DEVELOPMENT OF AQUACULTURE

IN THE COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS:

A FEASIBILITY STUDY

by

STEPHEN G. NELSON and WILLIAM J. FITZGERALD, JR.

Prepared for

The Center for Tropical and

Subtropical Aquaculture

UNIVERSITY OF GUAM MARINE LABORATORY

Technical Report No. 96

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EXECUTIVE SUMMARY

The CNMI has two significant economic advantages to the development of aquaculture. The first is low cost of labor and minimal regulations regarding the importation of alien labor. Besides the reduced cost of labor, this allows the expedient importation of expertise in experienced alien labor. The second major advantage is the low corporate tax rate (95% rebate on the US IRS mirror tax).

The major constraint to aquaculture development is the high price of land, and its limited availability. Land values are expected to escalate even further. The limited domestic market will also constrain the scale of aquaculture operations.

In light of the above, there is potential in the CNMI for developing a small aquaculture industry. This would help diversify the economy, generate government revenue, and reduce imports. A summary of recommendations is presented below.

SUMMARY OF RECOMMENDATIONS

NATURAL RESOURCES: Identify grow-out methods which will allow optimal use of land. Pursue the lease of suitable government lands for aquaculture development. Protect coastal water quality so that the development of commercial aquaculture will be possible. Assure that indigenous aquatic species are not adversely affected by species introduced for aquaculture.

GOVERNMENT SERVICES: Establish a Lead Agency for the aquaculture program to advocate and coordinate research, development, planning, and economic aspects of the industry.

REGULATORY/LEGAL: Determine the potential application of current regulatory and legal requirements on the development of aquaculture. Determine if modifications of current regulatory and legal requirements will be needed to implement effective and efficient government policies towards aquaculture development. Determine if aquaculture is to be considered an acceptable use of public land.

SUPPORT SERVICES WITHIN THE CNMI: Expand support services in proportion to development of the aquaculture industry. Limit subsidized support services to the smaller, resident, commercial developments.

CAPITAL: Encourage foreign investment in aquaculture. Pursue specific investments that will facilitate access to export markets.

MANPOWER: Evaluate the manpower needs of the aquaculture industry in relation to the labor force on a periodic basis.

TRAINING: Establish a technical training program of a scale appropriate to meet the resident manpower development requirements only if desired over the importation of foreign labor. Coordinate governmental and private bodies in t he training and employment of residents of CNMI. Promote aquaculture as a career. Include aquaculture workshops and short-courses in the College of the Northern Mariana's curriculum. Incorporate an aquaculture demonstration operation into the proposed Model Farm of the College. Integrate training programs of the College with the establishment of a demonstration farm and with the support of the lead agency in aquaculture.

INTEGRATION OF RESOURCES: Identify opportunities where aquaculture activities can be integrated with those in other sectors.

MARKET: Improve the database on seafood products entering the commercial market. Provide more in-depth analysis and monitoring of the different aspects of the market supply and demand as industry develops. Concentrate on stabilizing production of consistently high quality products to fill the local market demands. Publicize aquaculture products and disseminate information on their nutritional value. Monitor and evaluate potential export markets for high-value products. Identify and develop potential export market niches in which the CNMI may competitively participate. Explore the development of a fish processing facility.

SPECIES EVALUATION: Explore the commercial culture of marine shrimp, milkfish, tilapia, and rabbitfish. All of these are being cultured commercially in other areas. Explore the culture of winged oysters in Garapan Lagoon for the production of blister pearls. Explore the production of giant clams for the tourist-related sashimi trade. Explore the small-scale production of edible seaweeds such as Gracilaria or Caulerpa, for the fresh vegetable markets.

PRODUCTION COSTS: Phase development of farms for any of the four selected species to meet the market demand for the product. Design farms for maximum efficiency, but be flexible to allow switching to production of different species as market opportunities arise. Closely monitor the market for each species to determine price elasticity so that the market price does not fall below an acceptable margin. Design farms to meet the intended market. The ponds should be of a size that allows the harvest to meet the market demand at an acceptable price.

GIANT CLAM HATCHERY: Determine the objectives of giant clam culture.
Determine if seed stock or grow-out stock could be better provided by existing facilities in the region. Explore markets for 1-year old clams in greater detail.

SYSTEMS: Explore semi-intensive to intensive culture systems. Defer pursuit of OTEC for aquaculture, but monitor its development in other locations. If the commercial viability is demonstrated, then solicitation of private investors, possibly through a joint venture, could be pursued.

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INTRODUCTION

In the islands of the Pacific, interest in the development of aquaculture has grown over the past 20 years, efforts in this field being initiated through fisheries development programs of the South Pacific Commission (SPC). Through this program of the SPC beginning in the mid-1950s, tilapia (Oreochromis mossambicus), a cichlid fish from Africa, was released on Saipan and Pagan in the first governmental attempt to develop aquaculture in the Northern Mariana Islands.

In the ensuing years, efforts at aquaculture development in the Commonwealth of the Northern Mariana Islands (CNMI) have been sparse; other problems have been more pressing and federal funding for aquaculture scarce. However, the Center for Tropical and Subtropical Aquaculture (CTSA) was recently initiated by federal mandate, and funds were made available through the United States Department of Agriculture. Administrative offices of the center are located at the Oceanic Institute in Hawaii. The center is addressing the needs of the aquaculture industry in Hawaii, Guam, the Federated States of Micronesia, the Republic of the Marshall Islands, Palau, American Samoa and the Commonwealth of the Northern Mariana Islands. Through the Industry Committee of this program, a need was identified within the CNMI to determine what types of aquaculture development might be feasible from both technical and economic standpoints. The CTSA Technical Committee recommended a study to address this need. This study was undertaken cooperatively between the CNMI Department of Natural Resources, Division of Fish and Wildlife and the University of Guam Marine Laboratory and follows a detailed preliminary study (Coastal Resources Management, 1985) prepared by the Northern Islands Company for the CNMI Coastal Resources Management Office. The specific requests of the study were:

- o identification of species appropriate for aquaculture in Saipan, Tinian, or Rota
- o analysis of development and operational costs of the four most likely aquaculture candidates
- o determination of development and operational costs and revenues for a small-scale giant clam hatchery facility at Tweksbury Park (Rota)
- o identification of suitable sites for aquaculture development on Saipan, Tinian, and Rota
- o identification of the opportunities for, and constraints to, the development of aquaculture on Saipan, Tinian, and Rota, and
- o identification of local interest in the development of commercial aquaculture

Information for the report was gathered from a variety of sources, including scientific and technical literature, unpublished technical reports, and interviews. We are especially appreciative of the support of the CNMI Division of Fish and Wildlife of the Department of Natural Resources.

NATURAL RESOURCES

WATER

The availability and quality of available water are obviously important considerations in planning for aquaculture development. An abundance of high quality water is essential for a successful aquaculture project and allows increased production at decreased risk. Water resources can be roughly divided into three categories: freshwater, seawater, and brackish water, although these actually are part of a continuum based on the amount of dissolved salts in the water. Each of these types of water can be, and is, used for commercial aquaculture. The type of water available will affect the species chosen for culture, and the amount of water available will influence decisions regarding the type of culture system to employ. Some species can be grown only within a narrow range of salinities; an example would be giant clams (Tridacna spp.), which can be raised in seawater but not in brackish water or freshwater. Other species can tolerate a wide range of salinities; milkfish (Chanos chanos) and mullet (Mugil cephalus), for example, can be cultured in freshwater, brackish water, or seawater. When water resources are limited, the potential scale of the aquaculture operation will also be limited. Also, under conditions of limited water supply, culture systems with various degrees of water treatment and recirculation may be employed. Conversely, aquaculture systems have been successfully employed in both the treatment and reuse of wastewater. Operational costs associated with the provision of adequate water for operation of an aquaculture facility are affected by: the distances over which water has to be pumped, the types of pre-treatment and/or post-treatment required, the amount of water reuse, the monitoring requirements, and other water quality control measures employed.

Freshwater

The source of freshwater in the Mariana Islands is the rain which falls directly on the relatively small land masses. Rainfall is seasonal, ranging from 75 to 121 inches per year (Integrated Renewable Resource Management for U.S. Insular Areas--citing U.S. Department of Commerce, NOAA). Surface water sources in the CNMI are limited; natural freshwater bodies in the CNMI include streams, springs, lakes, and swamps (Table 1). However, in most cases the streams are too small to support commercial aquaculture. The lakes on Pagan are not accessible from the perspective of a potential producer, especially with the recent volcanic activity there. Lake Susupe on Saipan is a habitat for the endangered moorehen Gallinula chloropus, known in Chamorro as "pulattat" (Engbring et al., 1986). The Marianas mallard Anas oustaleti at one time inhabited the wetlands of Lake Susupe, but has not been sighted since 1967 (Engbring et al., 1986). The extinction of the Marianas mallard illustrates the need to protect the limited wetlands in the CNMI. Also, there is concern for the conservation of the indigenous aquatic fauna (Table 2), and the natural freshwater ecosystems in the CNMI are poorly known. The potential effects of introduced fresh-water organisms on existing freshwater organisms should be carefully weighed against the anticipated benefits of the introductions.

The rapidly developing tourist industry in the CNMI places stress on supplies of freshwater, particularly in Saipan. Potable water on Saipan is obtained from groundwater aquifers rather than from surface-water sources, but there remain problems of supplying sufficient freshwater for residents and tourists. Even in some of the more expensive hotels on Saipan, the salt in the freshwater is concentrated enough to be tasted. Some of the hotels have developed their own sources of freshwater; others are considering the use of reverse osmosis to purify the brackish water obtained from wells so that it can be used in the hotels.

Table 1. List of streams and lakes in the CNMI (from Best and Davidson, 1981).

ISLAND	WATER BODY	COMMENTS
Pagan	Lagona Lake	16 m deep
Pagan	Sinalung Lake	3 ha, 20 m deep
Pagan	Pialama Spring	Cool spring
Pagan	Paliat Spring	no description
Rota	W. Haofina Spring	perennial, interrupted
Rota	E. Haofina Spring	perennial, interrupted
Rota	Babao Stream	perennial, continuous
Rota	Keko Stream	perennial, interrupted
Rota	Fatguan Stream	perennial, interrupted
Saipan	Lake Susupe	191 ha, 3 m deep
Saipan	Halailai Stream	intermittent
Saipan	Denni Stream	intermittent
Saipan	Pitot Stream	intermittent
Saipan	Hasngot Stream	intermittent
Saipan	Talofofo River System	mostly perennial
Saipan	Fahang Stream	intermittent
Saipan	Nanasu Stream	intermittent
Tinian	Hagoi Lake	17 ha, 5 m deep
Tinian	Marpo Marsh	0.3 ha, 3 m deep

Given the limited availability of freshwater, the potential for commercial freshwater aquaculture for food production in the CNMI is limited. However, development of aquaculture systems which primarily serve in the purification of wastewater could be explored. Such systems have been successfully employed by metropolitan districts in the United States.

Table 2. Freshwater organisms reported from the CNMI (from Best and Davidson, 1981).

GROUP	ORGANISMS
Crustaceans	Atyid shrimp Macrobrachium lar amphipods
Gastropods	Thiara granifera Thiara scabra* Neritina sp. neritids
Fish	Anquilla sp. Awaous guamensis Eleotris fusca Gambusia affinis Kuhlia sp. Oreochromis mossambicus Sicyopus leprurus Stiphodon elegans

* Thiara scabra reported via personal communication with B. Smith.

Aquaculture systems for wastewater treatment are primarily designed to allow aquatic microbes and plants to remove nutrients. It is possible to consider these organisms as the basis of an aquatic food chain leading to the production of freshwater fish. However, consumers in the CNMI would probably be reluctant to purchase fish cultivated in such systems. The financial value of such wastewater aquaculture systems would lie in the treatment of the water, not in the production of food fish.

Brackish Water

Commercial brackish water aquaculture is usually developed in areas, such as mangrove swamps, estuaries, and deltas, where freshwater from rivers is mixed with seawater. However, since the rivers are small in the CNMI, it follows that there are no extensive estuarine areas or mangrove swamps. However, brackish water is available from wells which extend just beneath the freshwater lens. The salinity of water obtained from such wells can be controlled by adjusting the depth of the intake, less saline water is usually obtained from shallower wells, although there is considerable variation between well sites in this regard. Such water is often suitable for aquaculture. The major disadvantage in the use of this groundwater is the cost; experimental drilling to locate a suitable well site is necessary, a well must be constructed, and suitable pumps must be purchased.

An advantage of using well water, provided it is of suitable quality, is that the water is naturally filtered through limestone rock, reducing the chances of contamination of the culture system with either the larvae of parasites and predators or with undesired algae.

Many freshwater fish and the freshwater prawn Macrobrachium rosenbergii can thrive in water which is slightly saline and thus unsuitable either for drinking or for agriculture. For example, the groundwater source of freshwater at the Guam Aquaculture Development and Training Center generally fluctuates between 3 and 5 ppt, but we are able to maintain carp, Asian catfish, and Thai catfish, all considered freshwater species, in good condition. Freshwater prawns can grow in water with even higher salinity.

Seawater

The majority of potential aquaculture sites in the CNMI have access to seawater. Areas adjacent to the coast are most suitable for marine aquaculture where the costs of pumping seawater, which vary with the scale and type of culture operation, can be minimized. Some commercial farms in other areas are able to avoid the use of pumps by relying on the ponds being flushed by tidal action; marine shrimp farms in Okinawa, for example, are designed in this way. However, most farms, especially those engaged in intensive production, require the increased control over water flow that is allowed by the use of pumps. Centrifugal pumps are commonly used to move seawater from coastal sources to ponds. The pumps and intake pipes must be protected from waves generated by tropical storms and typhoons. The water pumped into the grow-out facilities must be screened to prevent predators or other undesirable species from entering the grow-out areas, and the intake will most likely require a coarse screen covering to prevent clogging of the intake pipe with small boulders and coral rubble often churned up by strong wave action.

Seawater can also be obtained from wells. The design of seawater supply systems will depend in part on the depth of the well. Centrifugal pumps are reliable, but if the depth to the ground water is more than 7 meters, the head will be too great for the draw of a centrifugal pump. In this case, either submersible pumps, which can quickly corrode in brackish or salt water, must be used or a pit must be dug to house the pump and reduce the head. Centrifugal pumps are also easier to service and should not need to be replaced as frequently as submersible pumps; for example, the centrifugal pumping system at the University of Guam Marine Laboratory was recently replaced after more than 15 years in operation.

Huguenin and Colt (1989) provide information on several parameters of seawater quality at both production and screening levels. Aspects of water quality important to or limiting production will depend on the species being cultivated; screening levels of important aspects of water quality are provided in Table 3 below.

Table 3. Seawater quality screening levels recommended by Huguenin and Colt (1989) for animal aquaculture.

PARAMETER	LEVEL
Ammonia	< 1 μg/l NH_3-N
Nitrite	< 0.05 mg/l NO_2-N
Dissolved Oxygen	> 90% saturation
Total Gas Pressure	< 76 mm Hg
Carbon Dioxide	5 mg/l CO_2
Hydrogen Sulfide	2 μg/l H_2S
Chlorine Residual	10 μg/l
pH	7.9 - 8.2
Cadmium	< 1 μg/l
Chromium	< 10 μg/l
Copper	< 1 μg/l
Iron	< 300 μg/l
Mercury	< 0.05 μg/l
Manganese	< 50 μg/l
Nickel	< 2 μg/l
Lead	< 2 μg/l
Zinc	< 10 μg/l

Monitoring and Control of Water Quality

Depending on the system requirements monitoring and perhaps altering aspects of the quality of the water used for aquaculture will be needed at several points: at the source, in the production facility, and at the point of discharge. Water quality characteristics from underground water sources on Guam are shown in Table 4.

Table 4. Ranges in water quality characteristics of water supply wells at Fadian Point Guam for 1988 to 1989. Data are micromoles per liter.

WATER SOURCE	IRON	SILICATE	NO_x	P
Cave Water	0 to 0.3	5 to 75	86 to 134	0.3 to 1.1
Brackish Well	0 to 0.9	4 to 44	6 to 104	0.1 to 1.2
Seawater Well	0 to 0.5	5 to 12	5 to 12	0.2 to 1.0

Data from Dr. Ernest Matson, University of Guam

LAND

From the standpoint of developing aquaculture, the islands of the CNMI may be considered land poor. There are many competing uses for land, particularly at low coastal sites, which must be considered when planning for aquaculture development. Competition for land use is intensified with increasing overall economic development. Competition for the use of land suitable for aquaculture restricts the sites available for aquaculture and raises the cost of the land. Land prices have escalated in recent years, driven primarily by the tourism industry and an influx of foreign investment. The availability of land may limit the size of individual farms which, in turn, affects economies of scale.

A substantial portion of land in the CNMI is in the public domain (Table 5). A recent study by Duenas and Swavely, Inc. (1990) reviewed all public land use and its zoning. With the homestead law in the CNMI, which guarantees the right of all residents to land for residential use, all suitable public land is projected to be fully utilized by the year 2020. This will constrain aquaculture development. The government must decide whether to modify this policy to allow the use of public land for aquaculture and determine which particular areas are best suited for commercial development (hotels, resorts, golf courses, and businesses), industrial activities, residential use, agricultural production, and conservation. In the absence of any government plan for land-use zoning, the increasing trend toward development may drive land prices up to the point that commercial aquaculture development will be impossible. In addition, a large portion of the coastal area in Tinian is held by the military, exacerbating the situation there. The government may wish to pursue the long-term lease of public lands for aquaculture development and to develop access roads in order to open up the sites which are suitable but to which access is limited.

Table 5. Status of land of Saipan, Tinian, and Rota.

ISLAND	PUBLIC	PRIVATE
Saipan	38%	65%
Tinian	80%	20%
Rota	65%	35%

Because of potential conflicts over land use, small-scale and intensive forms of aquaculture development are attractive from a technical standpoint. However, the economics of such systems would have to be examined on a case by case basis. One possibility which may be considered is combining small-scale aquaculture ventures with other commercial activities; a small-scale, giant clam culture operation, for example, could provide a sashimi product for restaurants while also, perhaps primarily, serving as a tourist attraction adjacent to a major hotel.

Potential sites

Potential sites for freshwater aquaculture were identified in the 1985 report produced by the CNMI office of Coastal Zone Management. A summary evaluation of these sites is provided in that report. Most are not suitable for commercial production, and freshwater is limiting throughout the CNMI in general. Given the limited availability of freshwater at accessible sites, the development of commercial-scale freshwater aquaculture in the CNMI is unlikely, but brackishwater and marine aquaculture are possible. We identified coastal areas where marine pond culture may be technically feasible. Criteria included land ownership, access to the sites, power availability, and physiography.

Saipan is undergoing a construction boom and hotels are being developed along most accessible coastal areas. Most of the area along the eastern coast, from Larua Katan Point in the north to Naftan Point in the south, has limited access and consists of cliffs--physiography unsuited to commercial pond culture. The southern coast is also primarily rocky cliffline. Much of the western coast is developed for businesses and residences. The most suitable area for aquaculture development then seems to be the area extending along the northwestern coast from Tanapag Harbor to Marpi Point. A private shrimp farm had been planned in the lower base area in this part of the island, and according to the Coastal Resources Office permit application submitted for this project, brackish water can be obtained from wells in this area. This portion of the island also has paved roads and electricity available.

On Rota, a paved road extends from the airport to Songsong village. This road passes through a gently sloping, low-lying area along the northwestern coast. This agricultural land is privately owned, with the exception of small areas devoted to public use, and much of the area would be suitable for small-scale pond culture. Seawater for such ponds could be pumped from the adjacent coastal water through pipes extending over the narrow reef-flat platform or, alternatively, the use of wells as a water supply may be possible. Similar sites are also present along the southern coast from East Harbor past Teneto Village; however, this is primarily a residential area and, thus, not suited for the development of commercial aquaculture. The southwestern and northern-most coasts of Rota are primarily steep cliffs with limited access--unsuitable for commercial aquaculture.

Coastal sites for marine aquaculture on Tinian are also very limited. More than two-thirds of the island of Tinian is controlled by the U.S. military. A large portion of the remaining land is under a long-term lease to the Micronesian Development Corporation and is being used for cattle ranching. Parcels of the public land in the coastal area just south of the harbor area are being released for private use, but this land will most likely be used for hotel and other, tourism related, development. The planned construction of hotels and casinos on Tinian make this land highly valuable and also unlikely that it will be used for aquaculture. The harbor area is heavily trafficked by cargo and fishing vessels, and this may compromise its potential as a site for aquaculture. However, the coastal area just north of the harbor is under joint public and military control. The land in this area is flat and seemingly suitable for pond construction; this is the most likely area for development of commercial pond aquaculture on Tinian.

RECOMMENDATIONS (NATURAL RESOURCES):

- o Identify grow-out methods which will allow optimal land use
- o Pursue the lease of suitable government lands for aquaculture development
- o Protect coastal water quality so that the development of commercial aquaculture will be possible

- Assure that indigenous aquatic species are not adversely affected by species introduced for aquaculture.

SUPPORT INFRASTRUCTURE

GOVERNMENT SERVICES

It is advantageous to have a lead agency setting an overall direction for aquaculture development. At present, the Division of Fish and Wildlife has taken the unofficial lead, but this has not been officially established. In the past, the lead has depended more on individuals taking an initiative rather than on an delegated lead agency. The Energy Office, and to a certain extent the Coastal Resources Management Program Office, has assumed this role in the past. The importance of a unified program with the consolidation of resources (manpower and funding) cannot be overemphasized.

There is often a tendency within government to segment and divide various aspects of a program into a number of departments, each striving for its own goals and authority to the detriment of the program as a whole. The effectiveness of the program will be dependent upon cooperation among government programs. The Lead Agency must be dynamic and have the ability to coordinate the government functions supporting the industry. However, the lead agency should not be viewed as dominating the other participating agencies. The idea is for the agencies to be cooperating in achieving common goals. Under the coordination of a properly functioning lead organization, focus can be placed on defining the long-range goals of aquaculture development. The establishment of a Lead Agency within one of the line agencies or the designation of a Special Assistant within the Governor's office to serve this function would facilitate the development of the industry.

RECOMMENDATION (GOVERNMENT SERVICES):

o Establish a Lead Agency for the aquaculture program to advocate and coordinate research, development, planning, and economic aspects of the industry.

o Focus on defining projects that will support the long-range development goals for aquaculture.

REGULATORY/LEGAL

Aquaculture is not directly addressed in legislation in the CNMI. However, efforts to initiate aquaculture will be subject to an array of laws and regulations intended for agriculture or fisheries. In addition, land use, water use, labor, environmental, navigational, public health, and general permitting laws and regulations can have an impact on different aspects of aquaculture.

Land Use

The "Restriction of Alienation of Land", an article within the Covenant to Establish a Commonwealth of the Northern Mariana Islands in Political Union with the United States, stipulates that real property can be owned only by persons of Northern Marianas descent; this may deter investment by others. However, persons who are not of Northern Marianas descent may lease land for up to 55 years. A legal decision on constitutionality of this law is pending. Also, it should be noted that foreign ownership of land is restricted in most countries, the United States being a notable exception. In practice, this restriction on ownership has often been by-passed through the use of an owner "in name only", with the deed essentially under the control of foreign interests.

Review and Establishment of Regulatory/Legal Framework

As pointed out in an FAO (1989) study, formulation of legislation governing aquaculture development should take into consideration:

o The purpose of the aquaculture industry (e.g., food production and markets (local or export), employment, production of an industrial product, sport and recreation);

o The resources and species it uses (e.g., water, land, finfishes, crustaceans, molluscs, algae);

o The systems or practices it uses for production (e.g., semi-intensive systems with earthen ponds, intensive systems with cages and net pens, enhancement in open waters, or integrated farming with plant crops and animal husbandry); and

o The environment in which production is conducted (e.g., coastal, in the ocean (bays and lagoons), along rivers and streams).

The FAO (1989) report on legislation governing aquaculture concludes there is a need for the following:

o An analysis of an individual country's needs and its policy towards the role of aquaculture in its society; and

o In light of that analysis, an examination of the legal regime and its policies to ascertain whether the needs are addressed.

In the case of the CNMI, which has no aquaculture industry, this type of analysis can be used to determine if additional legislation is needed.

Zoning

Currently there are no zoning regulations in the CNMI. However, a Zoning Commission has been established to develop a plan to be considered for adoption into law. While the lack of zoning seemingly eliminates a potential regulatory constraint to aquaculture development, the lack of zoning can be detrimental since no land is specifically designated for aquaculture. The pace of economic development in the CNMI has been rapid, and the use, for other purposes, of land suitable for aquaculture decreases the potential for aquaculture development.

Permits

Permit requirements for aquaculture are minor compared with other U.S. locations. Permits are usually required from the Coastal Resources Management Program and the Environmental Protection Agency for the construction phase of aquaculture. If the development is in a wetland, an Army Corps of Engineers permit is required. The Environmental Protection Agency and the Division of Environmental Quality regulate point source discharges; a National Pollution Discharge Elimination System (NPDES) permit will be required of an aquaculture facility. If facilities extend into navigable waters, an Army Corps of Engineers permit will be needed, as well as a Submerged Lands Lease from the Department of Natural Resources.

The Department of Natural Resources also issues permits for the importation of live aquaculture species. The Coastal Resources Management Program has jurisdiction over the Commonwealth Territorial Sea (an area which extends 12 miles beyond an archipelagic baseline, and all inland areas within 150 feet of the shoreline, with the exception of U.S. Government land. The agency has jurisdiction over wetland, the port, and the adjacent industrial area, as well as the lagoon. It regulates all commercial activities within the lagoon area and issues permits for conducting various commercial water recreational activities. In addition, the agency has jurisdiction over the entire area of all islands as far as the siting of major projects are concerned.

RECOMMENDATIONS (REGULATORY/LEGAL):

- o Determine the potential application of current regulatory and legal requirements on the development of aquaculture.
- o Determine if modifications of current regulatory and legal requirements will be needed to implement effective and efficient government policies towards aquaculture development.

o Determine if aquaculture is to be considered an acceptable use of public land.

SUPPORT SERVICES WITHIN THE CNMI

There are no support services in the CNMI specifically established for assisting aquaculture development. However, a number of services targeted for the agriculture and fisheries sectors apply to aquaculture. These include the following services.

<u>Heavy equipment program of the Department of Natural Resources</u>

The Department of Natural Resources (DNR) has one bulldozer that is available for clearing agricultural land and that can be used for construction of aquaculture ponds. The cost of the rental is subsidized by the government to a total cost of $3.95/hr.

<u>Assistance from the USDA Soil Conservation Service</u>

The Soil Conservation Service (SCS)has a field office in Saipan and branch offices in Rota and Tinian. Through the Agricultural Conservation Program a farmer can receive cost-sharing assistance in solving conservation and environmental problems. Areas relevant to aquaculture include the establishment of permanent vegetative cover, the control of animal waste, and windbreak restoration. Also, arrangements for the analysis of soil samples can be made through the SCS; the samples are sent to the University of Guam for analysis.

<u>Water analysis and information through EPA and USGS</u>

The Environmental Protection Agency (EPA) can provide basic water analysis. The United States Geological Survey (USGS) can provide information on water flow rates and ground water characteristics. The addresses of these agencies are:

Regional Administrator
Environmental Protection Agency
Attention E-4
215 Fremont Street
San Francisco, CA 94105

United States Geological Survey
6th Floor, Room 6110
300 Ala Moana Blvd.
Honolulu, Hawaii 96850

Extension program, College of the Northern Mariana Islands

The agricultural extension program, as part of the Land Grant Program is in the early phase of development at the College of the Northern Mariana Islands. Services can be provided if demand in aquaculture develops. A Memorandum of Understanding with the Department of Natural Resources for cooperative development of extension services has been approved. Extension services are being transferred from DNR to the Land Grant Program.

RECOMMENDATIONS (SUPPORT SERVICES WITHIN THE CNMI):

o Expand support services in proportion to development of the aquaculture industry.

o Limit subsidized support services to the smaller, resident, commercial developments.

OTHER SUPPORT SERVICES

Technical assistance and information regarding aquaculture can be obtained through a variety of regional programs such as those indicated below.

Extension services

Agriculture Experiment Station
College of Agriculture and Life Sciences
University of Guam
UOG Station
Mangilao, Guam 96923

The Agriculture Experiment Station (AES) at the University of Guam supports research and development projects in aquaculture. AES researchers at Guam include specialists in the analysis of soils and in aquaculture economics.

Cooperative Extension Service
Northern Marianas College
Commonwealth of the Northern Marianas

The Northern Marianas College is part of the Land Grant College Program of the USDA. Their Cooperative Extension Service (CES) provides advice to local farmers.

If the extension agents here are provided training and information concerning aquaculture; they could serve an important role in aquaculture development.

Cooperative Extension Service
College of Micronesia
P.O. Box JF
Tofol, Kosrae
Federated States of Micronesia

The Cooperative Extension Service (CES) of the College of Micronesia and the Center for Tropical and Subtropical Aquaculture (CTSA) has been providing aquaculture extension support to the U.S.-affiliated Pacific islands since 1989. The extension agent will provide aquaculture information and assistance, including on-site assistance, upon request.

Cooperative Extension Service
College of Agriculture and Life Sciences
University of Guam
UOG Station
Mangilao, Guam 96923

The Cooperative Extension Service (CES) of the University of Guam has been involved with aquaculture development on Guam and in the region since 1980 and has an extension agent specializing in aquaculture. Assistance in soils analysis is also available.

Guam Aquaculture Development and Training Center
Office of Economic Development and Planning
Guam Department of Commerce
Agana, Guam

This is a recently established facility managed by the Guam Department of Commerce. One the goals of the program is to produce post-larval shrimp and juvenile fish in support of aquaculture throughout the region. Training programs in aquaculture are planned for the future. This is a major facility, and it is dedicated to aquaculture development.

Marine Laboratory
University of Guam
UOG Station
Mangilao, Guam 96923

The University of Guam Marine Laboratory has been involved in aquaculture research and development throughout the region. Areas of expertise of the research faculty include community ecology, invertebrate biology, microbiology, water quality, natural products chemistry, aquaculture, fisheries, and phycology. The laboratory has a Marine Extension agent who has experience in aquaculture and fish handling. Advanced training in aquaculture is available.

Water and Energy Research Institute (WERI)
University of Guam
UOG Station
Mangilao, Guam 96923

The water quality laboratory of WERI is well equipped and capable of conducting a variety of water analyses useful to aquaculturists. The institute has specialists in water analysis, hydraulic engineering, and toxicity.

Regional Organizations

Center for Tropical and Subtropical Aquaculture
Dr. Kevan L. Main, Director
The Oceanic Institute--Makapu'u Point
Waimanalo, HI 96795

This program is one of the regional centers for aquaculture development recently established. The program is funded by the United States Department of Aquaculture. The program funds projects to aid the development of aquaculture in Hawaii and the U.S-affiliated islands of the Pacific.

Pacific Aquaculture Association
Chairman: Mr. Mike Gawel
Department of Resources and Development
Division of Marine Resources
Federated States of Micronesia Government

P.O. Box PS-12
Palikir, Pohnpei Island
Federated States of Micronesia 96941

The Pacific Aquaculture Association was recently established to review and prioritize aquaculture development projects in the U.S.-affiliated islands of the Pacific. The organization is funded through the U.S. Department of Interior.

SOURCES OF TECHNICAL INFORMATION

Information concerning aquaculture can be obtained from professional journals, newsletters, periodicals, and other technical literature. Many of these sources of information can be accessed through bibliographic services.

Journals

Aquaculture
Department of Animal Science
254 Animal Science Building
University of California
Davis, California 95616 USA

This is an international journal dedicated to aquaculture. Approximately eight volumes are published per year with 4 issues per volume. Subscription is approximately $882 per annum.

Aquaculture and Fisheries Management
Blackwell Scientific Publications, Ltd.
Osney, Mead, Oxford OX2 0EL
Great Britain

This is an international journal which publishes papers dealing with theoretical and practical aspects of aquaculture, conservation of marine and freshwater fish, fisheries management. It is published quarterly. Subscriptions cost $231 per year.

Asian Fisheries Science
Asian Fisheries Society
MC PO Box 1501
Makati, Metro Manila
Philippines

This is the journal of the Asian Fisheries Society. It is published two times per year. The annual subscription price is $9.00 for members, $12.00 for non-members, $16.00 for member institutions, and $25.00 for non-member institutions. Airmail delivery outside of Asia is an additional $8.00.

International Journal of Aquaculture and Fisheries Technology
Circulation Division, c/o Fuji Technology Press, Ltd.
Daini Bunsei Bldg, 1-11-17 Toranomon, Minato-ku
Tokyo 105, Japan

This is an international journal published bimonthly to provide a forum for the publication of research results, technical improvements, business news, and commentary on developments in aquaculture.

Journal of Applied Aquaculture
Food Products Press, Inc.
10 Alice Street
Binghamton, New York 13904-1580 USA

This is a new international journal devoted to research about the production, domestication, and husbandry of aquatic animals and plants.

Journal of Aquaculture in the Tropics
Oxford & IBH Publishing Co. Pvt. Ltd.
22 Park Mansion, Park Street
Calcutta 700 016 India

This journal is published two times each year; the subscription price is $45.00 per year.

Journal of the World Aquaculture Society
Managing editor: Ronald L. Thume
World Aquaculture Society
16 E. Fraternity Lane
Louisiana State University
Baton Rouge, LA 70803 USA

This journal is published quarterly by the World Aquaculture Society (WAS). Library subscriptions are $75 per volume in the United States, $81 in Canada, South

America and Mexico, and $96 in all other countries. Individual memberships in WAS, which include a subscription to the journal, are $30.

Progressive Fish Culturist
American Fisheries Society
5410 Grosvenor Lane, Suite 110
Bethseda, Maryland 20814 USA

This quarterly journal is published by the American Fisheries Society. The subscription price is $19 per volume within the US and $22 per volume elsewhere.

<u>Periodicals</u>

Aquaculture Magazine
Subscription Department
P.O. Box 2329
Asheville, NC 28802 USA

This monthly provides informative articles concerning aquaculture. The annual subscription price of $19.00 includes the annual Buyers Guide issue, a useful directory of aquaculture materials and services

Aquaculture Situation and Outlook Report
ERS-NASS
P.O. Box 1608
Rockville, MD 20849-1608 USA

This economic summary of aquaculture in the United States is published twice per year by the Commodity Economics Division, Economic Research Service, United States Department of Agriculture. Subscription rates in the United States are $12 for one year, $23 for two years, and $33 for three years. Rates are 25% higher for subscriptions mailed outside the United States. Single copies are $8 each. The report may be accessed electronically; call (202)447-5505 for details.

Catfish/Aquaculture News
P.O. Box 199
Ridgeland, MS 39157

This monthly newsletter covers the aquaculture industry in the United States with emphasis catfish farming. Subscriptions are $20.00 for one year and $35.00 for two years.

Water Farming Journal
Carroll Trosclair & Associates
3400 Neyrey Dr.
Metairie, LA 7002 USA

This news magazine, covering aquaculture activities in the United States, is published monthly. Subscriptions are $18 per year.

World Aquaculture Magazine
World Aquaculture Society
16 E. Fraternity Lane
Louisiana State University
Baton Rouge, LA 70803 USA

This magazine is published by the World Aquaculture Society (WAS). Individual subscriptions are free to members of the society. Library subscriptions are $30 per year.

Newsletters

Applied Phycology Forum
P.O.B 18381, Boulder, Colorado 80308

This is a nonprofit newsletter published under the auspices of the International Seaweed Association and the Applied Phycology Section of the Phycological Society of America. The Forum is published 3 times per year. Subscriptions are $8.00 per year.

Aquaculture and Fisheries Development in the Western Pacific
c/o Guam Cooperative Extension
College of Agriculture and Life Sciences
University of Guam
UOG Station
Mangilao, Guam 96923

This is an occasional newsletter providing information relevant to the development of fisheries and aquaculture in the islands of the Western Pacific. Subscription is free.

Aqua Farm News
Aquaculture Department
Southeast Asian Fisheries Development Center
P.O. Box 256
Iloilo City, Philippines

This is a bi-monthly newsletter covering aquaculture within Asia. It is produced by the Audiovisual-Print Section, Training & Information Division of the SEAFDEC Aquaculture Department. Airmail subscription is $26.00 per year.

BRAIS Newsletter
Brackishwater Aquaculture Information System
c/o Library, SEAFDEC
Aquaculture Department
P.O. Box 256
Iloilo City,
Philippines

This is a quarterly publication of the SEAFDEC Aquaculture Department.

INFOFISH Trade News
INFOFISH
P.O. Box 10899
50728 Kuala Lumpur
Malaysia

This publication provides wholesale and retail prices of seafood products throughout the world. Subscriptions are $350 per year in industrialized countries.

Marshall Islands Aquaculture
Post Office Box 745
Majuro, Marshall Islands 96960

This occasional newsletter provides information on the aquaculture of giant clams in the Marshall Islands. There is no charge for the newsletter.

MMDC Bulletin
Micronesian Mariculture Demonstration Center
P.O. Box 359
Koror, Republic of Palau 96940

This is an occasional newsletter describing the activities of the facility in Palau. A good source of technical information regarding the culture of giant clams. It is free.

Naga, the ICLARM Quarterly
International Center for Living Aquatic Resources Management (ICLARM)
MC P.O. Box 1501
Makati, Metro Manila
Philippines

This quarterly newsletter provides information on tropical fisheries and aquaculture. Airmail subscriptions are $20 per year in developed countries.

NCRI News
National Coastal Research Institute
NMSC, Newport, Oregon 97365

This the newsletter which provides information on the projects funded by National Coastal Research Institute (NCRI), many of which involve aquaculture. It is free to interested parties.

Pearl Oyster Information Bulletin
South Pacific Commission
Post Box D5, Noumea Cedex
New Caledonia

This is an informal newsletter to provide for the exchange of information between individuals interested in Pearl oysters in the Pacific islands.

Regional Notes
The Oceanic Institute
Makapuu Point
Waimanalo, HI 96795

This newsletter is produced jointly by the Oceanic Institute and the University of Hawaii. It is free and covers information concerning the projects funded through the Center for Tropical and Subtropical Aquaculture.

SEAFDEC Newsletter
Southeast Asian Fisheries Development Center
Olympia Bldg., 4th floor
956 Rama IV Road
Bangkok 10500
Thailand

This quarterly newsletter covers all aspects of fisheries, including aquaculture. Subscription price is $6.00 per year via surface mail and $10.00 per year via air.

SEAFDEC Asian Aquaculture
Aquaculture Department of the Southeast Asian
Fisheries Development Center
Information Division
P.O. Box 256
Iloilo City
Philippines

This is a quarterly newsletter. Subscription price via air mail is $27.

The Crustacean Nutrition Newsletter
Home Office Manager
The World Aquaculture Society
16 E. Fraternity Lane
Baton Rouge, LA 70803

This newsletter serves crustacean researchers in the World Aquaculture Society. It is published once per year. Annual subscriptions are $3.00.

The Oceanic Institute Newsline
The Oceanic Institute
P.O. Box 25280
Honolulu, HI 96825

This newsletter provides general information on the aquaculture research and development activities of the Oceanic Institute. It is available at no charge.

The Outrigger
P.O. Box 159
Kolonia, Pohnpei
Federated States of Micronesia 96941

This newsletter is produced by the Community College of Micronesia and focuses on general aspects of aquaculture that are of interest in Micronesia. It is free.

The Grouper Watcher
Caribbean Marine Research Center, c/o Florida State University Marine Laboratory
Rt. 1, Box 456, Sopchoppy, Florida 32358

This is an informal semi-annual newsletter edited by Dr. Pat Colin which provides information on all aspects of the biology of groupers.

Clamlines
ICLARM Coastal Aquaculture Center
P.O. Box 438
Honiara, Solomon Islands

This quarterly includes short articles on giant clam culture, information on research being conducted at the Coastal Aquaculture Center, and information on other giant clam projects around the world. There is no charge for the newsletter.

<u>Bibliographic Services</u>

Aquaculture Information Center,
National Agricultural Library, Room 304
Beltsville, MD 20705

This federal program provides information and database searches on a wide variety of topics relevant to aquaculture.

Current References in Fish Research
Victor Cvancara Prof
Route 1, 296 E. Hagen Road
Chippewa Falls, WI 54729

This annual bibliographic listing of fisheries science articles is available for $15.00 per copy. The references are indexed by first author, by scientific name, and by keywords in the titles.

Brackishwater Aquaculture Information Service (BRAIS)
SEAFDEC Aquaculture Department
Tigbauan, Iloilo
Philippines

This service specializes in reference material in support of the research and development needs of the Southeast Asian and Pacific regions.

Pacific Regional Aquaculture Information Service
David Coleman or Rick Hanna
Science and Technology Reference Dept.
Hamilton Library, 2550 The Mall
University of Hawaii, Manoa
Honolulu, HI 96822
Telephone: (808) 948-8263
Fax: (808) 955-6950
Bitnet: Coleman @UHCCUX.BITNET or
Hanna @UHCCUX.BITNET

This services provides aquaculture literature searches for researchers and aquaculturists in the Pacific islands.

Pacific Island Marine Information Service (PIMRIS)

R.F. Kennedy Library
University of Guam
UOG Station
Mangilao, Guam 96923

The University of Guam can provide literature searches of a variety of bibliographic databases through DIALOG.

Other Information sources:

Aquaculture Development and Coordination Program--
Food and Agriculture Organization
Via delle Terme di Caracalla
00100 Rome, Italy
Tel: 5797-6470

FINANCIAL RESOURCES

Local Investment

The Commonwealth Development Authority oversees the Economic Development Loan Fund (EDLF) which provides low-interest loans. Two types of programs are available: one to provide direct loans and one to provide guarantees for loans with commercial lending institutions. Aquaculture is an activity which would meet all of the criteria targeted by the EDLF program. These include the following:

o "Use locally available raw material." (e.g., feed materials, and natural resources of water and land)

o "Make use of technologies to provide employment opportunities and training of local people."(e.g., creation of new employment and training opportunities from field helper to manager)

o "Have a good potential for increasing exports and decreasing imports."(e.g., replacement of imported fisheries products and the development of export markets)

o "Lower costs within the Commonwealth and improve the efficiency standards of goods and services within the Commonwealth."(e.g., reduction of costs for high-value seafood products and increased availability of a high-quality products)

A priority area of the EDLF is agriculture, which aquaculture usually falls under for loan purposes. However, historically the amount of loans through EDLF in the area of agriculture have been the least, falling just below the amounts allocated for fisheries (Table 6). Future programs of EDLF will emphasize agricultural and fisheries development. Aquaculture can provide opportunities for diversification of the economy, for development of export products, and for replacement of imports to help improve the balance of trade in the CNMI.

The EDLF's future plans are "to participate actively in providing economic pilot projects either through direct or joint participation with U.S. or foreign companies and eventually transfer its invested interest to the local private sector."

This will provide an excellent avenue for stimulating the interest of local entrepreneurs who may not be familiar with aquaculture technology. Through a demonstration and pilot aquaculture operation, opportunity is provided for collection of important data used in refining estimates of the cost of operations and of revenue generation; this information will help in determining the level of risk to lending institutions (private and public). It will also provide hands-on training for those entrepreneurs interested in investing in, or establishing, a commercial aquaculture farm. Joint ventures can minimize investment and risk to the government while stimulating development of the industry. Section 702(c) of the Covenant stipulated that $500,000 is reserved each year for small loans to farmers, fishermen, and related cooperatives. The federal (USDA) Farmers Home Loan Program can make loans for aquaculture; however, qualification requirements make it difficult to obtain a loan from this program.

Table 6. Direct loans by category 1980-84 (EDLF, 1985). Data are expressed in thousands of dollars.

CATEGORY	1980	1981	1982	1983	1984	TOTAL
Agriculture	100.0	216.9	0.0	436.4	246.6	999.9
Fishing	3.5	198.4	341.8	193.3	418.7	1,155.7
Services	175.0	158.1	784.0	85.0	424.5	1,626.7
Construction	37.3	1.0	460.0	330.0	685.0	2,562.3
Tourism	0.0	1.2	20.5	475.3	500.0	2,287.3
Retail	10.0	9.4	964.0	171.5	121.4	10,676.9

Foreign Investment

To make full use of its competitive advantages, the CNMI must distinguish itself and its products to attract foreign capital. A location's relative advantages in tangible production factors (land, labor, or capital) and intangibles (e.g., amenities, life style, education and research services, cultural institutions, etc.) are part of its economy's product mix. Fundamental principles of economic development must be applied to compete as a location for new or expanded economic activity; the CNMI must promote well defined products to a segmented base of investors. Competitive advantages of the economy as a whole, as well as those specific to an aquaculture industry, need to be identified and promoted. They form the foundation for designing development policies. Typical competitive advantages (location specific advantages) include:

- o Developed internal markets
- o Abundant natural resources
- o Inexpensive labor
- o Well developed infrastructure
- o Telecommunication capabilities
- o Transportation logistics (internal and external)
- o Investment incentives
- o All areas that make it easier for multi-national corporations to achieve greater returns.

Competitive advantages specific to development of aquaculture in the CNMI include:

- o Warm consistent temperatures
- o Pristine marine water resource
- o Nearness to a major fishery market (Japan)

Competitive advantages to general business development include:

- o Open-door policy to foreign investment
- o Favorable tax structure
- o Inexpensive labor
- o Allowance for importation of labor

To attract foreign private investment the government needs to be aware of what foreign investors are looking for in a location. This can include a range of features, not all of which can be addressed by a single location. Key areas include the following:

- o Access to raw materials on favorable terms.
- o Access to new markets, or better access to existing markets.
- o Denying access to competitors.
- o Reduced costs.
- o Hedging political, taxation, or exchange risk through diversity of location.

To promote the economic development of the CNMI, foreign private investments can be sought for a number of reasons including:

- o Private foreign capital for long-term investment.
- o Access to overseas markets on assured, fair-price terms.
- o Transfer of international and sophisticated technology, production, marketing, and management skills.
- o Net economic benefits flowing to the economy through job creation and economic growth with stability.

Foreign private investment can occur through a number of means. These include:

- o Wholly foreign-owned enterprises. This is suitable for high-risk, high-technology, capital intensive ventures.
- o Partially foreign-owned enterprises, including joint ventures.
- o Production-sharing contracts. Foreign investor meets all costs in return for share of production (usually limited to exploitation of natural resources such as oil or minerals).
- o Provision of service under contract.
- o Turnkey projects. These provide technology, management and marketing expertise.

Since Japan represents a potentially important export market, it would be logical to pursue a joint venture with an organization that could facilitate entry into that market in addition to bringing the needed capital and expertise.

Technical assistance may be available to the CNMI through the Overseas Fisheries Cooperative Foundation (OFCF) of Japan. OFCF was established in 1973 as a non-profit organization. It is engaged in cooperative fishery development with nations abroad to promote amicable relations between these nations and the Japanese fishing industry. OFCF's operations are carried out with funds contributed by the Japanese Government. Although OFCF is directed toward the development of fisheries activities, a linking of aquaculture production with the processing and marketing of fishery products in general is an avenue that could be pursued as an area of technical assistance from OFCF.

Investment Incentives

Investment incentives are used by national and state governments throughout the world. If used wisely, together with performance requirements, such incentives can be important tools to stimulate economic growth. Countries compete for the investment capital of businesses by providing a variety of such incentives. However, involvement in this often intense competition between governments can be counter-productive. When deciding the type of incentives to be used, it is critical to evaluate them from both the government's and business' perspective. When evaluating from the business perspective, it is important to know how the incentive weighs in the decision to invest or not. This decision usually involves a complex process with interactions among several variables. In addition to the available investment incentives, these variables include financial, logistical, competitive, and strategic factors, as well as risk, legal structure, and geographic location.

Incentives can also be divided between those targeted at foreign or external investment sources and those targeted at local or internal sources. Investment incentives that address both of these sources of capital should be considered in the development of a strategy for promoting economic growth. The policy makers, and those who carry out the programs, need to be cognizant of the use of investment incentives as tools for implementing economic development. Imprudent and indiscriminate use of incentive programs can result in lost revenues and may have little or no impact on the business decision-making process.

The CNMI offers a generous package of incentives to attractive foreign investment. With the repeal in 1983 of the Foreign Investor's Business Permit Act of 1970, which limited foreign investment, an open-door policy has prevailed. One of the major incentives is the favorable tax structure which allows for a 95% rebate on taxes paid under the CNMI Income Tax (mirrors the U.S. Internal Revenue Service Code). A business gross revenue tax of up to 5% of gross business income applies to all businesses except banking, agriculture, fishing, manufacturing, ocean shipping, and wholesale activities. These exceptions are taxed at a lower rate of between 1% to 2% of gross income. Agricultural and fisheries production is exempt from the gross revenue tax for the first $20,000, with income in excess of $20,000 taxed at the rate of 1%.

Since aquaculture is usually considered an agricultural or fisheries activity by most countries, it is be expected that aquaculture would also be taxed at the lower rate. The personal income tax on gross income ranges from 2% to 9%. There are no real property taxes.

The other major incentive for doing business in the CNMI is the relatively inexpensive labor. Although the local labor force is small, the importation of foreign labor is allowed because immigration is under the authority of the CNMI government. This allows the foreign investor to bring in skilled labor for aquaculture. Initially, at least 10% of the work force must be local residents, and the percentage of local residents must increase to 20% after 5 years.

RECOMMENDATIONS (CAPITAL):

- o Encourage foreign investment in aquaculture.
- o Pursue specific investments that will facilitate access to export markets.

LABOR

Manpower

With an effective unemployment level of 0% in the CNMI, a new industry will have difficulty in recruiting labor. This is already evident in the large percentage (52%) of alien workers in the labor force (preliminary results of 1990 census). As the economy shifts away from an agrarian based economy to service oriented (including tourism) and "white collar" positions, it will become more difficult to recruit from the resident labor pool for aquaculture, and the limited availability of labor could be a constraint. However, with the current liberal immigration policy of the CNMI, alien labor could be brought in to fill the void. The agricultural and other sectors of the CNMI economy have recruited from a foreign labor pool. This is evident in the number of alien workers presented in Table 7.

The importation of foreign labor is allowed under the CNMI immigration and naturalization rules. Businesses must provide evidence that jobs cannot be filled by residents prior to being allowed to recruit foreign labor. Employers must post $2,000 bonds for each of the non-resident workers and must be responsible for feeding and housing them. The manpower required by the aquaculture industry ranges from unskilled to highly trained technical and managerial personnel. As the industry grows, a training program will be required to fill the need for skilled personnel. Persons with a college degree in the biological sciences would be most suitable for technical and managerial positions with large aquaculture farms. Since most interested farmers and entrepreneurs lack practical experience and specific knowledge in aquaculture practices, technical training programs should be provided to fill this manpower training need. The manpower requirements for aquaculture can be divided into three levels of skill:

1) Unskilled labor will be needed to maintain the farm. Duties would include the cutting of grass, pumping of water, draining of water, pond bank repair, minor mechanical repair and maintenance, carpentry, feeding, harvesting, sorting, and delivery. This level of personnel will constitute the main labor force. On-the-job training would be sufficient to meet this demand. However, education at the secondary level stressing training and employment opportunities in aquaculture/agriculture should be encouraged to stimulate this manpower base.

2) Skilled/managerial personnel will be needed to oversee all operations on a farm. The degree of skill required will vary according to the size and complexity of the operation and species raised. Some species (e.g., shrimp) are more difficult to raise requiring a higher level of skill than others (e.g., tilapia). A local training program for this group of personnel would assure an adequate pool of qualified labor. Skills required at this level include:

Table 7. Non-resident work permits issued by employment sector and by island - 1986.

SECTOR	SAIPAN	TINIAN	ROTA	TOTAL
Agriculture, Forestry	344	65	75	484
Manufacturing	128	0	10	138
Quarrying	36	0	0	36
Transportation & Utilities	129	116	1	246
Wholesale Trade	71	0	2	73
Retail Trade	561	25	18	604
Construction	3,387	141	109	3,637
Garment	2,423	0	0	2,423
Restaurants	350	6	2	358
Night Clubs	736	66	12	814
Hotels	412	8	49	469
Private Households	902	69	60	1,031
All Others	1,047	10	17	1,074
Total	10,526	506	355	11,387

From Department of Commerce and Labor.

o general knowledge of the biology of the species cultured and of pond ecology,

o abilities to calculate stocking rates, determine feeding rates, and estimate population size and biomass;

o skills in harvest scheduling, water quality determination (e.g, oxygen, pH), and

o basic business management skills necessary to maintain financial records, cash flow projection, procurement and sales, and preparation of financial statements.

3) Highly skilled resource personnel are needed to provide technical and professional expertise in aquaculture. This group would provide the instruction base in the proposed training program. Their background should include a formal education in aquaculture or a related field and working experience in aquaculture. This group, along with private consulting groups, will provide information on matters such as site selection, pond design and construction, species selection, biology, physiology, and

behavior of the species cultured, pond ecology, the prevention, diagnosis and treatment of diseases, and economic analysis. Such personnel may be associated with government programs in aquaculture or agriculture (e.g, Division of Fish and Wildlife, College of CNMI). However, large farms may require such personnel on their staff.

RECOMMENDATIONS (MANPOWER):

o Evaluate the manpower needs of the aquaculture industry in relation to the labor force on a periodic basis.

TRAINING

A technical training program could be coordinated and managed jointly by the College of CNMI and the Division of Fish and Wildlife because both groups disseminate technical information to the public and are involved in related (agriculture/fisheries) work. The mechanical aspects of establishing a program could be coordinated with the Job Training Partnership Act Program and the College of CNMI. The Job Training Partnership Act Program can provide funds for the salaries of the instructors, supplies and materials, and any equipment needed in the training program. The College of CNMI could provide the facilities. A training program could bring together the island's experts in the appropriate fields from the government, College and private sectors. This might involve qualified staff from the College of CNMI, Department of Commerce and private firms. A permanent training program will most likely not be needed; an ad hoc training program will probably be adequate.

The Community College's Agriculture Extension Program currently offers extension service to the agriculture sector, and the College expressed interest in providing support for aquaculture. In addition, the College plans to expand their services with the addition of a Water Analysis Laboratory. The extension program is supported through the Smith and Lever program (extension service) and the USDA Hatch Program (research). The proposed extension budget of $2.1 million for 1990 provides an adequate funding base with flexibility to incorporate aquaculture services. The College offers special short courses and workshops in various areas under their extension program. The use of the existing agricultural extension program is the most logical means of providing education and training in aquaculture, since there is an established mechanism for providing the service.

In addition, the College is planning to develop a Model Farm. Funding for the farm is included in the 1990 budget at $153,000. If the farm is suitably located, integration of an aquaculture facility into the program, supported by the Farm Apprentice Program, would provide an excellent way to promote aquaculture as well as to provide training. Another potential funding source that could assist in aquaculture development in the CNMI is through the Sea Grant Program, for which the College is eligible.

An aquaculture training program could be set up. Upon completion of this program, the Job Training Partnership Act Program could assist graduates who desire additional on-the-job training by providing placement into private or government operated aquaculture facilities. This approach would be advantageous because it would provide a means to round out the training program with work experience. The private sector would provide the position so that these trainees could broaden their skills and gain the confidence and skills necessary to operate an aquaculture farm. The private sector would jointly share the cost of employment of these trainees with the Job Training Partnership Act Program, which will pay up to 50% of the wages during the training period. This training program could also be extended to the unskilled level of personnel to provide them with hands-on training and the opportunity for gainful employment in the private sector. The training program (Basic Aquaculture Technology) would also satisfy the requirement of technical competence needed in order to obtain a loan from the government Economic Development Loan Fund (EDLF).

The recruitment of personnel from other areas will be necessary if the industry expands faster than the training program can provide qualified personnel. The importation of foreign labor is the most likely means of meeting the manpower needs. Foreign investors may want to have experienced managerial personnel with whom they are familiar, especially in the initial stage of an operation when most problems are encountered. In these cases, the non-resident worker entry permit and foreign investor visa will aid in establishment of the business. The foreign manager can then train a replacement from locally hired staff, perhaps through a training program coordinated through the Department of Commerce and Labor and the Job Training Partnership Act Program.

RECOMMENDATIONS (TRAINING):

- o Establish a technical training program of a scale appropriate to meet the resident manpower development requirements only if desired over the importation of foreign labor.

- o Coordinate governmental and private bodies in the training and employment of residents of CNMI.

- o Promote aquaculture as a career.

- o Include aquaculture workshops and short-courses in the College of the Northern Mariana's curriculum.

- o Incorporate an aquaculture demonstration operation into the proposed Model Farm of the College.

- o Integrate training programs of the College with the establishment of a demonstration farm and with the support of the lead agency in aquaculture.

INTEGRATION OF RESOURCES

There is potential for integrating resources and activities with other sectors of the economy. For example, it would be useful to see how aquaculture fits into the overall development plan for agriculture. Areas of interest include the following:

- o A local feed mill could facilitate both aquatic and terrestrial livestock production.

- o The reservoirs proposed to facilitate aquaculture development could also be used to support irrigation of terrestrial crops. Food-production systems which conserve water should be encouraged. For example, aquaculture discharge from freshwater ponds could be used to irrigate crops. Also, irrigation return water could be used to maintain optimal salinity in brackish water ponds.

- o A fish-processing plant might allow development and penetration of markets for dressed fish and fillets. Other small-scale industries may be facilitated by establishment of a fish processing plant. For example, production of value-added products, such as smoked fish, may be economically feasible. In addition, the by-products of a fish processing plant could be used in the small-scale production of fish emulsion for use as fertilizer for ornamental plants.

RECOMMENDATIONS (INTEGRATION OF RESOURCES):

- o Identify opportunities where aquaculture activities can be integrated with those in other sectors.

MARKET ASSESSMENT

MARKET EVALUATION

Targets of aquaculture production will be determined by the market demand as well as by the technical capacity of production. To evaluate the markets for aquaculture products, it is necessary to have available a data base on similar products that are currently marketed in the CNMI. The data base could be used to identify products that are competitive with those that could be produced by a local aquaculture industry. The current sources of this type of data include: 1) Division of Fish and Wildlife Division's import data (via air transport only), 2) Fish and Wildlife Division's commercial landings data, and 3) Department of Finance's import commodities (ocean freight). Improvement in the data base, especially regarding imports by sea, should be pursued. This would allow more accurate market estimates and aid in the identification of products that could be replaced through aquaculture.

The commercial landing data collected by the Division of Fish and Wildlife accurately represents the domestic fishery products entering the commercial market. The current system collects data from dealers on the island of Saipan. The Division of Fish and Wildlife estimates that more than 90% of all CNMI commercial landings are made in Saipan. The Division of Fish and Wildlife further estimates that more than 90% of total commercial landings since 1983 have been recorded in this data base. The market structure and channels in the CNMI are composed of the components identified in Figure 1.

A key element in market analysis is estimating the proportion of the fisheries imports that can be replaced by aquaculture production. This is done by identifying the imports that are the same as, or similar to, those that could be produced through aquaculture. However, new markets will be created and existing markets expanded by the increased availability of high-quality local products. Among the important criteria in maximizing the market for specific seafood products is a consistent supply. The domestic catch fluctuates substantially during the year. Peaks in the catch are influenced by both seasonal fluctuations in species abundance and by limitations on fishing imposed by the weather. Seasonal species include mahimahi, yellowfin tuna and skipjack tuna, species that constitute a large proportion of the total catch. Seasonal fluctuations in seafood availability could be dampened through aquaculture production.

As the aquaculture industry develops, more in-depth analysis and monitoring of the different aspects of the market supply and demand will be required.

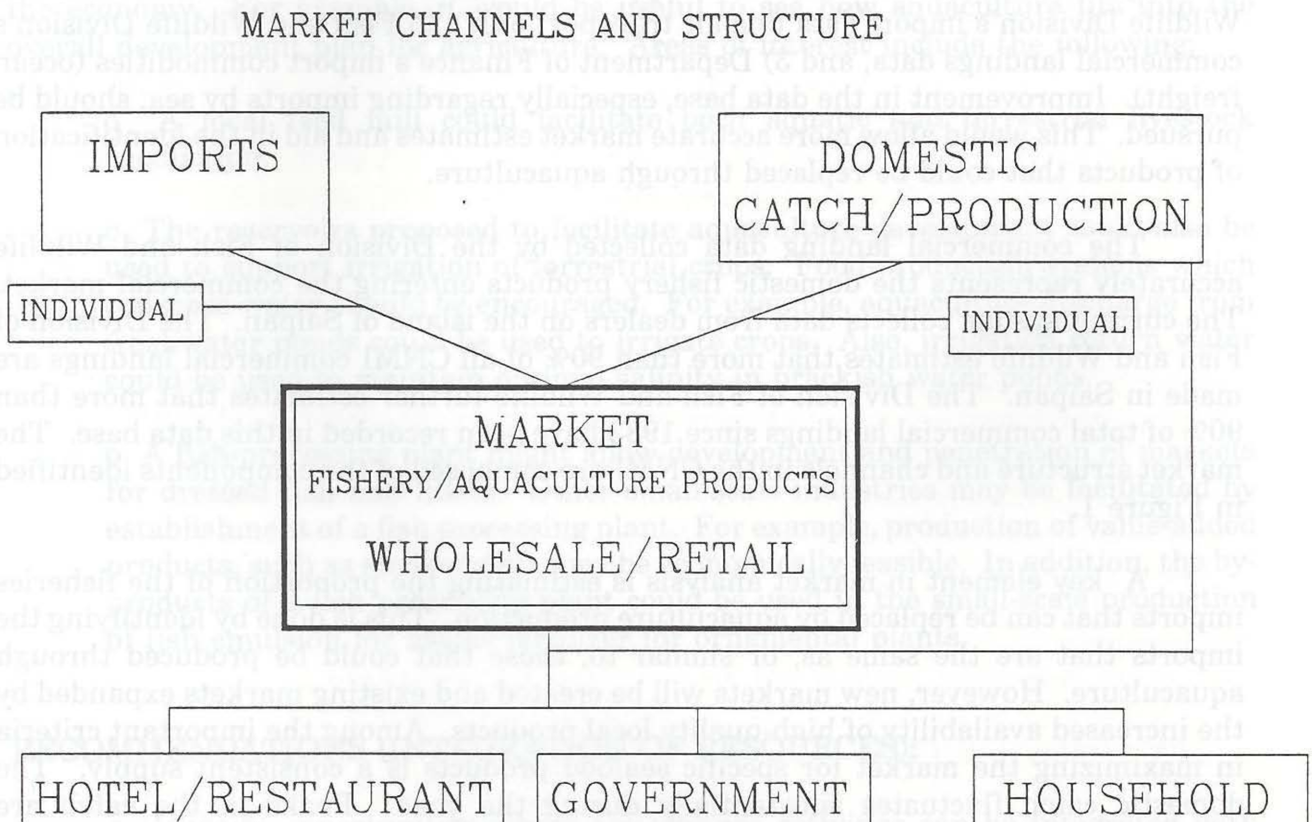


Figure 1. GNMI Market Channels and Structure

LOCAL MARKET

Aquaculture products will compete primarily with whole fisheries products. The numbers of residents and non-resident workers in the CNMI are shown in Table 8. Adding dependents the total (1989) population in the CNMI is 50, 861. Together with the data shown in Table 9, consumption of fresh or frozen whole fisheries products by the domestic population (resident and non-resident alien population including dependents residing in the CNMI) is 249,219 kgs yr^{-1} (4.9 kg $capita^{-1}$ yr^{-1} x 50,861 population). This assumes that the per capita consumption in the CNMI is similar to that of Guam (Myers et al., 1983). The total estimated annual seafood consumption by the domestic population is 691,710 kgs $year^{-1}$ (13.6 kg^{1} $capita^{-1}$ yr^{-1} x 50,861 population) kg $capita^{-1}$. This is based on the annual per capita consumption of seafood in Guam (Callaghan, 1978). This estimated annual consumption does not include that of visitors.

Table 8. 1989 Population (Source: Stewart, 1990).

ISLAND	RESIDENTS	NON-RESIDENTS*	TOTAL
Saipan	20,165	17,563	37,005
Rota	1,816	501	2,068
Tinian	1,258	730	1,800
Northern Isl.	145	0	128
Total	23,258	18,794	41,001

*Does not include dependents residing in the CNMI.

Table 9. Estimated annual per capita seafood consumption (kg) in Guam by product category.

CATEGORY	PERCENTAGE*	PER CAPITA**
Canned	31.2%	4.2
Frozen	26.1%	3.6
Fresh	36.1%	4.9
Dried & Smoked	6.6%	0.0
Total	100.0%	13.6

*From Callaghan, 1978; **From Myers et al., 1983.

Callaghan (1978) reported differences between ethnic groups in their per capita consumption of fish. In order from the largest consumption, they consisted of Filipino, Japanese, Chinese, Chamorro, Korean, Micronesian and Caucasian (Table 10). Differences in species preferences were also found. These differences should be taken into consideration in projecting market demands for specific species (e.g,. rabbitfish are purchased primarily by Chamorros and Micronesians). Product diversification is important in an ethnically diverse community such as in the CNMI.

Table 10. Weekly household consumption and expenditures (US$) on fishery products by consumer group (Callaghan, 1978).

GROUP	FREQUENCY CONSUMED	EXPENDITURE
Filipino	2.56	15.97
Japanese	2.56	12.14
Chinese	1.67	9.90
Chamorro	1.34	11.51
Korean	1.13	6.72
Micronesian	1.03	8.68
Caucasian	.92	4.34

The resident population of the CNMI is approximately 75% Chamorro and 25% Carolinian. The non-resident population is mainly Asian, and this is the fastest growing sector of the total population. Asians consume the most seafood per capita (Table 10). The ethnic composition should be considered in deciding the species to culture. For example, to target the large percentage of the non-resident Filipinos (Table 11), tilapia and milkfish would be most suitable.

Another factor that influences purchases of seafood is income level. For example, a wage earner with more disposable income would be more inclined to purchase higher value products, such as shrimp and certain fish. Figure 2 shows the number of wage earners and the average annual income per worker. The average income in the CNMI has declined since 1985. This is attributed to the influx of non-resident workers, who in many cases are working for less than the minimum wage. This trend reflects a growing low-income subsector of the population. This group, which has less disposable income, would tend to purchase the lower priced species such as tilapia. This trend is likely to continue because alien workers are still being brought in to meet the requirements of the growing visitor industry.

Table 11. Ethnic composition of alien population - 1989.

GROUP	NUMBER	PERCENT
Filipino	18,893	60
Korean	3,865	14
Chinese	2,683	10
Japanese	896	3
Other	1,266	4
Total	27,603	100

From Immigration and Naturalization Services.

The rapid economic growth in the CNMI is reflected in increases in commodity imports (Figure 3) and tourism. The demand for seafood should increase dramatically over the next 10 years. This will be mainly attributed to the rapid growth in the domestic population (mainly in the non-resident alien population) and in the number of visitors. Both of these sectors of the market are presented in Tables 12 and 13 and in Figure 4.

Table 12. Projected population in the year 2015 (Source: Public Use Plan, 1990, Duenas and Swavely, Inc).

ISLAND	RESIDENT	NON-RESIDENT	VISITOR*	TOTAL
Saipan	52,309	33,904	5,878	92,091
Tinian	2,374	4,122	627	5,696
Rota	4,321	18,122	3,527	23,007
Total	59,004	56,148	10,032	125,184

*Equivalent number of full-time residents.

The total commercial domestic catch is presented in Figure 5. This does not include the catch of subsistence and recreational fishermen, which do not sell their catch. A recent study of the domestic fishery on Guam showed that 60% of the total catch does not enter commercial markets and is given to relatives and friends or consumed by the fishermen (Knudson, 1987); therefore, a large portion of the total catch never reaches a commercial market. Assuming a similar situation in the CNMI then only approximately 40% of the total domestic catch enters the commercial market channels.

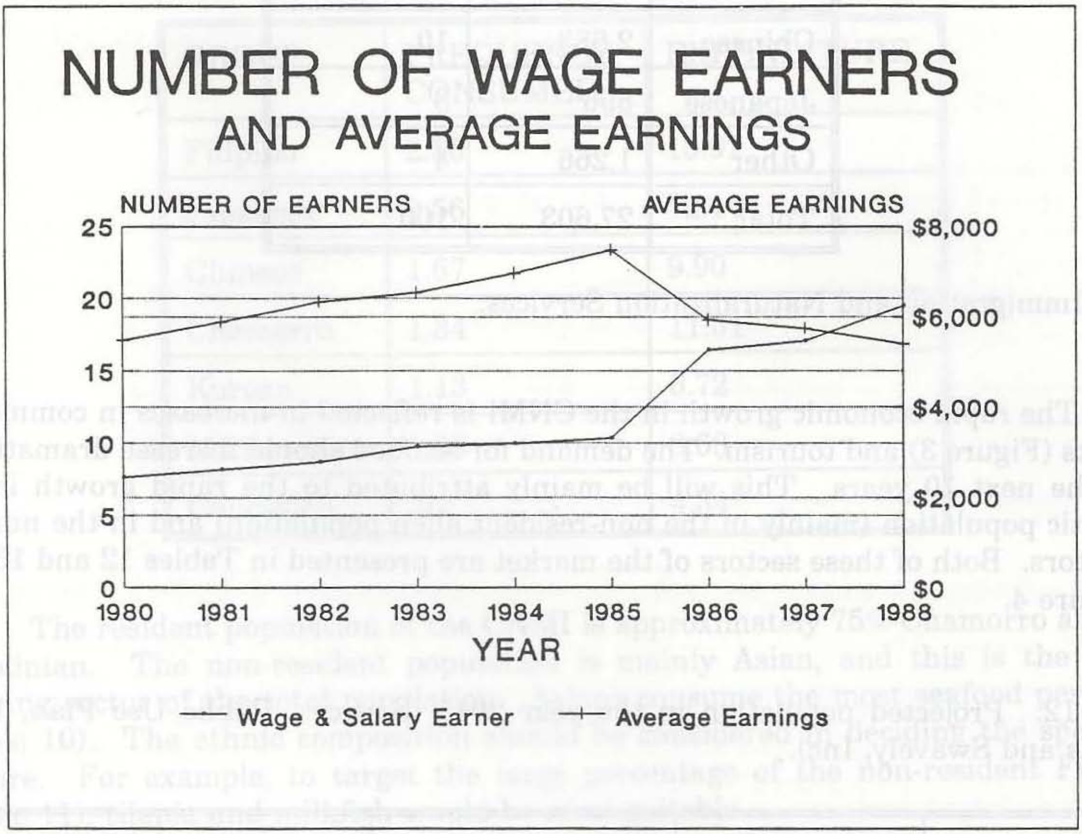


Figure 2. Number of Wage Earners and Average Earnings.

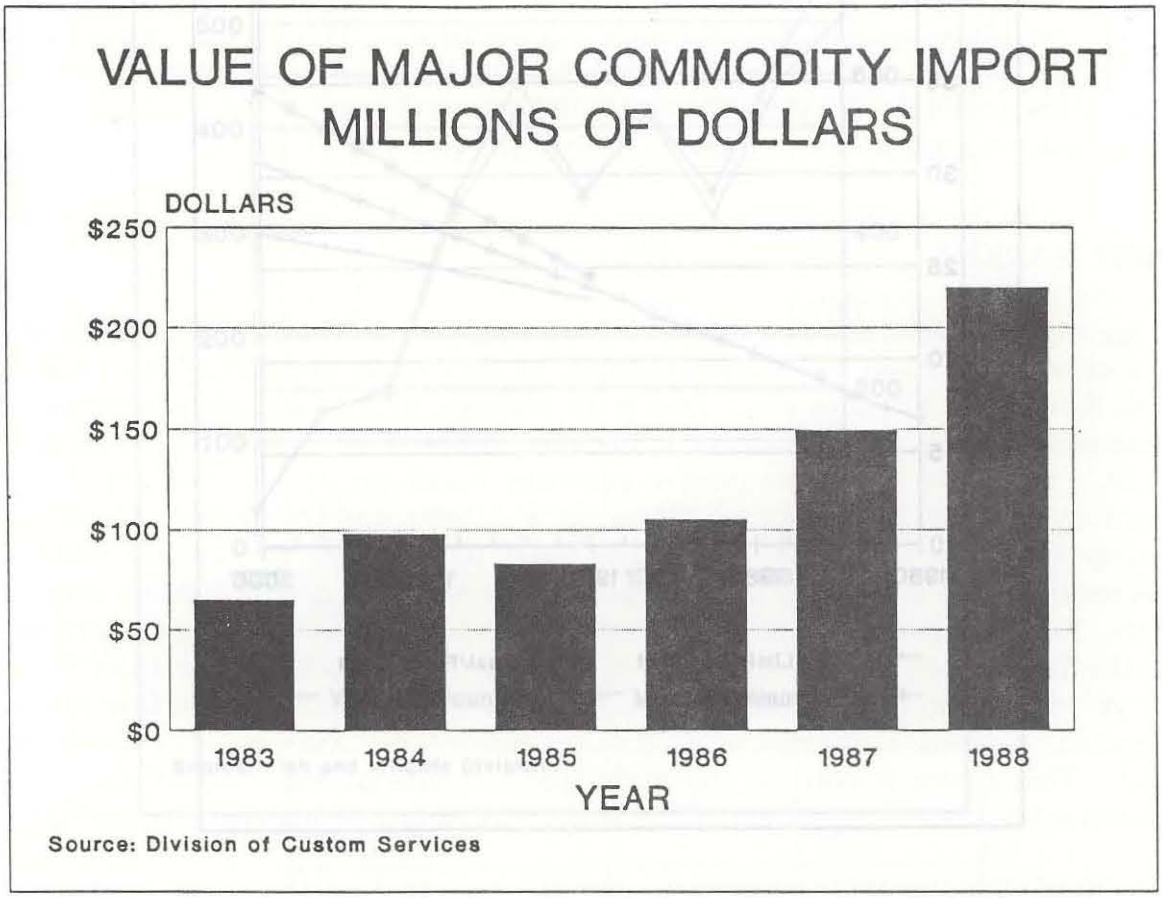


Figure 3. Value of commodity imports for the CNMI.

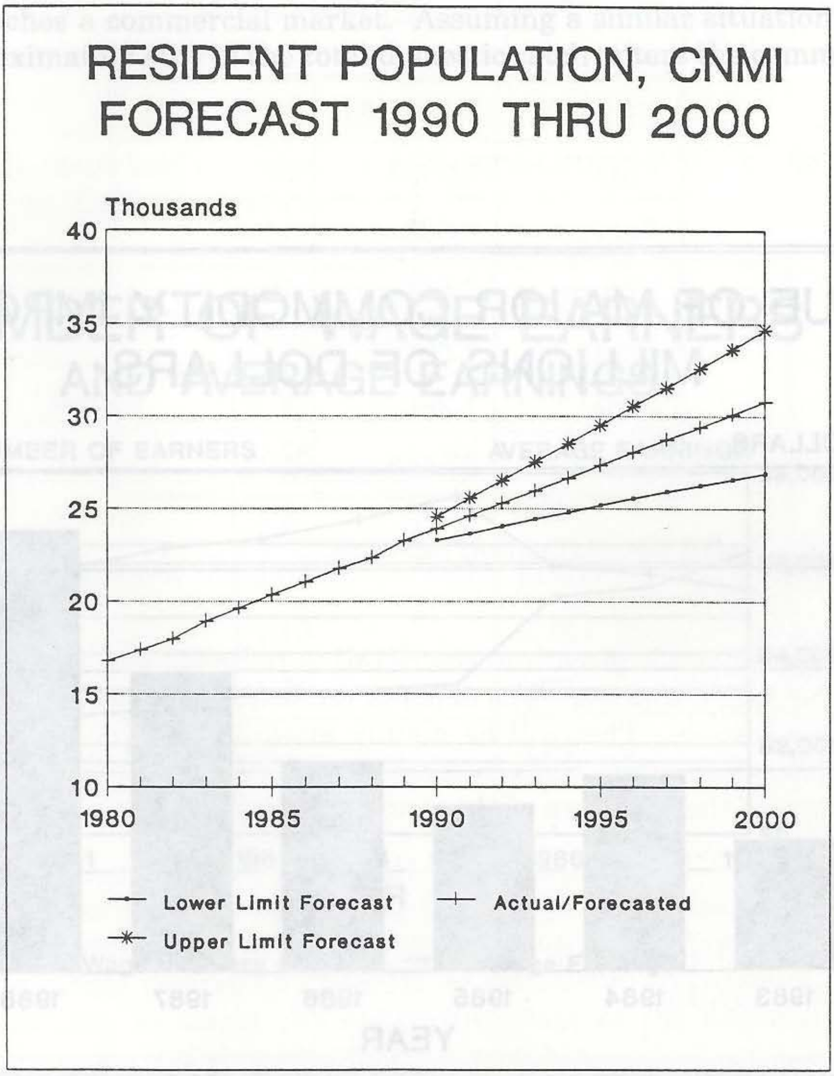


Figure 4. Forecasted resident population, 1990 through 2000

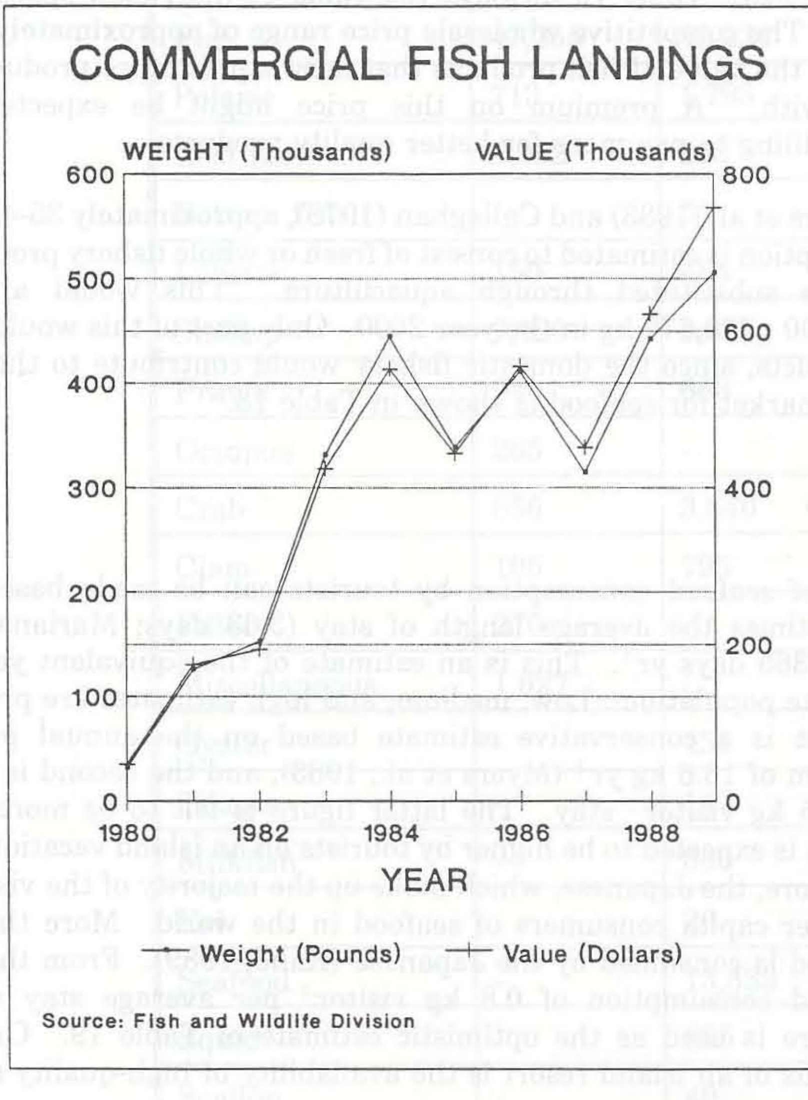


Figure 5. Domestic fishery's commercial landings.

Tables 13, 14, and 15 provide information on the air-freight imports by product type, origin, and importer category. These imports would be mainly comprised of whole-fish fishery products. Imports by sea amounted to $1.53 million in 1989 (Department of Finance). Table 16 displays the value of individual species in the commercial market. The competitive wholesale price range of approximately $3.85 to $4.40 kg^{-1} represents the value of fish products that most aquaculture products would have to compete with. A premium on this price might be expected if the consumer/buyer is willing to pay more for better quality products.

Based on Myers et al. (1983) and Callaghan (1978), approximately 35-40% of the total seafood consumption is estimated to consist of fresh or whole fishery products that potentially could be substituted through aquaculture. This would amount to approximately 321,000 - 440,670 kg in the year 2000. Only part of this would be filled by aquaculture products, since the domestic fishery would contribute to the market. The projected local market for seafood is shown in Table 18.

TOURIST MARKET

An estimate of seafood consumption by tourists can be made based on the number of visitors, times the average length of stay (3.63 days; Marianas Visitor Bureau), divided by 365 days yr^{-1}. This is an estimate of the equivalent year-round residents added to the population. Low, medium, and high estimates are provided in Table 19. The first is a conservative estimate based on the annual per capita consumption in Guam of 13.6 kg yr^{-1} (Myers et al., 1983), and the second is based on a consumption of 0.5 kg $visitor^{-1}$ stay. The latter figure is felt to be more realistic because consumption is expected to be higher by tourists on an island vacation than by residents. Furthermore, the Japanese, which make up the majority of the visitors, are among the largest per capita consumers of seafood in the world. More than 80 kg $capita^{-1}$ yr^{-1} of seafood is consumed by the Japanese (Kano, 1989). From this rate of consumption, seafood consumption of 0.8 kg $visitor^{-1}$ per average stay would be expected. This figure is used as the optimistic estimate of Table 19. One of the anticipated attractions of an island resort is the availability of high-quality seafood.

In Table 20, the 1990 estimate is a projection based on the actual number of visitors in the first four months of the year. The figure of 573,016 visitors for 1990 represents a 72% increase over the number of visitors in 1989. The number of visitors has grown at an average annual rate of 37% over the past five years. The composition of visitors to the CNMI is 75% from Japan, 18% from the U.S. (including Guam), 3% from Korea and 1% from Australia. The total visitor expenditure in 1989 was recorded at $261.5 million, or an average of $866.44 per visitor stay. A forecast of the number of visitors (Figure 6) projects growth in visitors to 2.9 million by the year 2000.

Table 13. Pounds of fish products imported into the CNMI via air freight.

PRODUCT	1988	1990*
Fish	47,255	52,234
Pelagic	713	1,793
Reef fish	5,162	213
Bottom fish	-	53
Lobster	150	464
Shrimp	7,120	5,533
Prawn	94	683
Octopus	265	-
Crab	856	3,840
Clam	105	795
Fillet	270	-
Miscellaneous	1,627	-
Oyster	-	451
Tilapia	-	147
Milkfish	-	500
Eel	-	20
Seafood	-	13,333
Squid	-	825
Scallop	-	40
Unspecified	-	781
Total	63,617	81,575

*Fish six months of 1990 (Source: Division of Fish and Wildlife, CNMI).

Table 14. Pounds of seafood imported into the CNMI via air freight, categorized by origin.

ORIGIN	1988	1989	1990*
Guam	12,490	10,635	6,591
Truk	9,159	5,839	2,233
Yap	2,077	3,472	1,167
Palau	35,074	28,536	29,678
Pohnpei	1,570	7,540	10,437
Marshalls	23	0	408
Philippines	2,417	18,247	29,624
Japan	535	1,505	861
USA	272	0	0
Hong Kong	0	1,915	384
Kosrae	0	62	192
Taiwan	0	40	0
Unknown	0	0	0
Total	63,617	77,846	81,575

*First six months of 1990 (Source: Division of Fish and Wildlife, CNMI).

Table 15. Pounds of fish imported into the CNMI via air freight, categorized by importer.

IMPORTER	1990*
Hotel	1,079
Restaurant	492
Wholesale	43,783
Retail	8,196
Private	28,025
Total	81,575

*First 6 months of 1990 (Source: Division of Fish and Wildlife, CNMI).

Table 16. Wholesale value and price of commercial landings. (Source: Division of Fish and Wildlife, CNMI).

SPECIES	1986 value	1986 price/lb	1987 value	1987 price/lb	1988 value	1988 price/lb	1989 value	1989 price/lb
Bigeye Scad	63,012	$1.87	18,441	$1.85	2,576	$1.75	23,221	$2.00
Jacks	1,256	1.92	1,109	2.28	-	-	-	-
Mullets	1,940	1.63	501	1.65	-	-	336	1.21
Bottom fish	20,530	1.72	43,634	1.76	58,686	1.75	23,100	1.82
Gindai (Flower snapper)	1,623	2.32	470	2.16	119	1.75	1,579	1.96
Grouper	2,327	1.95	1,056	1.83	-	-	1,060	2.36
Onaga	3,853	3.01	1,045	2.77	4,819	3.01	8,710	4.39
Opakpaka	1,633	2.07	2,107	2.30	676	2.59	902	2.10
Uku (Gray snapper)	859	2.96	-	-	-	-	-	-
Reef fish	111,189	1.55	105,645	1.62	161,132	1.57	322,201	1.56
Wrasse	31	1.50	-	-	77	1.13	23	1.75
Rabbitfish (Hitting)	10,879	1.87	6,443	1.98	10,269	1.93	13,235	1.96
Rabbitfish (Menahac)	-	-	583	1.48	-	-	-	-
Rudderfish	3,856	1.55	434	1.84	115	1.75	1,540	2.06
Emperor (Maute)	12,999	1.76	22,447	1.80	4,751	1.93	6,029	1.90
Squirrelfish	2,843	1.63	533	1.68	-	-	-	-
Parrotfish	8,710	1.56	5,133	1.65	16,658	1.59	21,169	1.61
Surgeonfish	7,352	1.55	9,988	1.56	12,905	1.59	16,938	1.58
Unicornfish	2,599	1.56	798	1.66	5,371	1.60	1,324	1.61
Goatfish	1,083	1.61	910	1.76	363	1.96	2,380	1.50
Troll fish	1,693	1.22	361	1.00	-	-	398	1.60
Barracuda	102	1.00	138	1.02	274	1.02	189	1.38
Dolphin (Mahimahi)	16,633	1.17	9,956	1.31	34,069	1.38	8,689	1.48
Marlin	2,224	1.05	2,231	1.13	1,226	1.17	6,084	1.33
Sailfish	114	1.25	107	1.60	-	-	-	-
Rainbow runner	842	1.29	684	1.30	4,358	1.25	249	1.75
Wahoo	9,421	1.30	13,582	1.27	12,466	1.33	1,961	1.56
Skipjack	213,195	1.02	145,198	1.12	253,236	1.19	262,905	1.28
Dogtooth tuna	4,241	1.37	6,458	1.26	4,189	1.26	4,901	1.65
Yellowfin tuna	18,549	1.37	11,437	1.37	17,443	1.42	13,766	1.70
Invertebrates	424	2.00	58	2.40	-	-	14,464	3.32
Lobster	21,072	3.28	15,612	3.12	14,616	3.88	115	2.04
Octopus	1,846	1.53	3,335	1.50	567	1.14	-	-
Shrimp	-	-	8	2.00	-	-	-	-
Squid	33	2.50	52	2.00	-	-	-	-
Assorted	5,716	2.04	9,030	1.48	-	-	153	1.w
Unknown	-	-	8,887	1.70	-	-	-	-
Total	554,676		448,410		621,693		757,618	

The domestic market price range for fresh whole fishery products will influence the price for aquaculture products. Table 17 presents the domestic retail price range for key species and species groups. The farm gate price will be below these prices unless the farmers sell directly to the consumer.

Table 17. Domestic retail market prices (dollar per pound) for whole fishery products.

PRODUCT	SAIPAN	TINIAN	ROTA
Bottomfish	$2.25-2.50	$3.00-3.50	$2.75-3.00
Onaga		4.00-5.00	2.00-2.50
Reef Fish	1.85-2.05	2.50-3.00	1.50-1.75
Rabbitfish	2.80-2.85	2.50	1.50-1.75
Yellowfin	1.75	1.50	
Wahoo	1.75		
Rainbow Runner	1.75		
Mahimahi	1.75		
Lobster	3.95		
Octopus	2.00		
Milkfish			2.98
Shrimp		9.49	

Table 18. Projected local market for seafood products in kg.

GROUP	1989 Low	1989 High	2000 Low	20000 High
Resident	316,310	379,570	418,785	502,542
Non-resident Alien	375,400	450,480	499,283	599,140
Total	691,710	830,050	918,068	1,101,682

Table 19. Conservative, median, and optimistic estimates of seafood consumption (in kg) by visitors as equivalent residents (Source: Marianas Visitors Bureau)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Visitors	117.1	117.6	111.2	124.0	131.0	142.3	163.5	194.2	245.5	333.3	573.0
Equivalent Residents	1.2	1.2	1.1	1.2	1.3	1.4	1.6	1.9	2.4	3.3	5.7
Kg Consumed											
Conservative	15.8	15.9	15.0	16.8	17.8	19.2	22.1	26.3	33.2	45.1	77.5
Median	58.6	58.8	55.6	62.0	65.9	71.1	81.7	97.1	122.8	166.6	286.5
Optimistic	93.7	94.1	88.9	99.2	105.5	113.8	130.8	155.4	196.4	266.6	458.4

* Values for 1990 are based on actual visitors for first four months projected out for the whole year.

Table 20. Forecasted seafood consumption (kg) by visitors for the year 2000.

GROUP	LOWER LIMIT	FORECASTED	UPPER LIMIT
Visitors	666,751	2,965,713	5,263,676
Equivalent Residents	6,641	29,495	52,350
Seafood Consumed (kg)			
Conservative	90,320	401,142	711,963
Median	333,876	1,482,857	2,631,838
Optimistic	534,200	2,372,570	4,210,940

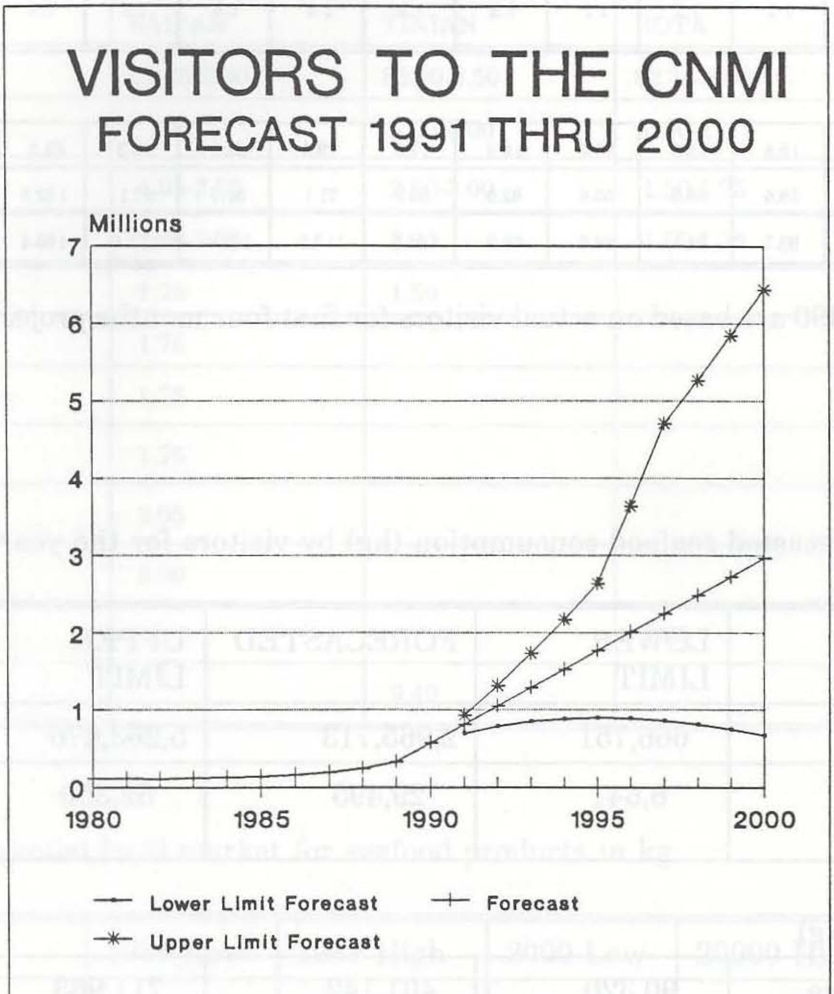


Figure 6. Forecasted Visitors, 1991 through 2000

With the rapid growth of the tourist market, this projection for the year 2000 suggests a major market for aquaculture products (Table 21). In general, high-value aquaculture products will be targeted for the tourist market.

Based on historical data, the number of visitors is forecasted to reach 2.9 million by the year 2000. However, realization of this increase will undoubtedly be constrained by the availability of hotels, airline capacity, availability of labor, and limitations of infrastructure. Still, the rapid increase in the visitor industry will provide a substantial high-end market for aquaculture products. In light of the above constraints, the actual number of visitors is likely to fall between the forecasted lower limit and the forecasted value for the year 2000. Figure 7 shows the potential market size over the forecasted range for the number of visitors in the year 2000.

SUMMARY OF DOMESTIC MARKET

There are three sources of fisheries products entering the commercial market (Table 21). They are: 1) domestic commercial landings, 2) air-freight imports, and 3) ocean-freight imports. The total of these reflects the commercial market size (Tables 21 and 22). There are two sectors within the domestic market. These are: 1) the domestic population and 2) the visitors. The former is comprised of residents and non-resident aliens residing in the CNMI. These projections are made, based on trends established by historical data, with the use of exponential smoothing (Holt two-parameter smoothing for forecasts). The estimates are based on the best data available and on the results of similar market studies. Such estimates are usually considered 90% accurate. However, the limited data base, and its accuracy, reduces confidence in the estimates. Also, several additional factors may affect the accuracy of the projections. These include public policy decisions, resource constraints, infrastructure constraints, and world economic conditions. The estimates should be considered only as a general guide.

The limited domestic market will be a constraint, and it will be difficult for producers in the CNMI to compete in the world market. Small pocket markets for high quality products will probably be the only opportunities for export. These markets need to be identified and actively developed.

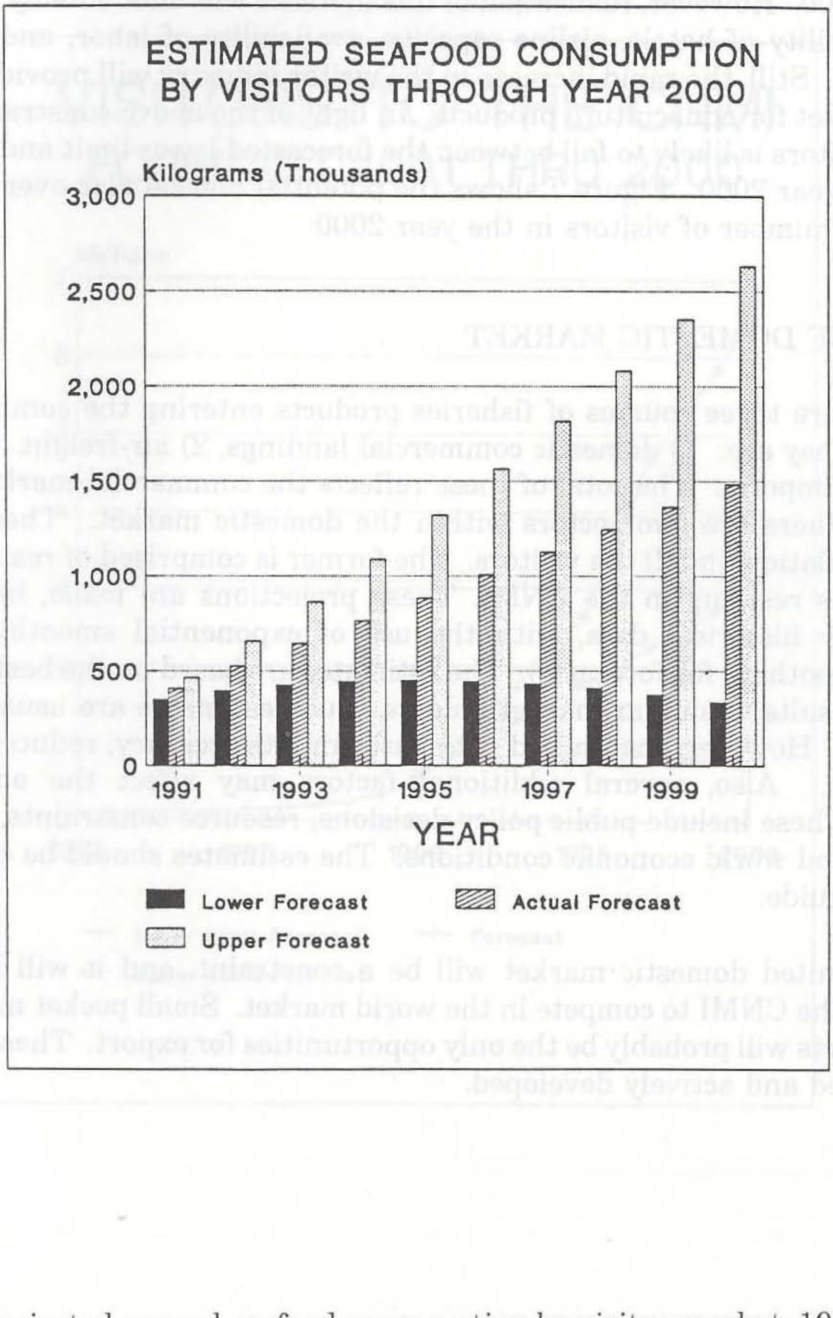


Figure 7. Projected annual seafood consumption by visitor market, 1991 through 2000.

Table 21. CNMI commercial 1989 seafood market (kg).

SOURCE	KILOGRAMS
Domestic Commercial Landings	229,794
Air Freight Imports	77,846
Ocean-Freight Imports	347,727
Total	655,367

Table 22. Seafood consumption (kg).

CONSUMER SECTOR	1989	2000
Domestic Population	691,710	918,040*
Visitors	166,640	908,365**
Total	858,350	1,826,405

* Based on domestic population of 30,793 residents plus 36,710 non-resident aliens, for a total of 67,503 in the year 2000.

** Based on the forecasted number of visitors; however, infrastructure and resource constraints will limit this growth, and the actual number of visitors is expected to fall between the lower limit and the forecasted number.

EXPORT MARKETS

A key factor in determining the markets available for export is the logistics of reaching those markets. Costs of shipping (weight of fish and packing material) and handling have to be considered. The sum of the production cost and the shipping and handling costs has to fall within the wholesale market price of the designated market. For Saipan to Guam, the cost of air freight for perishable products is $0.60 kg^{-1} (Continental airlines). It costs $4.56 kg^{-1} for airfreight shipping to Japan. Table 23 lists airfreight costs for other potential market destinations. These costs are substantial and will present market entry barriers to all but higher-value products.

Regional Markets

Regional markets are likely to be the initial targets for exported aquaculture products. The largest regional market, Guam, imports approximately $10 million of fisheries products annually. This market is readily accessible through numerous daily flights from the CNMI. However, with Guam's growing aquaculture industry, exports to Guam would have to be competitive. Other islands in the region also represent potential markets, even though limited in size. The advantage of entering regional markets as the first stage in a progressive development of export products are:

- o The nearness of the market,
- o The minimal restrictions of entry, and
- o The lower demands in terms of product consistency, quality, and supply as compared to larger foreign markets (e.g., Japan).

Table 23. Air-freight costs for perishable products for different potential market destinations from the CNMI.

DESTINATION	COST ($/kg)
Saipan-Guam	$ 0.60
Rota-Guam	0.35
Saipan-Japan	4.56
Saipan-Honolulu	11.01
Saipan-Los Angeles	19.99

Source: Continental Airlines cargo agent quotation 9/13/90.

Japanese Market

There are daily direct and one-stop (Guam) flights from the CNMI to Japan, with flight times of approximately 3 hours. This allows the shipment of aquaculture products from the CNMI to one of the world's largest seafood markets--Japan. The fish marketing structure in Japan is very complex, a chain with many inter-connecting links. Figure 8 represents the typical flow of products in the fishery market. To enter the Japanese market, contact with an importer in Japan must be made. A listing of the members of the Japan Marine Products Association, which provides the address of the importers, and identifies the types of products they import is available from:

Japan Marine Products Importers Association
Yurakuncho Building
10-1,1-chome, Yurakuncho, Chiyoda-ku
Tokyo, Japan
phone: (03) 214-3407/8
Cable address: FISHIMPORT TOKYO

Substantial effort may be required to establish the initial arrangements, and constant diligence will be needed to maintain the supply of a high quality product on a consistent basis. There are extensive standards and regulations concerning seafood quality that must be complied with. A summary of the requirements of Japan for the Importation of Fish and Fishery Products can be obtained from:

National Marine Fisheries Service
Office of Utilization Research
Washington, D.C. 20235

The best quality chilled fish commands a very high price in the Japanese whole-fish market, higher prices being obtained only by live fish. However, the highest prices for chilled fish are obtained only for species suitable for use as sashimi, and these must be of the freshest quality. Fish not meeting these criteria will sell for much less, at prices similar to those for frozen fish. It is this sector of the Japanese market, the market for chilled whole fish, that provides the greatest opportunities for aquaculture products from the CNMI. Groupers are examples of fish that obtain high prices and that could be cultured in the CNMI; groupers can obtain US $15 to $30 kg^{-1} (Philipson, 1989).

Frozen fish in Japan is largely sold at fixed prices, usually in large quantities. The exception to this is fish that are blast frozen in the round. If correctly handled and quickly frozen, such fish can be thawed before sale and used for sashimi or sushi. Blast frozen fish may obtain prices close to those for chilled fish (Philipson, 1989).

An emerging trend in the Japanese seafood market (Kano, 1989) is a shift to purchasing higher valued seafood products. The most apparent reason for this is the drop in the US dollar against the Japanese yen over the past several years. This has resulted in higher export prices, in terms of the US dollar, increasing the incentive of overseas suppliers to export to Japan. At the same time, lower consumer prices in terms of the yen increase the incentive of Japanese consumers to purchase imported seafoods. The improved economic status of the consumer in Japan and the rising per capita income ($20,833 in 1987) have stimulated a movement to medium and high-value products. There is an:

- Increase in per capita seafood consumption,

  Japan has the largest per capita seafood consumption in the world. The annual per capita seafood consumption has been reported to be over 80 kg.

- Increased preference for high-value seafood products,

  Species such as shrimp, sashimi-tuna, seabream, octopus, squid/cuttlefish and fish roe are preferred over the lower priced species such as mackerel and skipjack.

  Income elasticity is the highest for frozen shrimp followed by tuna and salmon. The fresh/frozen crustacean market was valued at $2.8 billion in 1988 and constituted 25% of the total value of fishery imports.

  There is a growing demand for live product forms. This accounts for approximately $130 million of the seafood market or 6.1% of the volume in the Tokyo Wholesale market. Airfreighted live imports, including shrimp, lobster and high-value finfish, have great potential in the Japanese market.

- New trends in product forms,

  There is a decrease in frozen fish and an increase in other processed forms, such as surimi, dried, salted, and canned products.

- New market channels,

  There is a growing trend away from traditional market channels and towards trade houses and retail chains. This has the effect of eliminating some of the middlemen and reducing the cost of the final product to the consumer.

- New market segments are emerging.

  High-value seafood market

  This consists of both expensive species and expensive product forms. Large shrimp, lobster, crab, crawfish, scallops, abalone, fish roe, sea urchin roe, and jellyfish have been identified as prime candidates to benefit from this trend.

  Value-added products market

  Examples of products in this market are surimi-based products and breaded shrimp, as well as ready-to-cook/ready-to-eat products.

Table 24 presents the average annual per capita expenditure in yen for food and for seafood. There has been only a moderate increase in expenditure in terms of the yen, but with the increase in purchasing power of the yen, in comparison to the US dollar, the consumption of seafood has increased and shifted to higher value products.

Assistance in assessing and entering Japanese, or other, export markets for aquaculture products can be obtained through National Marine Fisheries Service/US and Foreign Commercial Service Special Industry Programs for Fish and Fishing Equipment. The objectives of the program are:

- o Facilitation of contacts between U.S. seafood producers and foreign buyers;
- o Collection and dissemination of export market information to the domestic industry; and
- o Sponsorship of promotional events and activities to assist the U.S. industry export fishing products and hardware to foreign markets.

Table 24. Japanese annual per capita expenditures (in yen).

CATEGORY	1980	1984	1985	1986	1987
Total Seafood Expenditure	35,362	38,234	38,857	38,985	39,117
Fresh/frozen	18,933	19,913	20,345	20,548	20,810
Dried/salted	6,336	7,164	7,244	7,244	7,146
Other forms	10,094	11,157	11,174	11,103	11,161
Dining Out	31,409	37,985	38,918	41,031	41,797
Total Food Expenditure	227,066	254,867	258,094	260,605	259,980

Source: Kano, 1989.

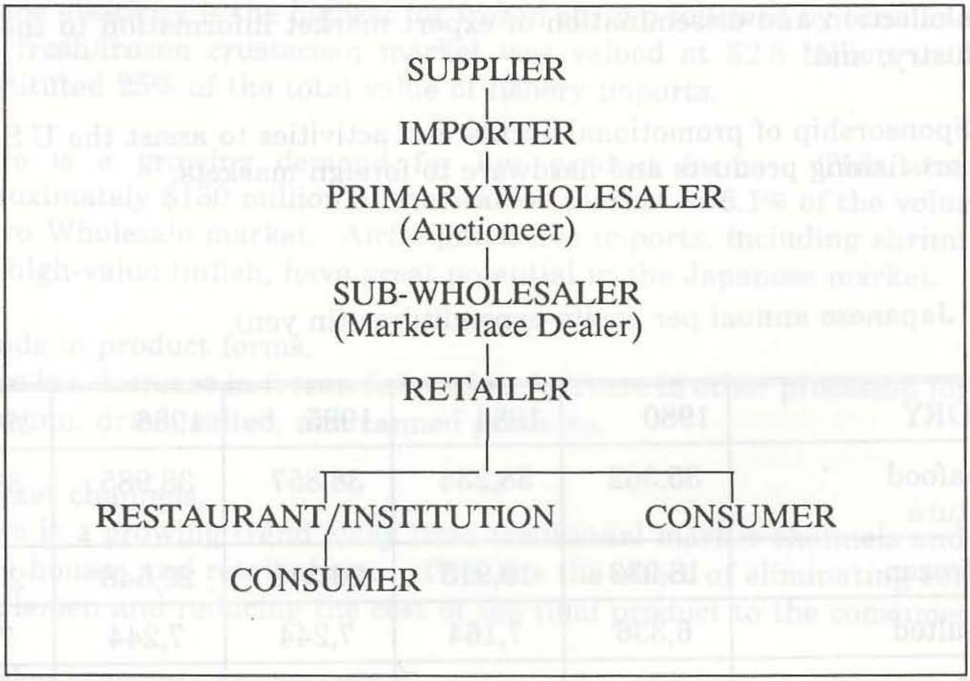


Figure 8. Typical flow of products in the fishery market in Japan

The program supports seafood export promotional activities to reduce the U.S. trade deficit in fisheries products and to revitalize the fishing industry. A full-time fisheries trade coordinator from NMFS is assigned to US&FCS headquarters to develop and implement seafood export programs. The program places a special interest on developing markets for fish and fishing products through:

- o Market research on seafood;
- o Participation in international trade shows, missions and other trade events targeted for the industry;
- o Development of guidelines for the export of fisheries products;
- o Study of trade and tariff barriers to increase fisheries exports; and
- o Concerted action to remove or reduce such barriers.

Assistance through this program can be obtained through the American Embassy in Tokyo. A fisheries trade specialist is based there to facilitate trade in fisheries products. Assistance in exporting products can be obtained through the U.S. and Foreign Commercial Service of the U.S. Department of Commerce, which offers programs and information to help exporters compete more effectively in the world marketplace. A global network of information on markets is provided through this program. Assistance is offered in market research, contacts, and promotion.

Capture of Niche Markets

The world market for frozen marine shrimp is very competitive. It is unlikely that producers in the Commonwealth will be able to compete in the world market, especially in light of declining shrimp prices worldwide. However, there may be opportunities to develop premium-price market niches for a high-quality products. This would apply to most species potentially produced through aquaculture in the CNMI.

World Market for Shrimp

Production of cultured marine shrimp in Thailand, Philippines, Indonesia, and China has increased the supply so that inventories in Japan, the primary Asian market, are at peaks. As a result, world prices for shrimp tumbled during the first months of 1989. The World Bank has warned that depressed prices will continue in the next three years unless new markets are developed for the Asian production. Markets in the United States and Europe will have to be pursued by Asian producers. Up to the first quarter of 1989 the build up of inventories in Japan kept the prices of shrimp relatively high, despite the explosion of cultured shrimp production in recent years (Globefish, 1989). The Japanese market imported a record amount of shrimp in the first quarter of 1989, raising inventories to an all-time high of 99,738 MT at the end of May 1989 (Infofish, 1989). Since then, the inventories have declined. After imposition of the 3% consumption tax in Japan (April, 1989) imports dropped. To reduce inventories, prices were lowered. The saturation of the Japanese market will influence the world shrimp market in the months to come. Asian shrimp producers will have to cope with declining prices or look beyond the Japanese market for additional outlets for their products. The European market offers potential for market expansion. Figure 9 indicates the size of the major world markets for shrimp.

In the first half of 1989, prices in the USA for shrimp of all sizes began to decline (Globefish, 1989). China is the leading shrimp exporter to the USA. Traders in Thailand, Philippines, and Indonesia are beginning to shift from the Japanese market to the USA and European markets. The recent (1989) strengthening of the US dollar compared to the yen (Figure 10) is likely to attract supplies from Asian countries to the US market which might give Japanese traders the opportunity to reorder their stocks.

Shrimp production from Taiwan has declined substantially over the past two years (1987-1989), largely as a result of a major disease problem. It has been estimated that it will take up to 4 years for Taiwan to recover to its previous production level (Globefish, 1989). Figure 11 indicates the price trend of frozen marine shrimp from 1988 through mid-1990. The substantial drop of 40 - 46% (depending on size category) in price from the peak in 1988 to bottoming in late 1989 will affect economic viability of shrimp farms. In addition, Figure 11 is in nominal dollars and does not account for inflation during the two-year period. The recent trend is toward a modest recovery in the price.

A study of trends in consumption and production, the impact of aquaculture operations on price development, and the role of developing countries in shrimp supply was conducted by INFOFISH during 1989.

RECOMMENDATIONS (MARKET):

- o Improve the database on seafood products entering the commercial market.
- o Provide more in-depth analysis and monitoring of the different aspects of the market supply and demand as industry develops.
- o Concentrate on stabilizing production of consistently high quality products to fill the local market demands.
- o Publicize aquaculture products and disseminate information on their nutritional value.

- o Monitor and evaluate potential export markets for high-value products.
- o Identify and develop potential export market niches in which the CNMI may competitively participate.
- o Explore the development of a fish processing facility.

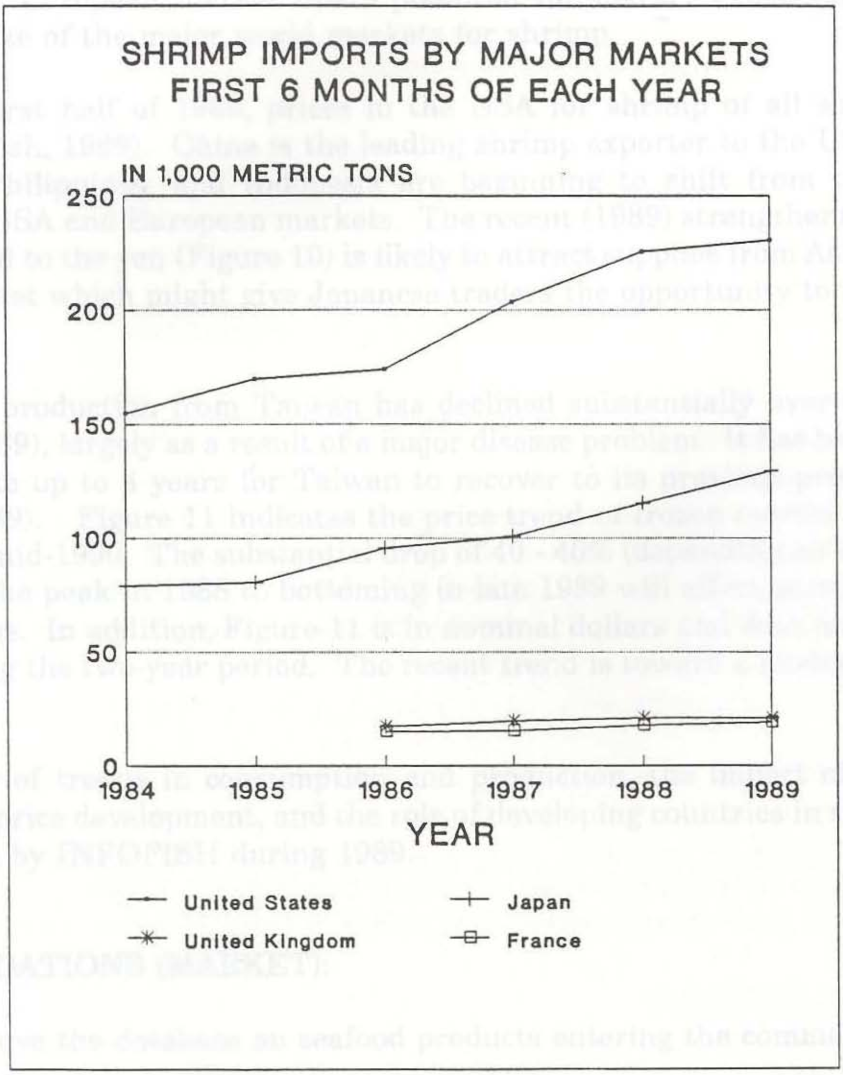


Figure 9. Shrimp Imports by Major Markets

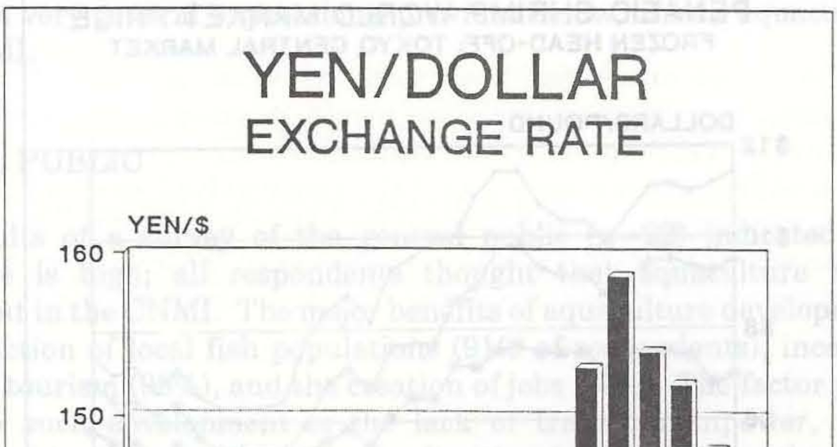


Figure 10. Currency Exchange Rate Yen/US$ (1989 - 1990)

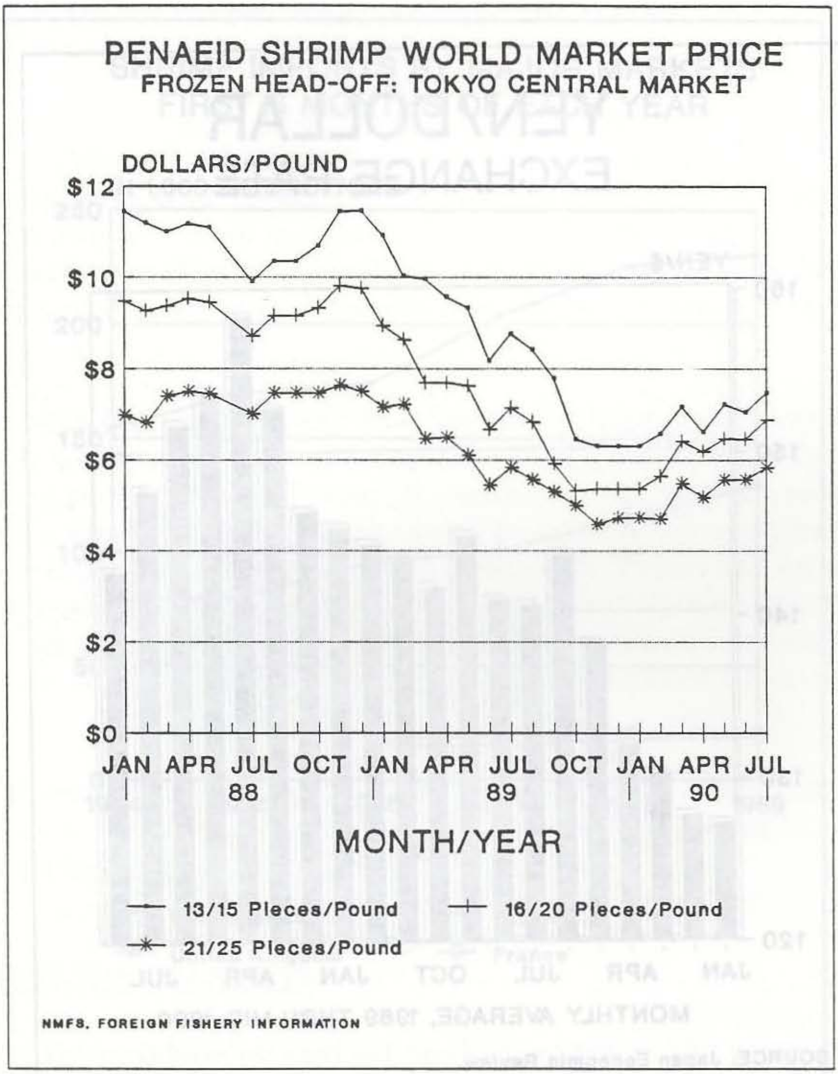


Figure 11. NMFS World Shrimp Prices

SURVEY OF INTEREST IN AQUACULTURE

To assess the level of interest in aquaculture development, we developed survey questionnaires that were administered to the general public, government officials, retail seafood outlets, restaurants and hotels. The questionnaires were administered by Mr. Richard Seman of the CNMI Division of Fish and Wildlife. There was no attempt at statistical analyses of the data obtained; the sample size was small and the purpose was only to gain very general impressions, provided below, of how aquaculture is perceived in the CNMI.

GENERAL PUBLIC

Results of a survey of the general public (n=22) indicated that interest in aquaculture is high; all respondents thought that aquaculture has potential for development in the CNMI. The major benefits of aquaculture development are expected to be protection of local fish populations (91% of respondents), income opportunities other than tourism (95%), and the creation of jobs (86%) The factor perceived as most limiting to such development is the lack of trained manpower, with 91% of the respondents identifying this as a major limiting factor. Among the options for action to be taken by the government to aid the development of aquaculture, the most popular were provision of technical training (100%) and hatchery operation (95%); the least popular, taxation of competing imports (68%). Interestingly, a high percentage of the respondents (76%) indicated that they might try starting or investing in an aquaculture operation.

RETAILER OUTLETS

The amount of fish and shellfish sold in Saipan is limited by the supply. Each of the 10 retailers surveyed indicated that they would purchase more seafood if it were available. Also, most of the retailers felt that cultured fish would be superior to wild caught fish in freshness, flavor, texture, and overall quality. Among the species that can be cultured and that are currently purchased, the most popular appear to be rabbitfish, groupers, and marine shrimp. Snappers were also popular, but the more desirable snappers are deepwater species such as Onaga, Opakapaka, or Gindai. Most retailers purchase fish more than 7 or 8 times per month.

The purchasing patterns of hotels and restaurants (n=10) differed somewhat from those of retailers. The species purchased by most of these establishments were freshwater and marine shrimp, snappers, and groupers, followed by seaweeds, giant clams, and milkfish. Timeliness, quantity, and price were all identified by a majority of the respondents in this category to present major difficulties in obtaining seafood. All of the buyers for hotels and restaurants listed reliability of supply, and quality as being very important, a majority also identified price and product form as being very important. Most of these buyers prefer to purchase fish that are more than 5 pounds in weight. Almost all the buyers purchase more than 150 pounds of fish per month, and all would pay a higher price for a product that was freshly chilled or alive compared to a frozen product of the same type.

FINANCIAL INSTITUTIONS

Of the three banks on Saipan that were surveyed, all were familiar with aquaculture as a business enterprise. Only one would consider providing a loan to an individual or corporation desiring to start an aquaculture enterprise in the CNMI; the other two might be willing to consider a loan if the risk involved was reduced through a government loan guarantee. A major concern for banks was that there has been no history of aquaculture in the CNMI. From the perspective of the lending institution, the lack of previous commercial aquaculture in the CNMI increases their risk in lending.

SPECIES EVALUATION

From a technical standpoint, the culture of many aquatic is possible. One of our objectives was to identify several species with potential for commercial cultivation in the CNMI. We used a number of criteria to help make this decision. These include:

o commercial culture of the species elsewhere,

o availability of juveniles,

o environmental tolerances compatible with conditions found in the CNMI,

o known domestic or foreign markets, and

o potential environmental impact of culture operation.

For the species selected, relevant literature was reviewed to obtain the information necessary for an economic analysis of their potential for commercial culture in the CNMI. Following the detailed accounts of the most promising species, information is presented on other species that either show promise or have been considered for culture in the region.

MILKFISH

TAXONOMY AND MORPHOLOGY

The milkfish is classified in the order Gonorynchiformes and the family Chanidae. This family has only one genus Chanos. The genus has only one species, also named chanos, although it has had many synonyms over the years (Gordon and Hong, 1986). Milkfish are elongate, cylindrical, silver-colored fish, with a ventral mouth and a deeply forked caudal fin.

NATURAL HISTORY

Milkfish occur throughout the tropical Indo-Pacific and are found in a variety of habitats, including lagoons, mangrove swamps, tidal flats, and freshwater streams. In nature, spawning occurs off shore at depths of 10 to 40 meters (Gordon and Hong, 1986).

ENVIRONMENTAL TOLERANCES

Milkfish are tolerant of a wide range of environmental conditions. They can survive temperatures from 10 to 40° C. They are euryhaline, surviving in freshwater, brackish water, and seawater, even in hypersaline waters with salinities in excess of 100 parts per thousand (ppt) (Crear, 1980).

GROWTH AND PRODUCTION

In culture in brackish water ponds on Guam, the growth of milkfish varies with season and with the rate of feed application. Fish grow from the five-inch size at which they are placed in the grow-out ponds to market size (1.5 lbs.) in 3 months during the rainy season, but it takes 5 months during the dry season (Nelson, in press). The difference in growth rate results from the limited water supply during the dry season.

Production depends upon the system used for culture. In Taiwan deepwater (2-3 m) ponds with supplemental feeding generally produce 8,000 to 10,000 kg ha^{-1}, while shallow water ponds produce 2,000 to 2,500 kg ha^{-1}.

FEEDING AND FEED CONVERSION

In the wild, milkfish are omnivorous, feeding on plankton, benthic organisms, and detritus (Gordon and Hong, 1986; Santiago, 1986).

On Guam, feeding during grow-out ranges from 3 to 5% of the fish weight per day, adjusted by the farmer depending on pond conditions and the behavior of the fish (Nelson, in press). The amount of feed offered is reduced on cloudy days or when only a few fish come to the feeders. Higher (5%) feeding rates are used when the fish are small; for larger fish the feeding rate is reduced to 3%.

In pond culture on Guam, the feeding conversion efficiency is generally between 2.0 and 2.3 pounds of feed per pound of fish produced (Nelson, in press). In deepwater pond culture in Taiwan a better feed conversion (1.3:1) is obtained (Liao and Chen, 1986).

Methods of rearing larval milkfish are similar to those used for the culture of other marine fishes (Kuronuma and Fukusho, 1984; Fukusho, 1985). The early stages of the larvae are fed with marine rotifers, brine shrimp nauplii, and copepods. In some cases the larvae of oysters are used as an initial feed.

REPRODUCTION

In spite of the long history of culture of milkfish and its importance on a world-wide scale, many aspects of its reproductive biology are poorly known.

Sex determination

Milkfish are not sexually dimorphic, and it is difficult to determine the sex of a mature fish. The method for determining the sex of mature broodstock is direct examination of gametes obtained by aspiration through polyethylene tubing (Lee, 1986); however, this method will not work for immature fish.

Reproduction in nature

Aspects of the reproduction of milkfish in nature are not well known. However, the reproductive periods differ with geographic location. In Taiwan the reproductive period lasts from May through August, while in the Philippines it lasts from March through December (Lee, 1986).

Maturation

Males appear to become sexually mature earlier than females; maturation occurs after 4 years in males and after 5 years in females (Lee, 1986). The effects of environmental conditions promoting maturation remain to be clarified. Maturation can also be stimulated by treating the fish with hormones (Lee et al. 1986b,c,d).

Induced spawning

Spawning in captivity can be reliably induced through the administration of hormones (Lee et al., 1986a).

STOCKING

Since there are no large populations of milkfish in the Mariana Islands, milkfish fry for commercial production will have to be either imported. Wild-caught and hatchery produced fry can be obtained from Taiwan.

Source of juveniles

Fry are available from Taiwan from May to September. Fry of two kinds, wild-caught and hatchery reared, are used; wild-caught fry are available in the early part of the season. Wild-caught fry cost $ 0.10 each, including shipping, and hatchery produced fry cost $ 0.05 each.

Stocking density

Two types of ponds, nursery and grow-out, are used in the commercial production of milkfish on Guam. In the 1-acre nursery ponds, fish are stocked with as many as 200,000 fish. When these reach a size of approximately 5 inches, they are stocked in 3,000 to 10,000 m^2 grow-out ponds at densities between 4,000 and 5,000 fish $acre^{-1}$ -- approximately 10,000 to 12,000 ha^{-1} (Nelson, in press).

In shallow-water ponds in Taiwan, the Philippines, and Indonesia, multiple-size stocking is common with larger, overwintered fish stocked together with new fry, and stocking rates dependent upon the sizes of the fish that are stocked (Liao and Chen, 1986). For new fry, stocking rates of 6,000 to 7,000 ha^{-1} are used in Taiwan, although some farms maintain low stocking rates (4,000 fry ha^{-1}) to achieve more rapid growth (Liao and Chen, 1986).

In deep-water pond culture in Taiwan, milkfish fingerlings 1.5 cm in total length are stocked at 12,000 ha^{-1}, and an additional 13,000 ha^{-1} are added after the market sized fish are harvested (Liao and Chen, 1986). However, stocking rates vary widely, and rates up to 50,000 fry ha^{-1} are used at some farms (Liao and Chen, 1986).

PREVIOUS AND CURRENT CULTURAL PRACTICES

Milkfish are the most extensively cultured marine fish (Chen, 1976) and have been cultured traditionally throughout Southeast Asia for centuries. Methods used for their culture include cage culture, pen culture, and pond culture. Two types of pond culture are prevalent; these are often termed the shallow-water pond method and the deep-water pond method. The shallow-water method is the traditional method characterized by relatively low stocking densities and reliance solely on the aquatic productivity of the pond--primarily that of the benthic algal mat--to supply food for the fish. The deep-water method is a modern method characterized by higher stocking densities and greater productivity fueled by providing the fish with commercially prepared feeds. Milkfish are often used in culture with other species, including shrimp (Penaeus monodon), mud crabs (Scylla serrata), sea bass (Lates calcarifer), and algae (Gracilaria spp.).

MARKET INFORMATION

On Guam, milkfish are purchased primarily by ethnic Filipinos. Wholesale prices fluctuate with availability and the degree of competition between producers. Wholesale prices are generally around \$2.00 lb^{-1}, and retail prices are usually around \$2.50 to \$3.00 lb^{-1}. Milkfish is the most important of the fresh and frozen whole fish imported to Guam. In 1981, 62.7 metric tons of chilled or frozen milkfish were imported to Guam from the Philippines (Myers et al., 1983). Guam does not categorize import records for fish according to species, so the volume of the current imports is unknown.

PROPOSED CULTURE METHODS FOR THE CNMI

The most appropriate method for culturing milkfish in the CNMI would be through "modern" pond-culture as practiced in Taiwan and on Guam. In this method the fish are cultured in ponds and fed pelletized feeds.

SIGANIDS

Siganids, commonly known as rabbitfishes, are herbivorous reef fishes that are popular throughout the tropical Pacific, particularly in the Mariana Islands. In addition they have been cultured in other areas in a variety of situations including ponds, raceways, and cages. The most likely candidates for commercial culture would come from species that are found in mangrove areas; this group includes the largest siganids and those that are likely to be tolerant of a wide range of salinities.

TAXONOMY AND MORPHOLOGY

In the scheme of Greenwood et al. (1966) species in the genus Siganus are classified in the Superorder Acanthopterygii, the Order Perciformes, the Suborder Acanthuroidei, and the family siganidae. There are 27 known species in the family.

Siganids are laterally compressed, oval shaped fish with a terminal mouth. The 13 dorsal spines have venom glands located at their bases and can produce a painful sting. Siganus spinus, one of the two most common species in the CNMI, is one of the smallest species and grows to 17 cm in length. The larger species, attains lengths of over 45 cm and weights of 2.3 kg. Gunderman et al. (1983) report that, in Fiji, females are larger than males.

NATURAL HISTORY

Adult S. vermiculatus are found in mangrove and coral reef habitats. The larvae, hatched from the benthic and adhesive eggs, develop in an oceanic environment until metamorphosis when they move into mangrove areas. At sizes below 120 mm, juveniles are found only in mangroves (Gunderman et al., 1983).

The two most common siganids in the CNMI are S. argenteus and S. spinus; both are common in nearshore waters. The juveniles of these species recruit to coral reef and seagrass habits, where they are often collected in large numbers by local fishermen. A third species S. punctatus is also found in the CNMI, but is relatively uncommon. Two other species, Siganus vermiculatus and a similar, undescribed, species have been collected from Guam and may also be present in the CNMI. All siganids are herbivorous as adults, feeding on macroalgae and seagrasses.

ENVIRONMENTAL TOLERANCES

Siganids are found in a wide variety of tropical marine habitats. Juvenile to adult S. vermiculatus, and ecologically similar siganids that are found in brackish waters, can survive a wide range of temperature and salinities. In general larval siganids are much more sensitive to environmental fluctuations than are adults.

Juveniles and adults

In Fiji, S. vermiculatus survived in ponds with temperatures fluctuating over the year from 19 to 38° C and in salinity from about 18 to 45 ppt (Gunderman et al., 1983). Juveniles showed signs of stress and hyperventilation at 32° C when the concentration of dissolved oxygen fell to 1.1 ppm. Tests on Guam showed that S. argenteus juveniles could survive temperatures above 33° C. for almost 3 days, but suffer 100% mortality within 20 hours after the temperature rises above 36° C (Tobias, 1976).

Gunderman et al. (1983) found that fry of S. vermiculatus caught in water with a salinity of 2 ppt survived a 24-h exposure to freshwater. Tobias (1976) found that S. argenteus began to show signs of salinity stress at 10 ppt, but could survive short term exposures to salinities as low as 6 ppt. We found juveniles of a new species of Siganus in water of 6 ppt salinity.

Larvae

Larvae are sensitive to temperature but tolerant of a fairly wide range of salinity. Larvae did not survive in ponds in Fiji where temperature fluctuated 4 to 6° C (Gunderman et al., 1983). On Guam larval mortalities were severe in the hatchery when the water temperature dropped to 24° C, a rare event in this part of the Pacific. Larvae survive in rearing tanks where salinities range from 26 to 34 ppt.

GROWTH

Although data are scant, indications are that siganids grow well in pond culture. Fish farmers on Guam have reported that the growth of rabbitfish that had inadvertently entered their milkfish ponds was surprisingly rapid. Early experiments in Fiji with the culture of Siganus vermiculatus in fertilized ponds, apparently without supplemental feeding, showed that the fish can reach a size of 190 g within 130 days (Lichatowich and Popper, 1975).

Growth trials in tanks with siganids have been undertaken at Okinawa at government fisheries stations. According to fisheries scientists there, the growth rates of siganids are such that commercial farming would be feasible, and further work, on larval rearing, is planned. Mr. Tsugio Katsumata has been conducting growth trials with Siganus guttatus and Siganus canaliculatus in Okinawa. He found that S. canaliculatus juveniles ranging in weight from 3.5 to 5.0 grams in August grew to the 200-g market size within 5 months. Temperature effects the growth of rabbitfish in Okinawa, a problem which will not be encountered in the CNMI. Mr. Katsumata found that S. guttatus stocked in the winter in Okinawa took 8 months to reach the 200-g market size but grew to 500 grams in the next 6 months. In both trials the fish were fed with carp feed at 5 to 10% of their body weight per day. Faster growth rates would be expected in pond culture at the higher environmental temperatures prevailing in the CNMI. The sets of data from Okinawa were among the best we were able to find. Although the trials were conducted in tanks, the researchers used feeds that are currently being used in commercial fish culture, and feeding rates were controlled.

Siganids can also be grown in sea cages and fish pens. For example, in the Red Sea Siganus rivulatus reared in 10 m^3 sea cages grew from 3 to 105 g in 150 days (Lichatowich et al., 1984); higher rates of growth would be expected in the CNMI, where temperatures are high throughout the year. In the Philippines, where environmental temperatures are similar to those in the CNMI, several species of siganids were cultured in floating cages in trials lasting 3 to 4 months (Horstman, 1975); these studies showed that siganids grow at rates ranging from 5.0 to 6.5 grams per week and reach sizes of 97 to 114 grams in 4 months. Bwathondi (1982) reported that, in Tanzania, Siganus canaliculatus grown in cages reaches commercial size in 6 months and that two crops per year are possible.

FEEDING

After metamorphosis, siganids are herbivorous, feeding primarily on marine macrophytes. However, in captivity they will readily take pelletized feeds. The larvae feed on planktonic organisms.

Adult food habits in nature

The diet varies according to habitat; fish from the reef areas feed on macroalgae and those inhabiting seagrass beds feed on seagrasses. Fish from mangrove areas feed on particles of mangrove roots as well as on epiphytic algae (Gunderman et al., 1983). On Guam, recruitment of large numbers of siganid fry results in noticeable reduction of the standing crops of macroalgae and seagrasses in nearshore habitats (Tsuda and Bryan, 1973). Preferences for particular species of macroalgae differ between species of siganids and between juveniles and adults (Paul et al., 1990).

Feed conversion

Published information concerning the growth and feed conversion efficiencies of siganids in culture are limited. Early work by Kissel (1972) found that ratio of feed to fish produced, or the food conversion ration (FCR) for Siganus rivulatus reared on pelletized feed in sea cages in the Gulf of Elat ranged from 2:1 to 4:1 (food conversion efficiency of 50 to 25%). More recent work (unpublished data) with Siganus guttatus in Okinawa found that the food conversion ratio ranged from 1.2:1 to 2.6:1, with the lowest values for food conversion ratio (FCR) found during the summer and the highest, during the winter. Research in the Philippines with Siganus guttatus reared in tanks on pelletized diets, found food conversion ratios ranging from 1.5:1 to 2.0:1 (Parazo, 1989). The efficiency of feed conversion would be expected to be better in ponds since the fish can also obtain nutrients from productivity within the pond. It would be reasonable to assume that siganids' cultured in ponds in the CNMI would exhibit feed conversion ratios around 1.2:1 to 1.5:1.

Larval feeds

In hatchery production, the first feed taken by siganid larvae is usually the marine rotifer Branchionus plicatilis. Usually the rotifers initially offered to the larvae are those which will pass through an 80 to 90-micron mesh. Other small food organisms are acceptable as first feed for siganids; these include fertilized eggs of oysters and sea urchins. Later the larvae are fed the newly hatched nauplii of brine shrimp Artemia salina, copepods, and finally, prepared feeds.

REPRODUCTION

Siganids spawn on a lunar cycle. In the case of S. vermiculatus in Fiji, spawning occurs during the morning of either the 7th or 8th day of the lunar cycle (Gunderman et al., 1983). Most siganids spawn on or near the new moon, but some spawn around the full moon (Tawada, 1988). The eggs most siganids are demersal and adhesive; only those of Siganus argenteus are non-adhesive, freely floating eggs.

Sex determination

There are no external morphological features that can be used to distinguish between the sexes. However, in general, the females are larger than the males. Sexes of mature, ripe individuals can be determined through samples drawn with a canula inserted into the gonadal duct.

Reproduction in nature

A striking feature of the siganids in the Mariana Islands, one familiar to all fishermen, is the predictable, episodic recruitment. At times so many juvenile rabbitfish settle on the reefs that algal stocks are dramatically reduced, sometimes even to the point where some of the newly settled juveniles die of starvation. Recruitment episodes of S. argenteus and S. spinus occur in April, May, June, and October on Guam (Kami and Ikehara, 1976). Siganid recruitment occurs from May to August in Okinawa (Tawada, 1988). When larval rabbitfishes appear in abundance they could be collected from the reef and stocked in ponds for grow-out. However, the abundance of juveniles in these recruitment episodes varies widely from year to year, and for commercial production a reliable source of juveniles must be available for stocking ponds.

Maturation

In Fiji, females mature at 240 grams (12 cm) at slightly less than 1 year of age (Gunderman et al., 1983). In Okinawa, S. spinus reaches sexually maturity in 10 months (Tawada, 1988). We have found that S. argenteus maintained in captivity became sexually mature at approximately 10 months of age on Guam.

Induced spawning

Rabbitfish can be induced to spawn through injection with Human Chorionic Gonadotropin (HCG). A dose of 1 IU g^{-1} of fish is usually effective at inducing spawning provided that the spawners are ripe.

STOCKING

Since siganid fry are not reliably abundant each year in the Mariana Islands, a commercial-scale industry based on the collection of local, wild fry will not be possible. Development of siganid culture will depend on the farmers being able to obtain hatchery-produced juveniles for stocking.

Source of juveniles

The culture of siganids in this region has been constrained by the lack of fry for stocking. A program has been initiated at the Guam Aquaculture Development and Training Center to supply juvenile siganids to farmers for commercial production. So far, production of siganid fry at GADTC has been limited, but more reliable production is expected in the future. Also, according to Dr. Jess Juario of the University of the Philippines, it is possible to obtain wild-caught juveniles from the Philippines. Salted siganid fry packaged in the Philippines are readily available in markets in Guam and Okinawa, so obviously fisheries for siganid fry already exist.

Stocking density

Data on optimal stocking densities for siganid grow-out are lacking. As a guide, the stocking densities used for the culture of milkfish (Chanos chanos) by commercial producers on Guam can be used; these generally range from 4,000 to 5,000 fish $acre^{-1}$ (approximately 10,000 to 12,000 ha^{-1}) (Nelson, in press). Since milkfish in these systems are stocked from nursery ponds at a relatively large size (3 to 5 inches) and since milkfish are marketed at a larger size (approximately twice the market size of siganids), then a conservative estimate of stocking density in the range of 6,000 to 8,000 fish $acre^{-1}$ (approximately 15000 to 20000 ha^{-1}) can be assumed for siganids. Stocking densities of milkfish in modern commercial production in Taiwan are in general 25,000 ha^{-1} or higher (Liao and Chen, 1986). Stocking densities will ultimately be determined by the carrying capacity of the pond, a factor which will vary with pond conditions and management practices.

MORTALITIES

The percentage of animals surviving to harvest in a culture system is an important factor determining the economic feasibility of the operation. This is major factor in hatchery production, but under normal conditions, this is not usually a significant factor in grow out. Larval fish are sensitive to environmental conditions and, mortalities are usually much heavier during the larval rearing phase than in the grow out phase.

Larval rearing

A major critical period in rearing the larvae of siganids is the period of transition from endogenous to exogenous sources of nutrition--the onset of feeding. Duray and Kohno (1988) reported mean survival of Siganus guttatus larvae grown under continuous lighting with a maximum survivorship of 41%.

Grow-out

Tamil (1978) reported mortalities of 13 to 15% for Siganus guttatus in cage and sea pen culture in the Philippines. In the absence of outbreaks of disease or parasites, mortalities are not usually significant during grow out in ponds.

PREVIOUS AND CURRENT CULTURE PRACTICES

Siganids are farmed traditionally in brackishwater ponds in the northern Philippines, where filamentous green algae serve as the major food source (Parazo, 1989). They are also farmed commercially in the Middle East, particularly in Saudi Arabia and the United Arab Emirates (White, 1988).

Previous attempts to raise larval rabbitfishes in Micronesia and other areas have been successful to varying degrees (May et al., 1974; Bryan and Madraisau, 1977; Akatsu et al., 1984; Hara et al., 1986), but following the pioneering work conducted at the Micronesian Mariculture Demonstration Center in Palau, the regular mass production of larvae of siganids has been achieved, and this only recently (Juario et al., 1985; Bagarinao, 1986; Hara et al., 1986). Early work, in the 1970's, at the

Micronesian Mariculture Demonstration Center and the University of Guam Marine Laboratory focused on several aspects of rabbitfish culture within the region, but these efforts were not sustained because, at the time, the costs of feed were high relative to the price of the fish, and siganid farming did not appear to be economically viable. However, the conclusions of the investigators on Guam were based largely on growth studies in which were compromised by diseased fish and deterioration of the improperly stored feed. Also none of the growth studies were conducted in ponds or under conditions similar to those which might be used in commercial production. As a result of improvements in the mass-production of siganid larvae, the improving economic climate for aquaculture development in general, and the perceived decline in local stocks there has been a resurgence of interest in these fishes.

MARKET INFORMATION

Local markets for rabbitfish are well established in the CNMI and Guam. The current supply of rabbitfish to markets in Guam, where they are sold for a retail price of \$3.60 lb^{-1}, comes primarily from imports from the Philippines and Palau. The local fishery cannot satisfy the demand. Siganids are among the most popular of reef fishes in both the CNMI and Guam. On Guam locally caught siganids are rarely found in the market. One fish outlet on Guam sets aside the Siganus argenteus and S. spinus acquired either for family use or for sale to preferred customers. Another fish outlet reported that local siganids do not stay on the market long because they are purchased soon after they are made available to consumers.

Siganids are also marketed in nearby Okinawa, so they would most likely be well received by Japanese tourists in the CNMI. According to Mr. T. Katsumata of the Okinawa Perfectual Fisheries Experiment Station, the price of whole siganids on the Okinawa market ranges from 800 to 1300 yen kg^{-1}. This is the price range for wild-caught fish that can be seen in the market, fish with marks from the gill nets with which they are captured; presumably higher prices could be obtained for fresh, cultured fish.

In several tropical Pacific areas, newly metamorphosed juvenile siganids are harvested as well as the adult fish; these young fish, known in the Chamorro language as "menahac", are particularly popular in Guam and Saipan. These fish are collected in years when siganid recruitment is high; they are sold door to door from coffee tins. Jars of siganid juveniles imported from the Philippines are also found in most of the grocery markets on Guam. Salted juveniles packaged in jars were seen on sale in the fish market at Naha, Okinawa where they are sold for 500 yen per 100 grams (personal observation, SGN).

PROPOSED CULTURE METHODS FOR THE CNMI

The culture of siganids in earthen ponds would probably be most suited for the CNMI, but smaller more intensively managed systems, such as tank or raceway culture, could also be explored. The successful mass production of siganid larvae at the facility in Guam will be necessary to provide a source of juveniles for stocking ponds at levels needed for commercial production, unless a source of fry can be identified in the Philippines.

TILAPIA

TAXONOMY AND MORPHOLOGY

The taxonomists have been busy in recent years dealing with species referred to under the common name tilapia. Tilapia is also a genus formerly containing more than 100 species, including Tilapia mossambicus and Tilapia niloticus, the two most commonly cultured species. The species were reclassified and placed into the genus Sarotherodon, and the most recent taxonomic revisions now place these species in the genus Oreochromis (Trewavas, 1983). The distinctions between the genera are based in part on their reproductive behavior; species of the genus Tilapia are substrate spawners, while those in the genera Sarotherodon and Oreochromis are mouthbrooding species. Species in the genera Sarotherodon and Tilapia are monogamous, while those in the genus Oreochromis are polygynous or polyandrous. These taxonomic changes have not been adopted by the American Fisheries Society, and so, many American authors still consider these species to be in the genus Tilapia (Stickney, 1988). A red hybrid tilapia is cultured in Taiwan; this is usually considered to be a cross between O. mossambicus and O. niloticus, but based on studies of genetic similarity, Wu and Wu (1983) thought it should be considered a variant of O. niloticus. However, in a recent paper describing the development of the red hybrid (Kuo, 1988), the scientist who developed the hybrid explains that the red coloration was originally found in specimens of O. mossambicus brought to the laboratory by farmers in southern Taiwan. A normally colored hybrid tilapia from Taiwan is currently being cultured commercially on Guam.

NATURAL HISTORY

The tilapias are freshwater and brackishwater species that evolved in Africa and the Near East. Some species, and particularly Oreochromis mossambicus, have been introduced and become established in aquatic habitats in many areas outside of their natural range.

ENVIRONMENTAL TOLERANCES

The tilapias are tolerant of a wide range of environmental conditions, an important factor that contributes to their successful introduction to warm-water habitats throughout the world (Philippart and Ruwet, 1982). They can be cultured in freshwater, brackish water, and even in seawater. They can tolerate oxygen concentrations as low as 0.1 mg l^{-1} and a range in pH of 5 to 11 (Stickney, 1988).

GROWTH AND PRODUCTION

Growth and production of tilapia are influenced by many factors, including the environmental factors and management practices. Males grow faster than females, and growth performance of fish of differing strains varies considerably.

Pruginin et al. (1988) found in intensive culture (30 fish m^{-2}) daily weight increases of various strains to range from 1.3 to 3.2 g day^{-1}; a red strain from the Philippines reached a size of 240 grams in 180 days, while a red O. mossambicus strain grew to just under 100 g in 220 days. In commercial production in Taiwan, it takes approximately 6 months for tilapia to grow from the larval stage to a 600 g market size (Liao and Chen, 1983). In brackish-water pond culture in Israel, where temperature was maintained at 26° C, the Philippine red hybrid reached sizes over 200 g in 160, days while the red O. mossambicus took 200 days to reach a size of 100 g (Pruginin et al., 1988). Commercial producers on Guam obtain market sized fish after 5 to 7 months of culture, the longer growing period producing larger fish. In Okinawa, juvenile O. niloticus stocked in May grow to approximately 200 grams within 6 months, and males reach 400 grams by the end of the year (Kakazu, 1988).

Production is influenced greatly by the stocking density and management practices. For example, tilapia production in Taiwan is between 13.5 and 18 tons ha^{-1} in ponds stocked with 3-4 fish m^{-2}, and under expert management 6 to 8 tons can be obtained per year from small (100 m^2) ponds stocked with 50 to 100 fish m^2 (Liao and Chen, 1983). Another example is from the United States where Solar Aquafarms, a commercial aquaculture company in southern California, has a farm located in Sun City that produces "golden tilapia" with an intensively managed recirculating tank system. Each tank is 96 feet in diameter and contains 225,000 gallons of water and 60,000 fish. According to the company brochure, 125,000 pounds of fish can be produced from each tank $year^{-1}$. This amounts to an annual production of approximately 17.7 kg m^{-1} or 176,617 kg ha^{-1} yr^{-1}!

FEEDING AND FOOD CONVERSION

Tilapias are omnivorous; in nature, adult tilapias feed largely on detritus (O. mossambicus) or phytoplankton (O. niloticus). In pond culture they are fed pelletized feeds usually ranging from 25 to 40% protein, with food conversion efficiencies ranging from 1.0 to 2.2 (Stickney, 1988). In Taiwan expected feed conversion is 1.3 to 1 (Liao and Chen, 1983) for tilapia cultured in ponds, and in Okinawa the efficiency of feed conversion (weight of feed to weight of fish produced) is from 1.1:1 to 1.4:1 (Kakazu, 1988).

REPRODUCTION

These fishes have a polygynous mating system, with the males defending breeding territories and mating with several to many females in succession. The females carry the fertilized eggs and later the fry in their mouths for about 2 weeks.

Sex determination

Sexual dimorphism is well developed, and when in breeding condition males are easily distinguished from females by their black coloration. The sex of the immature fish can be determined fairly reliably by experienced technicians through examination of the area surrounding the genital opening.

Maturation

The age of maturation is highly variable in these fishes. They can become sexually mature as early as two months of age. Controlling reproduction of the fishes in the culture ponds is a major problem with the culture of tilapia. Uncontrolled breeding is a problem because, as a result, the farmer ends up with a pond full of a large number of small fish rather than a lesser number of large fish.

STOCKING

The fish will breed readily in the ponds, but commercial tilapia culture operations prefer to obtain seed stock from a hatchery to insure large numbers of fish of uniform size. Commercial farmers on Guam obtain juvenile tilapia from producers in Taiwan. According to Stickney (1988) typical stocking densities of tilapia in ponds are around 10,000 ha^{-1}. However, in Taiwan, tilapia are stocked in ponds at rates of 30,000 to 40,000 ha^{-1} and in small (100 m^2), intensively managed ponds fish are stocked at 50,000 to 100,000 ha^{-1} (Liao and Chen, 1983).

On Guam, commercial producers obtain juvenile hybrid tilapia from Taiwan. These cost $0.04 to $0.05 per fish, including the cost of shipping. The juveniles are stocked in grow-out ponds usually at 4 to 5 fish m^{-2} (40,000 to 50,000 ha^{-1}).

PREVIOUS AND CURRENT CULTURAL PRACTICES

The tilapias have been cultured in a wide variety of situations, including in ponds, ricefields, cages, tanks, and raceways, but they are most often cultured in ponds. Summaries of the techniques of tilapia production are available in numerous published sources. In the semi-intensive culture of tilapia in Taiwan (Liao and Chen, 1983), aerated grow-out ponds are stocked at 3-5 fish m^{-2}; two crops are obtained with annual yields of 27 to 45 tons ha^{-1}. On Guam hybrid tilapia obtained from Taiwan are cultured commercially. Aerated, earthen ponds are stocked at about 40,000 to 50,000 fish ha^{-1}

and grown to market size in 5 to 7 months. The fish are harvested by seine and placed in temporary holding pens at the edge of the pond. They are then transferred live to market.

MARKET INFORMATION

On Guam, Oreochromis mossambicus and hybrid tilapia obtained from Taiwan are cultured on a commercial scale in freshwater and brackish water ponds (Nelson, 1988a). The price for tilapia fluctuates, but it is generally between \$2.00 and \$ 2.50 lb^{-1} at the local flea market. The price depends on the size of the fish and also on the supply from competing farms. In addition, some Chinese restaurants on Guam are maintaining live fish, tilapia and catfish, in aquaria for viewing and selection by diners. A single, large tilapia prepared in a Chinese restaurant on Guam sells for \$25.

The culture of tilapia on Guam has resulted in the replacement, in domestic markets, of tilapia imported from the Philippines. Tilapia production through aquaculture on Guam has increased steadily in recent years to the current level of over 125,000 kg yr^{-1}, nearing the point of saturating the local market.

Export markets could be explored. In the United States some tilapia producers are targeting the large Asian markets in large cities such as in Los Angeles. Also, tilapia filets are becoming more common even in the outlets of the major grocery chain stores. For example, in San Francisco tilapia filets were recently being advertised for sale at \$4.50 lb^{-1} (personal observation, WJF).

PROPOSED CULTURE METHODS FOR THE CNMI

Brackish or marine pond culture of tilapia with methods similar to those in practice on Guam may be suitable for Saipan. Smaller, more intensively managed systems would also be suitable. It is recommended that tilapia not be cultured on Tinian or Rota. Because tilapia have already become established in Lake Susupe, their culture on a small-scale there is feasible. However, Rota and Tinian remain free of tilapia, and the introduction of tilapia to these islands should be discouraged as a caution against the potential negative impact of these fish on the indigenous freshwater and brackish water fauna (Nelson and Eldredge, in press). In areas where tilapia have not been introduced, such as Rota and Tinian, the culture of these fish is not recommended. Tilapias have well-documented abilities to become established in aquatic ecosystems, often with regrettable consequences.

ECONOMIC RED ALGAE

The red seaweed Polycavernosa tsudae, which is common in several areas of Guam and Saipan, is marketed on a small-scale on Guam and may prove suitable for commercial culture in the CNMI. Commercial culture of similar species for human consumption has recently been established in Hawaii.

TAXONOMY AND MORPHOLOGY

Polycavernosa tsudae was formerly referred to as Gracilaria edulis in publications from Micronesia. However, specimens throughout Micronesia were studied in detail (Meneses and Abbott, 1987), and the alga was determined to be a new species, Polycavernosa tsudae. The type specimen for this species was collected in Garapan Lagoon in Saipan in 1985. The genera Polycavernosa and Gracilaria are very similar, both morphologically and ecologically; the genera are distinguished by the morphology and development of the reproductive structures (Xia and Abbott, 1985). Because of these similarities, the information provided below includes data on species of both genera. Although there has been considerable confusion regarding the taxonomy of this group, the fine points of taxonomy are not likely to have much effect on either the development of seaweed culture systems or on marketability of the product.

These branching plants are 12 to 17 cm high with branches of 1 to 11 mm diameter. The amount of branching and thallus color are highly variable. The thallus coloration is often used as an indicator of nutritional status, with nitrogen-limited plants being paler. The phycobiliproteins of the red accessory pigments increase when surplus nitrogen is available. A translation of a descriptive Chinese name for Gracilaria thalli with morphology similar to Polycavernosa tsudae is "dragon's moustache".

NATURAL HISTORY

Polycavernosa tsudae is found in a variety of shallow-water habitats but is most abundant in areas where the thalli are afforded protection against storm damage and browsing by herbivorous fishes. In Saipan, this species is abundant in some areas of Garapan lagoon; a variety on Guam is found in turbid areas receiving freshwater input and is particularly abundant in the small bays (Sella, Cetti, and Talafofo) of southern Guam.

ENVIRONMENTAL TOLERANCES

Species of Polycavernosa and Gracilaria are hardy and thrive under a wide range of environmental conditions.

Temperature

A study by James (1982) showed that thalli of Polycavernosa tsudae (referred to as G. edulis at that time) were photosynthetically active from 10 to 40° C, the range of temperatures examined. The maximum rate of photosynthesis increased with temperature.

Salinity

Chiang (1981), citing unpublished theses of the National Taiwan University, reports that Gracilaria in Taiwan grows salinities ranging from 5 to 50 ppt. James (1982) showed that the rates of photosynthesis of Polycavernosa tsudae were not significantly affected by salinity within the range of 10 to 30 ppt.

GROWTH AND PRODUCTION

Growth and production of numerous species of Gracilaria have been determined in a wide variety of environmental settings. These the data were reviewed by McLachlan and Bird (1986). The terms growth and production are not synonymous and, in fact, are often negatively correlated, particularly in dense cultures. Growth is usually expressed as percent increase in weight day^{-1}, while production is usually expressed as the biomass produced per unit area per unit time.

Research projects at the University of Guam Marine Laboratory have generated some data on the ecology and culture of Polycavernosa on Guam and Saipan; cultivation trials have been carried out in tanks (Nelson et al., 1980), in cages in small bays (Nelson and Tsutsui, 1982), and with thalli attached to ropes suspended from a floating raft (Nelson et al., 1980). Growth rates of Polycavernosa and Gracilaria thalli range between 2 and 7 % day^{-1} in shallow nearshore waters of the Mariana Islands (Nelson et al., 1980; Nelson et al., 1982; Nelson and Tsutsui, 1982).

The commercial production of Gracilaria in ponds in Taiwan generally ranges from 10,000 to 20,000 dry kg ha^{-1} yr^{-1} (Chen, 1976); this production is to supply seaweeds for use in the agar industry. Debusk and Ryther (1984) reported that, in tanks stocked with Gracilaria at a density 1.5 kg m^{-2}, rates of production increased with increasing rates of exchange, ranging from a low of 15 g dry weight m^{-2} day^{-1} (at a 1-day water residence time) to a high of 35 g dry weight m^{-2} day^{-1} (at a water residence time of approximately 1 hour).

LIMITING FACTORS

In natural habitats, major factors which may limit the growth or distribution of seaweeds include: competition for light or space with other species, availability of light and nutrients, water motion, and browsing by fishes and invertebrates. In culture systems these factors can be controlled to achieve maximum yields.

Nutrients

Availability of nitrogen is often limiting growth in marine plants; growth and productivity of P. cavernosa can usually be increased through increasing the availability of dissolved nitrogen. Ammonia is taken up more rapidly by thalli of P. cavernosa than is nitrate. Ammonia appears to be taken up by diffusion whereas the nitrate uptake system is induced by exposure to elevated nitrate levels (Nelson and Tsutsui, 1981a). Also, ammonia can be taken up at night and does not inhibit nitrate uptake (Nelson and Tsutsui, 1981a). Because ammonia is so rapidly taken up, pulse fertilization can be used to reduce the growth of epiphytes. Ryther et al. (1981) found that Gracilaria soaked in nutrient medium for 6 hours could continue to grow for up to 2 weeks before growth was limited by nutrient deficiency.

Carbon

In intensive seaweed cultures, depletion of dissolved carbon can limit production (Bidwell et al., 1985), carbon supply can be maintained at levels adequate to sustain production by continuous (flow-through) renewal of the culture media or by adding carbon dioxide such that the pH is maintained between 8.3 and 9.0 (Bird, 1989).

Light

James (1982) found that rates of photosynthesis by thalli of P. tsudae reach saturation at light levels of approximately 150 microEinsteins meter^{-2} sec^{-1} and that the saturation level occurs at higher light levels at increased temperatures. The relation between rates of photosynthesis and light would also be affected by the nutritional status of the thalli, since the content of light-gathering pigment is affected by nitrogen availability. In intensive cultures of Chondrus crispus, Bidwell et al. (1985) found that aeration that results in a thallus being brought to the surface and exposed to light approximately once per minute provides the highest rates of photosynthesis. With this pulsed exposure, individual plants will grow more slowly than those exposed to continuous light, but when plants are sufficiently dense--dense enough to allow complete light absorption--productivity per tank can increase by up to 50% with pulsed light exposures. In this system optimal rates of aeration were found to be 0.05 $m^3m^{-2}h^{-1}$ (Bidwell et. al., 1985).

Water exchange rates

In intensive systems water exchange provides nutrients and dissolved carbon, removes wastes, and provides stable temperatures. Maximum turnover times of 10 to 20 hours were used in intensive cultures of Chondrus crispus (Bidwell et al., 1985).

Grazing

Of major concern with the cultivation of Polycavernosa, and other seaweeds, in reef areas is the loss of thalli to browsing by herbivorous fishes (Nelson and Tsutsui, 1982). Browsing by fishes, particularly by siganids, has also been a problem in the culture of Eucheuma in Pohnpei (Doty, 1987). Suggested remedies include harvesting the browsing fishes, and situating grow-out areas at locations where herbivorous fish populations are low (i.e. in areas of reduced salinity in the case of Polycavernosa). Another strategy is to increase the size of the seaweed farm so that the percentage loss to browsers will be reduced; this work if browser populations are limited by recruitment, as commonly thought, rather than by food.

Epiphytes

The main epiphytes causing problems in the commercial culture of Gracilaria in Taiwan are species of Enteromorpha, Chaetomorpha, and Ectocarpus (Chiang, 1981). These are controlled in pond culture by raising small milkfish in the pond with the seaweeds; when the fish become larger and begin to consume the Gracilaria then they must be removed (Chiang, 1981). In intensive systems, epiphytes can be controlled by the application of herbicides, but it is preferable to adjust the culture conditions such that the epiphytes are at a competitive disadvantage in relation to the alga being cultured (Neish, 1979).

REPRODUCTION

The life cycle of species of the genera Polycavernosa and Gracilaria is tri-phasic with gametophyte, tetrasporophyte, and carposporophyte generations. The latter phase is parasitic, dependent on the gametophyte on which it is formed through sexual reproduction. In these genera, the gametophyte and the tetrasporophyte are morphologically similar or isomorphic. The diploid tetrasporophyte produces haploid tetraspores through meiosis; these grow into either male or female gametophytes that are haploid. The spermatia released from the male gametophyte fertilize the carpogonia of the female gametophyetes. These fertilized carpogonia lead to the development of diploid carposporophytes, which produce carpospores that develop into tetrasporophytes, completing the life cycle (Dawson, 1966). For practical purposes, such as aquaculture, cuttings are used to increase the number of thalli.

STOCKING

The stocking density of Polycavernosa is an important determinant of growth and production in extensive or intensive culture. Healthy cuttings are used for stocking and selection of particularly fast growing strains or thalli for future stockings could lead to enhanced production.

Source of thalli for stocking

Thalli for stocking can be obtained from cuttings from either wild or cultured thalli. Strains with desirable characteristics can readily be developed as a result of the ease of vegetatively reproducing Polycavernosa and Gracilaria.

Stocking density

Stocking densities used in the commercial pond production of Gracilaria in Taiwan are about 5,000 to 6,000 kg ha^{-1} (Chiang, 1981). Saunders and Lindsay (1979) used a stocking density of 0.5 kg m^{-2} in an experimental intensive system tested in British Columbia. DeBoer and Ryther (1977) used stocking densities ranging from 180 to 4,000 g m^{-2}, and Bird et al. (1981) used stocking densities of 2.6 kg m^{-2} in experimental intensive culture systems. Bird (1989) recommends stocking densities on the order of 2 to 5 kg m^{-2} for intensive seaweed culture systems in general.

PREVIOUS AND CURRENT CULTURE PRACTICES

These seaweeds can be cultured in a wide variety of situations. Most commercial production is accomplished in ponds, but they have also been grown on lines and in tanks.

Pond culture

Several species of Gracilaria are cultured in ponds in southern Taiwan. Most of this production is used in the agar industry, but the development of abalone (Haliotis diversiolor supertexta) mariculture is creating an increasing demand for Gracilaria for use a feed (Chiang, 1981). These ponds are usually 50 to 80 cm in depth, depending on the temperature, and are often stocked with other species such as milkfish (Chanos chanos), mangrove crabs (Scylla serrata), or black tiger prawns (Penaeus monodon). From one-half to two-thirds of the volume of the pond is exchanged every 2 to 3 days to maintain the salinity and to provide nutrients to the thalli.

Intensive culture

Several types of intensive culture systems have been devised for the production of Gracilaria (and Polycavernosa) (Bird, 1989). Floating enclosures constructed of polyethylene bags suspended from a log framework were examined for the commercial production of Gracilaria in Canada (Lindsay and Saunders, 1980); production from these enclosures reached 13.4 g dry weight m^{-2}. In general these systems must be well aerated in a manner that will produce a vertical circular flow in the rearing containers; a major factor limiting production in intensive culture systems is the availability of dissolved carbon, which can be supplied either by increasing the flow of seawater through the rearing units or by adding carbon dioxide such that the Ph of the water is maintained between 8.3 and 9.0 (Bird, 1989). Tank systems are being currently in use in the commercial production of Gracilaria for use as a fresh vegetable in Hawaii.

MARKET INFORMATION

Thalli of Polycavernosa are popular as a vegetable among a portion of the Filipino population on Guam and are harvested and marketed on a small scale. They are sold either fresh or frozen, but prior to being frozen the thalli are dipped in hot water until they turn from their normal reddish brown coloration to green. The seaweed is prepared and served pickled in either vinegar or lemon juice flavored with soy sauce. On Guam this alga is abundant in areas where there is freshwater input from streams, but a particularly suitable variety is also abundant in areas of Garapan Lagoon in Saipan (Nelson et al., 1982).

PROPOSED CULTURE METHODS FOR THE CNMI

Intensive tank culture systems are recommended for the CNMI with the objective of supplying a fresh vegetable to local markets, particularly targeting the Japanese tourist market.

The culture of giant clams has been received considerable attention in recent years. Species of giant clams reported to occur in the CNMI are T. maxima, T. crocea, and T. squamosa (Fujioka, 1984). However, it is doubtful that T. crocea occurs in the CNMI (B. Smith, personal communication). For culture, the most likely candidate would be Tridacna derasa, a species for which seed can be obtained from the Micronesian Mariculture Demonstration Center in Palau.

TAXONOMY AND MORPHOLOGY

Tridacna derasa is classified in the family Tridacnidae, the giant clam family. There are two genera in the family, Tridacna and Hippopus, and there are seven extant species in the family, five in the genus Tridacna and two in the genus Hippopus (Lucas, 1988). This is the second largest species of the Tridacnidae, second to T. gigas, reaching lengths of up to 60 cm (Lucas, 1988). The shell of this species is smooth in comparison to other species of Tridacna, thus the common name "smooth giant clam" (Lucas, 1988).

NATURAL HISTORY

Giant clams are found throughout the tropical Pacific in areas of thriving coral reefs. They are among the objects of traditional, subsistence fisheries in these areas and are even kept in clam gardens in some islands. The clams have a symbiotic alga in their mantle tissues that provides them with nutrition and allows them to lead an autotrophic existence.

ENVIRONMENTAL TOLERANCES

There is little conclusive information on the environmental tolerances of giant clams. However, available data should be considered in selecting sites for ocean-nurseries or grow-out. Fine sediments are detrimental to the clams because their ability to take advantage of the symbiotic alga within their tissue will be compromised in turbid water. In sandy areas the clams could be buried from movements of the sediment resulting from wave action.

Light

Light is important in the culture of giant clams because the photosynthetic activity of the symbiotic zooxanthellae provides the clams with an important source of nutrition; giant clams have been shown to grow in illuminated tanks filled with filtered seawater (Fitt and Trench, 1981). Mingoa (1988) reported that juvenile Tridacna gigas require a Photon Flux Density of 150 to 200 uE m^{-2} sec^{-1} for maximum photosynthesis. Fisher et al. (1985) reported that juvenile T. gigas reach photosynthetic saturation at 500 uE m^{-2} sec^{-1} but that larger clams do not reach saturating light levels even at ambient surface levels, over 2000 uE m^{-2} sec^{-1}. Presumably the responses to light of T. derasa would be similar to those of T. gigas.

Temperature

Estacion and Braley (1988) reported that T. gigas growing in intertidal ponds suffered reduced rates of growth and increased mortalities during the months when the water temperature reached 35° C.

Salinity

According to Heslinga et al. (1986), sites for the grow out of giant clams should have salinities within the range of 33 to 35 ppt.

Exposure

The tolerance of giant clams to periods of exposure increases with size; adult clams can withstand up to 4 hours of emersion daily without detrimental effects on growth (Lucas et al., 1988).

GROWTH AND PRODUCTION

According to Heslinga et al. (1986), T. derasa would be expected to reach a size of 7-8 cm in 18 to 24 months at Palau, and 27.5 cm after 6 years. However, Munro (1988) indicates that the reported growth rates of clams from Palau are higher than those usually found in other areas; he attributed this to better conditions for growth in Palau and to the culling of slow growing clams practiced at the Micronesian Mariculture Demonstration Center (Heslinga et al., 1986). Most studies indicate that T. gigas grows more rapidly than T. derasa (Crawford et al., 1988; Munro, 1988).

REPRODUCTION

Heslinga and Fitt (1987) and Lucas (1988) provide general descriptions of the life cycle of giant clams. In summary, tridacnid clams first become sexually mature as males and then become simultaneous hermaphrodites with individual adults producing both sperm and eggs. The fertilized eggs, 100 microns in diameter, develop into a veliger larvae that settles when it reaches a shell length of about 200 microns. The settled clams pick up zooxanthellae from the environment; the symbionts are not passed to the larvae from the parent.

Spawning and maturation

Giant clams become sexually mature as males after two or more years (Lucas, 1988) and become fully sexually mature after approximately 5 years (Heslinga and Fitt, 1987). In tropical areas the spawning of giant clams occurs throughout the year. In the hatchery, the fact that Giant clams respond to the presence of eggs in the water can be used to control the timing of spawning (Munro and Heslinga, 1983; Crawford et al., 1986; Lucas, 1988). Giant clams can also be induced to spawn by injection with serotonin (Braley, 1985; Crawford et al., 1986), by elevated temperature (Fitt and Trench, 1981), and by exposure to hydrogen peroxide (Fitt and Trench, 1981). The objective is to induce the clams to release eggs, because egg release is almost always accompanied by the release of sperm by the same clam or by others in the tank (Crawford et al., 1986).

STOCKING

Stocking densities differ between the nursery, ocean-nursery, and grow-out phases of culture. Braley et al. (1988) report that nursery tanks in their facility for culturing T. gigas are stocked at 5 m^{-2}. Barker et al. (1988) provide estimates of stocking density for the commercial production of T. gigas; they envision that 1000 clams, 6 to 8 months of age, would be stocked per 1.1 x 2 meter cell in the ocean-nursery phase. In Palau, clams are reared during the ocean-nursery phase in cages made from 60 x 60 cm trays (Heslinga et al., 1986); the initial stocking density recommended for clams 8 to 13 months of age is 50,000 clams. These are transplanted twice during the nursery phase: at 13 to 18 months of age to other cages at a density of 37,500 clams per tray and later, at 18-24 months of age, to still other cages at a density of 10 to 12 clams per tray. An estimated 40% survival during this phase can be expected. Barker et al. (1988) estimated that densities of 3-year old clams would be 96,000 clams ha^{-1} in a commercial operation producing T. gigas.

MORTALITIES

Mortality is a major factor in determining the economic viability of giant clam aquaculture. In general mortalities are severe in the larval phase, although the ability of culturists to obtain large numbers of eggs can overcome this problem. In the nursery phase, ectoparasites can be a source of mortalities. In the ocean-nursery phase, the clams must be protected against both predators and ectoparasites, but large clams in the grow-out phase suffer little mortality.

Larval rearing

Mortalities during the larval period are high, often with less than 1% of the larvae surviving to settlement (Fitt and Trench, 1984). From the observed differences in larval size and mortality between spawns, Fitt and Trench (1984) suggested that egg size or quality may differ between spawns and that the practice of induced spawning may exacerbate these differences in egg quality. Recent improvements in hatchery techniques developed by Braley et al. (1988) involving the stocking of nursery tanks with swimming veligers rather with fertilized eggs show promise in increasing survival; with this method, mean survival from eggs to D-stage larvae was 60%.

Nursery (juvenile) phase

According to Heslinga and Munro (1983) in Palau clams are stocked, when about 5 mm in length, in raceways. The clams are placed, at densities up to 1000 m^{-2}, in plastic Nestier shellfish trays filled with basalt chips 1-cm in diameter. From the raceways the clams are planted at the ocean-nursery sites.

Ocean-nursery phase

Mortality during the ocean-nursery phase is dependent on site. For example Bell and Pernetta (1988) found that mortalities ranged from 7% to 100% in trials at Motupore Island; sites where pyramidellids (ectoparasitic shelled opistobranchs) were found had the heaviest mortalities. A heavy infestation of pyramidellid snails was recently found in juvenile Tridacna derasa received from Palau at the Guam Aquaculture Development and Training Center; the snails became a problem, reaching levels of 60 snails per clam in the raceways used to hold the clams. Similar introductions of parasitic snails along with clams have been reported from a research project at Harbor Branch, Florida and from the Waikiki Aquarium in Honolulu (Mr. John Wise, personal communication, August 23, 1990).

An overall survival rate of 41% was reported for various ocean-nursery methods examined by Barker et al. (1988). In the Philippines, survival during the ocean-nursery phase for several species of giant clams ranged from 0 to 74% for growth periods ranging from 15 to 24 months (Estacion, 1988).

Grow-out phase

Clams over 200 mm in shell length can be grown successfully without being enclosed in a protective container. At Motupore Island Research Center in Papua New Guinea, researchers found 100% survival when giant clams 115 to 160 mm long were removed from protective cages of the ocean-nursery phase (Bell and Pernetta, 1988).

PREVIOUS AND CURRENT CULTURAL PRACTICES

Techniques for spawning and rearing several species of giant clams (f. Tridacnidae) have been developed. Work has been primarily with two species, Tridacna derasa and T. gigas. Techniques for the culture of giant clams in Micronesia have been developed and demonstrated at the Micronesian Mariculture Demonstration Center (MMDC) in Palau (Heslinga and Perron, 1983; Heslinga et al., 1984; Heslinga and Watson, 1985). In 1984, MMDC produced more than 100,000 juvenile giant clams, 80,000 of which were second generation offspring (Heslinga and Watson, 1985). Many of the Pacific islands have received clams produced by the Micronesian Mariculture Demonstration Center. Island groups within the region that have received juvenile clams from Palau include Guam, Saipan, Pohnpei, Kosrae, the Marshall Islands, Truk, and Yap. The MMDC program is now attempting to expand the hatchery and nursery capacity to produce large numbers of one-year-old live clams for test marketing.

Smaller giant-clam hatcheries have been established in the Marshall Islands and Pohnpei. The hatchery in Pohnpei, operated by the government, is currently raising clams for stock enhancement. The hatchery in the Marshall Islands is located on Milli Atoll and is operated by a private investor. A government-sponsored hatchery for giant clams is being established in Kosrae.

Juveniles are usually produced in land-based hatcheries and transferred to protective containers in an ocean-nursery area. Several types of containers have been designed and tested to varying degrees in reef areas. The types of protective containers include mesh-covered plastic trays, steel-mesh boxes lined with plastic mesh, "lines" constructed of plastic mesh with mesh base, "covers" of plastic mesh without a base, and plastic mesh "exclosures" supported by floats (Barker et al., 1988).

Interest is high in giant clam cultivation in other Pacific locations. Major research projects focusing on the cultivation of T. gigas are under way in Australia, the Philippines, and in the Solomon Islands. In Okinawa, research on farming of the boring clam T. crocea has been underway at Ishigaki Island since 1979 (Murakoshi, 1986); it was found for this species that planting the seed in pits increased survival and the clams grew to over 6 cm in shell length after 4 years.

In Australia, the commercialization of giant clam farming is being vigorously pursued. As described by Braley (1989) the cultivation of clams in fringing reef habitats is being examined by maintaining the clams within various types of benthic enclosures.

Juvenile Tridacna derasa have been brought in for trials at Rota and Saipan, but the trials were frustrated by poaching. The government of Rota brought in 100 4- or 5-year old clams and placed them on the reef flat where they were lost to poaching; additional shipments for trials are planned. A house resolution which requests the

Marianas Public Land Corporation (MPLC) to designate land in the Tanapag area of Saipan for giant clam farming has been referred to committee for further study (Marianas Variety News, Oct. 19, 1990).

MARKET INFORMATION

Markets for giant clams already exist. Giant clam products that are marketed include the adductor muscle, the shell, small live clams for the aquarium trade, and small chilled clams for use as sushi. Heslinga and Perron (1983) estimated that markets for giant clam in Asia, including Hong Kong, Singapore and Japan, have an annual value in excess of $100 million. However, Tisdell (1990) indicated that this estimate may be too high; based on recent market estimates he suggested that the Asian market for adductor muscle would not support many clam farms. Also, it normally takes about five years to grow the adductor muscles to marketable size. Though there is a market for clams in the aquarium trade, Tisdell (1989) estimates that the world demand probably does not exceed 150,000 clams per year, a demand which could be met by 2 clam farms. A more likely product to be produced in the CNMI would be the smaller clams for sushi. A popular species in the sushi bars of Okinawa is T. crocea. Although giant clams are not familiar to most mainland Japanese, a likely market to be targeted for giant clams produced in the CNMI would be that associated with the restaurant trade that caters to the Japanese tourist.

PROPOSED CULTURE METHODS FOR THE CNMI

Either tank or reef culture methods for giant clam production could be considered for the CNMI.

MARINE SHRIMP

TAXONOMY AND MORPHOLOGY

The genus Penaeus is classified within the family Penaeidae, the Suborder Natantia, and the Order Decapoda, of the Class Crustacea. There are approximately 318 species of penaeid shrimp. Those cultured within the tropical and sub-tropical Pacific include P. monodon, P. stylorostris, P. japonicus, and P. vanemmei. The information provided here focuses primarily on P. monodon.

Penaeids are sexually dimorphic with females generally growing faster and reaching larger sizes than males. Penaeus monodon is one of the larger species of penaeids and reaches sizes of 5 kg^{-1} in pond culture (Cook and Rabanal, 1978).

NATURAL HISTORY

This species is found throughout much of the Indo-Pacific area. Larvae and juveniles are found in near shore estuaries and mangroves, but adults are found in deeper water, to 162 m (Solis, 1988).

ENVIRONMENTAL TOLERANCES

Successful, profitable culture of P. monodon requires careful monitoring and control of the culture environment. Particular attention to aspects of water quality, such as pH and the levels of dissolved oxygen and ammonia, is required. Environmental factors can have important indirect effects as well; for example, a prolonged dry season can result in elevated pond salinity and temperature, which in turn allows an excessive growth of benthic algae (Apud, 1988).

Salinity

Juvenile and adult P. monodon are tolerant of a wide range of salinities, from 3 to 45 ppt. However, species differ in their optimal salinities for culture. According to Liao and Chao (1983), P. monodon grows slowly at high salinities, so brackish water must be available for successful culture; P. vannamei can grow at higher salinities but will not reach the size of P. monodon.

Temperature

Penaeus monodon can survive temperatures up to 37.5 °C, but, in general, penaeid growth is optimal between 26 and 30° C (Cook and Rabanal, 1978). Tseng

(1988) reports that P. monodon can not tolerate water temperatures above 33° C for long periods.

Dissolved Oxygen

The lowest level of dissolved oxygen that can be tolerated by young shrimp, 0.5 to 0.6 g, ranges from 0.1 to 0.3 cc per liter, dependent on salinity, temperature, and the concentration of dissolved nitrate (Liao and Huang, 1975). In general dissolved oxygen concentrations above 2 ppm are necessary for good growth (Cook and Rabanal, 1979).

Water quality

Low pH, such as might be caused by acidic soils, is detrimental, and mortalities can be expected if the pH falls below 5 (Cook and Rabanal, 1978). The pH also affects the toxicity of dissolved ammonia in the pond water. Ammonia toxicity results in reduced growth and increased mortalities, but generally, levels below 0.10 mg NH_3 l^{-1} are acceptable (Licop, 1988).

GROWTH AND PRODUCTION

Chiang and Liao (1985) report that P. monodon grows from 1 gram to 30 to 40 grams within 15 to 20 weeks in Taiwan. Also in Taiwan, P. monodon were found to grow to over 25 g in 140 days (Chen et al., 1988). In Tahiti, early trials with P. monodon resulted in the production of 25-g shrimp after 7 months. A comparison of 11 species by Liao and Chao (1983) indicated that the three fastest growing species are P. monodon, P. japonicus, and P. vannamei.

In Taiwan, production of two crops yr^{-1} of P. monodon in semi-intensive culture with initial stocking densities of 20 to 30 juveniles m^{-2} typically yields from 1.4 to 9.6 tons ha^{-1} (Liao and Chao, 1983), but yields up to 12 tons ha^{-1} have been achieved. In intensive systems with running water and stocking rates of 160 juveniles m^{-2}, production in Taiwan averages 4.5 to 24 tons ha^{-1}, reaching 35 tons ha^{-1} in some cases (Liao and Chao, 1983).

FEEDING

In intensive and semi-intensive culture systems, supplemental feed must be provided. A number of brands of feeds formulated especially for marine shrimp are available. Feed with a protein content of approximately 40% was found to be optimal for culturing P. monodon in French Polynesia (Aquacop, 1977). In intensive cultivation of P. monodon in Taiwan, feeds of 37 to 40% protein are used (Chen et al., 1989). Farmers on Guam pay approximately \$ 0.40 lb^{-1} for shrimp feed.

Feeding rates

Recommended feeding rates depend on shrimp size and decrease as the shrimp grow. In Taiwan, feeding rates of 14 to 20% day^{-1} are recommended for shrimp weighing less than 2 g and lower rates of 3 to 4% day^{-1} for shrimp weighing over 30 g (Chiang and Liao, 1985). In the Philippines feeding rates for P. monodon are reported to range from 8 to 12% for shrimp less than 1 g up to 3.0% for prawns weighing 30 to 35 g (Apud, 1988).

Feed conversion

Liu and Mancebo (1983) reported feed conversion efficiencies of 56 to 59% for P. monodon in semi-intensive culture in the Philippines. Feed conversion (wet weight of prawns produced per unit dry weight of feed) in cultivation trials with P. monodon in Tahiti ranged from 1.1 to 4.1 (Aquacop, 1977). Chen et al. (1989), analyzing data from 20 ponds in Taiwan, reported feed conversion ratios ranging from 1.39 to 2.15. In India groups of P. monodon fed various experimental diets exhibited feed conversion ratios of 1.2 to 1.6 (Hajra et al., 1988).

REPRODUCTION

The culture of marine shrimp depends requires a sufficient supply postlarvae for stocking ponds. In the culture of some species, the farmers still depend on fishermen to obtain ovigerous females for spawning. However, maturation and spawning of pond reared P. monodon can be achieved. The ability to control the reproductive cycle of a species being cultured helps in preventing the introduction of diseases from females collected from the wild.

Sex determination

The female possesses a cleft-like thelycum for sperm storage at the base of the 4th and 5th periepod; on males, the endopodite of the first abdominal appendage is modified to form a conical petasma (Tseng, 1988).

Maturation

The age at which females first mature ranges from 7 to 12 months (Aquacop, 1979). For P. monodon, the number of eggs per female is around 569,000, increasing with size of the female (Villegas et al., 1986). French scientists at Tahiti reported that the fecundity of P. monodon females between 45 and 130 grams was 60,000 to 600,000

(Aquacop, 1979). Broodstock are held at a density of 3 to 5 shrimp m^{-2} at a male/female ratio of 1:1 or 1:2; shucked clams and oysters serve as the primary food of the broodstock (Chwang et al., 1986). Maturation of the gonad is stimulated by eyestalk ablation (Primavera, 1978; Aquacop, 1977). Maturation is affected by various factors, including nutrition, light intensity, photoperiod, and water quality; details of induced maturation are described in the review by Primavera (1988).

Spawning

According to Chwang et al. (1986), following eye-stalk ablation, the females may spawn naturally with mature males; if they do not, the female may be artificially inseminated (Chwang et al., 1986). Shrimp density in the spawning tank should be approximately 1 shrimp m^{-2} (Chwang et al., 1986). Females can spawn several times; in Tahiti, 6 female P. monodon produced 19 spawns in three months (Aquacop, 1979). Spawning is always observed between 8:00 P.M. and 1:00 A.M.

STOCKING

There are no stocks of Penaeus monodon in the CNMI, so post-larvae must be obtained from a hatchery. The Guam Aquaculture Development Center is attempting to establish a viable hatchery for P. monodon. Once this facility has achieved routine production of post-larvae, these would be available to commercial growers in the CNMI. Farmers in Guam have acquired post-larvae from Taiwan or Hawaii, but the air-freight charges make the post-larvae expensive. Also, when larvae are brought in from distant sources the probability increases that the larvae will either suffer high mortalities or be weakened by the long transport time.

Extensive culture

In traditional extensive culture of P. monodon in Southeast Asia, shrimp are typically stocked at 5,000 ha^{-1} (Tiro et al, 1986). For extensive culture of P. monodon in the Philippines shrimp are stocked at 2,000 to 10,0000 ha^{-1} (Apud, 1988).

Semi-intensive culture

Liu and Mancebo (1983), for semi-intensive culture trials with Penaeus monodon in 0.25 ha earthen ponds with cement dikes, used stocking densities of 127,000 to 121,856 shrimp ha^{-1} (12.7 to 12.2 shrimp m^{-2}). In New Caledonia, the French stock P. stylorostris at densities of 15 post-larvae m^{-2} in commercial, semi-intensive production (Goxe et al., 1988). In the Philippines semi-intensive production of P. monodon is accomplished at stocking densities ranging from 20,000 to 80,000 shrimp ha^{-1} (Apud, 1988). Stocking rates for the semi-intensive commercial production of P. monodon in

Taiwan is 20 to 30 juveniles m^{-2} (200,000 to 300,000 ha^{-1}), while stocking densities for highly intensive production are 160 juveniles m^{-2} (1,600,000 ha^{-1}).

Intensive pond culture

Aquacop (1977) obtained good growth of P. monodon in 12 m^3 ponds stocked at 50 m^{-2}. Promising results were obtained in recent intensive cultivation trials with P. monodon in Taiwan. Culture trials were conducted in 0.14 ha ponds each stocked with 600,000 postlarvae (Chen et al., 1989); in these 4.5-month trials the average yield was 1212 kg $pond^{-1}$ with production ranging from 8.7 to 21 tonnes ha^{-1} $crop^{-1}$. In the Philippines, stocking densities from 100,000 to 400,000 shrimp ha^{-1} are used in intensive cultivation of P. monodon with optimal densities in the range of 150,000 to 250,000 ha^{-1} (Apud, 1988).

MORTALITY

In extensive culture in Taiwan, survival of P. monodon after 5 months is around 70 to 75% (Tseng, 1988). For semi-intensive culture, in ponds stocked at around 40 postlarvae m^{-2}, survival is about 70%, while for semi-intensive culture, with a stocking rate of around 23 m^{-2}, mean survival is 78 % (Chiang and Liao, 1985). In the Philippines, survival of P. monodon was reported to be 60 to 80% in commercial culture (Apud,1988). Survival of P. monodon in Tahiti in semi-intensive culture ranged from 80 to 100% (Aquacop, 1977). Survival of P. monodon in intensive culture in Taiwan ranges from 40 to 68% (Chen et al., 1989).

PREVIOUS AND CURRENT CULTURE PRACTICES

Traditional extensive culture of the black-tiger prawn Penaeus monodon in brackish-water earthen ponds stocked at 5,000 ha^{-1}, as practiced in much of Southeast Asia, typically yields 100 to 300 kg ha^{-1} yr^{-1}; but these yields can be substantially increased through careful pond management (Tiro et al., 1986; Liu and Mancebo, 1983).

An example of conservative semi-intensive culture can be found at New Caledonia, where Penaeus stylorostris is being commercially produced (Goxe et al., 1988). This is a joint venture between IFREMER, France Aquaculture, and the territorial government of New Caledonia. Yields of over 4 tonnes ha^{-1} $year^{-1}$ are achieved under routine conditions with a stocking density of 15 post-larvae m^{-2} and two crops produced annually.

The work of Liu and Mancebo (1983) in the Philippines provides another example of semi-intensive culture of marine shrimp at conservative stocking rates. Their production trials with Penaeus monodon were carried out in 0.25-ha earthen ponds with cement dikes; ponds were stocked at 127,000 to 121,856 shrimp ha^{-1} (12.7 to 12.2 shrimp m^{-2}). Yields after a 106-day production period were 3,808 to 4,008 kg ha^{-1}; the feed conversion ratio was 1.7 to 1.8 on feed consisting of 37% protein. A description of the development of commercial P. monodon production is presented by Chiang and Liao (1985).

Intensive culture of P. monodon was carried out in Taiwan in 1.4-ha ponds, 2.2 m deep and stocked with 600,000 postlarvae (Chen et al., 1989); after a grow-out period of 4.5 months, production in these ponds ranged from 848 to 1550 kg per pond (8.7 to 21.0 tonnes ha^{-1} $crop^{-1}$). The shrimp in these trials were fed commercial feed with a protein content of 37 to 40%.

Results of the intensive production trials with the white shrimp Penaeus vannamei in an intensive, earthen bottom, round-pond, system at the Oceanic Institute in Hawaii were recently published by Wyban and Sweeney (1989). The trials were conducted in a 337-m^2 pond with a water depth of 0.9 m; the stocking density was 45 shrimp m^{-2} and the yield was 14,812 kg ha^{-1} over a 74-85 day culture period. In these trials conversion of a high-protein (42%) feed was 2.0 to 2.5. These investigators also found that the there was a significant positive correlation between growth and water temperature between the range of 26° to 29° C; growth rates at the higher temperatures were approximately 2.8 to 3.0 g $week^{-1}$. Even higher stocking densities--75 m^{-2}--for P. vannamei were used by these researchers at the Oceanic Institute in a 2,000 m^2 commercial prototype pond (Wyban et al., 1988); this system produced 9,120 kg ha^{-1} in an 88-day period with 2.0 kg of shrimp produced per kg of feed.

Intensive prawn cultivation is practiced in other nearby areas. One such example is provided by a prawn farm on the island of Ishigaki in Okinawa visited by one of us (S.N.), where the production of Penaeus japonicus is practiced on a commercial basis. The prawns are grown in 40,000-m^2 ponds aerated by paddle-wheels at night, and initially stocked at a density of 30 m^{-2}. According to Mr. Unesuko, the farm manager, yields of approximately 600 to 700 g m^{-1} yr^{-1} are achieved (6,000 to 7,000 kg ha^{-1} yr^{-1}).

MARKET INFORMATION

There is a ready market for marine shrimp on Guam, and frozen shrimp are routinely imported from the Philippines and southeast Asia. Fresh or live shrimp are expected to be popular in Saipan markets, particularly those related to the tourism industry, if reliable production schedules of high-quality products can be achieved.

Additional markets exist in the United States and Japan, both major importers of shrimp. In 1986, the United Stated imported more than 223,000 metric tons of shrimp with an estimated value of $1.4 billion (United States Department of Commerce, 1988), and in 1988, Japan imported more than 260,000 metric tons of shrimp at a value of over US$2.5 billion (INFOFISH Trade News, August 1989). A variety of product forms of shrimp are marketed in both Japan and the United States, but the primary forms of frozen imported shrimp are whole, headless, and peeled. Prices vary between species of shrimp, product forms, and size categories. Larger shrimp command a higher price per kilogram. Some recent wholesale prices of frozen headless shrimp in Japan are shown in Table 25.

Aspects of the economics of shrimp culture vary widely depending on the system being employed, input costs, and markets. However, the cost of feed is often a primary factor in determining overall operating costs. For example, the cost of production of Penaeus orientalis in China during 1985 was estimated at about US$ 2.00 per kilogram and a major portion of this (77 percent) was attributed to the cost of feed (Shang, 1989).

Table 25. Wholesale prices (US$ per kg) for headless frozen shrimp in the markets of Japan in mid 1989.

COUNT	BLACK TIGER	WHITE	PINK/BROWN
<8	19.50	--	--
08/12	14.00-16.50	17.00-17.50	--
13/15	10.50-12.00	15.00	--
16/20	8.50-10.10	11.30-12.00	7.50
21/25	7.50- 9.50	10.00-10.60	7.80
26/30	6.20- 8.50	8.50- 8.80	7.50
31/35	6.20- 8.10	7.70	6.80
71/90	3.00- 4.60	3.00-3.50	3.60

Source: INFOFISH Trade News, August 1989

In Okinawa, according to Dr. Tsuyoshi Uehara (Associate Professor, Dept. of Biol., University of the Ryukyus), both fresh and chilled shrimp are popular commodities in the local market place. Some seafood restaurants sell live shrimp, usually P. japonicus, known locally as "kuruma ebi". Live P. japonicus can also be found at the fish market in Naha. The prawn preferred by the Japanese, and therefore the prawn with the highest market value, is Penaeus japonicus, and this species is being commercially cultured in Okinawa for export to mainland Japan. According to producers in Okinawa, P. japonicus can grow at environmental temperatures higher than typically found at Okinawa, such as might be experienced in the CNMI; however, under such conditions the quality of the flesh is diminished. Because of this, P. japonicus would not be the best candidate for culture in the CNMI. However, as a result of the low temperature during the winter, P. monodon are not cultured in Okinawa but are imported from other countries. Therefore, development of a market for live or chilled P. monodon, raised in the CNMI, could be explored; it is a short flight from Saipan to Okinawa.

PROPOSED CULTURE METHODS FOR THE CNMI

Semi-intensive or intensive culture of P. monodon would be the most appropriate methods for prawn culture in the CNMI. Post-larval shrimp for stocking are expected to be available in the near future from the Guam Aquaculture Development and Training Center in Guam. Shipping time from Guam to Saipan, Rota, or Tinian is short, so the health of the post-larvae should not be compromised during their transport from the hatchery to the production sites.

OTHER SPECIES

Grouper

There are lucrative markets for live grouper, particularly in Hong Kong, Malaysia, and Singapore. At least one company (Monodon Philippines Incorporated) has expressed interest in culturing groupers to be offered live through seafood restaurants catering to Japanese tourists in both Guam and Saipan. Currently a commercial venture in Palau is holding groupers for live shipment to Hong Kong. Prices for live grouper vary considerably with species. Examples of wholesale prices for live grouper are provided in Table 26. In most cases, grouper are fed trash fish. According to Tseng and Ho (1988), Epinephelus tauvina have an efficient digestive system. More than 95% of the feed is absorbed if at least 36 hours are allowed between feedings; lower digestive efficiencies are obtained with more frequent feedings. A particularly high priced grouper is the pantherfish, or senorita, (Epinephelus altevelis). The pantherfish occurs on Guam, but it is rare; in addition to its popularity as a food fish, the young are attractive and highly sought for the aquarium trade.

The costs associated with the cage culture of carnivorous fishes are high, and the economic feasibility of culturing groupers depends on their high market value. By rough estimate (Tseng and Ho, 1988), food costs in the culture of the red grouper Epinephelus akaara account for about 35-50% of the total production costs, excluding the cost of purchasing young fish for stocking. Therefore the cost of trash fish and the conversion efficiency are major factors in determining the economic viability of grouper culture. Since groupers will not eat food which falls out of the water column, they are sometimes cultured with bream which serve as scavengers and also stimulate the groupers to feed (Tseng and Ho, 1988). Cultured red grouper Epinephelus akaara in Hong Kong grow to 30 cm SL in about 5 months (Tseng and Ho, 1988).

For grouper culture to be developed in the CNMI, a source of juveniles would need to be identified. Even if sufficient numbers were available, collection of juveniles from the reefs of the CNMI would not be a good solution. Removing juveniles could result in reduced populations of large groupers, a situation that would not be well received by local fishermen and divers. Wild-caught fry for stocking could possibly be obtained from the Philippines or from other islands in Micronesia. Groupers are presently being collected in Palau and shipped live to markets in Hong Kong, and there is interest in establishing a similar industry in Pohnpei. A list of the larger groupers found in Micronesia is shown in Table 27. Work on refining the hatchery production of groupers is being undertaken in several nearby areas, including Okinawa and Thailand. Also, work on the larval rearing of grouper is beginning at Guam. If fry can be obtained, the cage culture of groupers could be considered, provided the cages can be adequately protected from storm waves. A cheap source of fish for feed, such as the by-catch of tuna boats, would also have to be identified.

Table 26. Wholesale prices of live grouper in Asian markets (Source: INFOFISH Trade News, 14/89).

SPECIES	SIZE (g)	US$/Kg	MARKET AREA
Epinephelus tauvina	500	6.52	Malaysia
" "	800	7.31	Malaysia
Cromileptes altivelis	600	35.89	Hong Kong
Plectopomus leotpardus	700	12.82	Hong Kong
" "	1000	23.07	Hong Kong

MULLET

Mullet are similar to milkfish in that they are tolerant of a wide range of salinities, from freshwater to seawater. Mullet have also been suggested as potential candidates for commercial culture within the region (Nelson, 1988a). A cooperative project between the Oceanic Institute in Hawaii, the Guam Department of Commerce, and the University of Guam is currently underway to assess the feasibility of culturing the grey mullet Mugil cephalus on Guam. Interest in mullet culture is high among the commercial producers in Guam, but there has been no production to date as a result of the lack of fry.

A list of mullet species found in the Mariana Islands is shown in Table 28. Fry of several species are abundant in the shallow, nearshore waters of the Mariana Islands, but these appear to grow slowly in comparison to milkfish (Nelson, 1988a). However, the Oceanic Institute has developed procedures for routinely spawning the grey mullet Mugil cephalus and mass-producing the larvae. A current project on Guam is examining the growth and marketability of pond reared Mugil cephalus, and if this species proves, in the production and market trials, to be desirable, then the hatchery technology developed at the Oceanic Institute will be transferred to the Guam Aquaculture Development Center to provide a source of mullet for stocking ponds throughout the region.

There is a market for mullet roe in Japan, with ripe female fish selling for up to $14 kg^{-1} (pers. comm., Clyde Tamaru of the Oceanic Institute). According to Chris Kelley of the Oceanic Institute, a mullet ovary sells for approximately $ 50.00.

Table 27. Maximum sizes of groupers growing to more than 40 cm in standard length that have been reported from Micronesia.

SCIENTIFIC NAME	COMMON NAME	cm	Kg
Aethaloperca rogaa	Redmouth Grouper	50	2.1
Anyperodon leucogrammicus	White-lined Grouper	41	nd
Cephalopholis argus	Peacock Grouper	42	nd
Cephalopholis sonnerati	Tomato Grouper	47	3.4
Cromileptes altivelis	Pantherfish	70	nd
Epinephelus caeruleopunctatus	Snowy Grouper	64	nd
Epinephelus ongus	Wavy-lined Grouper	40	nd
Epinephelus socialis	Tidepool Grouper	42	nd
Epinephelus tauvina	Greasy Grouper	64	nd
Epinephelus miliaris		45	nd
Epinephelus maculatus	Highfin Grouper	45	nd
Epinephelus chlorostigma	Brown-Spotted Grouper	60	nd
Epinephelus malabaricus	Malabar Grouper	170	90
Epinephelus fuscoguttatus	Blotchy Grouper	89	15+
Epinephelus microdon	Marbled Grouper	61	nd
Epinephelus cyanodus	Yellowfin Grouper	75+	nd
Epinephelus lanceolatus	Giant Grouper	260	400
Plectropomus areolatus	Squaretail Grouper	60	nd
Plectropomus laevis	Saddleback Grouper	90+	22
Plectropomus leopardus	Leopard Coral Trout	68	nd
Plectropomus oligocanthus	Blue-lined Coral Trout	65	nd
Variola albimarginata	Whitemargin Lyretail	45	nd
Variola louti	Lyretail Grouper	56	nd

Table 28. Maximum lengths of mullets reported from the Mariana Islands (Source: Myers, 1989).

SCIENTIFIC NAME	COMMON NAME	LENGTH (cm)
Chaenomugil leuciscus	Acute-jawed mullet	46
Crenimugil crenilabrus	Fringelip mullet	50
Liza vaigiensis	Yellowtail mullet	51
Valamugil engelii	Engel's mullet	15
Valamugil sehili	Bluespot mullet	48

FRESHWATER PRAWNS

The freshwater prawn Macrobrachium rosenbergii has been commercially cultured in southern Guam at farm sites near streams with adequate supplies of freshwater supplies of freshwater throughout the year. Two crops per year are possible in tropical areas, with a conservative yield of over 4600 kg ha^{-1} yr^{-1} (FitzGerald and Nelson, 1979). The prawns are a high-value product and have been readily marketed on Guam for over \$ 7.00 lb^{-1} for whole animals sold at the pond site. Although prawns have been produced on Guam, development of commercial production has been constrained by the lack of post-larvae for stocking the ponds. The Guam Aquaculture Development and Training Center has a program, funded by the Center for Tropical and Subtropical Aquaculture, targeting the production of post-larval Macrobrachium to encourage farmers on Guam to resume production. If the hatchery is successfully established then post-larvae would also be available to farmers in the CNMI, if desired. However, the hatchery on Guam has recently had difficulties with larval production.

Since a related prawn, Macrobrachium lar, is present in the streams of the CNMI, it may not be obvious that a hatchery is needed to produce the post-larval shrimp for stocking ponds. The reason is that, although juveniles and adults of these species survive and grow in freshwater, the larval stages will develop only in brackish water--a mixture of freshwater and seawater. Therefore, the prawns cannot reproduce in the ponds as some beginning farmers hope. A hatchery is required for the production of post-larvae. A prawn hatchery requires clean sources of freshwater and brackish water for successful operation. Operation of the hatchery requires trained technicians, and the health and development of the larvae must be monitored throughout the 35-day period from hatching to metamorphosis. Guam farmers found it difficult and expensive to have post-larval prawns shipped in from hatcheries in Hawaii or other areas; they experienced high mortality of post-larvae that they brought in from Hawaii. Others on Guam have attempted to start their own small-scale hatcheries for freshwater prawns, but later the attempts were abandoned.

SEA URCHINS

Sea urchin roe is a popular culinary item in many countries; Japan imported more that 3,690 metric tons of sea urchin roe in 1987 (Bruce, 1988). According to Dr. Uehara of the University of the Ryukyus, the Okinawa Perfectual Fisheries Experiment Station has initiated a major project to develop the culture of sea urchins. The primary species of interest in Okinawa is Tripnuestes gratilla which has a milder flavor than the popular species from the Japanese mainland. Wholesale prices for sea urchin row currently are $9.36 to $32.40 per tray containing between 230 and 260 grams of roe (INFOFISH Trade News 15/89, August 15), and the price in retail outlets is reported to be $10 for 50 g (Bruce, 1988).

Although research in the propagation of tropical sea urchins is underway, commercial ventures are unlikely to be realized in the near future. At the Okinawa Prefectural Fisheries Experiment Station, research under the direction of Mr. S. Inoha has been directed toward developing methods of holding sea urchins so that the weight of the gonad increases. For example, T. gratilla collected from the wild may have a gonad weight of 10% and sell for 4,000 Yen per 200 urchins or 20 Yen per urchin; however, if the urchins are held and fed at 27° C, the gonad weight increases to 20% and the urchins will bring a price of 200 Yen each -- a ten- fold increase in price by doubling the gonad weight!

PEARL OYSTERS

The commercial production of pearls has been successful at several other Pacific islands location, most notably in French Polynesia and the Ryukyu islands. Round pearls are produced by Pinctada margaritefera and half-round pearls are produced by the winged oyster Pteria penquin. In many cases the juveniles used to seed the culture beds are collected from areas of natural spatfall. However, techniques have been developed to produce juveniles in hatcheries. The owner of a successful pearl culture operation at Ishigaki Island stated that the production of pearls in the CNMI is possible and that his company would be willing to enter into a joint venture, providing the necessary expertise and technology in exchange for an exclusive right of purchasing the pearls produced.

Particularly attractive is the culture of Pteria penquin for the production of half-pearls. Pteria grow rapidly, and the techniques required for producing half pearls are not as demanding as those used in the production of round pearls. The production of round pearls in Pinctada requires skilled technicians to insert a round shell bead and a piece of mantle tissue into the pearl oyster; the oyster then produces a pearl around the bead. The production of half pearls with Pteria requires less technical expertise; the method involves attaching a form, in the shape of the desired product, to the shell of the oyster and waiting for it to become covered with nacre.

ECONOMIC SEAWEEDS

Seaweeds constitute a potentially important economic resource within Micronesia (Nelson, 1988b) and in the CNMI. The commercial uses of seaweeds are varied, including human consumption and the production of phycocolloids. The major interest in several Pacific islands is in the culture of phycocolloid-bearing seaweeds for use in the production of carrageenan and agar. This interest stems from the growing worldwide demand for these phycocolloids and from the successful establishment of commercial farms for seaweeds in Taiwan, the Philippines, and other tropical areas. However, a study by McHugh and Philipson (1988) determined that the high freight charges in the region exclude producers in the Pacific islands from markets in either Europe or the United Sates. Uwate (1987) surveyed potential seaweed buyers in a study for Yap state and reported that the existing markets may be difficult to penetrate except through joint-ventures with existing firms. The limited protected reef areas for potential production in the CNMI and the prevailing economic situation in the industry dictate against the development of seaweed cultivation in the CNMI for the purposes of phycocolloid production. However, the culture of seaweeds for human consumption, particularly for use in the hotels and tourist-oriented food outlets, may be feasible; this type of culture can be carried out on a small scale and viable farms producing seaweed as a fresh vegetable have been established in the Philippines, Okinawa, and Hawaii. Given the limited shallow coastal areas, the most reasonable approach to the cultivation of seaweeds in the CNMI would be the relatively small scale production of seaweeds for use as a fresh vegetable.

When considering seaweeds to cultivate in the CNMI for human consumption, one species comes immediately to mind--one that is presently harvested and consumed in Guam and the Northern Mariana Islands. This is the green alga Caulerpa racemosa, locally known as "ado" in Chamorro or as "sea grapes" in English, The species is traditionally popular as a pickled vegetable in the Mariana Islands and often found as a dish offered during special occasions at fiestas. Thalli of this seaweed are generally collected from the shallow areas around the islands when it is in abundance. This alga is also sometimes marketed at the weekly flea-markets of Guam. Similar species are commercially cultivated in nearby areas, and the relevant technologies might be applied to the development of the small-scale production of these species in the CNMI. In December of 1989 fresh sea grapes were being offered for sale in 1/2 pound lots for $1.00 each at the weekly flea market on Guam.

Systems for the culture of Caulerpa have been developed in other areas, notably in the Philippines and in Okinawa. The species being cultivated is Caulerpa lentillifera. This species similar to Caulerpa racemosa, which is commonly harvested in the Mariana Islands. In the Philippines, according to Trono and Ganzon-Fortes (1988), the culture of Caulerpa was pioneered in Cebu where small (0.1 to 0.25 ha) ponds, 30 to 60 cm in depth, are stocked at 100 g m^{-2} (1000 kg ha^{-1}); production from a 1-ha farm would typically fall between 12,200 and 15,000 kg yr^{-1}. Trono and Denila (1987) found that the growth rates of Caulerpa lentillifera in Philippine ponds are influenced by stocking density, with growth rates of up to 32 g m^{-2} day^{-1} in ponds stocked at 500 g m^{-2}. They also found that growth in the ponds was seasonal, highest in the dry months of the summer and lower during the rainy season; if the salinity falls below 30 ppt the crop will be lost (Trono, 1989). The thalli produced in this manner are harvested by hand; both fresh and salted Caulerpa are exported from the Philippines to Japan (Hurtado-Ponce, 1988; Trono, 1989).

There are numerous other edible seaweeds in the waters of the CNMI that might well be the targets of future research and development efforts. For example, Asparagopsis taxiformis is found year round on submarine terraces in shallow waters 3 to 7 meters deep (Tsuda, 1982); this species is highly valued as a condiment in Hawaii, where it is marketed in dried form for this purpose.

RECOMMENDATIONS (SPECIES EVALUATION):

- o Explore the commercial culture of marine shrimp, milkfish, tilapia, and rabbitfish; all of these are being cultured commercially in other areas.

- o Explore the culture of winged oysters in Garapan Lagoon for the production of blister pearls;

- o Explore the production of giant clams for the tourist-related sashimi trade;

- o Explore the small-scale production of edible seaweeds such as Gracilaria or Caulerpa, for the domestic and tourist-related fresh vegetable markets

DEVELOPMENT AND OPERATIONAL COSTS FOR SELECTED SPECIES

Four organisms were selected as the most appropriate for initial aquaculture development in the CNMI. These are marine shrimp, rabbitfish, milkfish, and tilapia. The operational cost scenarios, shown in Appendix A, for the different species are based on sets of assumptions about the cost components. These components are based on the best information available or, where possible, on actual costs as they apply to the CNMI. Conservative estimates were used to project potential returns on investment.

It should be noted that the input costs and production variables used in the projections are estimates, and confidence in the estimates varies between the scenarios presented. The projected return is subject to variation from risks associated with the cultivation of live organisms. These projections are models used to gain insights into potential investments. Aquaculture systems are complex, dynamic, and interactive, and as additional biological and market data become available, more precise economic models will be possible.

Biological, physical, and economic considerations are required in undertaking an aquaculture venture and in determining which species to raise. These include site characteristics, water quality, environmental conditions, availability and cost of postlarvae or fry, availability and cost of feed, management capability and experience, and market structure. The assumptions used in the operational cost scenarios are detailed below.

BIOLOGICAL

Stocking rate

The number of seedstock per a given area or volume (usually per square meter of bottom area or cubic meter of water volume). This figure is a key variable in the different types of culture (e.g., intensive vs. extensive). The stocking rate or density also varies widely between species.

Survival rate

The percentage of surviving culture organisms harvested from the original total seedstock stocked in the culture system.

Crops per year

Many species can reach harvest size in less than one year. This figure represents the number of crops (total harvest) that can be produced in a twelve-month period. This figure may be a fraction of a year.

Feed conversion rate

The amount of feed in weight provided for the entire culture period to produce one unit of harvest weight (e.g., 3 pounds of feed to produce 1 pound of fish).

Harvest body weight

The average size in weight (kg) of a single cultured organism of the particular species at harvest.

PHYSICAL

Farm pond area

The size (hectares) of the total pond area under water for a given farm.

Labor requirement

The number of full time persons required per given pond area. This figure can be less than one. To determine the total labor force for a given size farm, the farm pond area is multiplied by the labor requirement.

FINANCIAL

Local Sale Price

The sale price ($/kg) of the product in the domestic market.

Export Sale Price

The sale price ($/kg) of the product in an export market. This can be for a regional market (e.g., Guam) or markets outside the region (e.g., Japan, or the U.S.).

Local market

The portion of the total production that is marketed in the domestic market.

Export market

The portion of the total production that is marketed as an export product.

Fry/Postlarvae cost

The cost of seedstock (e.g., fry or postlarvae) per unit number (e.g., \$.10 per fry).

Feed cost

The cost of supplemental feed used per unit weight (\$.50 kg^{-1}).

Electrical power rate

The cost per kilowatt hour unit. (Commercial rate for Rota \$.17 kwh^{-1}, Tinian and Saipan \$.16 kwh^{-1}).

Electric power demand

The total electrical power demand in kilowatt hours per hectare to operate the farm for one year. This is based on the power consumption to fill one hectare pond for each crop and a daily water exchange of 15%. Ten percent of this total is added for general farm use (e.g., house, security, lighting).

Chemical costs

The total cost of chemicals (e.g., fertilizers, lime, drugs, etc.) used per unit pond area of the farm for one year.

Miscellaneous costs

This covers the costs of items not included in the other specific cost areas.

License fee costs

This consists of the fees for licenses and permits for carrying out a commercial aquaculture operation.

MANAGEMENT COST

Base salary

This is the portion of the management salary that is incurred regardless of farm size.

Incremental salary

This is the portion of the management salary that is based on increasing management responsibilities as the size of the farm increases over 5 hectares. In larger farms (e.g., 50 ha), a portion of this may be used to hire an assistant manager.

Wage

This is the hourly wage rate for labor plus benefits. The minimum wage in the CNMI is \$2.15 hr^{-1}; however, farming and fishing businesses are exempt from the minimum wage. Wage rate for non-resident labor in agriculture ranges from \$1.50 to \$2.00.

Lease

This is the lease fee per unit of farm pond area per year.

FIXED ASSETS

Pond construction

The cost of constructing a unit area of pond (i.e., \$/ha).

Building cost

The total cost of a storage and equipment building and housing, if the size of the farm requires on-site housing. It is considered that a farm of 5 ha and above requires on-site housing for security and monitoring of the farm in case of emergencies. This is the total cost and varies according to the size of the farm. The cost is based on a minimum of \$20,000 for 5 ha and \$500 for each additional hectare.

Land cost

If the land is purchased, it is the total price of the land.

Equipment cost

The cost of all equipment items purchased (e.g., pumps, generators, vehicle, etc.). The cost is based on a minimum of \$25,000 plus \$1,000 for each hectare over 5 hectares.

Working capital rate

Working capital is calculated as 50% of the total annual costs minus depreciation expense. This is based on the assumption that it would take 6 months for the cash inflow from harvest sales to meet or exceed the cash outflow. Working capital needs vary slightly between species and management practices. For example, the cost and revenue differences depend on growth rate of the species, stocking rates and schedules, feeding practices and feed quality, pond design and size, and the degree of automation.

Total equity

This consists of the portion of the total investment into the farm that is from the owners.

Total investment

This is the sum of the capital investment by the owners (equity) plus the amount of the investment from loans.

Depreciation schedule

The depreciation expense schedules are based on the straight line method, which is the most financially conservative means to depreciate such capital expenses.

Ponds

It is assumed that the ponds are earthen and constructed according to engineering specifications. The life is 15 years for depreciation purposes.

Building

The buildings are reinforced concrete block construction. The life expectancy is 15 years.

Equipment

The life expectancy varies for the different types of equipment. This ranges from 1 to 15 years depending on the specific equipment item. A conservative average of 5 years is assumed.

Size of loan

The total principal of the loan or loans that constitute the portion of the total investment that is borrowed.

Loan terms

The number of years stipulated for repayment.

Interest rate

The interest rate charged by the lending institution, which may include various charges (e.g., insurance) incorporated into the interest rate.

Insurance premium rate

The annual premium paid for insurance, which would include the various types of insurance (e.g., liability, health, crop, vehicle, etc.).

Property tax rate

The property tax rate is calculated as a percentage of the assessed value of the property the farm occupies. This is not charged to property that is leased; it is considered incorporated as part of the lease payment.

Gross Receipts Tax

A tax levied on the gross business income. Agriculture and fisheries activities are exempt from the GRT on the first $20,000 of income and taxed at the rate of 1% thereafter.

Corporate tax rate

The prevailing corporate tax rate under the local tax code. NMITT taxes follow the U.S. Internal Revenue Service tax code; however, it provides for a 95% tax rebate. The effective tax rate is 2% after rebate.

Inflation rate on lease

This rate represents the increase in the average annual lease payments.

Inflation rate on operations

The average rate of inflation that is assumed to impact on the annual costs of operations during the period.

The production costs are composed of variable costs (supplies, electricity/fuel, labor, and miscellaneous) and fixed costs (salary personnel, land, depreciation, interest, license fee, insurance, and accounting). Labor represents a mixed cost. A fixed portion consists of labor costs that are incurred regardless of the level of operation; thus, it is assumed that the working farm owner or manager receives an annual salary. The variable portion of labor costs consists of the temporary/occasional labor that is hired on a daily basis for harvest, major pond maintenance, or stocking activity, plus full-time labor exclusive of management. Labor costs include the salary, workman's compensation insurance, and all benefits. Electricity/fuel is also a mixed cost; however, the fixed portion is relatively small, and to simplify the handling of this cost, it is treated as being completely variable. The cost of land is treated as lease payments, based on the prevailing rate for agricultural land in Saipan. Specific sites may vary and this should be taken into account. Costs of brackishwater or mariculture sites that are located near the coastline will likely be higher due to competing uses of the land.

Tax considerations are not entered into the calculations; thus, the different species can be compared without added artificial distortion of differences in operational tax rates due to variation in organizational structure. A percentage of the production from farms may be sold directly to the consumer. Because the farms would most likely market differ in proportions of their total harvest sold directly to consumers, variations in marketing practices should be considered separately by each farmer in light of his unique alternatives. Furthermore, the impact of tax expense should not be overlooked when calculations are done to determine the profitability potential of a specific farm.

The linear break-even charts (Figures 12 through 15) visually represent the production volume break-even points for the various species, based on the different scenarios for each of the selected species. However, these figures are generalized and individual farms, which have differences in physical, management and capital structure, should be evaluated individually. The results presented in Appendix B indicate that the break-even point as a percentage of the actual production is the lowest (≤ 25%) for the tilapia (Scenario 2 & 4), milkfish (Scenario 2 & 4) and shrimp (Scenario 2 & 4). The break-even points for the siganids (Scenario 2 & 4) and shrimp (Scenario 1 & 3) are below the 50% point, while those over 50% of the actual production required to reach the break-even point are tilapia (Scenario 1 & 3), milkfish (Scenario 1 & 3) and siganids (Scenario 1 & 3). Under the assumptions used, shrimp culture affords the greatest margin of production above the break-even point while the siganid culture affords the least. Thus, the investment scenarios shown for siganids would be considered higher risk since a relatively small decrease in production could prevent the farm from reaching the break-even point. A break-even point that is near or above the expected industry average production level would indicate a high risk.

Figure 12. Break even graphs for Milkfish

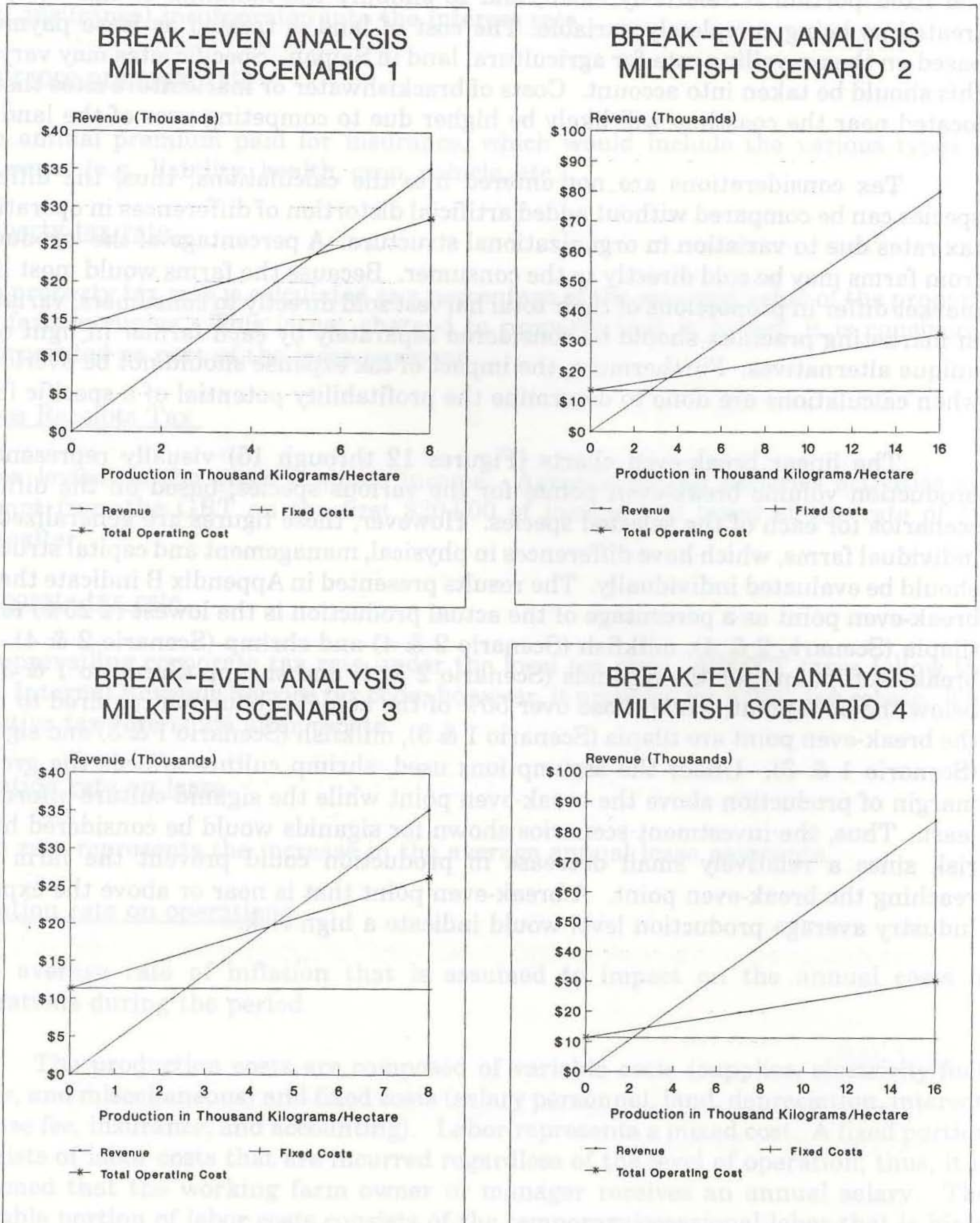


Figure 13. Break even graphs for Tilapia

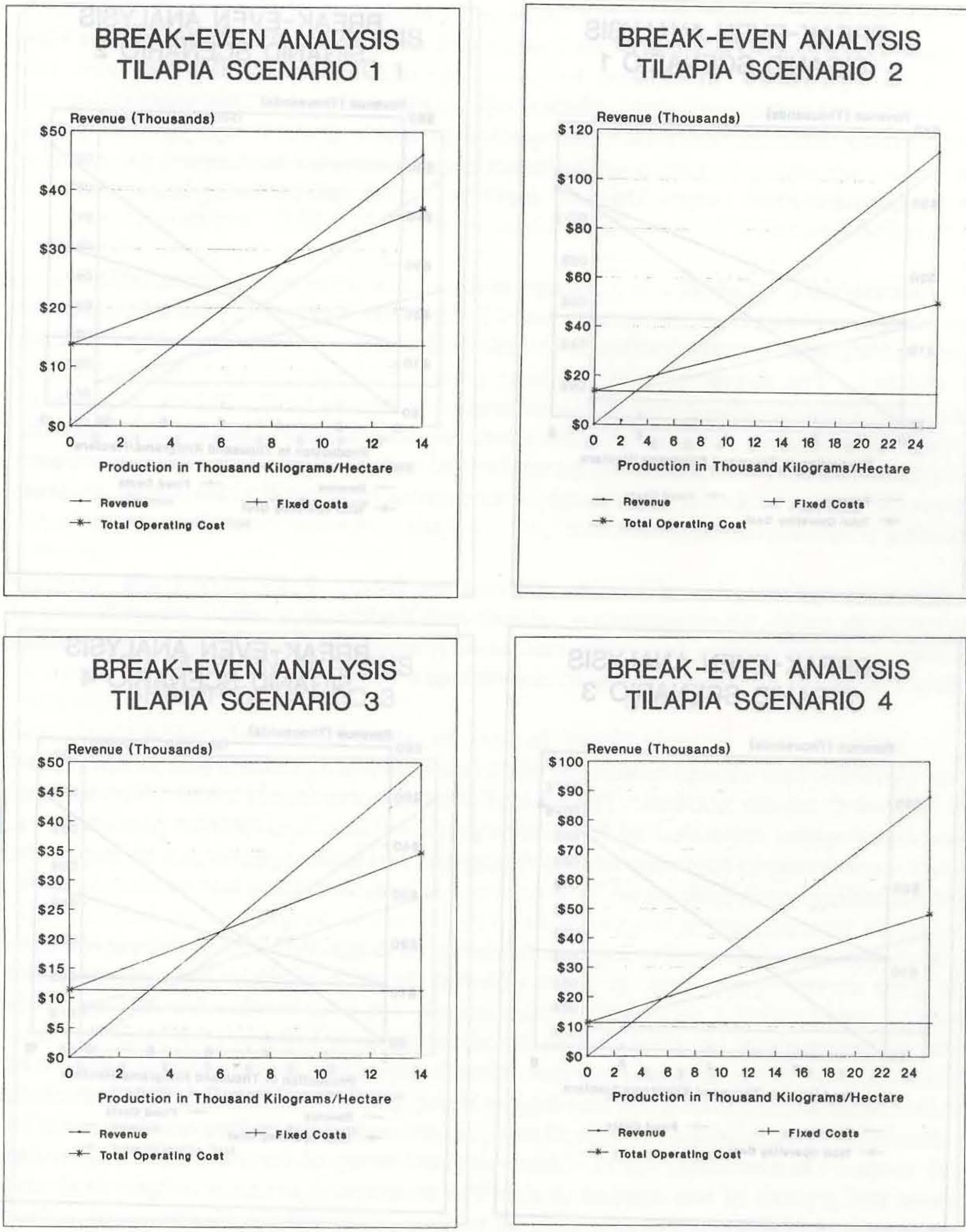


Figure 14. Break even graphs for Siganids

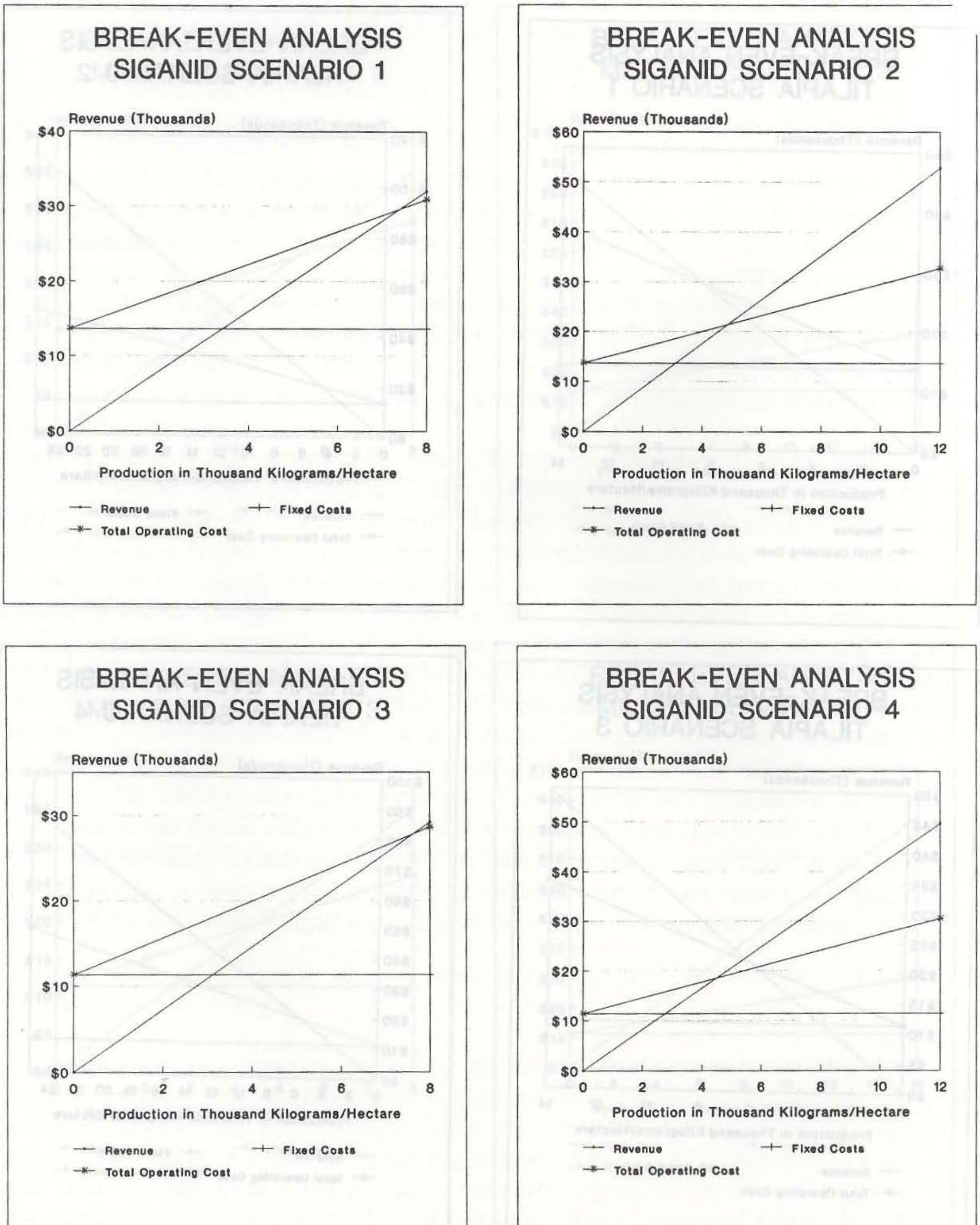
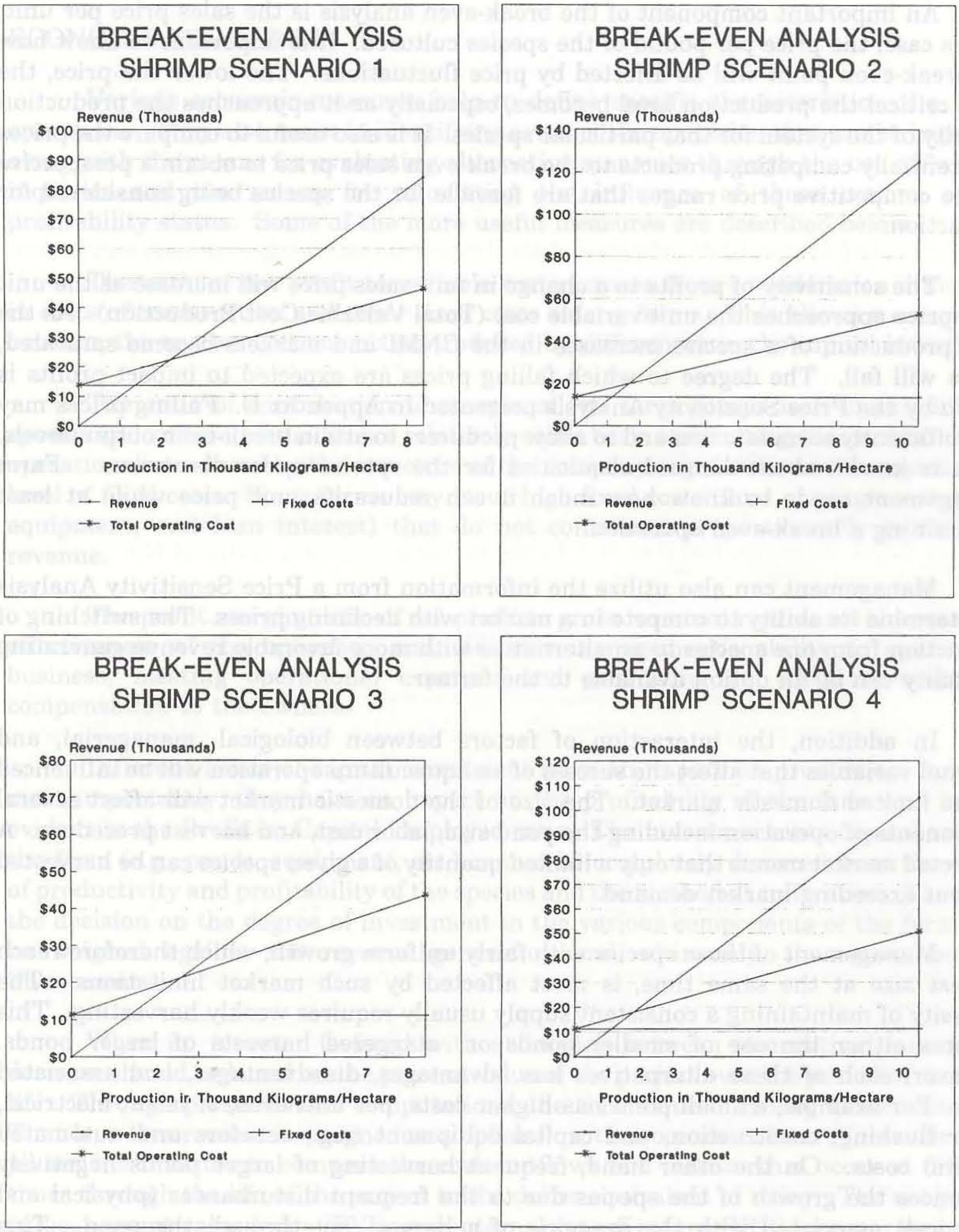


Figure 15. Break even graphs for Penaeids



The potential impact on profitability of a change in production level is further illustrated by the Production Sensitivity Analysis in Appendix C.

An important component of the break-even analysis is the sales price per unit, in this case, the price per pound of the species cultured. It is important to know how the break-even point will be affected by price fluctuations. The lower the price, the more critical the production level becomes, especially as it approaches the production capacity of the system for that particular species. It is also useful to compare the prices of potentially competing products to the break-even sales price to obtain a perspective on the competitive price ranges that are feasible for the species being considered for production.

The sensitivity of profits to a change in unit sales price will increase as the unit sales price approaches the unit variable cost (Total Variable Cost/Production). As the total production of a species increases in the CNMI and markets become saturated, prices will fall. The degree to which falling prices are expected to impact profits is shown by the Price Sensitivity Analysis presented in Appendix D. Falling prices may not sufficiently stimulate demand to allow producers to attain break-even output levels. Little is known about demand elasticities for the species under discussion. Farm management needs to know how much it can reduce its unit price while at least maintaining a break-even operation.

Management can also utilize the information from a Price Sensitivity Analysis to determine its ability to compete in a market with declining prices. The switching of production from one species to an alternative with more favorable revenue generating capability can be an option available to the farmer.

In addition, the interaction of factors between biological, managerial, and external variables that affect the success of an aquaculture operation will be influenced by the limited domestic market. The size of the domestic market will affect several components of operation including the pond size, labor cost, and harvest procedure. A restricted market means that only a limited quantity of a given species can be harvested without exceeding market demand.

Management of those species with fairly uniform growth, which therefore reach harvest size at the same time, is most affected by such market limitations. The necessity of maintaining a consistent supply usually requires weekly harvesting. This requires either the use of smaller ponds or staggered harvests of larger ponds. However, each of these alternatives has advantages, disadvantages, and associated costs. For example, a small pond has higher costs, per unit area, of labor, electrical, water flushing, construction, and capital equipment (e.g., aerators and automated feeders) costs. On the other hand, frequent harvesting of larger ponds negatively influences the growth of the species due to the frequent disturbances (physical and biological) associated with the dragging of a harvest net through the pond. This decreases feed conversion and total production, which subsequently reduces the potential financial returns.

ECONOMIC MEASURES

Various economic measures help to define specific characteristics of a farm's operations. They also assist in identifying areas of the operation that can be improved, along with the means for evaluating alternative scenarios through the use of "what if" inquiries and the means for calculating the influence of these actions on the profitability status. Some of the more useful measures are described below.

The ratio of net profit to variable cost removes from consideration differences in costs of construction and other fixed costs among farms. This allows a comparison between the species without bias introduced by differences in the capital investment.

The ratio of contribution to margin allows for a comparison of the different species and culture methods on a relatively equal basis eliminating the variation in the operations introduced by the structure of the company organization with regard to the level of fixed costs. Some farms may incur high fixed costs (land, management salary, equipment, and loan interest) that do not contribute proportionately to the total revenue.

The profit margin (ratio of net profit to gross revenue) represents the cost-price effectiveness of the operation and indicates management's ability to operate the business, meeting operational expenses and generating an adequate margin of compensation to the owners.

Different levels of capital investment have an impact on production; however, most importantly, they have an impact on the profitability of the farm and become evident in the Profit on Capital Employed ratio. The investment into capital assets of the farm (e.g., ponds, equipment, etc.) cannot be completely divorced from the degree of productivity and profitability of the species and the method of cultivation. Therefore, the decision on the degree of investment in the various components of the farm must be weighed against the revenue generation and, ultimately, the return on that investment.

When an investor is faced with a decision between alternative projects, the decision should be based on the present value of the project over the period of economic life. Through present value computations, the time value of money is accounted for. That is, a lower value is assigned to a dollar flow that occurs at future intervals. This allows the investor to compare the cash outflows and inflows that occur at different times through the life of the project to the dollar equivalent of today. The net present value, present value index (PVI), and internal rate of return (IRR) incorporate present value calculations. Each of these values has advantages and disadvantages that should be realized. These results should be cross referenced with profit criteria to assist in identifying areas where input adjustments or alternatives may improve the revenue return.

Factors that should be considered when evaluating the decision criteria are the size of the investment and possible limitations in investment capital. The PVI, IRR, and payback allow for the comparison of projects of different size or length of economic life.

In summary, in performing an overall financial analysis to better decide which species or other alternatives may impact on the entrepreneur's investment and return in the operation of an aquaculture farm, the following evaluations should be considered:

- Volume break-even. This is the volume of production that covers total costs of production.

- Sales price break-even. This determines the degree of flexibility in pricing and the impact of a price change on the production required to break-even.

- Profitability Ratios. These include Profit on Capital Employed (ROE), Ratio of Net Profit to Gross Revenue, Ratio of Net Profit to Variable Costs, Ratio of Net Profit to Total Costs, and Return on Total Investment.

- Alternative projects (methods or species). This includes evaluation of Net Present Value, Present Value Index, Internal Rate of Return, and Payback Period

A break-even analysis that takes into consideration the significant variable and fixed costs associated with each species will contribute a needed component in evaluating alternative species. It is important that this component of the decision process not be taken out of context and isolated from the whole analysis spectrum.

OPERATIONAL COST SCENARIOS

The four scenarios presented for each species are varied on key components of inputs as well as the outputs of production. These mainly consist of the size of the farm and production level. Sensitivity analysis on the four species are presented for the following major variables.

- Price Received

- Quantity of Production

The feed, labor, and postlarvae or fry costs are the major variable costs. Varying these could have a significant impact on profits. For example, the percentage of the total annual operating costs attributed to feed ranges from 25% to 53% in the four selected species. A reduction in the cost of feed, or the more efficient use of feed, could have a significant impact on the ROI. In the case of penaeid shrimp culture, postlarvae costs range from 26% to 30% of total annual operating costs. The cost of postlarvae may decrease as total demand for postlarvae in the region increases reducing production costs of the regional hatchery.

Operational Costs for Marine Shrimp

The scenarios presented for marine shrimp are for the cultivation of Penaeus monodon under semi-intensive method of cultivation. Other species of penaeids could be substituted with minor modifications. The key variables that are modified under the different scenarios are the farm size and market share at the different prices. Investment in marine shrimp culture would show an acceptable return under all four scenarios (farm sizes). However, as a larger portion of the production enters the export market greater risk to world market fluctuations would be expected. This would also require greater sophistication in marketing, particularly in regard to entry to the export market. An example of the potential value of the product at different levels of production and area under cultivation is presented in Table 29.

Table 29. Wholesale value of Penaeid shrimp culture under different production scenarios.

PRODUCTION ($kg\ ha^{-1}$)	10 ha	25 ha	50 ha	75 ha	100 ha
5,000	$ 0.52	$ 1.12	$ 2.12	$ 3.12	$ 4.12
10,000	0.92	2.12	4.12	6.12	8.12
15,000	1.32	3.12	6.12	9.12	12.12
20,000	1.72	4.12	8.12	12.12	16.12
25,000	2.12	5.12	10.12	15.12	20.12

Value determined for first 30,000 kg at \$12 kg^{-1} for domestic market with the balance of production at \$8 kg^{-1} for export market. 25-30 count per kg shrimp.

Operational Costs for Siganids

Estimated operational costs for the grow-out of siganids are based on information derived from experimental culture in Philippines, Okinawa and elsewhere. There is a higher level of uncertainty with this species than with the other three species evaluated. The inputs and outputs for the cultivation of the other three species are well documented. Work is underway in Guam, Yap, and Pohnpei to better define these variables for siganid cultivation. To allow for this level of uncertainty, the analyses are limited to two farm sizes, each under a conservative scenario and a more optimistic scenario with regard to the key assumptions (feed conversion, stocking density, survival, production and market price). The sensitivity analyses for price and production levels provides further insight into the economic impacts of these key variables.

Operational Costs for Milkfish

The scenarios presented for milkfish (Chanos chanos) are similar to those for penaeids in that the key variables are farm size and market share. The export market for milkfish may be limited in the region. Guam would be the most likely export market within the region; however, production of milkfish in Guam is nearing the market capacity. Guam has exported a limited amount to Naru in the past.

The limiting factor in milkfish culture is obtaining adequate numbers of fry on a regular basis. Milkfish tends to be an ethnically preferred species. Locations with large Filipino populations are potential markets. Hawaii and the U.S. West Coast are potential markets for export, but production from the CNMI would have to compete with products from Kiribati and the Philippines. In Japan, milkfish is not a preferred species and receives a low price. The return on investment ranges from 17 to 160% under the different scenarios. All of the scenarios offer an attractive return.

Operational Costs for Tilapia

Tilapia culture is a viable enterprise under the four scenarios. However, the return is lower than for shrimp or milkfish culture. Only two farm sizes are considered under the scenarios, since production from 10 hectares of ponds would be expected to saturate the domestic market. An export market is not considered, because current prices would make competing in an export market very difficult. The possibility of entering the specialized market for tilapia used as sashimi in Japan could be explored; however, production for this market requires very strict sanitation and culture guidelines to eliminate potential human health hazards from parasites.

RECOMMENDATIONS (PRODUCTION COSTS):

- o Phase development of farms for any of the four selected species to meet the market demand for the product.

- o Design farms for maximum efficiency, but be flexible to allow switching to production of different species as market opportunities arise.

- o Closely monitor the market for each species to determine price elasticity so that the market price does not fall below an acceptable margin.

- o Design farms to meet the intended market. The ponds should be of a size that allows the harvest to meet the market demand at an acceptable price.

SMALL-SCALE GIANT CLAM HATCHERY

Tweksbury Park on Rota has been identified as a possible site for construction of a giant-clam hatchery. The area is located near a suitable source of seawater on a relatively protected area of the coast. The purpose of the hatchery would be for the production of 1-year-old giant-clam stock for grow-grow-out on the reef. Before developing a giant clam hatchery facility at Tweksbury Park or other sites in the CNMI, the objectives of giant clam culture should be thoroughly evaluated. This would include, in addition to economic feasibility, aspects of the long-term program development. Among the first steps is to determine the purpose of giant clam culture. It may be to restore natural stocks, to support a subsistence fishery, or to develop commercial production for local or export markets.

Only on the basis of providing support for commercial cultivation could the construction of a giant clam hatchery be justified from an economic standpoint. The other purposes for clam culture would be best served by purchasing 1-year old clams from a regional facility, such as MMDC. Only commercial cultivation is considered here. A facility to meet an annual production of 90,000 year-old stock is described.

OPERATIONAL COSTS FOR GIANT CLAMS

The cost of building and equipping a small hatchery for the production of giant clams is estimated to range from $213,320 to $332,460 and is based, in part, on a hatchery design that was recommended by Mr. Gerald Heslinga for the seed production of <u>Tridacna</u> <u>derasa</u> on the island of Kosrae in the Federated States of Micronesia (Heslinga, 1988). Additional information was obtained from a recent manual on the culture of giant clams (Heslinga, 1990). The facility would be staffed by one technician who is knowledgeable about water pumps, piping, and carpentry. In addition, one biologist experienced in giant clam culture and two biological aides would be required. The biologist/manager would reside at the facility. Operating costs are estimated to be approximately $83,807 to $119,478 per year as detailed in Appendix E.

Specifics of the proposed facility and its production capacity are as follows:

<u>Tanks</u>

A total of 20 tanks will be required. These include 2 spawning tanks (4m x 1m x 1m), 8 transition tanks (10m x 2m x 0.6 m), 2 seed-culture tanks (10m x 2m x 0.6m), and eight 1-year-grow-out tanks (10m x 2m x 0.6m). Transition tanks are required for periods of transition (spat attachment through 5-month-old seed, seed through 1-year-old grow-out, and 1-year-old to market) and for down time. The need for transition tanks depends on the efficiency of operation; they can serve as additional grow-out tanks as hatchery efficiency increases.

Water flow

An optimum is 3 exchanges per day. A total tank volume 128 m^3 (1,280,000 l), requires a pumping capacity of 889 liters per minute

Survival

Survival from egg to 1-cm seed is estimated at 0.1%. Although survival is low, this is not a constraint, because the fecundity of the clams is very high. Survival from seed to one-year-old clams is estimated at 75%. Prior to grow-out the seed are culled for larger animals. Approximately 50% goes on for grow-out to 1-year old clams.

Production

A 10-tank system (with additional transition tanks) can produce 30,000 one-year-old clams per year with 20% of tank space devoted to production of 1-cm seed (5 months old). Two 20-m^2 tanks with 200 0.02-m^2 trays can produce 120,000/year of 1 cm seed (3,000 seed m^{-2} yr^{-1}) with 50% used for grow-out of one-year-old clams. Production consists of 2 batches per year with 5 months required to reach 1 cm. Two months of down time each year are expected for tank cleaning and preparation for the next cycle. Approximately 80% of tank space will be devoted to production of 5-6 cm 1-year old clams:

Eight tanks (20 m^2/tank with a total tank area 160 m^2) with 200 0.2-m^2 trays per tank at 375 clams m^{-2} (75 clams $tray^{-1}$) for a total of 7,500 clams $tank^{-1}$ are assumed in production. Two crops per year (15,000 clams $tank^{-1}$ $year^{-1}$) are assumed. Calculated production (= Stocking x Survival) of 15,000 clams $tank^{-1}$ x 8 tanks) x 0.75 gives an estimated 90,000 one-year-old clams $year^{-1}$.

As a comparative base for the cost of production of the various giant clam products, Table 30 presents the sale prices of giant clam products from the Micronesian Mariculture Demonstration Center.

FACILITY DESCRIPTION

A major consideration in hatchery design is the seawater system. There are many different types of pumps and designs for delivering seawater to aquaculture facilities. The choice of system and pump depends on several factors, including the amount of water to be supplied to the facility, the total head (i.e., distance and elevation pumped), the water quality requirements of the organisms being raised, the amount of exposure to wave damage of the pump site, and the water source. A centrifugal pump would be appropriate for the site. Because seawater is highly corrosive, pumps designed for seawater should be used. Centrifugal pumps which are lined with fiberglass are available. The location of the intake pipe should be carefully planned.

Table 30. Giant clam (Tridacna derasa) product price listing from MMDC for June 1990.

PRODUCT	MINIMUM DIAMETER (cm)	UNIT PRICE
5-month-old (seedstock)	0.5	0.5
1-year-old	5.0	5.0
2-year-old	9.0	9.0
3-year-old	12.0	12.0
5-year-old (broodstock)	27.0	27.0

The Tweksbury site is located on limestone which would allow the percolation of seawater into the ground water. The site is approximately 4 m above sea level, which allows the use of a shallow well. A well with an excavated base for a centrifugal pump is recommended. The use of a land-based well would minimize potential storm damage and provide seawater that has been filtered naturally, through the limestone substrate.

The impact of the discharge from an aquaculture facility on the receiving water must also be considered. A survey of marine organisms in the area would be useful in the prediction and prevention of environmental problems. However, the discharge from a small hatchery for the production of giant clams would not likely pose a threat to existing marine life. Since the clams harbor zooxanthellae, which can support their host through their photosynthetic activity, the clams do not need to be fed. Also, although the clams excrete ammonia, as do most other marine animals, the zooxanthellae take up ammonia. In spite of this, chemicals used in the treatment or prevention of diseases may be used, so an assessment of anticipated environmental impact would be prudent.

PRODUCTION

Estimated production from the proposed facility is based on a strategy to produce one-year-old clams. Clams of this age are in the size range appropriate both for stocking into ocean grow-out and for sale to the potential sashimi/sushi and aquarium trade markets. Production of one-year-old clams allows flexibility in channelling the product to the different market segments. Longer culture periods increase exposure to loss and thereby increase risk. The strategy in commercial production is to optimize production capacity while minimizing risk. Targeting production for one to 1.5-year-old clams would, therefore, be the best strategy.

MARKET

Giant clam products can be classified into five categories: 1) aquarium-trade products, 2) sashimi/sushi products, 3) clam mantle meat, 4) adductor muscle, and 5) shell. The first two categories would be the primary markets targeted by the proposed hatchery. The latter three, entail prolonged ocean grow-out, and this requires substantial, protected, reef or lagoonal areas. Also, these must be areas which can be controlled by the commercial producer (i.e. ownership of the area or strict control through lease).

There is currently a market for the aquarium trade in the United States, with wholesale prices ranging from $3.00 to $5.00 per clam (Tisdell, 1990); this is for clams that are 5-8 cm in diameter (12-18 months old). Ornamental clams such as <u>Hippopus hippopus</u> are preferred. This market is in the early stages of development and still rather limited. Maintaining the clams in seawater aquariums requires specialized lighting. The limited nature of the market in Australia is emphasized by Tisdell and Wittenberg (1990). The estimated annual market in Australia is 5,000 clams at a wholesale price of A$3.00 - A$10.00 (US$2.36 - $7.88) per clam (Tisdell, 1990). To target this market, promotional efforts would have to be made through the various trade and hobbyist magazines as well as through the major wholesalers.

The product envisioned for the sashimi/sushi market consists of giant clams served on the half shell. This requires a clam of 5 to 8 cm diameter (1 to 1.5 years old). This market, if successfully developed, has the greatest potential. There currently exists a market in Okinawa for this product. Prices range from 1200 to 2000 yen per kilogram ($7.80 to $13.00/kg) for the live clam in the shell (CTSA Newsletter, 1990).

The Center for Tropical and Subtropical Aquaculture (CTSA) has a project underway that will be evaluating the giant clam markets in Hawaii, Guam, Japan, Australia, and the U.S. mainland for the aquarium trade and the sashimi/sushi markets. In addition, a production economics project is expected to be funded by CTSA in 1991.

The market for clam meat (exclusive of adductor muscle) is considered limited and specialized. It is estimated that up to 22 tons ha^{-1} of edible meat could be produced with the harvest of 5 year old clams (Heslinga and Watson, 1985). Tisdell (1990) noted that there was no outlet for the clam meat in Taiwan; there is considerable uncertainty, in general, about the existing and potential demand for giant clam meat, and conflicting views have been expressed. Limited pocket markets have been identified in some Pacific areas. Tisdell and Wittenberg (1990) identified a limited market among Tongan descendants in Australia. A retail price of A$5-12/$kg^{-1}$ (US$3.94-9.45 kg^{-1}) was stated as the range the market would support. Heslinga (1990) cites a market for meat (whole) in Okinawa of 20 kg day^{-1} with a high of 9,700 yen kg^{-1} (US$64.67 kg^{-1}) for small T. crocea to 2,000 yen kg^{-1} ($US13.33 kg^{-1}) for large T. squamosa.

Important factors in determining price are species, freshness, and size. Smaller sizes receive a higher price. Heslinga (1990) estimated that there is a market demand in Okinawa for 300,000 2-year-old clams. There is a wide range in price between geographical location as well as between the farm-gate price and the retail price. In addition, species preferences differ between geographic locations. Therefore, this product market segment needs further definition to assess its potential and to determine strategies for development.

The adductor muscle is currently the only giant clam product that has an established world market. An older clam (5-7 years) is required to obtain adductor muscles of a size suited to this market. Frozen adductor muscle in Taiwan reaches $25 kg^{-1} (Heslinga, 1989). It is a popular product in Asian counties. A farm-gate price of $10 kg^{-1} is assumed by Munro (1985) in his economic assessment of giant clam culture. Clam shells are in demand for various purposes as novelty items, entree serving dishes, soap dishes, ash trays, etc. A market in the Philippines has been identified (Munro, 1985) as a substantial market. The price ranges along a declining scale from $.75 kg^{-1} for the smallest shells to $.10 kg^{-1} for shells more than 50 cm in length. This was considered the high end of this market. Species differentiation occurs for different uses of the clam shells. A survey conducted by Tisdell (1990) in Australia indicated a wholesale price of A$1.55 (US$1.22) and a farm-gate price of A$.78 (US$.61) for a 15-20 cm shell. Similar markets are expected to exist in the United States, Japan, and Europe. There is a large variability and uncertainty in the markets for the different product categories. A recent study by Curren et al. (1990) indicated a general over expectation in the farm-gate price obtainable for the giant clam products. This applied mainly to the islands, including Rota, that have been exposed to outside tourists.

PRODUCTION COST

The production capacity of the facility is based on levels currently obtainable on a routine basis at MMDC. The Tweksbury facility would have to go through a start-up phase that would be expected to take from 2 to 5 years before reaching a production level comparable to an established facility with skilled staff. Therefore, the total operational costs during this phase should be allowed for support of the facility until revenue generation starts to off-set the operational costs.

The production cost for the proposed facility is broken down for the two main product stages, seed (spawning through the first 5 months of culture) and one-year-old clams. The total annual operating cost of $83,807 - $119,478 would be allocated to these two product stages as follows: 50% for seed production (spawning through 1-cm clam) and 50% for one-year-old clam production. The major operating cost is labor. Seed production involves the greatest amount of labor; however, it occupies the least tank space (two 12-m ton tanks and two 4-m ton tanks). One-year grow-out requires the greatest amount of labor, but this consists mainly of lower cost, semi- and un-skilled labor. Based on this allocation of costs, the unit cost for seed is $.35 to $.50. The unit cost for the one-year-old clam for the 5 to 12 month culture period is $.47 to $.66. Therefore, the total unit cost for the one-year-old clam is $.81 to $1.16. The unit cost for both of the product stages are above the MMDC sale price for the respective price. As indicated in Table 30, the price for seed from MMDC is $.10 compared to the $.35 - $.50 unit cost at Tweksbury. The price for a one-year-old clam from MMDC is $1.00 compared to the $.81 to $1.16 at Tweksbury.

Economies of scale of the hatchery operation affect the unit cost of production. Tisdell et al. (1990) reported an estimated unit production cost of 1-year-old Tridacna gigas in Australia of A$1.43 - 2.01 (US$1.12 - 1.58) at a production level of 100,000 1-year-old clams and A$.41 - .54 (US$.32 - .42) at a production level of 500,000 1-year-old clams per year.

RECOMMENDATIONS (GIANT CLAM HATCHERY):

- o Determine the objectives of giant clam culture.
- o Determine if seed stock or grow-out stock could be better provided by existing facilities in the region.
- o Explore markets for 1-year old clams in greater detail.

AQUACULTURE SYSTEMS

POND CULTURE

Pond culture is probably the most common form of aquaculture. Pond culture systems are usually categorized as extensive, semi-intensive, and intensive based on the stocking rate, the inputs (i.e., energy, capital, feed, etc.), and the production per unit area. There are no sharp boundaries between these types of systems, and with technological improvements and intensification of culture, systems once considered as intensive come to be viewed as semi-intensive. However, examples of extensive systems are the traditional culture systems in southeast Asia. Extensive systems have relatively low rates of stocking and production depends to a large extent on the natural productivity of the pond, which may be enhanced by fertilization. Significant commercial production from such systems require relatively large areas for ponds. Since land for ponds is limited in the CNMI, extensive aquaculture systems would not be practical. Given the limited size of the domestic markets, semi-intensive systems or small-scale intensive systems are likely to be most practical for the production of species to be marketed locally. Large-scale intensive systems may be practical for production destined for world export markets, such as for the production of marine shrimp. In pond culture, as the stocking rates and production per unit area increase, so do the requirements for the control and monitoring of pond conditions; in general, risk also increases with intensification.

Following success in Asia, enthusiasm is growing for the use of small, round, earthen ponds for the production of marine shrimp, and such systems are being tested at the Oceanic Institute in Hawaii (Wyban et al., 1988) and similar intensification in shrimp culture is being examined in the southern U.S. (Sandifer et al., 1987, 1988). It may be possible to employ similar intensive technologies in the CNMI.

CAGE CULTURE

The designs of cages for culturing fish vary widely depending on the species cultured, the body of water in which the cages are to be deployed, and production economics. Intensive cage culture is the usual means of producing high-value species such as trout, salmon, yellowtail, and grouper; however, the cage culture of lower-value species such as tilapia and carp have proven commercially viable in some areas. With the possible exception of Lake Susupe on Saipan, there are no large bodies of freshwater or brackish water in the CNMI where cage culture could be practiced. Culture of marine fish in cages in the CNMI is conceivable, but there are a number of problems with this method of culture that would need to be considered (Beveridge, 1987). These include:

- o Risks involved with cage culture are high, particularly in the Mariana Islands, resulting from the possibility of losses during rough seas accompanying the frequent typhoons and tropical storms;

- o Cages may interfere with other marine activities, alter current patterns, and affect the behavior of wild fish stocks;

- o Cages are vulnerable to poaching and vandalism; and

- o Pollution form the feces and uneaten feed resulting from cage culture operations may negatively impact coral communities.

TANK OR RACEWAY CULTURE

Intensive tank and raceway culture has proven commercially viable for fish culture in many areas. Examples include the production of trout in the United States and Europe, tilapia in the United States, and marine algae in Hawaii. From a technical standpoint such systems are attractive for development in the CNMI. Land-based tank and raceway culture systems require less land than pond culture systems, are not as vulnerable to storm damage, are easily harvested, and afford a greater amount of environmental control to the culturist. However, such systems usually require a higher degree of capital investment, and increased sophistication in the monitoring and management of water quality.

Marine plants have been cultured commercially in tank and raceway systems. A successful commercial venture in Hawaii produces economic seaweeds (Gracilaria sp.) for the fresh vegetable market. Examples of larger scale operations in this category are found in commercial ventures producing microalgae (Chlorella and Spirulina) marketed as a diet supplement in the health food industry.

Theoretically, with careful design, closed-system, environmentally controlled culture systems can be used for commercial aquaculture production. Components of such systems include:

- o tanks or raceways

- o biofilters

- o clarifiers

- o aeration or oxygenation devices

- o pumps

- o foam fractionators or protein skimmers
- o automatic feeders
- o water treatment facilities

Closed-system aquaculture has been of interest to investors because culture operations could then be set up at locations which would otherwise be unsuitable. For example, marine shrimp could be raised in closed systems at inland locations near large markets, with the culture system housed in warehouses near urban centers. With little information available on commercial recirculating systems, it is difficult to assess the economic feasibility of the concept.

OCEAN GROW-OUT

Marine organisms can be cultured in un-enclosed coastal areas. Ocean ranching is a popular term referring to the use of such methods for production of marine animals; it involves the release of juveniles in the marine environment, and the subsequent management of the stocks. Most of the current methods for growing out giant clams involve this concept. This concept can also be applied to marine plants, usually under the term marine agronomy. An example is the culture of economic seaweeds (such as Eucheuma) as practiced in the Philippines, Indonesia, Kiribati, Fiji, and other areas of the Pacific. For ocean ranching to be feasible, commercial producers must be able to purchase or lease suitable nearshore areas. A constraint to this method of culture in the CNMI is that stocks placed in the marine environment must be protected against predators, poachers, tropical storms, and vandalism.

OCEAN THERMAL ENERGY CONVERSION AND AQUACULTURE

Ocean Thermal Energy Conversion (OTEC) technology has expanded to secondary uses including aquaculture. Potential economic benefits from aquaculture and other products that utilize the effluent (both warm and cold water) from OTEC has stimulated interest in both private and public sectors. Aquaculture research in this area has included the culture of abalone, lobsters, sea urchins, microalgae, seaweed, Opihi, salmon, and trout.

The Ocean Thermal Energy Conversion Research Development and Demonstration Act (US Public Law 96-310) enacted July 1980 encourages the development of ocean thermal energy through research and demonstration projects. Such projects could be funded under this act through the U.S. Department of Energy. The purpose of the act is to accelerate ocean thermal energy production, and it sets energy production goals up to the end of the 20th century. The main form of energy produced is electricity; however, it may also take the form of an "energy product equivalent", which is defined as "an energy carrier including, but not limited to ammonia, hydrogen, or molten salts or an energy-intensive commodity, including ... nutrients for aquaculture." The production and utilization of these products, and others, should be considered as an integral part in the design of any OTEC power plant. In addition, the products of aquaculture can contribute to the "energy product equivalent" of an OTEC operation, enhancing its economic viability.

Ocean Thermal Energy Conversion (OTEC) as a means of generating electricity from a renewable energy source has potential in the CNMI due to the large temperature differences between surface waters (27 to 30° C) and deep waters (4.4 to 7° C). Specifically, this temperature difference (approximately 22° C) is utilized to control the physical state of ammonia, or a similar intermediate liquid, between a liquid and a gaseous form. The energy stored in the form of heat from the sun in the warm surface waters is used to evaporate the ammonia. The energy liberated in changing from the liquid state to the gas is utilized by a turbine to generate electricity, while the cold deep water transfers the gaseous ammonia back to the liquid form producing a net energy gain. In this process very large quantities of cold, nutrient- enriched, deep water is pumped through the system and discharged. This large cold water supply (approximately 500,000 gallons per minute for a 50 megawatt OTEC plant) has the potential for use in a number of secondary applications, of which one is aquaculture.

The U.S. Congress has found it to be in the national interest to accelerate the development of OTEC and has included aquaculture operations as a potential coexistent form of energy production, along with electricity. Because of the temperature of the deep water brought to the surface in an OTEC operation, cold-water species would be most suitable for culture. The culture of warm water species as suggested by Buck and Roney (1980) would be compromised as a result of the low temperature of the effluent (approximately 10° C).

The Natural Energy Laboratory of Hawaii (NELH) is a state- sponsored research facility that examines the application of OTEC technology. Its mission is to provide sites for research, development, demonstration, and commercialization of natural energy resources and other compatible scientific and technological investigations (Fast and Tanoue, 1988). This has included work on aquaculture. NELH serves as a research facility and as an incubation facility for the commercialization of the application of OTEC technology. The adjacent Hawaii Ocean Science and Technology Park (HOST) provides for the commercial development of OTEC applications, which has mainly consisted of aquaculture activities. The main advantages of the deep water are that it allows better control of temperature, provides a supply of nutrients, and eliminates pathogens. In some cases support for this concept has been so enthusiastic that aquaculture has become a major impetus for the development of this technology, not just a secondary activity of OTEC electrical power generation.

Economic analyses of OTEC-relate aquaculture have been limited. However, an examination of the economics of salmon culture utilizing OTEC in Hawaii concluded that it was not economically feasible (Loudat et al., 1989). Changes in the production factors and operational costs over time could improve the economics of salmon culture and other aquaculture activities related to OTEC operation. If an OTEC plant were established in the CNMI, this would provide a unique opportunity to develop the related aquaculture technologies. However, at this stage it would be best to monitor development of OTEC technology in other areas before pursuing this highly capital intensive technology.

RECOMMENDATIONS (SYSTEMS):

- o Explore semi-intensive to intensive culture systems.

- o Defer pursuit of OTEC for aquaculture, but monitor its development in other locations. If the commercial viability is demonstrated then solicitation of private investors, possibly through a joint venture, could be pursued.

IMPLEMENTATION STRATEGY

Development of an aquaculture industry is accomplished by strategies that set forth objectives to be accomplished in progression. Since there is no existing aquaculture industry, a joint partnership between the government and private sector should facilitate the initial development of the industry. This will help reduce the risk that the private sector would have to undertake to initiate aquaculture in the CNMI. Furthermore, it would minimize the costs to the government with its inherent inefficiencies. The production side of the industry should be exclusively dependent on the private sector for development. Support services, such as research, training, and extension can best be served by the public sector.

STRATEGIES FOR DEVELOPING COMMERCIAL AQUACULTURE IN THE CNMI

The strategies are presented in a logical sequence. Some strategies will overlap and continue into subsequent strategies.

Strategy I. Establish a Unified Policy Regarding the Type and Level of Aquaculture Development to be Pursued.

A unified policy regarding aquaculture should be established. First, a determination of whether aquaculture is to be a high, medium, or low priority, or not promoted at all, must be made. Interrelated activities (e.g., permit issuance, land availability/acquisition, accommodation of labor requirements, etc.) should be coordinated among all the appropriate government agencies. The policy should originate from the Governor's office and be followed by the respective agencies. Providing mixed messages to investors regarding the government's policy towards aquaculture is detrimental to development.

Strategy II. Establish a Lead Government Agency to Coordinate and Facilitate the Provision of Government Services.

To pursue aquaculture development, a lead agency should be established. All government activities related to aquaculture that are not directly under, or transferred to, that agency should coordinated through the lead agency. It is important to have a coordinated approach to aquaculture development for efficient use of available resources (personnel and funds).

Strategy III. Initiate An Aquaculture Demonstration Farm.

An aquaculture demonstration farm should be initiated. This will create awareness of aquaculture, facilitate the transfer of technology through hands-on training, and serve to promote aquaculture to local and foreign entrepreneurs. The demonstration farm could be part of the College of CNMI's Model Farm.

Strategy IV. Promote the Potential of Aquaculture.

Promotion of aquaculture as a potential investment to entrepreneurs, both resident and foreign, should be pursued. However, it is critical that, prior to promotion, all of the support activities (e.g., extension, market data, and start-up information) are available. The promotional program should consist of information brochures delineating the opportunities and the steps to start an aquaculture operation. During investment promotion tours by government officials, aquaculture should be identified as an area for foreign investment in the CNMI.

Strategy V. Provide the Extension and Technical Resource Base.

Extension services will be a key factor in the successful development of aquaculture. An extension program should be associated with the lead agency in aquaculture. The extension program would serve as a source of technical information and to coordination of specialized technical services, as well as to facilitate the permitting and regulatory process an entrepreneur would have to complete in the start-up phase.

Strategy VI. Facilitate Transfer of Technology.

Technology transfer will be a responsibility of the extension program. As new technology develops, an active effort should be made by extension agents to keep abreast of new developments. The dissemination of the technology to the industry should be through workshops as well as on an individual basis.

Strategy VII. Target Production for Import Substitution.

The most readily accessible, established market is the domestic market for fishery products. Production in the CNMI, especially in the initial stage, should be targeted at substitution of imported fishery products that can be economically produced in the CNMI to compete with the imported product in price and quality. Targeting initial production for the domestic market should be the major emphasis in the initial stages of aquaculture industry. This would even apply to operations that would ultimately be designed for the export market, since a portion of the production could replace imports in the local market, as well as receive a higher price than the general world market price. Therefore, selection of species, production scale, and methodology should be appropriate for the domestic market. Diversity of production will be an important factor. It should be noted that only certain species, and possibly only certain product forms (e.g., fresh), will be substituted by local production. The product must be competitive without the addition of tariffs on imports, or distortions will be introduced into the market and the consumer would ultimately pay a higher price.

Strategy VIII. Target Production for Export.

Targeting production for export markets is the logical graduation in market development. This would be limited to a few species that could compete in export markets. These markets may be within the region (Guam) or specific foreign markets (Japan's live or fresh high quality market). The transition from domestic to export targeted production could be accomplished gradually as the markets and channels are identified and developed. Development of marketing skills and production capability and stability are essential to progressing to external markets. The process of selection of species and production methodology (e.g., stocking intensity, harvest size, post-harvest handling) should include consideration of requirements of the export market.

Strategy IX. Develop Marketing Channels for Aquaculture Products.

Both domestic and export marketing channels should be developed. In the case of the domestic market, this could involve product development (e.g., new species, or product form) or improvement of marketing channels from the farm to the consumer. Development of marketing channels for export will require a sophisticated marketing effort. Depending on the market, a substantial effort may be required. Joint partnerships with an individual or corporation that has access to that market would facilitate development of these channels. The government could also play an important role in researching and identifying all the procedures required to enter a market and possibly assist in the initial entry into that market.

Strategy X. Minimize the Potential Impact of Pathogens.

A program should be implemented to monitor the health of imported fish for culture, along with a continual monitoring of existing stock. Introduction of infectious virulent pathogens with imported fish stock can have a significant negative effect on a developing aquaculture industry. The cooperation of prospective importers could be enhanced through education in this area.

An outline of such a monitoring program would include the following:

o Determine which fish pathogens are present in the natural waters and ponds of CNMI (baseline data);

o Know the area or origin of each species imported and the diseases prevalent in these areas for each of the species;

- o Define pathogens that are to be excluded. This must be done in order to limit the inspection process to pathogens with a high probability of having a negative impact on cultured species;

- o Set up an inspection program establishing standard diagnostic techniques or procedures for importations of aquatic animals. This would consist at a minimum of a spot check for the listed pathogens. The establishment of diagnostic and isolated quarantine facilities would be the optimum situation; however, until the industry reaches a substantial size to support such a facility a satisfactory alternative would be required.

- o Provide sole authority to the responsible agency for inspection and for the issuance of health certificates or clearances; and

- o Limit importations in the future, if possible, to those from a regional facility (e.g., Hawaii, Guam, Palau) that has an established screening and health monitoring procedure during the rearing of juveniles. This would greatly reduce the hazard of introducing pathogens.

The above monitoring program represents an ideal situation; however, its full implementation would depend on the development level obtained by the industry. Alternative procedures at least in the initial stages of development would have to be implemented for some of the steps identified above. For example, in place of a diagnostic and quarantine facility, health certificates should be obtained from the source of the seed stock. However, caution should be exercised in obtaining stock from Asian sources, because regulations and procedures for the issuance of health certificates often do not exist, and in some cases the certificates are questionable.

PERSONS INTERVIEWED

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ABBREVIATIONS

AES - Agriculture Experiment Station
AFRC - Anuenue Fisheries Research Center
BRAIS - Brackishwater Aquaculture Information Service
CES - Cooperative Extension Service
CNMI - Commonwealth of the Northern Mariana Islands
CTSA - Center for Tropical and Subtropical Aquaculture
EDLF - Economic Development Loan Fund
FSM - Federated States of Micronesia
GADTC - Guam Aquaculture Development and Training Center
HIMB - Hawaii Institute of Marine Biology
IFREMER - Institut Francais pour l'Exploitation de la Mer
MMDC - Micronesian Mariculture Demonstration Center
NELH - Natural Energy Laboratory of Hawaii
NMFS - National Marine Fisheries Service
NPDES - National Pollution Discharge Elimination System
OFCF - Overseas Fisheries Cooperative Foundation
PAA - Pacific Aquaculture Association
PRAIS - Pacific Regional Aquaculture Information Service
SEAFDEC - South East Asian Fisheries Development Center
SPF - Specific Pathogen Free
UOG - University of Guam
UOGML - University of Guam Marine Laboratory
US - United States
USDA - United States Department of Agriculture
US&FCS - United States and Foreign Commercial Service
WERI - Water and Energy Research Institute, University of Guam

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Appendix A. Production Scenarios

A.1 Chanos chanos (milkfish)

SPECIES: CHANOS CHANOS — AQUACULTURE PRODUCTION SCENARIOS

ASSUMPTIONS		1	2	3	4
BIOLOGICAL					
Stocking Rate (Fry/sq m)	SR	1	2	1	2
Survival Rate	SUR	80.00%	80.00%	80.00%	80.00%
Crops Per Year	CPY	2	2	2	2
Feed Conversion Rate	FCR	2	1.3	2	1.3
Harvest Body Weight (kg)	HBW	0.5	0.5	0.5	0.5
PHYSICAL					
Farm Pond Area (ha)	FPA	5	5	10	10
Labor Requirement (people/ha)	LR	0.5	0.5	0.5	0.5
FINANCIAL					
Sale Price of Product ($/kg)					
Local Market	SPLM	$4.40	$5.00	$4.40	$5.00
Export Market	SPEM	$4.40	$5.50	$4.40	$5.50
Market Share (%)					
Local Market	MSLM	100.00%	100.00%	50.00%	50.00%
Export Market	MSEM	0.00%	0.00%	50.00%	50.00%
Fry Cost ($/Fry)	PLC	$0.08	$0.08	$0.08	$0.08
Feed Cost ($/kg)	FC	$0.50	$0.50	$0.50	$0.50
Electrical Power Rate ($/kw hr)	EPR	$0.17	$0.17	$0.17	$0.17
Electric Power Demand (kw hr/ha/year)	EPD	12,000	12,000	12,000	12,000
Chemical Costs ($/ha/year)	CC	$250.00	$250.00	$250.00	$250.00
Miscellaneous Costs ($/ha/year)	MC	$400.00	$400.00	$400.00	$400.00
License Fee Costs	LFC	$750.00	$750.00	$750.00	$750.00
Management Cost					
Base Salary (upto 5ha)	MCBS	$25,000.00	$25,000.00	$25,000.00	$25,000.00
Incremental Salary (>5ha: $/ha)	MCIS	$1,000.00	$1,000.00	$1,000.00	$1,000.00
Wage ($/hr)	W	$2.50	$2.50	$2.50	$2.50
Lease ($/ha/year)	L	$1,200.00	$1,200.00	$1,200.00	$1,200.00
Fixed Assests					
Pond Construction Cost ($/ha)	PCC	$15,000.00	$15,000.00	$15,000.00	$15,000.00
Building Cost (Initial)	BC	$20,000	$20,000	$22,500	$22,500
Land Cost ($/ha)	LC	$0	$0	$0	$0
Equipment Cost	EC	$25,000	$25,000	$35,000	$35,000
Working Capital Rate (% TVC)	WCR	40.00%	40.00%	40.00%	40.00%
Total Equity	TE	$74,138.95	$82,138.95	$108,577.90	$124,577.90
Total Investment	TI	$174,138.95	$182,138.95	$308,577.90	$324,577.90
Depreciation Schedule (years)					
Ponds	DSP	15	15	15	15
Building	DSB	15	15	15	15
Equipment	DSE	5	5	5	5
Size of Loan	SL	$100,000	$100,000	$200,000	$200,000
Loan Term (years)	LT	15	15	15	15
Interest Rate	IR	10.00%	10.00%	10.00%	10.00%
Insurance Premium Rate (%)	IPR	10.00%	10.00%	10.00%	10.00%
Property Tax Rate (%)	PTR	0.00%	0.00%	0.00%	0.00%
Gross Receipts Tax Rate (%)	GRT	1.00%	1.00%	1.00%	1.00%
Corporate Tax Rate	CTR	2.00%	2.00%	2.00%	2.00%
Inflation Rate on Lease (Annual)	IRL	5.00%	5.00%	5.00%	5.00%
Inflation Rate on Operations	IRO	5.00%	5.00%	5.00%	5.00%

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PRODUCTION					
Unit Production (kg/ha/crop)	UP	4,000	8,000	4,000	8,000
Total Production (kg/farm/year)	TP	40,000	80,000	80,000	160,000
REVENUE (R)		$176,000.00	$400,000.00	$352,000.00	$840,000.00

OPERATING EXPENSES (ANNUAL)	1	2	3	4
VARIABLE COSTS				
Labor				
Full Time Staff	13,000.00	13,000.00	26,000.00	26,000.00
Occassional Labor				
Feed	40,000.00	52,000.00	80,000.00	104,000.00
Postlarvae	8,000.00	16,000.00	16,000.00	32,000.00
Electricity	10,200.00	10,200.00	20,400.00	20,400.00
Chemicals	1,250.00	1,250.00	2,500.00	2,500.00
Miscellaneous	2,000.00	2,000.00	4,000.00	4,000.00
TOTAL VARIABLE COSTS (TVC)	74,450.00	94,450.00	148,900.00	188,900.00
FIXED COSTS				
Salary Personnel				
Full Time Manager	25,000.00	25,000.00	35,000.00	35,000.00
Land Rent	6,000.00	6,000.00	12,000.00	12,000.00
Interest on Loan	6,480.71	6,480.71	12,961.42	12,961.42
Loan Principal	6,666.67	6,666.67	13,333.33	13,333.33
Depreciation				
Ponds	5,000.00	5,000.00	10,000.00	10,000.00
Building	1,333.33	1,333.33	1,500.00	1,500.00
Equipment	5,000.00	5,000.00	7,000.00	7,000.00
License Fee	750.00	750.00	750.00	750.00
Insurance	12,000.00	12,000.00	20,750.00	20,750.00
Property Tax	0.00	0.00	0.00	0.00
TOTAL FIXED COSTS (TFC)	68,230.71	68,230.71	113,294.76	113,294.76
TOTAL OPERATING COST (TOC)	$142,680.71	$162,680.71	$262,194.76	$302,194.76
GROSS RECIPTS TAX (GRT)	$1,560.00	$3,800.00	$3,320.00	$8,200.00
OPERATING PROFIT (OP)	$31,759.29	$233,519.29	$86,485.24	$529,605.24
CORPORATE TAX (CT)	$635.19	$4,670.39	$1,729.70	$10,592.10
NET PROFIT (NP)	$31,124.10	$228,848.90	$84,755.54	$519,013.14
RETURN ON EQUITY (ROE)	41.98%	278.61%	78.06%	416.62%
RETURN ON INVESTMENT (ROI)	17.87%	125.65%	27.47%	159.90%

Unit Variable Cost ($/kg)	$1.861	$1.181	$1.861	$1.181
Total fixed Cost/ha	$13,646.14	$13,646.14	$11,329.48	$11,329.48
Total Variable Costs/ha	$14,890.00	$18,890.00	$14,890.00	$18,890.00
Total Costs/ha	$28,536.14	$32,536.14	$26,219.48	$30,219.48

A.2. Oreochromis mossambicus (tilapia)

SPECIES: Oreochromis mossambicus (Tilapia) AQUACULTURE PRODUCTION SCENARIOS

ASSUMPTIONS		1	2	3	4
BIOLOGICAL					
Stocking Rate (Fry/sq m)	SR	4	6	4	6
Survival Rate	SUR	70.00%	85.00%	70.00%	85.00%
Crops Per Year	CPY	2	2	2	2
Feed Conversion Rate	FCR	2	2	2	2
Harvest Body Weight (kg)	HBW	0.25	0.25	0.25	0.25
PHYSICAL					
Farm Pond Area (ha)	FPA	5	5	10	10
Labor Requirement (people/ha)	LR	0.5	0.5	0.5	0.5
FINANCIAL					
Sale Price of Product ($/kg)					
Local Market	SPLM	$3.30	$4.40	$3.30	$4.40
Export Market	SPEM	$2.50	$2.50	$2.50	$2.50
Market Share (%)					
Local Market	MSLM	100.00%	100.00%	50.00%	50.00%
Export Market	MSEM	0.00%	0.00%	50.00%	50.00%
Fry Cost ($/Fry)	PLC	$0.05	$0.05	$0.05	$0.05
Feed Cost ($/kg)	FC	$0.50	$0.50	$0.50	$0.50
Electrical Power Rate ($/kw hr)	EPR	$0.17	$0.17	$0.17	$0.17
Electric Power Demand (kw hr/ha/year)	EPD	12,000	12,000	12,000	12,000
Chemical Costs ($/ha/year)	CC	$250.00	$250.00	$250.00	$250.00
Miscellaneous Costs ($/ha/year)	MC	$400.00	$400.00	$400.00	$400.00
License Fee Costs	LFC	$750.00	$750.00	$750.00	$750.00
Management Cost					
Base Salary (upto 5ha)	MCBS	$25,000.00	$25,000.00	$25,000.00	$25,000.00
Incremental Salary (>5ha: $/ha)	MCIS	$1,000.00	$1,000.00	$1,000.00	$1,000.00
Wage ($/hr)	W	$2.50	$2.50	$2.50	$2.50
Lease ($/ha/year)	L	$1,200.00	$1,200.00	$1,200.00	$1,200.00
Fixed Assests					
Pond Construction Cost ($/ha)	PCC	$15,000.00	$15,000.00	$15,000.00	$15,000.00
Building Cost (Initial)	BC	$20,000	$20,000	$22,500	$22,500
Land Cost ($/ha)	LC	$0	$0	$0	$0
Equipment Cost	EC	$25,000	$25,000	$35,000	$35,000
Working Capital Rate (% TVC)	WCR	40.00%	40.00%	40.00%	40.00%
Total Equity	TE	$90,938.95	$117,938.95	$142,177.90	$196,177.90
Total Investment	TI	$190,938.95	$217,938.95	$342,177.90	$396,177.90
Depreciation Schedule (years)					
Ponds	DSP	15	15	15	15
Building	DSB	15	15	15	15
Equipment	DSE	5	5	5	5
Size of Loan	SL	$100,000	$100,000	$200,000	$200,000
Loan Term (years)	LT	15	15	15	15
Interest Rate	IR	10.00%	10.00%	10.00%	10.00%
Insurance Premium Rate (%)	IPR	10.00%	10.00%	10.00%	10.00%
Property Tax Rate (%)	PTR	0.00%	0.00%	0.00%	0.00%
Gross Receipts Tax Rate	GRT	1.00%	1.00%	1.00%	1.00%
Corporate Tax Rate	CTR	2.00%	2.00%	2.00%	2.00%
Inflation Rate on Lease (Annual)	IRL	5.00%	5.00%	5.00%	5.00%
Inflation Rate on Operations	IRO	5.00%	5.00%	5.00%	5.00%

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PRODUCTION					
Unit Production (kg/ha/crop)	UP	7,000	12,750	7,000	12,750
Total Production (kg/farm/year)	TP	70,000	127,500	140,000	255,000
REVENUE (R)		$231,000.00	$561,000.00	$406,000.00	$879,750.00

OPERATING EXPENSES (ANNUAL)	1	2	3	4
VARIABLE COSTS				
Labor				
Full Time Staff	13,000.00	13,000.00	26,000.00	26,000.00
Occassional Labor				
Feed	70,000.00	127,500.00	140,000.00	255,000.00
Postlarvae	20,000.00	30,000.00	40,000.00	60,000.00
Electricity	10,200.00	10,200.00	20,400.00	20,400.00
Chemicals	1,250.00	1,250.00	2,500.00	2,500.00
Miscellaneous	2,000.00	2,000.00	4,000.00	4,000.00
TOTAL VARIABLE COSTS (TVC)	116,450.00	183,950.00	232,900.00	367,900.00
FIXED COSTS				
Salary Personnel				
Full Time Manager	25,000.00	25,000.00	35,000.00	35,000.00
Land Rent	6,000.00	6,000.00	12,000.00	12,000.00
Interest on Loan	6,480.71	6,480.71	12,961.42	12,961.42
Loan Principal	6,666.67	6,666.67	13,333.33	13,333.33
Depreciation				
Ponds	5,000.00	5,000.00	10,000.00	10,000.00
Building	1,333.33	1,333.33	1,500.00	1,500.00
Equipment	5,000.00	5,000.00	7,000.00	7,000.00
License Fee	750.00	750.00	750.00	750.00
Insurance	12,000.00	12,000.00	20,750.00	20,750.00
Property Tax	0.00	0.00	0.00	0.00
TOTAL FIXED COSTS (TFC)	68,230.71	68,230.71	113,294.76	113,294.76
TOTAL OPERATING COST (TOC)	$184,680.71	$252,180.71	$346,194.76	$481,194.76
GROSS RECEIPTS TAX (GRT)	$2,110.00	$5,410.00	$3,860.00	$8,597.50
OPERATING PROFIT (OP)	$44,209.29	$303,409.29	$55,945.24	$389,957.74
CORPORATE TAX (CT)	$884.19	$6,068.19	$1,118.90	$7,799.15
NET PROFIT (NP)	$43,325.10	$297,341.10	$54,826.34	$382,158.59
RETURN ON EQUITY (ROE)	47.64%	252.11%	38.56%	194.80%
RETURN ON INVESTMENT (ROI)	22.69%	136.43%	16.02%	96.46%

		1	2	3	4
Unit Variable Cost ($/kg)	Total Variable Costs)/(Total Production)	1.664	1.443	1.664	1.443
Total Fixed Cost/ha		$13,646.14	$13,646.14	$11,329.48	$11,329.48
Total Variable Costs/ha		$23,290.00	$36,790.00	$23,290.00	$36,790.00

A.3. Siganus sp. (rabbitfish)

SPECIES: SIGANUS SP. — AQUACULTURE PRODUCTION SCENARIOS — 09-Sep-90

ASSUMPTIONS		1	2	3	4
BIOLOGICAL					
Stocking Rate (Fry/sq m)	SR	2	3	2	3
Survival Rate	SUR	80.00%	80.00%	80.00%	80.00%
Crops Per Year	CPY	2	2	2	2
Feed Conversion Rate	FCR	2	1.3	2	1.3
Harvest Body Weight (kg)	HBW	0.25	0.25	0.25	0.25
PHYSICAL					
Farm Pond Area (ha)	FPA	5	5	10	10
Labor Requirement (people/ha)	LR	0.5	0.5	0.5	0.5
FINANCIAL					
Sale Price of Product ($/kg)					
Local Market	SPLM	$4.00	$4.40	$4.00	$4.40
Export Market	SPEM	$3.30	$3.85	$3.30	$3.85
Market Share (%)					
Local Market	MSLM	100.00%	100.00%	50.00%	50.00%
Export Market	MSEM	0.00%	0.00%	50.00%	50.00%
Fry Cost ($/Fry)	PLC	$0.10	$0.10	$0.10	$0.10
Feed Cost ($/kg)	FC	$0.50	$0.50	$0.50	$0.50
Electrical Power Rate ($/kw hr)	EPR	$0.17	$0.17	$0.17	$0.17
Electric Power Demand (kw hr/ha/year)	EPD	12,000	12,000	12,000	12,000
Chemical Costs ($/ha/year)	CC	$250.00	$250.00	$250.00	$250.00
Miscellaneous Costs ($/ha/year)	MC	$400.00	$400.00	$400.00	$400.00
License Fee Costs	LFC	$750.00	$750.00	$750.00	$750.00
Management Cost					
Base Salary (upto 5ha)	MCBS	$25,000.00	$25,000.00	$25,000.00	$25,000.00
Incremental Salary (>5ha: $/ha)	MCIS	$1,000.00	$1,000.00	$1,000.00	$1,000.00
Wage ($/hr)	W	$2.50	$2.50	$2.50	$2.50
Lease ($/ha/year)	L	$1,200.00	$1,200.00	$1,200.00	$1,200.00
Fixed Assests					
Pond Construction Cost ($/ha)	PCC	$15,000.00	$15,000.00	$15,000.00	$15,000.00
Building Cost (Initial)	BC	$20,000	$20,000	$22,500	$22,500
Land Cost ($/ha)	LC	$0	$0	$0	$0
Equipment Cost	EC	$25,000	$25,000	$35,000	$35,000
Working Capital Rate (% TVC)	WCR	40.00%	40.00%	40.00%	40.00%
Total Equity	TE	$78,938.95	$82,538.95	$118,177.90	$125,377.90
Total Investment	TI	$178,938.95	$182,538.95	$318,177.90	$325,377.90
Depreciation Schedule (years)					
Ponds	DSP	15	15	15	15
Building	DSB	15	15	15	15
Equipment	DSE	5	5	5	5
Size of Loan	SL	$100,000	$100,000	$200,000	$200,000
Loan Term (years)	LT	15	15	15	15
Interest Rate	IR	10.00%	10.00%	10.00%	10.00%
Insurance Premium Rate (%)	IPR	10.00%	10.00%	10.00%	10.00%
Property Tax Rate (%)	PTR	0.00%	0.00%	0.00%	0.00%
Gross Receipts Tax Rate (%)	GRT	1.00%	1.00%	1.00%	1.00%
Corporate Tax Rate	CTR	2.00%	2.00%	2.00%	2.00%
Inflation Rate on Lease (Annual)	IRL	5.00%	5.00%	5.00%	5.00%
Inflation Rate on Operations	IRO	5.00%	5.00%	5.00%	5.00%

PRODUCTION					
Unit Production (kg/ha/crop)	UP	4,000	6,000	4,000	6,000
Total Production (kg/farm/year)	TP	40,000	60,000	80,000	120,000
REVENUE (R)		$160,000.00	$264,000.00	$292,000.00	$495,000.00

OPERATING EXPENSES (ANNUAL)	1	2	3	4
VARIABLE COSTS				
Labor				
Full Time Staff	13,000.00	13,000.00	26,000.00	26,000.00
Occassional Labor				
Feed	40,000.00	39,000.00	80,000.00	78,000.00
Postlarvae	20,000.00	30,000.00	40,000.00	60,000.00
Electricity	10,200.00	10,200.00	20,400.00	20,400.00
Chemicals	1,250.00	1,250.00	2,500.00	2,500.00
Miscellaneous	2,000.00	2,000.00	4,000.00	4,000.00
TOTAL VARIABLE COSTS (TVC)	86,450.00	95,450.00	172,900.00	190,900.00
FIXED COSTS				
Salary Personnel				
Full Time Manager	25,000.00	25,000.00	35,000.00	35,000.00
Land Rent	6,000.00	6,000.00	12,000.00	12,000.00
Interest on Loan	6,480.71	6,480.71	12,961.42	12,961.42
Loan Principal	6,666.67	6,666.67	13,333.33	13,333.33
Depreciation				
Ponds	5,000.00	5,000.00	10,000.00	10,000.00
Building	1,333.33	1,333.33	1,500.00	1,500.00
Equipment	5,000.00	5,000.00	7,000.00	7,000.00
License Fee	750.00	750.00	750.00	750.00
Insurance	12,000.00	12,000.00	20,750.00	20,750.00
Property Tax	0.00	0.00	0.00	0.00
TOTAL FIXED COSTS (TFC)	68,230.71	68,230.71	.13,294.76	113,294.76
TOTAL OPERATING COST (TOC)	$154,680.71	$163,680.71	$286,194.76	$304,194.76
GROSS RECEIPTS TAX (GRT)	$1,400.00	$2,440.00	$2,720.00	$4,750.00
OPERATING PROFIT (OP)	$3,919.29	$97,879.29	$3,085.24	$186,055.24
CORPORATE TAX (CT)	$78.39	$1,957.59	$61.70	$3,721.10
NET PROFIT (NP)	$3,840.90	$95,921.70	$3,023.54	$182,334.14
RETURN ON EQUITY (ROE)	4.87%	116.21%	2.56%	145.43%
RETURN ON INVESTMENT (ROI)	2.15%	52.55%	0.95%	56.04%

Unit Variable Cost ($/kg)	$2.161	$1.591	$2.161	$1.591
Total Fixed Cost/ha	$13,646.14	$13,646.14	$11,329.48	$11,329.48
Total Variable Costs/ha	$17,290.00	$19,090.00	$17,290.00	$19,090.00
Total Cost/ha	$30,936.14	$32,736.14	$28,619.48	$30,419.48

A.4. Marine Shrimp

SPECIES: PENAEUS MONODON (Semi Intensive) AQUACULTURE PRODUCTION SCENARIOS

SSUMPTIONS		1	2	3	4	09-Sep-90
BIOLOGICAL						
Stocking Rate (PL's/sq m)	SR	20	25	20	25	
Survival Rate	SUR	70.00%	70.00%	70.00%	70.00%	
Crops Per Year	CPY	2	2	2	2	
Feed Conversion Rate	FCR	2	2	2	2	
Harvest Body Weight (kg)	HBW	0.03	0.03	0.03	0.03	
PHYSICAL						
Farm Pond Area (ha)	FPA	5	5	10	10	
Labor Requirement (people/ha)	LR	0.5	0.5	0.5	0.5	
FINANCIAL						
Sale Price of Product ($/kg)						
Local Market	SPLM	$10.00	$12.00	$10.00	$12.00	
Export Market	SPEM	$6.50	$8.00	$6.50	$8.00	
Market Share (%)						
Local Market	MSLM	100.00%	100.00%	50.00%	50.00%	
Export Market	MSEM	0.00%	0.00%	50.00%	50.00%	
PL Cost ($/PL)	PLC	$0.03	$0.03	$0.03	$0.03	
Feed Cost ($/kg)	FC	$0.90	$0.90	$0.90	$0.90	
Electrical Power Rate ($/kw hr)	EPR	$0.17	$0.17	$0.17	$0.17	
Electric Power Demand (kw hr/ha/year)	EPD	12,000	12,000	12,000	12,000	
Chemical Costs ($/ha/year)	CC	$250.00	$250.00	$250.00	$250.00	
Miscellaneous Costs ($/ha/year)	MC	$400.00	$400.00	$400.00	$400.00	
License Fee Costs	LFC	$750.00	$750.00	$750.00	$750.00	
Management Cost						
Base Salary (upto 5ha)	MCBS	$25,000.00	$25,000.00	$25,000.00	$25,000.00	
Incremental Salary (>5ha: $/ha)	MCIS	$1,000.00	$1,000.00	$1,000.00	$1,000.00	
Wage ($/hr)	W	$2.50	$2.50	$2.50	$2.50	
Lease ($/ha/year)	L	$1,200.00	$1,200.00	$1,200.00	$1,200.00	
Fixed Assests						
Pond Construction Cost ($/ha)	PCC	$15,000.00	$15,000.00	$15,000.00	$15,000.00	
Building Cost (Initial)	BC	$20,000	$20,000	$22,500	$22,500	
Land Cost ($/ha)	LC	$0	$0	$0	$0	
Equipment Cost	EC	$25,000	$25,000	$35,000	$35,000	
Working Capital Rate (% TVC)	WCR	40.00%	40.00%	40.00%	40.00%	
Total Equity	TE	$109,178.95	$122,738.95	$178,657.90	$205,777.90	
Total Investment	TI	$209,178.95	$222,738.95	$378,657.90	$405,777.90	
Depreciation Schedule (years)						
Ponds	DSP	15	15	15	15	
Building	DSB	15	15	15	15	
Equipment	DSE	5	5	5	5	
Size of Loan	SL	$100,000	$100,000	$200,000	$200,000	
Loan Term (years)	LT	15	15	15	15	
Interest Rate	IR	10.00%	10.00%	10.00%	10.00%	
Insurance Premium Rate (%)	IPR	10.00%	10.00%	10.00%	10.00%	
Property Tax Rate (%)	PTR	0.00%	0.00%	0.00%	0.00%	
Gross Receipts Tax Rate	GRT	1.00%	1.00%	1.00%	1.00%	
Corporate Tax Rate	CTR	2.00%	2.00%	2.00%	2.00%	
Inflation Rate on Lease (Annual)	IRL	5.00%	5.00%	5.00%	5.00%	
Inflation Rate on Operations	IRO	5.00%	5.00%	5.00%	5.00%	

ODUCTION					
Unit Production (kg/ha/crop)	UP	4,200	5,250	4,200	5,250
Total Production (kg/farm/year)	TP	42,000	52,500	84,000	105,000
/ENUE (R)		$420,000.00	$630,000.00	$693,000.00	$1,050,000.00

OPERATING EXPENSES (ANNUAL)	1	2	3	4
VARIABLE COSTS				
Labor				
Full Time Staff	13,000.00	13,000.00	26,000.00	26,000.00
Occassional Labor				
Feed	75,600.00	94,500.00	151,200.00	189,000.00
Postlarvae	60,000.00	75,000.00	120,000.00	150,000.00
Electricity	10,200.00	10,200.00	20,400.00	20,400.00
Chemicals	1,250.00	1,250.00	2,500.00	2,500.00
Miscellaneous	2,000.00	2,000.00	4,000.00	4,000.00
TOTAL VARIABLE COSTS (TVC)	162,050.00	195,950.00	324,100.00	391,900.00
FIXED COSTS				
Salary Personnel				
Full Time Manager	25,000.00	25,000.00	35,000.00	35,000.00
Land Rent	6,000.00	6,000.00	12,000.00	12,000.00
Interest on Loan	6,480.71	6,480.71	12,961.42	12,961.42
Loan Principal	6,666.67	6,666.67	13,333.33	13,333.33
Depreciation				
Ponds	5,000.00	5,000.00	10,000.00	10,000.00
Building	1,333.33	1,333.33	1,500.00	1,500.00
Equipment	5,000.00	5,000.00	7,000.00	7,000.00
License Fee	750.00	750.00	750.00	750.00
Insurance	12,000.00	12,000.00	20,750.00	20,750.00
Property Tax	0.00	0.00	0.00	0.00
TOTAL FIXED COSTS (TFC)	68,230.71	68,230.71	113,294.76	113,294.76
TOTAL OPERATING COST (TOC)	$230,280.71	$264,180.71	$437,394.76	$505,194.76
GROSS RECEIPTS TAX (GRT)	$4,000.00	$6,100.00	$6,730.00	$10,300.00
OPERATING PROFIT (OP)	$185,719.29	$359,719.29	$248,875.24	$534,505.24
CORPORATE TAX (CT)	$3,714.39	$7,194.39	$4,977.50	$10,690.10
NET PROFIT (NP)	$182,004.90	$352,524.90	$243,897.74	$523,815.14
RETURN ON EQUITY (ROE)	166.70%	287.22%	136.52%	254.55%
RETURN ON INVESTMENT (ROI)	87.01%	158.27%	64.41%	129.09%

Unit Variable Cost ($/kg)	$3.858	$3.732	$3.858	$3.732
Total Fixed Cost/ha	$13,646.14	$13,646.14	$11,329.48	$11,329.48
Total Varible Costs/ha	$32,410.00	$39,190.00	$32,410.00	$39,190.00
Total Cost/ha	$46,056.14	$52,836.14	$43,739.48	$50,519.48

Appendix B. Breakeven Analysis

SELECTED SPECIES UNDER DIFFERENT SCENARIOS

PROFIT LEVEL ($/ha)

	TILAPIA (Scenarios)				MILKFISH (Scenarios)				SIGANID (Scenarios)				SHRIMP (Scenarios)			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Projected Production Per Hectare (kg/ha/year)	14,000	25,500	14,000	25,500	8,000	16,000	8,000	16,000	8,000	12,000	8,000	12,000	8,400	10,500	8,400	10,500
Breakeven Point (kg)	8,341	4,615	9,166	5,645	5,375	3,573	4,462	2,784	7,420	4,858	7,609	4,462	2,222	1,650	2,580	1,808
Breakeven as % of Production	60%	18%	65%	22%	67%	22%	56%	17%	93%	40%	95%	37%	26%	16%	31%	17%
Sales Revenue at Breakeven	$46,200	$112,200	$40,600	$87,975	$35,200	$80,000	$35,200	$84,000	$32,000	$52,800	$29,200	$49,560	$84,000	$126,000	$69,300	$105,000
Cost of Production Per Hectare	$36,942	$50,443	$34,625	$48,126	$28,534	$32,542	$26,217	$30,225	$30,934	$32,738	$28,617	$30,421	$46,053	$52,832	$43,737	$50,515
Profit Per Hectare (Before Tax)	$9,258	$61,757	$5,975	$39,849	$6,666	$47,458	$8,983	$53,775	$1,066	$20,062	$583	$19,139	$37,947	$73,168	$25,563	$54,485
Assumed Farm Gate Price	$3.30	$4.40	$2.90	$3.45	$4.40	$5.00	$4.40	$5.25	$4.00	$4.40	$3.65	$4.13	$10.00	$12.00	$8.25	$10.00

Production levels for each species are considered a reasonable worst case/best case range

Calculation inputs

Total Fixed Cost/ha	$13,646.14	$13,646.14	$11,329.48	$11,329.48	$13,646.14	$13,646.14	$11,329.48	$11,329.48	$13,646.14	$13,646.14	$11,329.48	$11,329.48	$13,646.14	$13,646.14	$11,329.48	$11,329.48
Farm Gate Price ($/kg)	$3.30	$4.40	$2.90	$3.45	$4.40	$5.00	$4.40	$5.25	$4.00	$4.40	$3.65	$4.13	$10.00	$12.00	$8.25	$10.00
Unit Variable Cost	$1.664	$1.443	$1.664	$1.443	$1.861	$1.181	$1.861	$1.181	$2.161	$1.591	$2.161	$1.591	$3.858	$3.732	$3.858	$3.732

Breakeven Point	(Total Fixed Cost/ha) /(Farm Gate Price – Unit Variable Cost)
Breakeven as % of Production	(Breakeven Production/ha)/(Assumed Production/ha)
Sales Revenue at Breakeven	(Breakeven Production/ha) x (Assumed Price/kg)
Cost of Production Per Hectare	
Profit Per Hectare (Before Tax)	

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Appendix C. Production Sensitivity Analysis

PROFIT LEVEL PER ($/ha)

ANNUAL PRODUCTION	TILAPIA (Scenarios)				MILKFISH (Scenarios)				SIGANID (Scenarios)				SHRIMP (Scenarios)			
kg/ha/yr	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
2,000					($8,568)	($6,008)	($6,251)	($3,191)	($9,968)	($8,028)	($8,351)	($6,251)				
4,000					($3,490)	$1,630	($1,173)	$4,947	($6,290)	($2,410)	($5,373)	($1,173)	$10,922	$19,426	$6,239	$13,743
6,000	($3,830)	$4,096	($3,913)	$713	$1,588	$9,268	$3,905	$13,085	($2,612)	$3,208	($2,395)	$3,905	$23,206	$35,962	$15,023	$26,279
8,000	($558)	$10,010	($1,441)	$4,727	$6,666	$16,906	$8,983	$21,223	$1,066	$8,826	$583	$8,983	$35,490	$52,498	$23,807	$38,815
10,000	$2,714	$15,924	$1,031	$8,741	$11,744	$24,544	$14,061	$29,361	$4,744	$14,444	$3,561	$14,061	$47,774	$69,034	$32,591	$51,351
12,000	$5,986	$21,838	$3,503	$12,755	$16,822	$32,182	$19,139	$37,499	$8,422	$20,062	$6,539	$19,139	$60,058	$85,570	$41,375	$63,887
14,000	$9,258	$27,752	$5,975	$16,769	$21,900	$39,820	$24,217	$45,637					$72,342	$102,106	$50,159	$76,423
16,000	$12,530	$33,666	$8,447	$20,783	$26,978	$47,458	$29,295	$53,775					$84,626	$118,642	$58,943	$88,959
18,000	$15,802	$39,580	$10,919	$24,797	$32,056	$55,096	$34,373	$61,913					$96,910	$135,178	$67,727	$101,495
20,000	$19,074	$45,494	$13,391	$28,811	$37,134	$62,734	$39,451	$70,051					$109,194	$151,714	$76,511	$114,031
22,000	$22,346	$51,408	$15,863	$32,825	$42,212	$70,372	$44,529	$78,189					$121,478	$168,250	$85,295	$126,567
24,000	$25,618	$57,322	$18,335	$36,839									$133,762	$184,786	$94,079	$139,103
26,000	$28,890	$63,236	$20,807	$40,853									$146,046	$201,322	$102,863	$151,639
28,000	$32,162	$69,150	$23,279	$44,867									$158,330	$217,858	$111,647	$164,175
30,000	$35,434	$75,064	$25,751	$48,881									$170,614	$234,394	$120,431	$176,711
32,000	$38,706	$80,978	$28,223	$52,895									$182,898	$250,930	$129,215	$189,247
34,000	$41,978	$86,892	$30,695	$56,909									$195,182	$267,466	$137,999	$201,783
36,000													$207,466	$284,002	$146,783	$214,319
38,000													$219,750	$300,538	$155,567	$226,855
Assumed Average Price/kg	$3.30	$4.40	$2.90	$3.45	$4.40	$5.00	$4.40	$5.25	$4.00	$4.40	$3.65	$4.13	$10.00	$12.00	$8.25	$10.00
Projected Production Level	14,000	25,500	14,000	25,500	8,000	16,000	8,000	16,000	8,000	12,000	8,000	12,000	8,400	10,500	8,400	10,500

Production levels for each species are considered a reasonable worst case/best case range

Calculation inputs

Fixed Cost/ha	$13,646.14	$13,646.14	$11,329.48	$11,329.48	$13,646.14	$13,646.14	$11,329.48	$11,329.48	$13,646.14	$13,646.14	$11,329.48	$11,329.48	$13,646.14	$13,646.14	$11,329.48	$11,329.48
Unit Variable Cost	$1.664	$1.443	$1.664	$1.443	$1.861	$1.181	$1.861	$1.181	$2.161	$1.591	$2.161	$1.591	$3.858	$3.732	$3.858	$3.732
Price/kg	$3.30	$4.40	$2.90	$3.45	$4.40	$5.00	$4.40	$5.25	$4.00	$4.40	$3.65	$4.13	$10.00	$12.00	$8.25	$10.00
Production (kg/ha/crop)	7,000	12,750	7,000	12,750	4,000	8,000	4,000	8,000	4,000	6,000	4,000	6,000	4,200	5,250	4,200	5,250
Crops/year	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

(production x price) – (production x unit variable cost + fixed cost/ha)

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BREAK-EVEN PRODUCTION LEVEL (kg/ha/yr)

FARM GATE PRICE	TILAPIA (Scenarios)				MILKFISH (Scenarios)				SIGANID (Scenarios)				SHRIMP (Scenarios)			
$/kg	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
$2.00	40,614	24,499	33,719	20,340												
$3.00	10,214	8,764	8,480	7,276	11,981	7,502	9,947	6,228	16,265	9,685	13,504	8,041				
$4.00	5,842	5,337	4,850	4,431	6,380	4,841	5,297	4,019	7,420	5,665	6,161	4,703				
$5.00	4,091	3,836	3,396	3,185	4,347	3,573	3,609	2,967	4,807	4,003	3,991	3,323	11,949	10,762	9,921	8,935
$6.00	3,147	2,995	2,613	2,486	3,297	2,832	2,737	2,351	3,555	3,095	2,951	2,570	6,371	6,017	5,289	4,995
$7.00	2,557	2,456	2,123	2,039	2,655	2,345	2,205	1,947	2,820	2,523	2,341	2,095	4,343	4,176	3,606	3,467
$8.00	2,154	2,081	1,788	1,728	2,223	2,001	1,845	1,661	2,337	2,129	1,940	1,768	3,295	3,197	2,735	2,655
$9.00	1,860	1,806	1,544	1,499	1,911	1,745	1,587	1,449	1,995	1,842	1,657	1,529	2,654	2,590	2,203	2,151
$10.00					1,677	1,547	1,392	1,285	1,741	1,623	1,445	1,347	2,222	2,177	1,845	1,808
$11.00									1,544	1,450	1,282	1,204	1,911	1,878	1,586	1,559
$12.00									1,387	1,311	1,151	1,088	1,676	1,650	1,391	1,370
$13.00													1,493	1,472	1,239	1,222
$14.00													1,346	1,329	1,117	1,103
$15.00													1,225	1,211	1,017	1,005
$16.00													1,124	1,112	933	923
$17.00													1,038	1,029	862	854
$18.00													965	956	801	794
$19.00													901	894	748	742
$20.00													845	839	702	696
Unit Variable Cost	$1.664	$1.443	$1.664	$1.443	$1.861	$1.181	$1.861	$1.181	$2.161	$1.591	$2.161	$1.591	$3.858	$3.732	$3.858	$3.732
Current Unit Price	$3.30	$4.40	$2.90	$3.45	$4.40	$5.00	$4.40	$5.25	$4.00	$4.40	$3.65	$4.13	$10.00	$12.00	$8.25	$10.00
Projected Production Level (kg/ha/yr)	14,000	25,500	14,000	25,500	8,000	16,000	8,000	16,000	8,000	12,000	8,000	12,000	8,400	10,500	8,400	10,500

Price levels for each species are considered a reasonable worst case/best case range

Breakeven point is pre-tax

Calculation inputs

Total Fixed Cost per ha	$13,646.14	$13,646.14	$11,329.48	$11,329.48	$13,646.14	$13,646.14	$11,329.48	$11,329.48	$13,646.14	$13,646.14	$11,329.48	$11,329.48	$13,646.14	$13,646.14	$11,329.48	$11,329.48
Unit Variable Cost	$1.664	$1.443	$1.664	$1.443	$1.861	$1.181	$1.861	$1.181	$2.161	$1.591	$2.161	$1.591	$3.858	$3.732	$3.858	$3.732
Production (kg/ha/crop)	7,000	12,750	7,000	12,750	4,000	8,000	4,000	8,000	4,000	6,000	4,000	6,000	4,200	5,250	4,200	5,250
Price/kg	$3.30	$4.40	$2.90	$3.45	$4.40	$5.00	$4.40	$5.25	$4.00	$4.40	$3.65	$4.13	$10.00	$12.00	$8.25	$10.00

(total fixed cost) / (unit price – unit variable cost)

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Appendix E. Giant Clam Hatchery Development and Operational Analysis.

E.1. Giant Clam Hatchery

GIANT CLAM HATCHERY TWEKSBURY PARK, ROTA

CAPITAL COSTS			DEPRECIATION SCHEDULE		
ITEMS	LOW	HIGH	YEARS	LOW	HIGH
Marine Survey and EIA	$3,000	$8,000	20	$150	$400
Site Preparation	$25,000	$45,000	20	$1,250	$2,250
Eighteen Culture/Grow-out Raceway Tanks (10m x 2m x 0.6m)	$36,000	$54,000	15	$2,400	$3,600
Two Spawning Tanks (4m x 1m x 1m)	$1,200	$1,600	15	$80	$107
Pump House	$2,000	$3,500	15	$133	$233
Office/Laboratory Building (45 sq m)	$22,500	$33,750	15	$1,500	$2,250
Residence (90 sq m)	$45,000	$67,500	15	$3,000	$4,500
Concrete Enclosure for Generator	$3,000	$4,500	15	$200	$300
Security Fence	$8,000	$12,000	10	$800	$1,200
Water Delivery and Drainage system	$15,000	$25,000	10	$1,500	$2,500
Seawater Well	$15,000	$20,000	15	$1,000	$1,333
Electrical System	$4,000	$8,000	10	$400	$800
Seawater Pumps (Two - 7 hp)	$3,500	$5,000	2	$1,750	$2,500
Generator	$8,000	$12,000	15	$533	$800
Blower	$6,000	$9,000	10	$600	$900
Compound & Disecting Microscope	$1,250	$2,250	10	$125	$225
Refractometer	$220	$360	2	$110	$180
Hand and Power Tools	$1,500	$2,500	5	$300	$500
Pickup Truck	$6,500	$9,000	5	$1,300	$1,800
Scuba Gear	$1,000	$1,500	5	$200	$300
Shellfish Culture Trays	$2,500	$3,000	2	$1,250	$1,500
Miscellaneous Laboratory Equipment	$650	$1,000	2	$325	$500
Computer System	$2,500	$4,000	5	$500	$800
TOTAL	$213,320	$332,460		$19,407	$29,478

E.2 Giant Clam (continued)

ANNUAL OPERATING COSTS		LOW		HIGH
Salary/Wages		$45,000		$63,000
Hatchery Manager (one)	18,000		27,000	
Marine Technician (one)	12,000		16,000	
Biological Aides (2)	15,000		20,000	
Benefits		$6,750		$9,450
(15% of Salary)				
Hatchery Supplies		$5,500		$7,500
Broodstock		$1,500		$2,000
Office Supplies		$500		$850
Fuel		$800		$1,500
Utilities		$3,600		$4,500
Communications		$750		$1,200
Depreciation		$19,407		$29,478
TOTAL		$83,807		$119,478

COST OF ANNUAL PRODUCTION	LOW	HIGH
Production Capacity of Seed (5 month old)	120,000	120,000
Unit Cost	$0.35	$0.50
Production Capacity of 1 Year Old Clams	90,000	90,000
Unit Cost (5 TO 12 Months)	$0.47	$0.66
Total Unit Costs	$0.81	$1.16