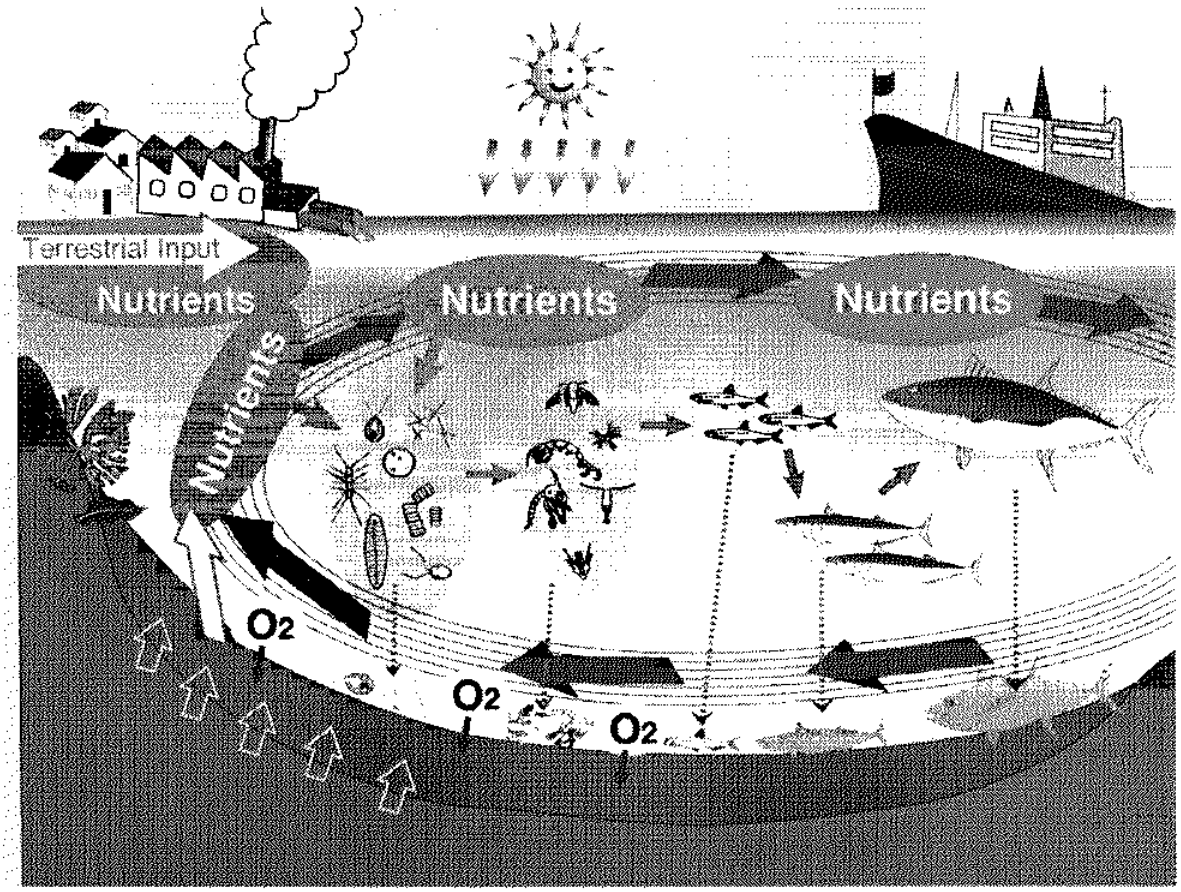


Figure 1. Material cycling in coastal environments (modified after JFRCA).

of pH, 7.8-8.4 for seawater, as WQC.

Suspended particulate matter (SPM)

In general, aquatic organisms, especially bottom-dwelling fish, can adapt to high concentrations of chemically non-reactive SPM. However, pelagic fish may show an escape movement from muddy waters. Furthermore, 5 mg/L of SPM can be fatal to juvenile striped knifejaw (*Oplegnathus fasciatus*). Natural population of phytoplankton can also be considered as SPM since SPM is defined as any substances trapped on a filter. Therefore, JFRCA recommends the man-induced SPM (such as from sewage and industrial effluents) of 2 mg/L for seawater as WQC.

Total phosphorus (TP) and total nitrogen (TN)

These are also used as indicators for eutrophication. However, it is difficult to determine the baseline concentration and to set a WQC, especially in coastal waters. Coastal waters are always influenced by land runoff and offshore currents. Nutrients are continuously supplied by lands and diluted with open-ocean seawater. Furthermore, natural causes such as upwelling can bring nutrient-rich waters to the surface.

The TP and TN are closely related to COD in seawater, and they are a sum of inorganic and organic forms of phosphorus and nitrogen, respectively. Living organisms such as phytoplankton are included in these fractions. By definition, these living organisms are also part of COD. Therefore, TN, TP, and COD are necessary for good environmental conditions for fisheries. There needs to be adequate levels of TP and TN to support good fisheries. After all, phosphorus and nitrogen are the nutrients for primary producers (Fig. 2).

Since the input of these nutrients and CODs

from lands is tightly regulated by the water pollution control legislation, TN, TP, and COD in seawater are mainly the results of organic production by primary producers, especially in nonpolluted areas. However, in a semi-enclosed water body where water circulation is restricted, TP and TN may be accumulated in the water column and they may trigger undesirable plankton bloom (red tide). An eventual collapse of the bloom can lead to the consumption of DO and higher COD values. Therefore, we need to seek desirable TP and TN levels to sustain primary producers, but not too much to produce high COD values (such as a production of red tide).

Satomi and Takayanagi (1987) reviewed the existing data of TN, TP, and COD in unpolluted coastal waters in Japan and recommended that 0.022 mg/L for TP and 0.32 mg/L for TN to meet the EQSWP COD value. Satomi (1983) also reported that higher populations of many commercially available marine species are found in the water having TP < 0.03 mg/L and TN < 0.3 mg/L. On the other hand, high populations of coastal fish such as mullet, sea bass, and sardine are found in the water having TP > 0.1 mg/L and TN > 1.0 mg/L (Satomi 1985).

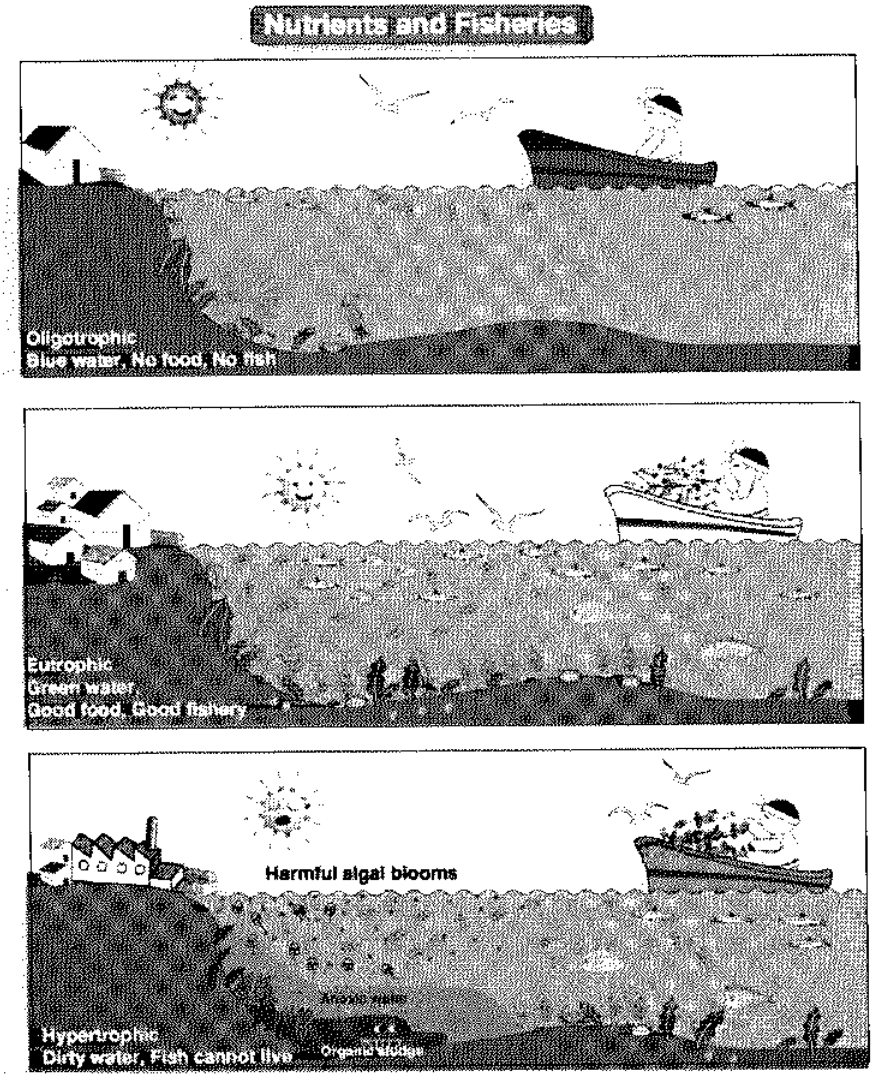


Figure 2. Nutrient levels and fisheries.

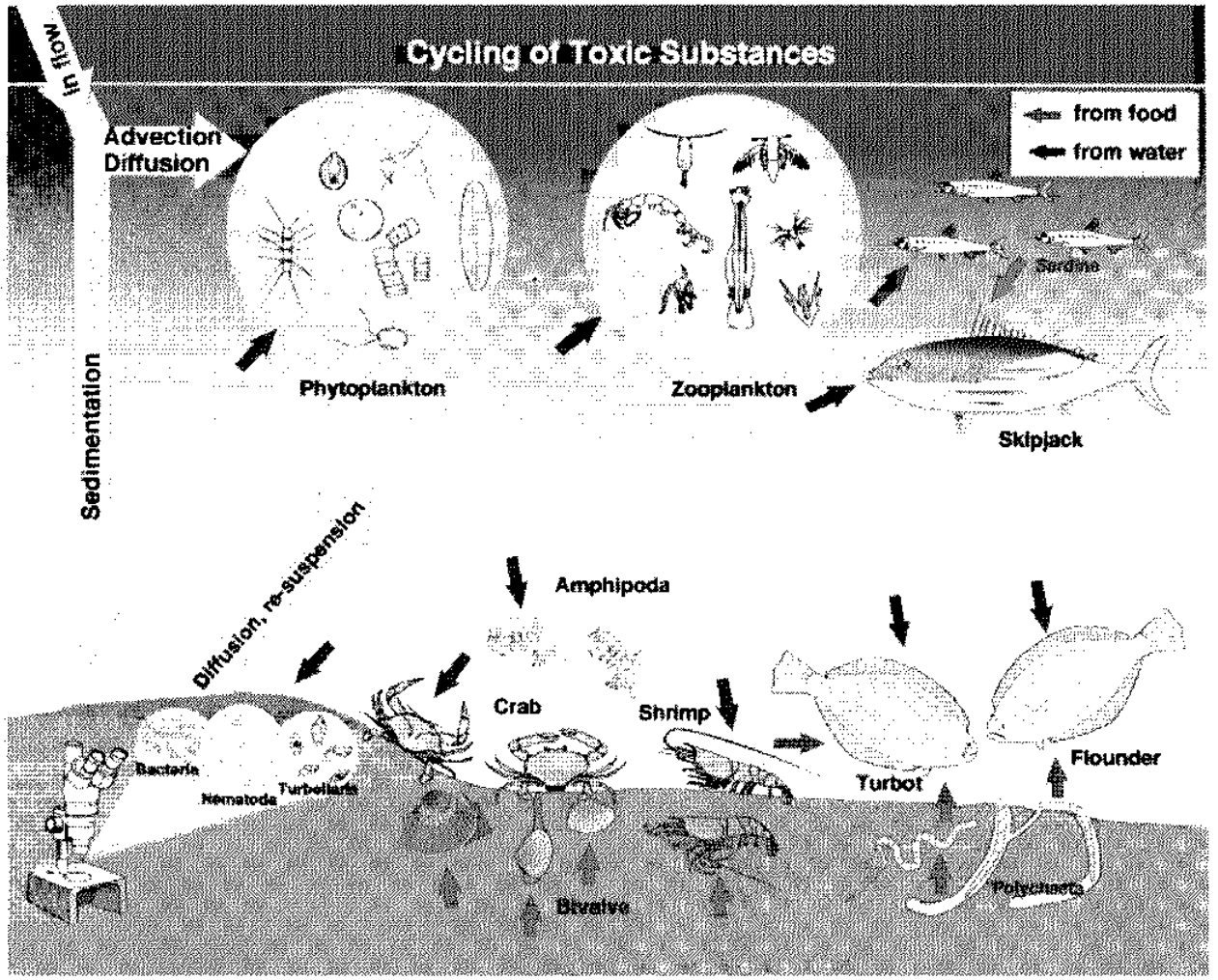


Figure 3. Cycling of toxic substances in coastal environments (modified after JFRCA).

By considering these reviews, JFRCA divides water bodies into three categories, and recommends TP values of 0.03, 0.05, and 0.09 mg/L and TN values of 0.3, 0.6, and 1.0 mg/L for open waters, coastal waters and nearshore waters, respectively.

Coliform bacteria, *Escherichia coli*

The main concern is for oyster aquaculture. The WQC needs to be determined based on the safe eating of uncooked oysters. The value of 70/100 ml is set by the food hygiene legislation for oyster aquaculture. Therefore, JFRCA adapted this value for oyster aquaculture, and recommends 1000/100 ml.

n-Hexane extracts

Remnants of oil spills and tar balls are included as n-Hexane extracts. Toxic effects of n-Hexane extracts may not be clear, but fish can accumulate odor-producing substances (Motohiro 1973). Bad smell certainly reduces the economic value. Recommended concentration is less than 0.001 mg/L, which is currently the detection limit.

Sediment parameters

Biogeochemical processes occurring in the sediments can affect the water quality. Sediment may act as a secondary source of contamination and may worsen all the water quality parameters described above. Therefore, WQC is also considered for sediments. Sulfide, COD, and n-

Table 2. Water quality criteria for metals in seawater by JFRCA and EAJ.

Metal	Concentration	
	JFRCA*	EAJ**
Al	0.1ppm	
As	0.01 ppm	0.01 ppm
B	4.5 ppm	
Br	1.0 ppm	
Cd	0.0001 ppm	0.01 ppm
Cl (as free chlorine)	0.02 ppm	
CN (as cyanide compounds)	<D.L. (0.001 ppm)	
Cr (as Cr + 6)	0.01 ppm	0.05 ppm
Cu	0.005 ppm	
F (as flouride compounds)	1.4 ppm	
Fe	1.0 ppm	
Fe	2 ppm	
Hg	0.0001 ppm	0.0005 ppm
Alkyl Hg	<D.L. (0.5 ppb)	<D.L. (0.5 ppb)
Mn	0.6 ppm	
Mo	0.07 ppm	
Ni	0.01 ppm	
Pb	0.003 ppm	0.01 ppm
Sb	0.002 ppm	
Se	0.01 ppm	0.01 ppm
Sn (as tributyl Sn compounds)	0.002 ppb	
Zn	0.01 ppm	

* Japan Fisheries Resources Conservation Association
** Environment Agency of Japan

Table 3. Water Quality Criteria for synthetic organic substances in seawater by JFRCA and EAJ.

Synthetic Organic Substances	Concentration	
	JFRCA*	EAJ**
1,1,1-Trichloroethane	1 mg/L	1 mg/L
1.1.2-Trichloroethane	0.006 mg/L	0.006 mg/L
1,1-Dichloroethylene	0.02 mg/L	0.02 mg/L
1.2-Dichloroethane	0.004 mg/l	0.004 mg/L
1,2-Dichloropropane	0.06 mg/L	
1,3-Dichloripropene	0.002 mg/L	0.002 mg/L
Benzene	0.01 mg/L	0.01 mg/L
Carbon Tetrachloride	0.002 mg/L	0.002 mg/L
Chloroform	0.01 mg/L	
cis-1,2-Dichloroethylene	0.04 mg/L	0.04 mg/L
CN (as cyanide compounds)	<D.L (0.001 ppm)	<D.L. (0.001 ppm)
Diazinon	0.04 g/L	
Dichloromethane	0.02 mg/L	0.02 mg/L
Dichloropropane	0.06 mg/L	
Linear Alkylbenzenesulfonate	0.002 mg/L	
p-dichlorobenzene	0.1 mg/L	
PCB	<D.L. (0.5 ppb)	
Simazine (2-Chloro-4,6-Bis(ethylamino)-1,3,5-Triazine)	0.003 mg/L	0.003 mg/L
Tetrachloroethylene	0.01 mg/L	0.01 mg/L
Thiodicarb	0.02 mg/L	0.02 mg/L
Thiuram	0.006 mg/L	0.006 mg/L
Toluene	0.4 mg/L	
Trichloroethylene	0.03 mg/L	0.03 mg/L
Xylene	0.4 mg/L	

*Japan Fisheries Resources Conservation Association
**Environment Agency of Japan

Hexane extracts have been chosen as the parameters. By reviewing the existing data, JFRCA recommends 0.2 mg/g, 20 mg/g, and 0.1% for sulfide, COD, and n-Hexane extracts as WQC, respectively.

Toxic chemicals

Cycling of toxic chemicals entering the marine environment is shown in Figure 3. Since there are two passages of these chemicals to marine organisms, through water and through food, toxic effects by both waterborne and food contaminants need to be considered. The WQC for heavy metals and selected organic chemicals are listed in Tables 2 and 3, respectively. These WQC values are based on the no-effect concentration level. By comparing the reported toxicity values from chronic toxicity test, early-life stage toxicity test, and acute toxicity test, the lowest value was taken as WQC. Environmental Quality Standards for Water Pollution for health items are also listed in Tables 2 and 3 for comparison.

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LITERATURE CITED

Chiba, K. 1983. The effect of dissolved oxygen on the growth of young silver bream. Bull. Jpn. Soc. Sci. Fish. 49: 601-610.

Davis, J. D. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review. J. Fish. Res. Board Can. 32: 2295-2332.

Japan Fisheries Resource Conservation Association. 1989. Final report of 5-year carrying capacity project. Japan Fisheries Resource Conservation Association, Tokyo. 1003 p. [in Japanese]

Japan Fisheries Resource Conservation Association. 1995. Water quality guidelines for living resources in aquatic environments. Japan Fisheries Resource Conservation Association, Tokyo. 68 p. [in Japanese]

Japanese Industrial Standard. 1993. Testing methods for industrial wastewater. JIS K 0102-1993. Japanese Standards Association, Tokyo. 327 p. [in Japanese]

Imabayashi, H. 1983. Effects of oxygen deficient water on the benthic communities. Bull. Jpn. Soc. Sci. Fish. 49: 7-15 [in Japanese].

Mori, I., T. Tokunaga, M. Kuwaoka, and T. Fujiki. 1973. Distribution of bottom fishes in relation to oxygen contents in the bottom water of Omura Bay. Bull. Jpn. Soc. Sci. Fish. 39 (7): 753-758 [in Japanese].

Motohiro, T. 1973. Water pollution by oil and some biological considerations. Japan Fisheries Resource Conservation Association, Tokyo. 82 p. [in Japanese]

Satomi, Y. 1985. Some problems on total nitrogen and phosphorus criteria. J. Water Wastewater Res. 27: 131-139 [in Japanese].

Satomi, Y. and k. Takayanagi. 1987. Water quality criteria for fisheries in Japan: total phosphorus and total nitrogen. Water Qual. Bull. 12(4): 163-165.

Saunders, R. L. 1963. Respiration in the Atlantic cod. J. Fish. Res. Board Can. 20: 373-386.

MARINE MAMMAL – GEAR INTERACTIONS: PROBLEMS, ACOUSTIC MITIGATION STRATEGIES, OPEN OCEAN AQUACULTURE

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ABSTRACT

Interactions between marine mammals and fishing gear have changed as fishing technology and activity have evolved. The interactions are wide ranging, and have included large seines for tuna with dolphins in the eastern tropical Pacific, cod traps and humpbacks in Newfoundland, harbor porpoise and gillnets all around the northern hemisphere, and seals and salmon aquaculture pens. Many of the mitigation strategies have been active acoustic devices targeted at a single marine mammal species. Moving aquaculture offshore to the open ocean presents a situation where a variety of interactions could occur due to the many marine mammal species present. Resolving the interactions will require new approaches to the multiple species situation. Further, because offshore aquaculture may be moving into significant marine mammal areas, special precautions must be taken to ensure that any conflict mitigation does not lead to excluding a species from habitat critical for its survival.

INTRODUCTION

To meet the demand for future grow-out space for finfish, aquaculture activities will have to move offshore, especially in New England. As offshore aquaculture activity begins, there is a need to consider all the potential situations that can develop with regard to marine mammals, and to address them from the beginning. This new level of aquaculture activity will require placing large, fixed net-pen structures at offshore sites. It is essential that these structures be designed to resist the weather and seas, to accommodate the fish adequately, and to avoid negative interactions with marine mammals. This new initiative in aquaculture should not be the victim of shortsighted design that results in conflicts with marine mammals, and hence a difficult start.

HISTORICAL OVERVIEW

As the demand for fish increased, the fishing industry expanded to meet this demand. This required more gear in the water. Technology evolved to optimize the ability of a single boat to haul more nets. For example, net twine which was traditionally a hemp or cotton-based material became monofilament nylon. This enhanced the fishing operation, but created problems for marine mammals. Nylon monofilament is virtually acoustically transparent (Vicedomine 1991), and its use led to marine mammal entanglements, damaging fishing gear and killing marine mammals.

In Newfoundland, Canada, this scenario existed in the inshore cod fish traps. Collisions with humpbacks always occurred according to the older fishermen. The collisions resulted in gear damage to the cotton and hemp lines. With the advent of stronger lines, more collisions happened with more whale entanglements. Over the period from 1979-1990, Lien (1994) reported that 30% of the marine mammals entangled in fishing gear in Newfoundland were dead. The response to this situation was to begin a program focused on developing an acoustic alarm to warn marine mammals about the presence of the fishing gear. A 4-kHz acoustic alarm resulted and was effective in reducing the marine mammal-fishing gear conflict.

A similar scenario exists with the gillnet fishery in the northern hemisphere with the entanglement of harbor porpoise. The old twine nets had minimal problems with entanglements, but the nets when soaked were difficult to haul due to the weight. The movement to synthetic monofilament nets improved the hauling efficiency, but rendered the nets virtually acoustically transparent. Entanglements of harbor porpoise became relatively commonplace. The mitigation strategy was to use an acoustic pinger to warn the harbor porpoise about the existence of the gillnets. This acoustic pinger has a fundamental frequency of 10 kHz with harmonics up to the 100-kHz range with a source level of approximately 135 dB re 1 μPa. The initial testing of this pinger, in experiments with a valid statistical design, indicates that it is very effective at deterring harbor porpoises from gillnets (Kraus et al., 1997).

Presently, the primary conflict between marine mammals and aquaculture gear is with the salmon net pens. Seals are predators to the fish in the net pens and the industry has developed the practice of using acoustic harassment devices (AHD) to scare the seals away from the pens. A commonly used AHD broadcasts a 10-kHz signal at 210 dB re 1 μPa with a 10% duty cycle every 4 sec. This is an effective deterrent for the seals, but the sound propagates a long distance, and there is some evidence that harbor porpoise in British Columbia, Canada, have been displaced due to the sound (Olesiuk et al. 1995).

In the examples stated above, there were a variety of interactions with marine mammals and fishing gear. The mitigation strategies have all been acoustic, and have been a reactive fix to the problem. The mitigation strategy for one species interaction can potentially lead to displacement or habitat exclusion of another species. To effectively address the potential for marine mammal interactions and acoustic deterrents in open ocean aquaculture, it is necessary to formulate a basic model of the acoustic propagation and how marine mammals fit into this environment and interact acoustically. This acoustic interaction scenario will provide a basis for understanding mitigation strategies.

ACOUSTIC PROPAGATION MODEL

The objective to developing a propagation model is to have an understanding of how a sound that is generated at a source travels a path and is received. Models can be simple and qualitative in which case they identify the salient features such as source, path, receiver. Or they can be a very quantitative sonar model with all the complexities one desires. The goal here is to present a simple model that explains qualitatively the propagation environment for marine mammals and fishing gear.

The basic propagation model has a source, path, and a receiver. This generic scenario is depicted in Figure 1. The source in the aquaculture case could be the sound from a deterrent device or sounds associated with the aquaculture activity. The former is meant to keep marine mammals away, but the latter could be a curiosity enhancer.

The path is the ocean between the source and receiver. This path is most likely short when considering the size of the oceans, but still it can be complicated due to local propagation effects. Topography, temperature profiles, and ambient noise are three factors that can readily effect the path. Figure 2 is a plot of the various components of ambient noise. The spectral

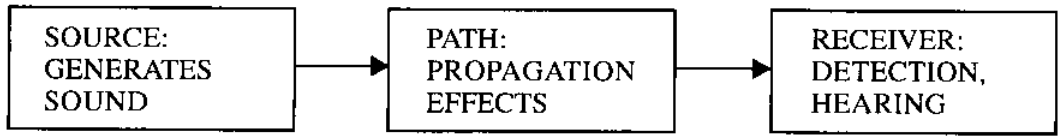


Figure 1. Source - Path – Receiver model for defining basic acoustic parameters.

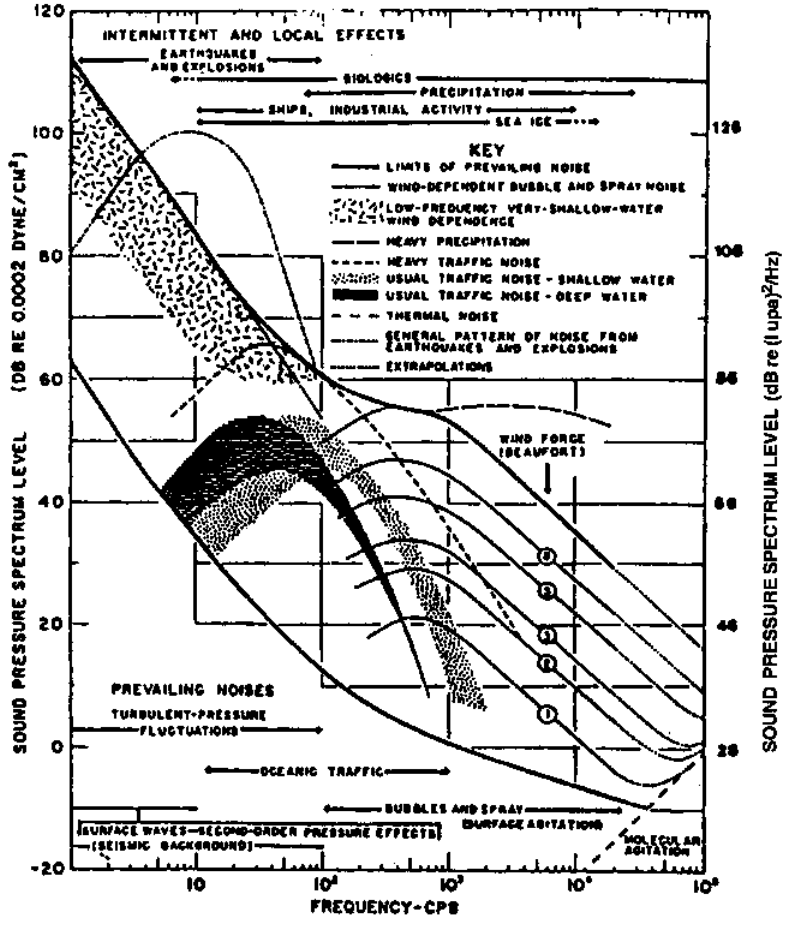


Figure 2. Ambient noise spectrum (Richardson et al. 1989)

content is presented as sound pressure level or sound pressure spectrum level. The latter presentation is more readily accepted in practice as the units $(\mu P)^2/Hz$ infer frequency dependence. The basic trends show that there is a higher level of ambient noise at lower frequencies with a steady decrease in level as frequency increases. Shipping and industrial activity typically have a frequency range from 10 Hz to 10 kHz. Biological sounds cover a wider range of the spectrum.

This basic model can provide insight into how a sound is propagated and its sound pressure level, how loud it is, at range from the source. There are two basic concepts to understand here: there is a zone of audibility and a zone of influence (Richardson et al. 1989).

The zone of audibility is determined by the ambient noise level. As sound propagates out from a source, its level is diminished due to spreading losses (geometric) and attenuation (true energy loss). These two loss mechanisms

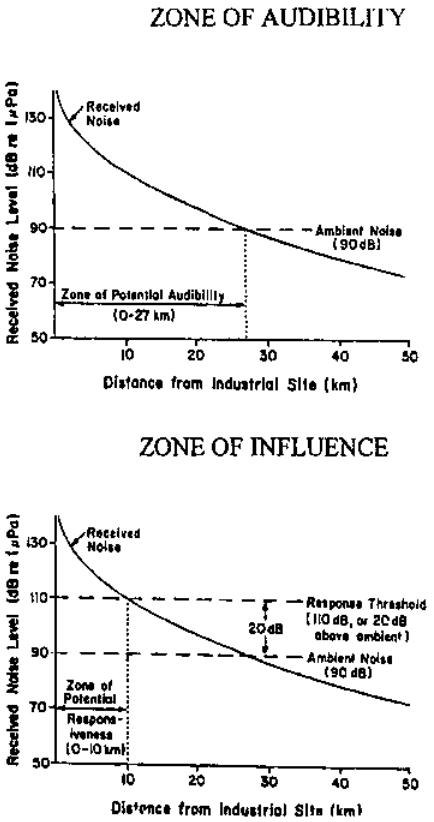


Figure 3. Graphical definitions of Zone of Audibility (A) and Zone of Influence (B) (Richardson et al. 1989)

are defined as transmission loss in sonar modeling. On a plot of sound pressure level vs. range, and a constant ambient noise level vs. range, the intersection of these two lines defines the zone of potential audibility. When the received sound pressure level is greater than the constant ambient noise level, then the sound can be heard. This occurs at shorter ranges. At longer ranges, the ambient noise is greater than the received sound pressure level; the sound is effectively inaudible. This concept is shown in Figure 3A.

The zone of influence is a modification to the above as it incorporates a response threshold. The response threshold is a sound pressure level above the ambient noise that is required for a marine mammal to determine that a specific sound is present. The effect of this response threshold is to reduce the range at which the two plots intersect. Hence, the zone of potential influence is a shorter range from the source than the zone of potential audibility. This is shown in Figure 3B.

This basic model is useful in defining the

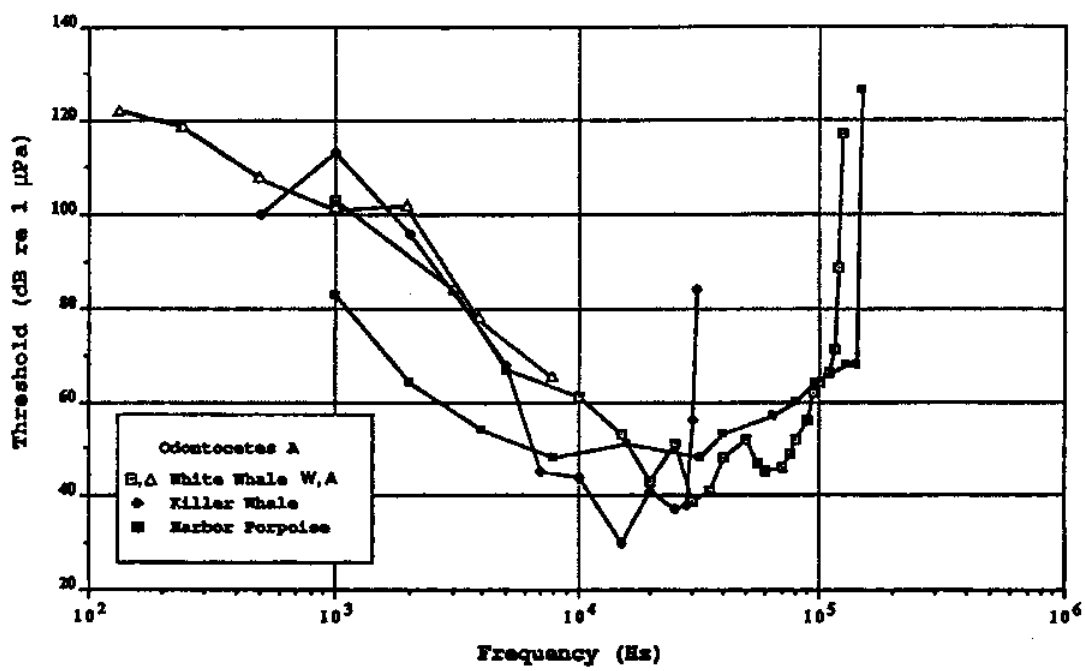


Figure 4. Underwater audiograms of several odontocetes: (A) white whale (White et al. 1978; Awbry et al. 1988); killer whale (Hall and Johnson 1972); harbor porpoise (anderson 1970a); (B) bottlenose dolphin (Johnson 1968a; Ljunblad et al. 1982c); Amozon river dolphin or boutu (Jacobs and Hall 1972); false killer whale (Thomas et al. 1978). (Richardson et al. 1989)

above concepts. The limitation is the use of a single number, constant level, for the ambient noise and the response threshold. As shown earlier, ambient noise has definite spectral characteristics. Upon close examination of marine mammal acoustics, it is apparent that they too have spectral characteristics to their acoustic behavior.

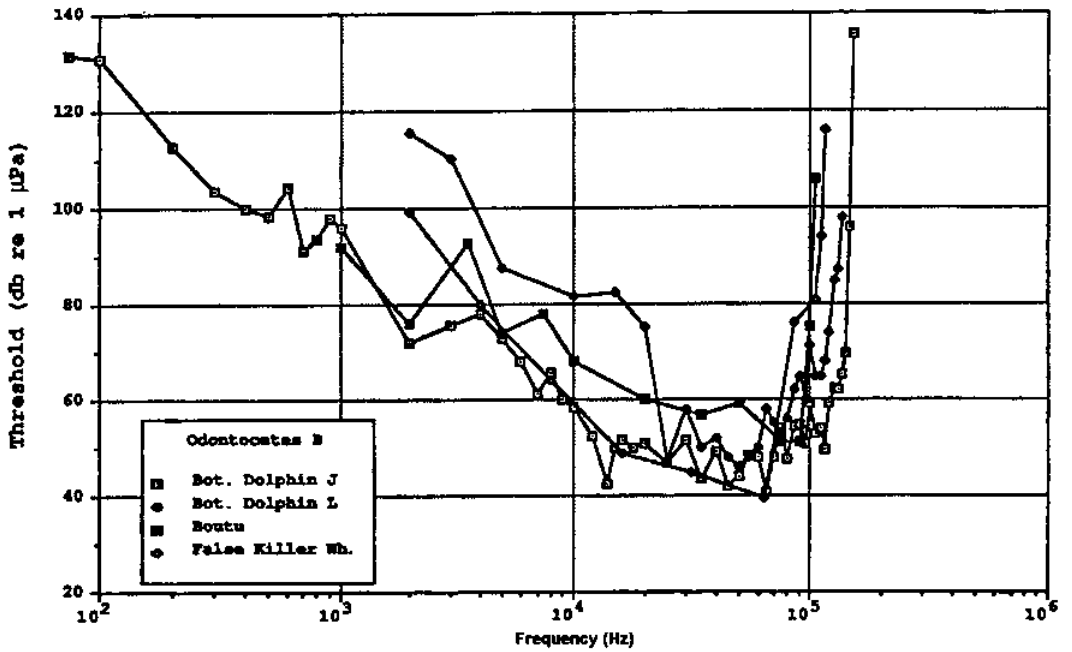


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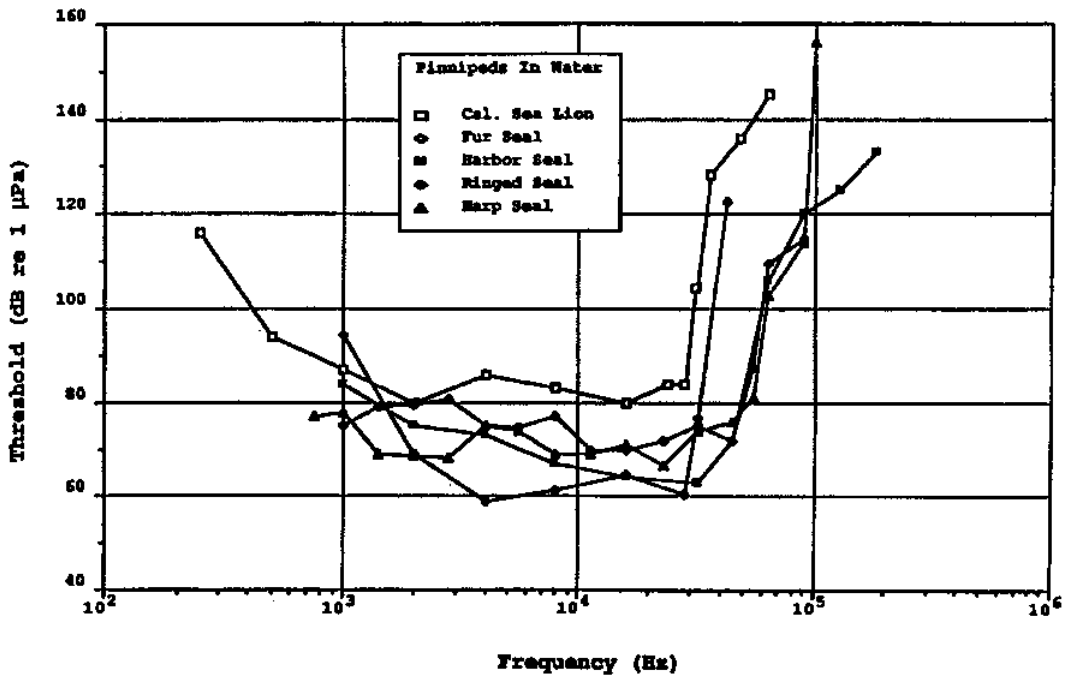


Figure 6. Underwater audiograms of several pinnipeds: California sea lion (Schusterman et al. 1972); average of two fur seals (Moore and Schusterman 1987); harbor seal (Møhl 1968a); average of two ringed seals (Terhune and Ronald 1975a); harp seal (Tehrune and Ronald 1972). (Richardson et al. 1989)

MARINE MAMMAL ACOUSTICS

Marine mammals are the receiver in the previous model. They have spectral characteristics associated with their receiving mechanisms, and also they have spectral content associated with various vocalization used for communication, navigating, and foraging. The effect of ambient noise and noise generated from aquaculture activities can potentially affect the intent of the marine mammal vocalizations.

Audiograms are the method of defining the spectral characteristics of hearing. Most audiograms have a band of frequencies over which the hearing is most sensitive. This band varies for different marine mammals, as well as the threshold or hearing sensitivity. The audiograms in Figures 4, 5, and 6 show typical results for a variety of marine mammals, both odontocetes and pinnipeds. There is a difference in the basic structure of these audiograms. The odontocetes are typically more sensitive between 10 and 108 kHz, while pinnipeds are more sensitive between 5 and 40 kHz. Also, the actual threshold for the odontocetes is in the 40-60 db area while the threshold for the pinnipeds is in the 60-80 db area.

The other aspect of marine mammal acoustics is their vocalizations. This activity has both spectral and source level characteristics. From Table 1, it is seen that a variety of type of sounds are produced. These sounds have different dominant frequencies, bandwidths, and source levels. The functions of the sounds are short and long distance communication, echolocation, and reproductive displays.

Introducing other sounds into the water column, on a continual basis, that can interfere with these behaviors can have adverse effects on the species. These "introduced sounds" can impact the ability of an animal to hear the

Species	Type of Vocalization	Frequency Range of Vocalizations (kHz)	Dominant Frequencies (kHz)	Source Level (dB re 1 µPa at 1 m)	References
White whale	whistles	0.26-20	2-5.9	-	Sjare and Smith 1986a,b
	pulsed tones	0.4-12	1-6	-	Sjare and Smith 1986a,b
	noisy vocalizations	0.5-16	4.2-8.3	-	Sjare and Smith 1986a,b
	echolocation clicks	40-120	variable	160-222	Au et al. 1985, 1987
Killer whale	whistles	1.5-18	6-12	-	Steiner et al. 1979; Ford and Fisher 1983;
	pulsed tones	0.5-25	1-6	160	Awbrey et al. 1982; Ford and Fisher 1983; Schevill and Watkins 1966
	echolocation clicks	0.1-35	12-25	180	Wood and Evans 1980
Northern right-whale dolphin	clicks	1-40+	40+?	180	Fish and Turl 1976
	whistles	?-16+	-	-	Leatherwood and Walker 1979
	tones	1-4	1.8, 3	-	Leatherwood and Walker 1979
Pacific white-sided dolphin	whistles	2-20+	4-12	-	Evans 1973; Caldwell and Caldwell 1971
	echolocation clicks	0.2-150	60-80	170	Evans 1973
Dall's porpoise	clicks	0.04-12, 125-135	-	120-168	Evans 1973; Evans and Awbrey 1984
Harbor porpoise	clicks	100-160	130	132-149	Möhl and Andersen 1973
	clicks	2	-	100	Busnel and Dziedzic 1966a; Schevill et al. 1969
Rough-toothed dolphin	clicks	16-100+	-	-	Norris and Evans 1967
	whistles	-	4-7	-	Busnel and Dziedzic 1966b
Short-finned pilot whale	whistles	0.5-20+	2-14	180	Fish and Turl 1976; Caldwell and Caldwell 1969
	echolocation clicks	0.1-100	-	180	Evans 1973
Sperm whale	clicks	0.1-30	2-4, 10-16	160-180	Backus and Schevill 1966; Levenson 1974; Watkins 1980a
Beaked Whale	whistles	3-16	-	-	Winn et al. 1970a
	clicks	0.5-26+	-	-	Winn et al. 1970a

Table 1. Characteristics of underwater sounds produced by Alaskan odontocetes whales. (Richardson et al., 1989)

behavioral sounds, thus potentially driving a species from a site. This is obviously the goal of acoustic deterrent devices. The key to effective design of these devices is to target a single species that is problematic to the aquaculture operation and minimize the effect on other species.

DISCUSSION AND SUMMARY

Historically, most fishing interactions have been single species and a reactive fix has been found. The key to an effective acoustic fix is to assume that the initialization of one species interaction is not exclusive for another. Alternatively, what deters one species could easily be the dinner-bell for another. A deterrent for one species could effectively impact the vocalization responses for another. Long term studies on marine mammal exclusion due to deterrent sounds have not been done yet. When considering an acoustic deterrent for aquaculture sites, specific local information about the ambient noise, propagation path and marine mammals needs to be assimilated for an objective, focused approach for solving the problem.

To facilitate objective approaches to marine mammal-aquaculture acoustic interactions, the following points need consideration. The database for auditory response of marine mammals needs to be enhanced. Threshold levels where sounds produce detrimental effects need to be clearly defined. Developing a better understanding between species vocalizations, environmental noise, and deterrent sounds is critical to effective use of sound as a warning/deterrent. These efforts will lead to a rational context for designing species specific acoustic alarms for use in offshore aquaculture.

LITERATURE CITED

Kraus, S., A.D. Read., A. Solow , K. Baldwin, T. Spradlin, E. Anderson, and J. Williamson. 1997. Acoustic alarms reduce porpoise mortality. Nature 388: 525.

Lien, J. 1994. Entrapments of large cetaceans in passive inshore fishing gear in Newfoundland and Labrador (1979-1990). Report of the International Whaling Commission, Special Issue 15.

Olesiuk, P. F., L. M. Nichol, P. J. Sowden, and J. K. B. Ford. 1995. Effects of sounds generated by an acoustic deterrent on the abundance of harbor porpoise (*Phocoena phocoena*) in Retreat Passage, British Columbia. Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, B. C.

Richardson, W. John, J. P. Hickie, R. A. Davis, D. H. Thomson, and C. R. Greene, 1989. Effects of offshore petroleum operations on cold water marine mammals: a literature review. API Publ. No. 4485, American Petroleum Institute, Washington, DC.

Vicedomine, J. 1991. Investigation of the acoustic interaction between harbor porpoise (*Phocoena phocoena*) and Gulf of Maine commercial gillnet fishing. MS thesis, Ocean Engineering Program, University of New Hampshire, Durham, NH.

NORTH AMERICAN LOBSTER CULTURE (*HOMARUS AMERICANUS*), HATCHERY METHODS, AND TECHNIQUES: A TOOL FOR MARINE STOCK ENHANCEMENT?

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ABSTRACT

The North American lobster (*Homarus americanus* Milne-Edwards) is fished intensively throughout its 11,000-km range resulting in only a fraction of these animals surviving long enough to reproduce. Success in marine stock enhancement programs suggest that enhancement may be possible for lobsters as well. Personnel at the lobster rearing facility of the New England Aquarium are studying the methodologies used in the culture of larval and juvenile lobsters, as well as explore the major considerations involved for initiating and carrying out a productive and effective lobster stock enhancement program.

INTRODUCTION

The American lobster is found naturally along the east coast of North America, from North Carolina to Labrador, being most abundant from Nova Scotia to New York (Herrick 1895). The major population centers, and therefore inshore fisheries, are located within the Gulf of Maine and in the New Brunswick and Nova Scotian coastal waters, where over 90% of the inshore landings are made (Cobb and Phillips 1980). During the last decade, areal expansion of the lobster fishery and the continued intense inshore fishery have focused attention on the relationship between animals in inshore and offshore areas. If consistent recruitment in coastal areas depends on egg production from offshore, heavy exploitation of offshore populations could impact all fisheries. The New England Fishery Management Council (NEFMC) currently considers the American lobster resource overexploited. There is currently no commercial culture for the North American lobster; however, these animals have long been reared in pilot scale projects, and have received a considerable amount of attention from aquaculturists. The reason for the attention is clear: lobster is a very popular seafood with a high market value. Lobster stock enhancement is not a new concept. Efforts to rear and culture lobsters have existed since the early 1880s (Addison and Bannister 1994). Lobster hatcheries originated in France and Norway over 130 yr ago, hatching and raising the European lobster *Homarus gammarus* (Herrick 1909). The first successful attempt at hatching *H. americanus* larvae was in 1885 at the newly established laboratory of the U.S. Fish Commission in Woods Hole, Massachusetts (Rathbun 1886). The world's first lobster culture facility was completed at St. Andrews, New Brunswick, Canada, in 1974. The work done at St. Andrews closed the lobster cycle from egg to broodstock. Because the private sector was not prepared for the direct transfer of this technology, potential governmental and academic research programs stalled. The popular perception of lobster aquaculture is that it is analogous to farming, in which lobsters produce eggs that are hatched, reared, and then sent to market. The other potential application however, is in marine stock or resource enhancement, whereby young of year lobsters are cultured and released to enhance natural stocks. To be able to move forward in this area of research however, it is important to disseminate the details of culturing such animals for these types of studies,

and relate what others have done to contribute to lobster stock enhancement.

MATERIALS AND METHODS

A year-round culturing facility for the American lobster is located in the Harold E. Edgerton Research Laboratory of the New England Aquarium. The culturing facility incorporates two separate systems: a cold seawater system (8-10°C) for holding gravid female lobsters, and a warm seawater system (18°C) for the production and growout of larvae and juvenile lobsters.

Broodstock system:

Female lobsters obtained through the Marine Research Station (Vineyard Haven, Massachusetts), New England Aquarium staff divers, or other similar sources are put through a strict quarantine process before they are integrated into the primary lobster recirculating system. When obtained, wild-caught females are first given a physical checkup in which they are visually inspected for lesions, infections, abnormalities, or anything else which looks or appears suspicious. In most cases, this procedure is often done off-site prior to bringing animals into the facility so as not to introduce diseased or abnormal animals. Animals then undergo a series of dips, swabs, and brushes. They are sprayed lightly with distilled water and large portions of the shell and joint areas are swabbed and/or brushed with a 10% solution of betadine. A small sample of eggs are removed and inspected microscopically for any severe cases of fungal or bacterial growth and are also analyzed for their current embryonic developmental stage by applying the Perkins eye index formula (Perkins 1972). In some cases, new lobsters are weighed, measured, and tagged as well. These lobsters remain in quarantine for up to 3 wk at which point they can be integrated into the rest of the system.

Larval system:

The larval rearing system consists of eight circular tanks or "kreisels" with cross-section conical bases (Figs. 1 and 2) each of 40-L capacity.

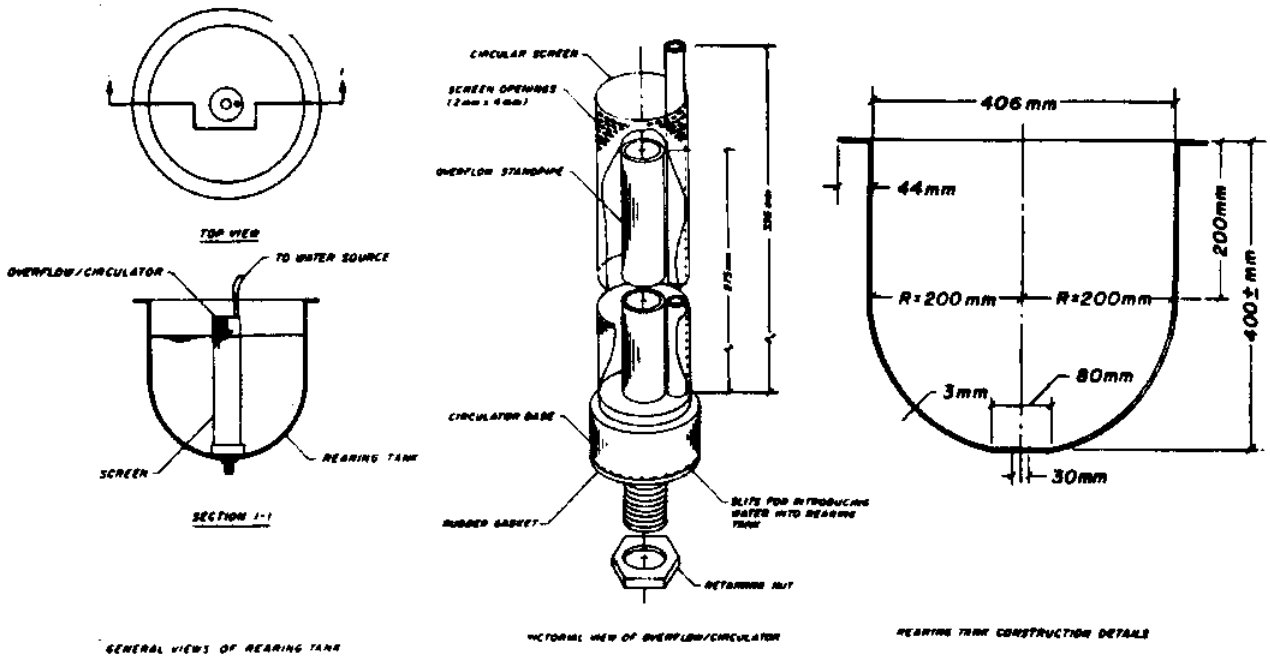


Figure 1. The kreisel or circulating rearing tank. (Modified from Schuur et al., 1976. With permission.)

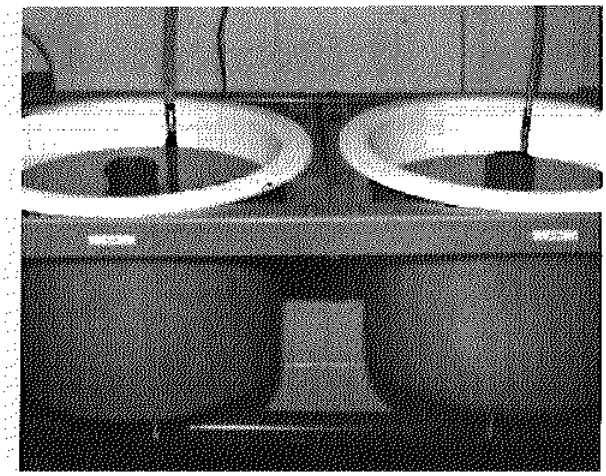


Figure 2. Planktonic kreisel. These 40-L tanks are ideal for larval culture. Cannibalism can be avoided by keeping the water moving and intensively feeding.

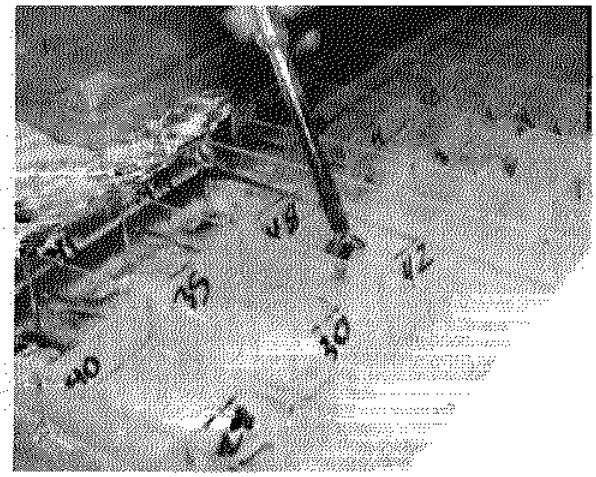


Figure 3. Juvenile holding tank tray. Probably one of the most unique attributes to lobster lab culture is the use of individual rearing compartments. Elevated and seated in shallow recirculating seawater trays, to flush out organics and keep water circulating, compartmentalizing animals allows for careful identification and cataloging of lobsters, as well as a tool for easy sorting and grading.

Water is pumped into the base of the tanks through a manifold with a series of offset holes producing a cyclonic upwelling water circulation. This is necessary to keep larvae dispersed and hence reduce losses by cannibalism. Kreisels are typically stocked with 2000 larvae each. Larvae are fed frozen brine shrimp *Artemia salina*, frozen mysids, and live amphipods. Larvae are typically held for 4 wk at 18-20°C during which they molt three times. Survival to the post-larval stage is variable, with 10%-15% typically surviving.

Juvenile system:

Once larvae have molted to the post-larval stage (stage IV), when they normally would be ready to assume a benthic existence in the wild, they are removed from the larval system and placed in individual holding trays or "condo trays" (Fig. 3). These shallow seawater trays, perforated with holes, allow them to be flushed of uneaten food and wastes and also allow for identification and cataloguing of lobsters. Water exchange in the cubicles is achieved by continuous circulation of water along the trays. These animals are then weaned off of the brine shrimp diet and introduced to a gelatin-bound diet called "Supergel" (Figs. 4 and 5).

Life Support: The Key to a Successful Hatchery

To efficiently culture and produce animals for potential resource enhancement, a sound and well-designed system should be used. Recirculating aquaculture systems (RAS) offer complete control over environmental growing conditions such as temperature, salinity, and water quality, while eliminating conventional concerns about weather and climatic conditions. Additionally, stock management and inventory control are greatly simplified. A properly designed RAS can be placed almost anywhere and used to produce a wide variety of aquatic animals. The following three components are excellent additions to any lobster hatchery setup.

Chiller units:

Continuous seed (larval) supply requires manipulation of either or both the spawning or hatching cycles (Waddy and Aiken 1992). Temperature is the dominant regulator for the continuance of year-round larval lobsters. To assist in this challenge, having one or more chiller units

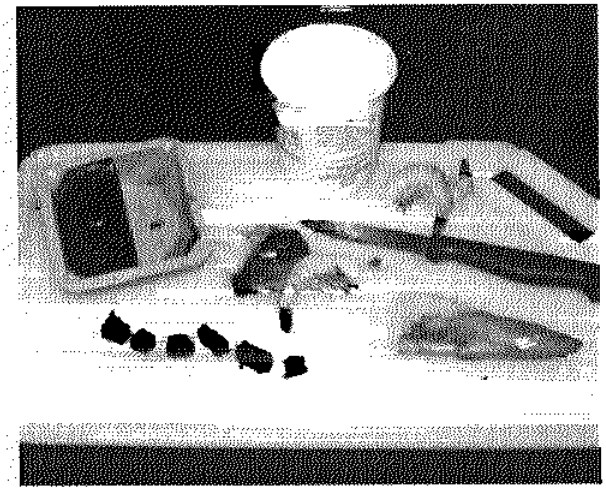


Figure 4. Aside from temperature, nutrition is the most important parameter governing the survival and growth of cultured lobsters. Adult brine shrimp is the staple food used here as well as enriched brine shrimp nauplii. Juvenile lobsters receive a gelatin-bound diet of brine shrimp, krill, kelp, spirulina, soy lecithin, bone meal, and crabmeat all pictured here.

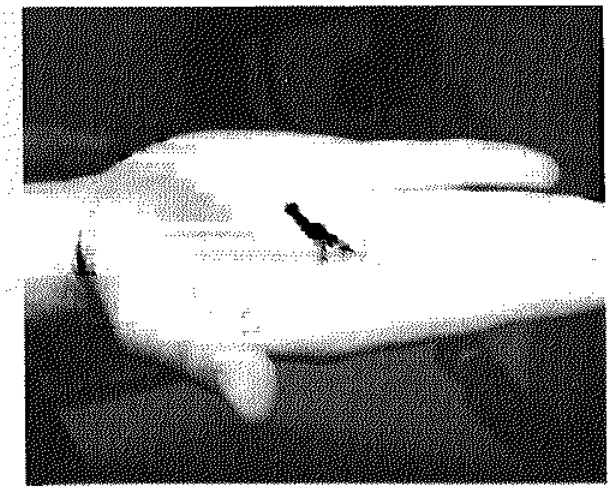


Figure 5. This 1-month-old, 9-mm *H americanus* is ready for transfer into the seawater condo tray system.

allows incubation periods which result in staggered hatch-out periods. This application of temperature greatly increases the chances to regulate and sustain a year-round population of larval lobsters.

Ultroviolet disinfection:

Ultraviolet radiation in the 200-300 nm range is extremely effective in killing most microorganisms.

Protein skimmer (foam fractionator):

Foam fractionation is a cost-effective and efficient means of removing fine suspended solids (<30 μm in size) and dissolved organic matter. Foam fractionation is accomplished by bubbling air through water to trap fine solids and organics which then generates a foam (Weeks et al. 1991).

DISCUSSION

A lobster does not achieve its benthic existence until some point in the fourth stage of development (Botero and Atema, 1987, Govind and Pearce 1989). Releasing these animals during fourth stage still exposes them to heavy predation. One management practice used in Europe is to rear juvenile lobsters for up to 1 yr or more before stocking them in appropriate benthic substrates which offer the proper habitat release component.

One excellent case study on lobster stock enhancement involves a comprehensive 6-yr study in Cardigan Bay in the Northwestern Wales district, UK (Cook 1995). The stock enhancement experiment carried out at Aberystwyth has demonstrated that releases of hatchery-reared juveniles onto carefully selected substrate can result in a good rate of recapture by the commercial fishery, with peak returns occurring between 4-6 yr after release. Differences are apparent between the inshore and offshore release sites. The Aberystwyth experiment failed to establish the optimum release size for juvenile lobsters. Carapace lengths as low as 14 mm produced very good returns, but the recapture rate of small lobsters (9 mm carapace length) was extremely poor (Cook 1995). This is an important aspect of lobster restocking because post-larval lobsters would be very inexpensive to produce in large numbers by mass rearing. It still seems inevitable that to rear juveniles through several molts with acceptably low mortality, individual compartments will be necessary to avoid cannibalism. The consequent

increase in space required, and particularly in husbandry and heating costs, means that the unit production cost of lobsters rises steeply the longer they are kept. Advantages to later release means a greatly increased survival; the disadvantage is at a much greater cost. The long period of intensive cultivation prior to release raises the potential stock enhancement cost considerably (Factor 1995). Any future lobster stock enhancement program should consider the following factors: (1) more detailed and extensive surveys of potential areas of suitable substrate within the particular test site or area, (2) an assessment of the natural recruitment patterns and population structure of lobsters within these areas with a view to assessing their suitability for enhancement, (3) a more rigorous investigation of the optimum release size for lobsters, (4) development of improved hatchery techniques in order to reduce the unit cost of the juvenile lobsters, and (5) a detailed appraisal of the economics of lobster stock enhancement.

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LITERATURE CITED

Addison, J.T. and R.C.A. Bannister. 1994. Re-stocking and enhancement of clawed lobster stocks: a review. Crustaceana 67(2): 131-155.

Botero, L. and J. Atema. 1987. Behavior and substrate selection during larval settling in the lobster, *Homarus americanus*. J. Crust. Biol. 2: 59-69.

Cobb, J.S. and B.F. Phillips, Editors. 1980. The Biology and Management of Lobsters, Vol. I. Academic Press, New York. 463 p.

Cook, W. 1995. A lobster stock enhancement experiment in Cardigan Bay. North Western and North Wales-Sea Fisheries Committee Report, Univ. Lancaster, 32 p.

Factor, J.R., (Editor). 1995. Biology of the Lobster *Homarus americanus*. Academic Press, New York. 528 p.

Govind, C.K. and J. Pearce. 1989. Critical period for determining claw asymmetry in developing lobsters. J. Exp. Zool. 249: 31-35.

Herrick, F.H. 1895. The American lobster: a study of its habits and development. Bull. U.S. Fish Comm. 15: 1-252.

Herrick, F.H. 1909. Natural history of the American lobster. Bull. U.S. Bur. Fish. 29: 148-408 +20 plates.

Perkins, H.C. 1972. Developmental rates at various temperatures of embryos of the northern lobster (*Homarus americanus* Milne-Edwards). Fish. Bull. 70: 95-99.

Rathbun, R. 1886. Notes on lobster culture. Bull. U.S. Fish Comm. 6: 17-32.

Schuur, A., W.S. Fisher, J.C. Van Olst, J.M. Carlberg, J.T. Hughes, R.A. Shleser, and R.F. Ford. 1976. Hatchery methods for the production of juvenile lobsters *Homarus americanus*. Sea Grant Publ. No. 48, Univ. California, Inst. Mar. Resour., La Jolla

Waddy, S.L. and D.E. Aiken. 1992. Environmental intervention in the reproductive process of the American lobster, *Homarus americanus*. Invertebr. Reprod. Dev. 22: 1-3, 245-252.

Weeks, N.C., M.B. Timmons, and S. Chen. 1991. Feasibility of using foam fractionation for the removal of dissolved and suspended solids for fish culture. Aquaculture (57): 101-106.

BLUE MUSSELS IN THE DIET OF JUVENILE JAPANESE FLOUNDER

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ABSTRACT

Blue mussels *Mytilus galloprovincialis* were used in the diet of juvenile Japanese flounder. The control diet mainly consisted of white fish meal, potato starch, and pollack liver oil, and part of the control diet was exchanged with freeze-dried meat, fresh meat, or fresh whole blue mussel in experimental diets. Fish of about 5 g in initial body weight were fed each diet to satiation, twice daily, 6 days\wk for 8 wk at 20°C. The final body weight and weight gain of fish fed diets containing freeze-dried and fresh blue mussel meat were higher than those fed the control diet ($p < 0.05$). These parameters in the whole blue mussel diet were comparable to the control. Addition of freeze-dried and fresh blue mussel meat to the diet did not affect the feed efficiency, while the feed efficiency of fish fed the whole blue mussel diet was lower than that of fish in the other treatments. Protein efficiency ratio was in the same range among all dietary groups tested. There were small differences in body composition, or hematological and hematochemical parameters of the cultured fish.

INTRODUCTION

Blue mussels are a nuisance organism for electric power plants located along the coast of Japan. Excessive mussel growth along water intake pipes constricts and impedes the inflow of cooling water. Generally, they are collected once or twice a year and buried in the landfill of the plant after incineration of organic matter. The removal and disposal require considerable cost; moreover, landfill space rapidly fills.

Several studies on the utilization of collected mussels have been conducted to work out the disposal problems; however, no effective ways but as a source of fertilizer have been developed. We previously reported that the freeze-dried meat of blue mussels *Mytilus galloprovincialis*, predominant in power plants of Japan, can effectively replace fish meal as a main ingredient in the diet of juvenile Japanese flounder *Paralichthys olivaceus*. In addition, blue mussel meat appears to stimulate the feeding behavior of the flounder (Kikuchi and Sakaguchi 1997). In this study, freeze-dried blue mussel meat, fresh mussel meat, and fresh whole mussel were used, and effects on the growth of juvenile flounder were examined to develop techniques for practical use of the blue mussel in the diet of fish.

MATERIALS AND METHODS

EXPERIMENTAL DIET

The formulation and composition of the experimental diets are shown in Table 1. The control diet basically consisted of 81.7% white fish meal, 10.8% potato starch, 3.0% mineral mixture, and 4.5% vitamin mixture. The basic ingredients of the control diet were replaced with fresh blue mussel meat at a rate of 17 and 33% (weight/weight) in diets 2 and 3, respectively. Five percent of the basic ingredients in the control diet were replaced by freeze-dried mussel meat in diet 4, and 20 and 30% with fresh whole mussel in diets 5 and 6, respectively. Live blue mussels obtained from a fish market were used. In diets 2, 3, 5, and 6, fresh blue mussel meat and whole blue mussels were minced and ground into a liquid (mostly water), and used as an ingredient in the diet. Freeze-dried mussel meat was prepared as described previously (Kikuchi and Sakaguchi 1997). Blue mussels in diets 2 through 6 replaced fish meal such that the ratio of white fish meal protein to

	Diet					
	1	2	3	4	5	6
Ingredient (%)						
White fish meal	81.7					
Potato starch	10.8	83.0	67.0	95.0	80.0	70.0
Mineral mixture*1	3.0					
Vitamin mixture*1	4.5					
Blue mussel meat-fresh		17.0	33.0			
Blue mussel meat-dried				5.0		
Whole blue mussel-fresh					20.0	30.0
Pollack liver oil*2	7.0*2					
Proximate composition (%)						
Moisture	4.9	4.7	4.4	5.2	3.9	4.5
Crude protein	45.1	45.4	45.5	44.8	44.9	42.6
Carbohydrate	20.7	20.5	21.1	21.0	19.8	19.8
Crude lipid	13.9	14.3	14.3	13.9	14.4	14.1
Crude ash	15.4	15.1	14.7	15.1	17.0	19.0

*1 Nippon Formula Feed Mfg. Co., Ltd.

*2 Riken Vitamin Co., Ltd. (Feed oil Ω);
Pollack liver oil was added to be 7.0 % in the diet after fomulation and drying.

Table 1. Composition of six dietary experiments containing whole, fresh meat, or freeze-dried meat of blue mussel for Japanese flounder in an 8-wk growth trial.

blue mussel protein was 98.7:1.3, 97.5:2.5, 97.5:2.5, 99.3:0.7, and 98.5:1.5, respectively. All feedstuffs, except the pollack liver oil, were ground, minced, and formed into spheres of about 2 and 4 mm in diameter using a twin extruder with additions of tap water. The formulated diets were dried in an air dryer at 20°C, and an equal amount of pollack liver oil was added to each diet. Diets were dried again and stored at -35°C until used.

As shown in Table 1, the crude lipid contents of all diets were similar to each other; however, the crude protein of diet 6 was lower than that of the others.

EXPERIMENTAL PROCEDURE

In July 1996, juvenile flounder of about 1 g in body weight were transported from the Chiba Prefectural Fisheries Experimental Station to our laboratory in Chiba Prefecture. Fish were reared in 2000-L tanks at 20°C with a commercial diet used for Japanese flounder (Higashimaru Foods Inc.), until the start of the feeding experiment. The feeding experiments were conducted for 8 wk beginning in August 1996 in two 2000-L tanks equipped with a closed recirculating seawater system. The tanks were placed in a room under natural light conditions and the water temperature was kept at 20 ± 1°C. At the start of the feeding experiment, the fish were transferred into floating net cages (25 x 35 x 25 cm - W x L x H) within the aquarium, 20 fish/cage, with three replications per dietary treatment. Fish were fed to satiation twice daily for 6 days/wk with each experimental diet. The body weight of each fish was measured at the beginning and at the end of the study after the fish were starved for 36 h. At the end of experiment, analyses of proximate composition of the whole body and of hematological and hematochemical parameters were conducted by the methods described previously (Kikuchi et al. 1994a, b).

Differences in proximate composition of the whole body, and the hematological and hematochemical parameters among treatments were tested for significance using the Mann-Whitney test (Campbell 1983). Data on final body weight, weight gain, feed efficiency, and protein efficiency ratio were analyzed for significance by Duncan's multiple range test (Duncan 1955).

RESULTS

The growth and feed performance data are shown in Table 2. All fish soon accepted the experimental diets and fed actively for the duration of the experiment. Survival rates were high in all dietary groups and most of the mortality was from

Diet	Average body weight(g)		Weight gain	FE*2	PER*3	DFC*4	Survival
	Initial	Final	(%)				(%)
1	4.6	28.2^{cd*5}	513^{b}	144^{a}	3.2^{ab}	2.1	100
2	4.6	29.7^{abc}	525^{b}	149^{a}	3.3^{a}	2.0	97
3	4.5	30.8^{ab}	569^{a}	147^{a}	3.2^{ab}	2.1	97
4	4.6	31.3^{a}	573^{a}	148^{a}	3.3^{a}	2.1	98
5	4.5	27.4^{d}	498^{b}	137^{b}	3.0^{c}	2.2	98
6	4.6	28.8^{bcd}	520^{b}	133^{b}	3.1^{bc}	2.3	98

*1 Average value of triplicate for each dietary group.

*2 Feed efficiency (%, weight gain/feed intake).

*3 Protein efficiency ratio (weight gain/dietary protein intake).

*4 Daily feed consumption (% body weight).

*5 Values in the same column having same superscript are not significantly different ($P>0.05$

Table 2. Growth data of Japanese flounder fed six experimental diets for 8wk*1

Diet	Hemoglobin (g/100ml)	Hematocrit (%)	Red blood cell (x10⁴/ml)	Protein (g/100ml)	Triglyceride (mg/100ml)	Glucose (mg/100ml)	Phosphate (mg/100ml)	Calcium (mg/100ml)	Chloride (mEq/L)
1	27.1±3.1^{abc*2}	5.1±0.9^{ab}	3.1±0.3^{a}	4.0±0.2^{a}	702±262^{a}	24.3±5.0^{a}	7.6±0.7^{a}	11.5±0.5^{a}	136±7.7^{a}
2	24.6±3.8^{bc}	5.2±0.5^{ab}	3.1±0.5^{a}	4.5±1.1^{a}	570±286^{ab}	21.7±4.3^{a}	7.7±0.6^{a}	11.5±0.6^{a}	134±2.3^{a}
3	27.4±2.4^{ab}	5.7±0.3^{a}	3.1±0.1^{a}	3.5±0.1^{b}	624±235^{ab}	22.0±6.6^{a}	6.8±0.2^{a}	11.4±0.4^{a}	138±5.4^{a}
4	23.0±2.4^{c}	5.2±0.7^{ab}	3.0±0.5^{a}	3.5±0.1^{b}	341±117^{b}	21.2±3.3^{a}	6.8±0.6^{a}	11.3±0.3^{a}	139±3.8^{a}
5	25.1±4.8^{abc}	4.9±0.4^{b}	3.0±0.1^{a}	4.2±1.4^{ab}	738±279^{a}	21.8±1.6^{a}	6.9±0.3^{a}	13.2±3.5^{a}	131±4.9^{a}
6	31.0±2.8^{a}	5.5±0.2^{a}	3.1±0.5^{a}	3.5±0.8^{ab}	744±219^{a}	28.2±6.9^{a}	6.8±0.2^{a}	11.4±0.1^{a}	137±5.8^{a}

*1 Means and standard deviations for five fish.

*2 See the footnote of Table 2.

Table 3. Hematological characteristics and contents of some plasma constituents of Japanese flounder fed six experimental diets for 8 wk*1

fish that jumped out of the net cages. Final body weight and weight gain of fish fed diets 3 and 4 were significantly higher than those in the control (p <0.05). These parameters in the other experimental groups were comparable to the control. Feed efficiency was similar for diets 1 to 4, and significantly higher than that of diets 5 and 6 (p <0.05). Some differences were observed in protein efficiency ratio; however, a significantly lower value vs. the control was obtained only in diet 5 (p <0.05). Final body weights and weight gain of fish increased as blue mussel in the diet increased (diets 1 to 3).

The hematological characteristics and the plasma constituents are shown in Table 3. All dietary groups were identical in terms of red blood cell counts. Although there were some fluctuations in hemoglobin and hematocrit values, no experimental dietary groups were significantly different from those of the control. Plasma protein in diets 3 and 4, and triglyceride in diet 4 were significantly lower than those in the control; however, there were not any differences in the other parameters.

The whole body composition of the cultured fish is shown in Table 4. No significant differences were observed among dietary groups on the basis of crude protein, crude lipid, and crude ash contents. The moisture content of fish fed diet 6 was significantly higher than that of fish fed diets 1 and 3 (p <0.05).

DISCUSSION

Similar trends as shown in the previous report (Kikuchi and Sakaguchi 1997)—superior growth, comparable feed efficiency, and protein efficiency ratio to the control—were observed in dietary groups which contained blue mussel meat (diets 2 to 4) in this study. Therefore, it is clear that the inclusion of blue mussel meat in the diet promotes feeding and growth of the flounder, even if it is a very small amount (5% on a dry basis). Furthermore, the positive effect on growth was not different whether the mussel was fresh or freeze-dried according to the results of this study (diets 3 and 4, Table 2).

Many studies have been conducted on stimulating the feeding behavior of fish with various kinds of organisms. Some amino acids such as glycine, alanine, and valine showed activity to fish, especially when two or three of them form complexes (e.g., The Japanese Society of Fisheries Science 1981). Ina and Higashi (1978) and Ina (1986) reported that amino acid fractions of blue mussels *Mytilus edulis* stimulated feeding activity of red sea bream *Chrysophrys major*. There is no useful information on feeding attractants for Japanese flounder; however, it is considered that amino acids in the mussel may contribute to the promotion of feeding activity of the flounder.

The final body weight and weight gain of fish fed diets containing whole blue mussel were similar to those in the control, although the feed

Diet	Moisture	Crude protein	Crude lipid	Crude ash
1	74.4±0.2[b*]	17.4±1.4[a]	4.2±0.6[a]	3.4±0.2[a]
2	74.5±0.9[ab]	18.2±1.9[a]	4.3±0.5[a]	3.5±0.1[a]
3	74.4±0.5[b]	17.3±2.6[a]	4.8±0.6[a]	3.5±0.1[a]
4	74.3±0.8[ab]	16.5±1.1[a]	4.7±0.3[a]	3.4±0.1[a]
5	75.1±1.1[ab]	17.2±1.5[a]	4.6±0.3[a]	3.4±0.1[a]
6	75.2±0.4[a]	17.7±2.1[a]	4.5±0.7[a]	3.3±0.1[a]

* See the footnote of Table 3.

Table 4. Proximate composition of the whole body of Japanese flounder fed six experimental diets for 8 wk (%)*.

efficiency was lower due to higher crude ash content in the diet. This means that even whole mussel can be used as an ingredient in the diet for the flounder if the inclusion level is low (up to 30% as fresh whole blue mussel), because fish feed actively and compensate for the high ash content of the diet as shown in increasing daily feed consumption (Table 2). Whole blue mussels *M. edulis* were used by Berge and Austreng (1989) as substitute for fish (argentine *Argentinus silus*) in a moist pellet for rainbow trout *Salmo gairdneri*. They showed that there was a tendency toward poorer growth and feed efficiency with increasing level of the blue mussel in the diet; however, statistical differences were not observed among dietary groups as shown in this study. They also stated that the mussel meat may be a good protein source and has a favorable fatty acid composition.

On the other hand, Grave et al. (1979) reported that rainbow trout fed frozen blue mussel *M. edulis* meat showed much higher growth, feed efficiency, and protein efficiency than those fed commercial trout pellets, when the daily ration levels were in the same range. Kitamura et al. (1981) reported that the growth of red sea bream *Pagrus major* fed moist pellets containing a powder of freeze-dried blue mussel *M. galloprovincialis* meat as a main ingredient was almost equal to that of fish fed commercial pelleted diets when the moist pellets were supplemented with Vitamin B1.

These studies and our previous work show that blue mussel meat can be considered as a replacement for fish meal in the diet for many kinds of fish. However, considering the high market price of blue mussels, it is hard to say that mussels can be used as an economically attractive ingredient for fish meal in the diet. Moreover, because many of the mussels obtained from power plants are shell and sometimes contain sludges and other contaminants, acquiring a large amount of meat is not considered to be cost effective. Therefore, from a practical point of view, it would be better to utilize its effect on feeding stimulation as an additive in the diet than as a main ingredient, at least for juvenile Japanese flounder.

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LITERATURE CITED

Berge, G.M. and E. Austreng. 1989. Blue mussel in feed for rainbow trout. Aquaculture 81: 79-90.

Campbell, R.C. 1983. Mann-Whitney test, pp. 55-59. *In:* Statistics for Biologists, 2nd ed. Baifukan, Tokyo. [In Japanese]

Duncan, D.B. 1955. Multiple range and F tests. Biometrics 11: 1-42.

Grave, H., A. Schultz, and R. Van Thielen. 1979. The influence of blue mussel, *Mytilus edulis*, and krill, *Euphausia superba*, on growth and proximate composition of rainbow trout, *Salmo gairdneri*, pp. 575-586. *In:* J.E. Halver and K. Tiews (eds.), Proceedings of the World Symposium on Finfish Nutrition and Fishfeed Technology, Vol.1. Heenemann, Berlin.

Ina, K. 1986. Artificial diet with plant protein for fish. Suisan no Kenkyu 5: 85-91. [In Japanese]

Ina, K. and K. Higashi. 1978. Surveys of feeding stimulants of the sea bream (*Chrysophrys major*). Nippon Nogeikagaku Kaishi 52: 7-12. [In Japanese]

Kikuchi, K. and I. Sakaguchi.1997. Blue mussel as an ingredient in the diet of juvenile Japanese flounder. Fish. Sci. 63: 837-838.

Kikuchi, K., T. Furuta, and H. Honda. 1994a. Utilization of feather meal as a protein source in the diet of juvenile Japanese flounder. Fish. Sci. 60: 203-206.

Kikuchi, K., T. Furuta, and H. Honda. 1994b. Utilization of soybean meal as a protein source in the diet of juvenile Japanese flounder, *Paralichthys olivaceus*. Suisanzoshoku 42: 601-604.

Kitamura, H., H. Mizutani, and Y. Dotsu. 1981. Rearing experiment on young of some fishes and decapodid crustaceans fed on the meat of the common mussel, *Mytilus edulis galloprovincialis*. Mar. Foul. 3: 23-27. [In Japanese]

The Japanese Society of Fisheries Science. 1981. Chemical sense of fish and feeding stimulants. Koseisha Koseikaku, Tokyo. 128 p. [In Japanese].