Guam Coastal Zone Management Program

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AQUACULTURE AND ITS POTENTIAL ENVIRONMENTAL IMPACT ON GUAM'S COASTAL WATERS

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AQUACULTURE AND ITS POTENTIAL ENVIRONMENTAL IMPACT ON GUAM'S COASTAL WATERS

by

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INTRODUCTION

Aquaculture has the potential of suppling a substantial portion of Guam's consumption of fishery products, which is almost exclusively imported to the island at present. Some of the worlds countries obtain 20 to 40 percent of their aquatic food products through aquaculture, including Indonesia, India, and China; while in the United States an estimated 2 percent of fishery products consumed (mainly oysters, catfish, and trout) are produced by aquaculture (Corbin, 1976). In addition to the on-island market, aquaculture is an industry that can produce an export product. Together, these features give aquaculture an important potential role in Guam's economy.

A properly managed, vertically integrated aquaculture system covers the whole spectrum of the production of aquatic species from energy input to the marketing of the product (i.e., hatchery operation, grow-out phase, manufacture of feeds, processing, and marketing of the product). The expansion of aquaculture into a large capital generating enterprise encompasses a number of managerial problems that must be overcome to be successful. The major areas of concern are species for culture, biological technology, engineering technology, site location, feed, manpower, marketing, as well as legal, institutional, and financial considerations. Such systems are being developed in the United States, especially in the culture of the channel catfish.

The development of aquaculture facilities, both marine and freshwater, requires a well thought out islandwide plan, that will take into consideration its positive as well as negative aspects in regards to the economy and environment. Guidelines must be placed on the development not to hinder, but to restrict abusive use of the island's natural resources. These guidelines will have to be part of a comprehensive plan and enforced by the involved governmental agencies.

LAND RESOURCES

Aquaculture development should be limited to the central and southern area of Guam, since the use of water from the lens system which is the main source of potable water for Guam would possibly put an excess demand on this finite water supply. In addition, the major part of the northern area consists of limestone which would be unsuitable for pondages due to its permeability. Plastic-lined or concrete tanks would be required. Full explotation of southern sites should be the priority.

Criteria for land to be used for aquaculture ponds are as follows: The soil should be of character to retain water, preferably having a minimum of 25% clay. Fertile soil is prefered, but marginal soil can be used through the addition of fertilizers and lime. The area should be free of flooding or corrective means can be made without excessive investment. The soil should be free of pollution that might endanger cultured species. Prior knowledge of the land use would be informative to the type of pesticides or chemicals used. The contour distance should be greater than or equal to 100 ft. (30.9 m) for every 10 ft. (3.1 m) horizontal rise (slope maximum 10%). The size of the ponds becomes smaller as the contour interval approaches 100 ft.; beyond this, pond construction of small ponds becomes too costly. The land to be useable must be accessible by vehicle year round. This is a requirement for proper management. The area must have suitable topography so as to allow the complete drainage of ponds.

An estimated total land area suitable and available (no permanent structures) for aquaculture on Guam is 3652 ha. This estimation is based on the soil type and terrain. Figure 1 shows the delineated areas and Table 1 shows the quantity of area within each site. The preferable soils are Pago and Inarajan clays. Of the two clays under the soil type number 6, the Agat clay is not suitable for ponds, mainly due to its excessive slope. The Atate clay (#6) is marginally acceptable. It depends on the depth at which the C horizon is located. There are ponds constructed on this soil type. The total estimated suitable land area does not indicate the potential developable land, since each site must be considered seperately with referral to the type and quantity of water supply available. This will then determine how much of a given site can be developed. Naturally, conflicts with other uses of the land (e.g., agriculture, housing development) will further limit the development.

All aquaculture practices within the marine environment are considered to be in navigable waters and thus requires a permit from the Army Corps of Engineers. Aquaculture sites for the culture of marine organisms are limited to areas that afford a reasonable degree of protection from surf, and storm damage. The major sites that afford such protection are Apra Harbor between the drydocks and Polaris Point (Sasa Bay) and Cocos Lagoon primarly in the area around Achang Bay (possible siganid culture in sea grass beds). The Inner Habor of Apra Harbor and the salt water pond adjacent to San Luis Point have suitable sites, but are restricted due to Naval operations. In addition, the Piti Channel area has suitable physical features; however, the possibility of toxic effluents from the nearby power plants have to be concidered. Small protected bays along the southeast coast of Guam (e.g., Pauliluc Bay, Agfayan Bay) can be utilized for small scale culture operations. The use of large areas of reef flats around Guam would be ill-advised due to the environmental impact such operations would have and the very limited degree of managebility of such sites without major construction and alteration of the reef flat areas. However, the impoundments on the reef flat created by the construction of the sewage disposal plant in Agana could be technically utilized for aquaculture.

Table 1. Land Area Suitable for Aquaculture.

Map Section	Soil Types											
	#2 Toto Clay Hectares		#3 Chacha-Saipan Clay Hectares		#6 Atate-Agat Clay Hectares		#9 Pago Clay Hectares		#10 Inarajan Clay Hectares		#11 Mucks Hectares	
	Total	Available	Total	Available	Total	Available	Total	Available	Total	Available	Total	Available
East Guam												
1.	8	8	793	238								
West Guam												
1.	45	45	16	0	162	130	40	16	25	12	163	147
2.			7	0	11	10	12	0	90	45	25	22
3.			79	35	4	4	60	0	10	10	32	0
4.			2	0	3	2	129	97	16	14	4	0
5.			20	0	20	10	89	45	125	100	4	4
6.			30	0	119	30	26	13	13	13	29	7
7.			10	0	34	0	56	56	54	0	8	2
8.			36	0	63	0	21	21	15	0		
9.			11	0	145	36	29	29	2	2		
10.					4	4	90	90	7	7		
11.					4	4			78	39		
12.					152	152			21	21		
13.					26	26			40	40		
14.					3	3						
15.					136	68						
16.					172	172						
17.					2	2						
18.					27	27						
19.					19	19						

South Guam												
1.					86	69	4	4	32	0	3	3
2.					25	25	3	3	4	4		
3.					20	20	26	13	15	15		
4.					32	16	3	3	3	3		
5.					6	6	24	0	145	102		
6.					7	7	17	17	9	9		
7.					35	35	6	6	2	2		
8.					43	43	24	24	23	23		
9.					15	15	52	52	64	51		
10.					5	5	285	285	4	4		
11.					579	579	5	5	2	2		
12.					36	36	3	3	59	59		
13.					161	129	10	10	8	8		
14.					39	39	5	5				
15.					31	31						
16.					5	5						
Total	53	53	1,004	273	2,231	1,759	1,019	797	866	585	268	185

WATER RESOURCES

Aquaculture is dependent on an adequate quantity and quality of water. The latter can be influenced by the use of pesticides or other chemical agents, sewage and other pollutants from the adjacent land. In the case of marine aquaculture it is also susceptable to oil spills. Possible deleterious effects of toxins or pollutants on cultured organisms are mortality, injury, interference with growth or other vital functions, concentration in the organisms to such an extent as to render them unfit for human consumption or making them unpalatable. Organisms under intensive aquaculture practices are often under physiological stress due to artificial diets being incomplete in nutritional needs, and unnatural crowded living conditions that possibly cause hormonal or other biochemical imbalance. Therefore, they are rather susceptable and vulnerable to further deterioration of water quality, often more so than organisms in the wild.

The average daily quantity of water that needs to be added to a pond to maintain the water level is 1.3% of the total volume. This is the water lost due to evaporation and seepage. Some water is gained through rainfall, but there is an average net lost of 34,000 gal/day/ha of pondage. Thus, this requires a minimum continuous water flow of 23.6 gal/min/ha. This figure is based on the actual operation of the Division of Aquatic and Wildlife Resources; ponds at Talofofo during 1974 to 1975. During this period, precipitation averaged 0.275 in/day and evaporation averaged 0.200 in/day. During periods of drought a larger volume flow will be required. Likewise, during periods of excessive rainfall, less volume will be required.

A large-scale development of pondage would necessitate the construction of a dam to assure an adequate flow of water during the dry season and to allow the full potential of the area to be developed. For the construction of a dam, a permit from the Army Corps of Engineers is required for rivers having an average annual flow of 5 cu. ft/sec or greater. A permit is also required from the Guam Environmental Protection Agency for the construction of any obstruction of a waterway. The construction of government-funded dams (e.g., proposed Ugum River Dam) should be encouraged so as to allow the fuller utilization of the island's water resources. Aquaculture would be greatly benefited by such conservation measures of the island's water supply. If no dam is to be constructed at the pondage site the maximum area that can be developed should be based on the minimum flow months of the year (Table 2&3). Following this procedure would greatly reduce the area that could be supported by the water supply. Drainage and filling of ponds should be coordinated to best utilize the water supply. Tables 2 & 3 gives the maximum area that can be developed using the average flow over a number of years for a given river system that has been monitored by the U.S. Geological Survey personnel. The criteria for this area of development is the damming of the river with the option of 25, 50, or 75% of the average flow being utilized for pondages. In areas with the river systems flow rate not being monitored, an estimated average discharge for one square mile of drainage area on Guam is 2 million gallons per day (personal communication, Chuck Huxel).

The use of wells and springs can serve as a main or supplemental water supply in the southern areas. Thorough aeration is generally required of well water before use in the ponds. This type of water supply has the

Table 2. Minimum Flow Recorded Permanent Monitor Stations. 1) 34,000 gal/day/ha. 2) 1.3% Evaporation seepage water/day. 3) 1 cu ft/sec = .646317 x 10^6 gal/day.

Station	Finile River	Umatac River	Geus River	Inarajan River	Tinaga River (Pauliluc River)
Number of Years Monitored	15	23	22	23	23
Cu ft/sec/month	3.25	6.30	0	32.89	7.43
Gal/day	70,018	135,727	0	708,579	160,071
Pond Area Supported Hectares (100% Utilization)	2.1	4.0	0	20.8	4.7
Long Term Average Flows					
Cu ft/sec/month	42.0	251.7	90.6	513.0	166.8
Gal/day	904,845	5,422,600	1,951,877	11,052,020	3,593,523
Pond Area Supported Hectares (25% Utilization)	6.7	39.9	14.4	81.3	26.4
Pond Area Supported Hectares (50% Utilization	13.3	79.7	28.7	162.5	52.8
Pond Area Supported Hectares (75% Utilization)	19.9	119.6	43.1	243.8	79.3

Imong River	Almogosa Spring	Almogosa River	Maulap River	Ylig River	Pago River	Total
14	19	4	4	23	24	
18.39	0.28	10.07	12.43	4.72	2.53	
396,192	6,032	216,947	267,791	101,687	54,506	
11.7	0.2	6.4	7.9	3.0	1.6	62.4
Long Term Average Flows						
297.6	108.0	169.8	129.3	846.0	720.0	
6,411,465	2,326,741	3,658,154	2,785,626	18,226,139	15,511,608	
47.1	17.1	26.9	20.5	134.0	114.1	528.4
94.3	34.2	53.8	40.9	278.0	228.0	1066.2
141.4	51.3	80.7	61.5	402.0	342.2	1584.6

Table 3. Discharge Measurement at Low Flow-Partial Record Station.

	Number of Years Measured	Average Minimum Flow Cu Ft/Sec/Month	Gal/Day	Area Supported (100% Utilization) Hectares
Fonte River	15	6.27	135,080	4.0
Masso River	11	5.52	118,922	3.5
Faata Springs	13	5.61	120,861	3.6
Taleyfac River	17	21.15	455,653	13.4
Cetti River	8	9.72	209,407	6.2
Lagafua River	23	19.14	412,350	12.1
Piga Springs	21	4.56	98,240	2.9
Astaban River	16	4.35	93,716	2.8
Laelae River	16	17.67	380,681	11.2
Toguan River	25	5.07	109,228	3.2
Siligin Spring	19	1.83	39,425	1.2
Ajayan River	14	8.61	185,492	5.6
Agfayan River	14	20.07	432,386	12.7
Aasamano River	16	28.68	617,879	18.2
Yledigao River	16	28.59	615,940	18.1
Fintasa River	16	23.22	500,249	14.7
Fensol River	16	5.10	109,873	3.2
Asalonso River	25	12.54	270,160	7.9
Agum River (Above Bubulao)	16	82.38	1,774,786	52.2
Bubulao River	16	113.01	2,434,676	71.6
Ugum River	16	213.90	4,608,240	135.5
Manengon River	16	19.11	411,704	12.1
Tolaeyuus River	6	150.78	3,248,389	95.5
Lonfit River	3	43.83	944,269	27.8
Sigua River	3	48.63	1,047,680	30.8
Atantano River	5	28.92	623,050	18.3
Madag River	16	7.47	160,933	4.7

advantages of a relatively stable quality, free of pollutants, and free of unwanted aquatic species.

SPECIES APPLICABLE FOR CULTURE ON GUAM

Guam affords an ideal climate for the culture of warm water species. Year round warm temperatures allow growth to be at its maximum rate with subsequent high yields. For species to be of value to culture on Guam, there would have to be an existing demand or a potential demand located on Guam or within an economical shipping radius (which would have to be defined for each species). The majority of cultured species will be exotic (introduced species) to Guam. It is highly preferable to use species of which the complete life cycle can be controlled. Species of subtropical and tropical orgin are most suited for Guam's climate. Temperate species will often be at their upper limit of temperature tolerance and unsuitable for economic culture due to raised metabolism, thus reducing the food conversion ratio.

In determining which species are suitable for aquaculture, both fresh and marine, the basic criteria is economic feasibility. All other factors, biological, technological, environmental, management, and market demand contribute to determining the economic success of a species.

Aquaculture on Guam inevitably will be limited to a few species that are proven to be most profitable to culture. The limited resources available (land and water)on Guam deters diversification of cultured species due to the economics involved in large scale culture, namely labor costs, optimum design for containment of a species (including a hatchery), processing costs, and market establishment.

Aquaculture can be divided into the raising of aquatic organisms caught from the wild, which would be called fish farming, and a second catagory, fish culture, which would be the raising of aquatic organisms through their entire life cycle in captivity. Aquaculture practises involving low stocking (from wild stock), low capital investment, no or minimal control of the aquatic environment, no supplemental feeding, little or no fertilization, low production/area, and being labor-intensive are considered extensive aquaculture practices. This type of aquaculture is common in underdeveloped countries throughoust southeast Asia. At the other end of the managerial spectrum in aquaculture is intensive aquaculture, which involves supplemental feeding, control over the complete life cycle, maximum control of the aquatic environment, high stocking density, high production/area, and is capital intensive. This paper deals mainly with the latter.

Aquaculture is similar to agriculture in that a selected species or group of species are confined to a given area from which a maximum production is obtained by the application of fertilizers, feeding, disease control, environment quality management, and control of predation. Biological and technological factors favoring intensive culture of a species have a low trophic level, (efficient food conversion), disease resistance, gregarious nature, rapid growth rate, control of the complete life cycle, high fecundity and survival, and hardy nature. A reliable source of juveniles is a necessity to a successful aquaculture business. This , in most cases, would necessitate knowledge of propagation and rearing of larval stages in a hatchery, since total reliance on wild stocks will result in unpredictable production.

Freshwater organisms

Macrobrachium rosenbergii

The giant Malaysian prawn (Macrobrachium rosenbergii) is endemic to the southeast Asia and Indo-Pacific area, with its furthest northeastward extent being to the Pälau Islands. Preliminary work on culture of M.

rosenbergii was done by Ling (1967) with subsequent investigation into the mass cultivation of the larvae by Fujimura (1970). Culture of this species is practiced in S.E. Asia, United States, Mexico, South America, Philippines, Micronesia, South Pacific, Taiwan, and Japan.

This is one of the most thorough scientifically investigated species with the intent of optimizing knowledge of its culture. The majority of the research has been carried out in the U.S. This extensive information contributes to the desirability of this species for cultivation, along with characteristics of complete control of the life cycle, relatively free of disease, suitable for polyculture, luxury product demanding premium prices, omnivorous feeding habits and applicable to intensive or extensive culture.

The production capability of this species on Guam is 4637 kg/ha/year (FitzGerald, 1975). This is based on the harvest of two crops per year. This production was carried out in a stagnant pond (no water discharge, only maintenance of water level). Supplemental feeding of a commercially prepared food, turkey starter (28% protein), was used. The use of a polyculture system is recommended, with Chinese carp being the secondary species. As with other crustaceans the occurrence of molting in the pond makes the prawns vulnerable to cannibalism; however, this can be minimized by providing numerous shelters.

At present the entrepreneurs engaged in the culture of this species on Guam receive post-larvae for stocking from the Hawaii Fish and Game Department through Guam's Division of Aquatic and Wildlife Resources at no cost, except for air freight charges. Hawaii has set a limit in the past of one million post-larvae (sufficient for stocking 5 hectares) as the maximum it can supply Guam. As Hawaii's prawn industry has grown its ability to supply Guam with post-larvae will terminate. A hatchery will have to be developed on Guam and a temporary alternate source of post-larvae found (e.g., Palau) to sustain existing farms and to meet the demands of the growing industry. Sixth the addition of a hatchery for prawns on Guam, the management and production capabilities will increase. Year round production of post-larvae will allow the use of a staggered stocking method which can increase production and allow a continuous supply of harvestable prawns to be available. Guam imports an estimated 500,000 pounds of shrimp per year. Production of *M. rosenbergii* could fill a large portion of this local market demand. Japan presents an enourmous foreigh market for prawn and fishery products with premium prices paid for 16-20 prawns/pound size.

Anguilla japonica

The freshwater eel *Anguilla japonica* is a catadromous species with the migration of mature eels to the sea for spawning and the return of the elvers to rivers. It is at this point that the elvers are captured and held before stocking in grow out ponds. All pond culture of this species is dependent on this capture of wild stock. Progress has been made on the artificial propagation of *A. japonica*, but it is still only on an experimental bases. The source of juveniles for stocking are Mainland China, Korea, Taiwan, and Japan, with the later two countries usually not being able to meet their own demand. There is the possibility of substituting a similar Australian - New Zealand species, *Anguilla australis*, since the supply of wild elvers is not always available in adequate quantity from the previously mentioned coutries. Other species suitable for culture are the European *A. anguilla* and the American *A. rostrata.*

Culture of this species is intensive and usually as a monoculture. The eels are carnivores by nature, but are fed on a commercially prepaired balanced diet. Production varies with the method used from less than 1 kg/m^2 in earthen ponds up to 60 kg/m^2 in concrete environmentally controlled tanks. Guam's Aquatic and Wildlife Resources' experimental eel culture was on a polyculture basis in a earthen pond. Growth was shown to be very rapid under the warm water conditions, with harvestable size obtained as early as after 4 months of culture. A key factor in good production results of this species is the ability to have close management control. This is mainly needed for the required sorting of size classes during the grow out phase, in addition to disease prevention, and observance of the general condition of the eels which is usually evident in feeding behaviour.

Guam has one entrepreneur engaged in eel culture. This is with the use of concrete walled ponds with an area of 2 hectares which will be expanded with future demands. The expected production from these ponds will be 100 mtons/year. The major market for the eels is Japan. There is a small local market, but future expansion of eel culture will be solely for an export market.

Pangasius sutchi

The S.E. Asian catfish Pangasius sutchi is generally grown as a monoculture, but polyculture can be used with suitable species (e.g., carp). They live in rivers, and lakes, and can be raised in ponds or cages. They will not reproduce in ponds since they require moving water for reproduction to occur. This fish has great potential for Guam due to its capability of high production per unit area (e.g., 75,000-95,000 kg/ha/year) (personal communication, Nukit). The species is omnivorous and is usually fed on a mixture of vegetable matter and fish. The main draw back to their production on Guam is the requirement of 20% or greater protein in their diet to obtain the desired growth rate. They also require a high feeding rate of 10-12% body weight/day. This necessitates an abundant supply of an inexpensive food source to fulfill dietary requirements. Possible areas of a cheap food source would occur with the development of a proposed vegetable cannery, livestock slaughter house, tuna cannery, or utilization of activated sludge from the waste treatment plants. The initial cultivation on Guam by the Division of Aquatic and Wildlife Resources met with unfavorable results which were mainly attributed to improper diet and the competition for food with *Tilapia*. There is a breeding stock being held at Aquatic and Wildlife Resources for future artificial propagation.

Clarias (Clariidae)

Clarias (*C. batrachus*, *C. macrocephalus*, and *C. fucus*) are other southeast Asian catfish that offer high production per unit area (80,000-90,000 kg/year/ha). They are easily bred in captivity, of hardy nature, and feed on a wide variety of vegetable and animal matter. *C. batrachus* is favored for culture through southeast Asia due to its more rapid growth rate. *C. batrachus* occurs on Guam and is usually found in swampy areas that are subject to drying up during periods of low rainfall. It has the characteristic of having an accessory air breathing organ that enables it to exist in oxygen poor waters and to leave pondages in search of food. The advantages of the ability to withstand low oxygen waters is obvious; however, its ability to leave a body of water and move across land requires precautions. It has the ability of burrowing into the mud to survive extensive dry periods. Due to this ability, a pond used for this species should not be altered with the culture of species that might become prey of the catfish (e.g., prawns), since complete eradication from a pond would be difficult as the result of their ability to burrow into mud. A possible solution to this would be a concrete tank culture system. The culture of these catfish would require a fencing enclosure around the pond to prevent escape. Clarias is presently imported to Guam's fish markets. The Division of Aquatic and Wildlife Resources is examining the feasibility of the commercial culture of C. batrachus on Guam.

Chinese Carp

These fish are mainly recommended on Guam as a secondary species to increase overall production by more fully utilizing the three dimensional space of the pond, and help maintain a balanced pond environment. Grass carp (Ctenopharyngodon idellus) are herbivores that help control grasses growing along the pond banks. Silver carp (Hypophthalmichthys molitrix) are microphagos herbivores, feeding on the phytoplankton. Big head carp (Aristichthys nobilis) are microphagos carnivores, feeding on zooplankton. Common carp (Cyprinus carpio) are detritus feeders. At present, stock is obtained from Taiwan, but they can be artifically propagated on Guam once a breeding stock is established.

Tilapia sp.

This genus of fish has a variety of feeding habits, but in general is an aggressive opportunistic feeder. They breed naturally at a high rate in ponds, thus overpopulating, causing a general reduced growth rate, and a crop of an unsuitable size mixture for marketing. Monosex culture would be the only suitable means of culture on Guam. This is done by the crossing of species to produce a hybrid progeny of all males, or by hormone in the feed of sexually indetermined fry to produce an all male population. In general, Tilapia are an invader species (often interfering with the culture of highly valued species) and are hard to eradicate from ponds where they are not desired. Their aggressive feeding takes food away from the desired cultured species. Tilapia would be suitable for use in stabilization ponds where they would feed on the natural productivity of the pond. It's low on-island market value would eliminate the desire to be cultured on a large commercial scale on Guam, unless market changes are made through product promotion. The catering to the Japanese tourist resturants with a live product to satisfy culinary tastes would support a limited production.

Soft Shell Turtle

The soft shell turtle (Trionyx sinensis) is a high-priced item that is considered a delicacy in Taiwan and Japan. Its culture is carried out in ponds with concrete or stone walls with an overhang to prevent escape. T. sinensis are mainly fed on trash fish and animal products. Growth of the turtle normally takes approximately two years before it reaches a harvestable size (600 g); however, this growth period could be reduced to about one year on Guam due to its favorable climatic conditions. Stocking varies according to the size of the turtle, and size segregation must be practised to prevent cannibalism. Reproduction occurs in special rearing ponds in which mature turtles (3 years or older) are placed. Egg laying occurs in a small brick enclosure with a sand floor. Hatching takes approximately 50 days.

Soft shell turtle culture on Guam was initiated on a small scale by a private entrepreneur. The initial venture proved unsuccessful due to an inadequate enclosure to prevent escape. A second entrepreneur has constructed three small ponds (7 m x 17 m) for the culture of turtles and carp. The marketing will be mainly in Taiwan. This is a rather limited culture for a special market.

Bait Fish

A key factor in the development of skipjack tuna fisheries in this area of the Pacific would be a suitable supply of bait fish. A number of species have been considered and used as bait fish including *Tilapia mossambica*, *Dorosoma petenense*, *Poecilia vittata*, *Poecilia mexicana*, *Sardinella melanura*, *Engraulus japonicus*, *Chanos chanos*, *Kuhlia sandviciensis*, mullets, and cyprinids (Gopalakrishnan, 1976). Live bait pole and line method of catching skipjack tuna is the most productive means at present for harvesting skipjack. Large purseseining boats have not proved to be viable in this area of the Pacific to present.

Important factors influencing the selection of a suitable bait fish are: to be prolific, continuous breeding, gregarious, of good growth rate, hardy (both in culture and during holding in bait wells), show suitable behavior, size, color, and shape to attract tuna, and must be accepted by fishermen for use. A promising genus that is presently being worked on in Hawaii and American Samoa is *Poecilia* (Baldwin, 1974; Swerdloff, 1973). This genus is suited to mass culture (Baldwin, 1972).

Brackish Water and Saltwater

Chanos chanos

The milkfish or sometimes called bangus (Chanos chanos) is a euryhaline fish with a tolerance of 0-35 ‰. It has been cultured on Guam on a small scale in freshwater by Aquatic and Wildlife Resources (FitzGerald, 1975), and in salt water by a group of Filipino workers. There is no means of artificial propagation at present. All stock must be caught from the wild. The closest possible supply of milkfish fry at present is Palau or Yap; however, their runs are too unpredictable in quantity and time to be a dependable source. Runs of fry have been reported on Guam but are too few and unpredictable, also. The major area of abundant milkfish fry runs is in the Philippines; however, they have enforced a moritorium on the export of milkfish fry. Until artificial propagation can be practised with this species or a stable supply of wild stock is established, further pursuit of the culture of this species on Guam would be futile.

Grey Mullet (Mugilidae)

The mullet is a marine species of fish, which enters estuaries and the lower extents of rivers. The salinity tolerance is similar to the milkfish in that they can adapt to freshwater or saltwater. Their distribution is wide spread with Mugil cephalus (the preferred species for culture) being a circumtropical species. Some of the favorable characteristics of this species are euryhaline 0-38 ‰, eurythermal 3-35 C, low trophic level (herbivore), and high quality flesh. M. cephalus naturally reproduces in salt water, but artificial propagation has recently become successful on a practical scale (Shehadeh and Norris, 1972).

Cultivation of mullets is usually in brackish water ponds, where they feed on plankton (both zoo and phytoplankton), benthic algae, and detritus. They also accept artificial feed. Growth varies with density of stocking and feeding from 200-500 g in one year. They can be raised as a monoculture, but more commonly are raised in a polyculture situation. On Guam, their culture would be mainly as a secondary species, filling a niche that the primary species does not occupy. Mullets are stocked at low densities. Their low production per unit area will eliminate their desireability for large scale culture on Guam.

Scylla serrata

The mangrove crab (Scylla serrata) is an extremely territorial and aggressive species which makes its economic culture very difficult. It is a high valued product, but the low production capability per unit area, under present culture methods, makes its cultivation unlikely for Guam. It does occur naturally on Guam. An unsuccessful small scale culture was attempted by Aquatic and Wildlife Resources in conjunction with one of the commercial pond operators, and a basic growth and natural history study was done at the Universtiy of Guam Marine Laboratory (Dickinson,1977).

The ability to culture S. serrata through its larval stages is known (Ong Kah Sin, 1964). A culture of this crab on a capital intensive rather than labor intensive scale is presently not practical. Developments along this methodology, which would be similar to that of the American lobster (Homarus americanus), is possible in the future. Its culture in Asian countries is on an extensive basis, and is usually only held for a short fattening period after its capture from wild stock before being marketed. Its commercial pond culture prospects being of significant importance is unlikely (Ong Kah Sin, personal communication).

Crassostrea gigas (Oysters)

An experimental culture of C. gigas was conducted at various locations around Guam by Aquatic and Wildlife Resources (FitzGerald, 1975). The general lack of biologically rich marine waters around Guam makes the culture of filter feeding organisms less productive than areas of productively rich waters. The Apra Harbor area appears to be the only feasible site around Guam for oysters or other filter feeding bivalves on a large commercial scale. Some of the sheltered small bays may afford a suitable area for a family consumption type of culture.

Mytilus (Mussels)

This bivalve mollusk is one of the most efficient feeding animals. It has a rapid growth rate with a high nutritional value, and excellent palatability. Mytilus culture would be limited to the same areas as oyster culture, namely the Apra Harbor area. The major means of culture would be raft culture.

Penaeid Shrimp

A number of penaeid species are suitable for culture; however, Penaeus monodon (the Philippine sugpo) along with P. japonica would probably be the most desired. Penaeid culture is usually carried out in tidal ponds. The filling and emptying of the ponds are correlated to the spring and neap tides. The maximum difference of a tidal cycle on Guam is 3.5 ft. This would be a limiting factor in the ability of this culture method. Utilization of pumps for water exchange would be necessary. Gravid females are usually caught from the wild, with the subsequent raising through the larval stages to post-larvae in captivity. Development of bringing about maturation and ovulation in captivity by eye stalk ablation is being refined so the whole life cycle can be completed in captivity.

Siganids

Rabbitfish (Siganus spinus, and S. argenteus) are very popular reef fish on Guam and throughout Micronesia. There is a wild stock available on Guam. In addition, artificial propagation is known (Bryan,et. al., 1975). S. spinus and S. argenteus are the two species that usually have large juvenile runs on Guam (Kami, 1976). Preferably S. argenteus, due to its better growth rate, would be stocked into ponds or enclosed areas of the reef or floating cages (Tsuda, et. al., 1976). The major drawback to the culture of this species is obtaining an economical food source that will produce an acceptable growth rate. Conditions for the culture of the prefered alga food for this species is known (FitzGerald, 1976), but supplemental protein has to be added to the diet to obtain rapid growth.

Grouper, Sea Bass, and Snapper

These species (Lutjanus argentimaculatus, Lates calcarifer, and Epinephelus tauvina) are suited for cage culture. They are high valued species. They are carnivores and require an inexpensive supply of scrap fish. This is the main deterent to culture of these species on Guam. If a tuna cannery or fishing industry develops on Guam, a possible cheap source of protein would be available. The complete life cycles of these species have been acheived in captivity (Wongsomnuk and Brohmanonda, personal communication).

Algae

Commercial culture of algae would be very limited due to the restriction on available areas that would be feasible for its culture on Guam. The only areas that would afford adequate protection from storm damage to crops wouldbe Apra Harbor and Cocos Lagoon. There is no developed local market so all of the production would have to be processed for export. Genera that could be used for culture on Guam would include *Eucheuma*, *Gracilaria*, *Gelidiella*, *Caulerpa*, *Porphyra*, and *Enteromorpha*. *Eucheuma*, *Gracilaria* and *Gelidiella* could be used in marine colloid production. *Enteromorpha*, *Gracilaria*, *Porphyra*, and *Caulerpa* could be used as human food. The use of alga as an animal feed (e.g., *Enteromorpha* in Siganid culture) could be feasible, but would be most economically based on the utilization of a waste nutrient source (e.g., effluent from pond culture). Various other genera have been used as cattle fodder (Jensen, 1972).

Present methods of algal culture are mainly labor-intensive. This will discourage its development on Guam until an efficient economically capital-intensive means of culture becomes viable. As for example an annual net income from a family-operated 0.5 hectare labor-intensive *Eucheuma* farm in the Philippines is $1360 (Deveau and Castle, 1976). Guam would be incapable of competing on a world-wide marine colloid market with such competition from labor-intensive countries. Capital-intensive methods of growing *Eucheuma* are being examined in Florida, but have not yet proven economically viable (Deveau and Castle, 1976).

FACILITIES FOR AQUACULTURE

Ponds

Earthen pond culture is the oldest and most widespread means of containing cultured species. Ponds vary greatly in size from less than 0.1 ha to over 40 ha. This depends greatly on the species being cultured, the intensity of the culture, and the terrain. The present general trend is towards smaller ponds (e.g., 0.1-1.0 ha ponds) since they afford closer management practices. Earthen ponds are constructed by the excavation of the soil from the pond area to form dikes. Heavy equipment (bulldozers and backhoes) should be equiped with LGP tracks (low ground pressure) since most ponds are constructed in areas consisting of soft soils. Conventionally equipped machinery would frequently become stuck or inoperative. As the soil is excavated and placed along the dikes it is firmly packed so that the bank does not allow leakage or possible breakage due to insufficent compaction. The soil should be free of vegetation, roots, and large rocks. It is preferable to minimize alteration as much as possible of the bottom and banks that are formed naturally by the terrain, since this soil is already compacted and less likely to allow seepage or breakage.

The actual lay-out of the ponds depends on the terrain. In V-shaped slightly obliquely truncated valleys, small diversion ponds can be constructed. In rounded off V-shaped valleys, barrage ponds or a series of linked diversion ponds are constructed. In V-shaped valleys that are slightly horizontally truncated, strongly truncated or totally truncated the use of linked or parallel diversion ponds is recommended (Huet, 1970).

The type of soil the pond is constructed of is crucial. The soil must have the characteristic of water retention. This usually requires a minimum clay content of 25%. Fertile soils are naturally preferred, but marginal soils that are unsuitable for agriculturial use can be utilized by the addition of fertilizers and lime (acidic soils). Mineral content of the soil should be examined. A high salt content can be deleterious to the culture of some species. Previous use of the land should be known. If pesticides were used the area may be unsuitable or require considerable leaching to remove the pesticide residue.

The width of the dikes depends on their use other than retaining the water. If vehicle access is required the width should be at least 6 m at the base and 3 m at the berm. Dikes separating ponds running parallel to each other can be of a reduced width if they are not intended for vehicle passage.

The slope of the banks varies according to the size of the pond. For ponds of the 0.1-1.0 ha size, an inside slope of 1:2 and an outside slope of 1:1 is recommended. Larger ponds require a 1:3-1:4 slope. The main purpose of sloping the banks is to reduce erosion of the banks by water movement. The dike height should be at least 30 cm above the surface of the pond water. Water level inside the pond should be 0.7 to 1.2 m deep. Historic review of maximum flood water height should be made, with the subsequent construction of the dike height to prevent entrance of flood waters into the pond. The addition of a grass with good soil retaining capabilities is also recommended as a cover and soil binder to extend the life of the banks. The planting of vegetation with large woody root systems is discouraged since this weakens the dikes and facilitates leakage.

The pond bottom should have a slope of 0.2 to 0.5% towards the drain.

It should be uniform in construction with no pot holes or roots remaining. It should also be compacted if possible while being bulldozed. A collection basin may be constructed at the drainage site. This basin should not exceed 10% of the pond area. The pond should be capable of complete drainage to facilitate eradication of undesired species, control of disease problems, and mineralization of the bottom soil.

Water addition to the pond is done at the end opposite to the drain. Dispersion of water is in a manner to prevent erosion of the bank and bottom. Aeration is accomplished by splashing or spraying the water as it enters the pond. The water source should be screened sufficiently to prevent introduction of unwanted species. It should be free of pollution, also.

Drains (e.g., sluice gate, monk, stand pipe) also vary in design and construction. However, the basic functions are to control water level (overflow), prevent escape of cultured fish (also introduction of undesired species from drainage canals), and to allow complete drainage of the pond. The preferred flow of water out of the pond is in such a manner that the bottom water is drained. Each pond should have its own drainage system that empties into a drainage canal. It is ill-advised to link ponds through the drainage, since this decreases management efficiency, and also increases the possibility of spreading of disease through all the ponds.

Culture of species in impoundments where a stagnant water flow method is used would impose the least direct burden on the environment due to its limited discharge (except during complete harvest). In addition it requires the least amount of water resources to maintain the system.

Flow-through systems for species requiring a very high water quality or so intensely stocked that a continual flow is necessary to maintain basic water quality requirements would be a means of culture that adds a continual and often substainal quantity of waste water.

Raceway Culture

Raceways are designed to allow a continuous large flow of water through the enclosure to facilitate flushing of wastes, maintenance of high oxygen levels, and in the case of circular designed raceways, the movement with the current of species of fish that tend to continually swim. Raceways are commonly used in trout and channel catfish (Ictalurus punctatus) culture. Due to the high water quality maintained in raceways, the stocking density is greater than that used in ponds, thus giving a higher production per unit area.

The application of a raceway to the culture of aquatic organisms can be diverse. Culture of filter feeding organisms (e.g., oysters) is feasible with the introduction of a water source containing a high density of planktonic food organisms. The system can be of an open or closed circulation type with flow rates suited to optimize delivery of food organisms, removal of waste products, and maintenance of desired oxygen level. The practice of polyculture is feasible within a raceway system as demonstrated by Ryther (1975) in the production of fish (Pseudopleuronectes americanus), shellfish (Crassostrea virginica, Mercenaria mercenaria), lobster (Homarus americanus), and macro-algae (Gracilaria foliifera, Agardhiella tenera) within a raceway system.

Raceway culture is a sophisticated capital intensive means of aquaculture. Its use on Guam could be applied to both fresh and marine-cultured species. However, the requirements of large water volume flow through a raceway would limit its use, especially for freshwater, unless the water is filtered and recycled.

Floating Cage Culture

This method of culture originated in Cambodia and has spread throughout the Mekong River system. Modified versions are used in the culture of numerous species both in fresh and marine waters throughout the world.

Cage culture allows the utilization of an existing body of water (lake, river, ocean) for the culture of species that will tolerate intense stocking in a confined space. This method of culture has the advantage over pond culture of usually requiring less initial capital investment. Operational expense can also be less (e.g., no water pumping expense); however, the life expectancy is less than that of a pond. Frequent cleaning of algae growth from the cage is necessary to prevent obstruction of water circulation which is necessary to flush wastes and renew oxygen levels.

Greater stocking densities are usually practiced in cages than ponds. Thus a species to be suitable to this type of culture must tolerate crowding. Examples of species that are used in cage culture are *Pangasius sutchi*, carp, sea bass, grouper, and red snapper.

The sizes of cages vary from a cubic meter to 625 cubic meters, which are essentially floating cages upon which the entrepreneur lives in a hut. A practical size range for use on Guam would be 10 m^3 to 200 m^3. A cage can be constructed of a number of materials, but the type that would be suitable to Guam would basically consists of a framework forming the structural shape of the cage, around which a netting material is attached to form the enclosure. This structure is attached to floating devices, or fastened to poles secured into the substratum where a tidal fluctuation does not occur. The net must extend beyound the water surface sufficiently to prevent the escape of the fish or introduction of undesired species. In cases with species that tend to jump (e.g., Pangasius sutchi) netting must be extened over the top.

On Guam, the utilization of cage culture can contribute very substantially to the total aquaculture production. For example, obtaining the use of a portion of Fena Lake for the purpose of fish cage culture would be a productive means of utilizing an existing asset. Possibly, a cooperative venture could be arranged with the Navy, who controls the lake. In addition, it could be used to augment production within dammed areas adjacent to large fish culture operations. This culture method would be very applicable to marine species also. In most cases this being the preferred means, since it does afford a higher degree of management as compared to penning in an area of a reef flat. However, the use of cages in the marine waters would require that they do not obstruct passage of vessels. Areas where this might be practiced would be Apra Harbor and Cocos Lagoon.

Raft and Stick Culture

Raft and stick culture methods are used for oysters and mussels. Stick culture being limited to shallow water. Oyster spat that have settled on collector shells are attached to a stick which is anchored into the substratum. This method of shellfish culture is susceptable to predation by benthic organisms and aerial exposure due to tidal fluctuation.

The raft culture method is more productive per area and a more manageable means of culture. This consists of a raft constructed of cross-members (usually wood) which are floated (e.g., attachment of 55 gallon oil cans). From the crossmembers are hung the culture lines. The materials used for construction and design vary.

ENVIRONMENTAL IMPACT DUE TO AQUACULTURE PRACTICES AND POLLUTION ABATEMENT MEANS

Intensive culture of aquatic species within ponds or other enclosures with the addition of fertilizers and supplemental feeds results in the production of large quantities of waste products both directly from the cultured species and from biological activity associated with this eutrophic environment. The discharge of this effluent into receiving waters can be a considerable pollution source, if not properly managed. Since the pond can be considered as a point source of eutrophication, pollution abatement measures must be designed into the system. The costs of these abatement measures can become the limiting factor in the viability of an operation and deserves careful examination by the entrepreneur. Three broadly grouped categories of polluting factors from the effluents of fish culture activities are recognized (Hinshaw, 1973). The first category includes the passing of pathogens and parasites into natural waters from hatcheries or ponds. The close proximity of species during culturing facilitates the transmission of disease. A second category is the prophylactic or therapeutic use of chemicals and drugs to control diseases and parasites. These can be introduced directly into the impoundment or through the feed. The third group are factors that affect the chemical or physical water quality of the recieving waters. Metabolic wastes from the fish, unused food, algae, and detritus from ponds can have adverse affects on the receiving waters. Increased biochemical oxygen demand, carbon dioxide, ammonia, nitrate, and nitrite levels would be associated with this effluent. The dissolved and suspended solid level would also contribute to the pollution factor of the effluents.

Water pollutants may alter natural conditions by reducing the dissolved oxygen, by changing the temperature, or by direct toxic action that can be lethal or more subtly, can affect the behavior, reproduction, and physiology of the organisms. Although a substance may not directly affect a species, it may endanger its continued existence by eliminating essential sources of food and metabolics. Furthermore, conditions permitting the survival of a given organism at one stage of its life may be intolerable at another stage.

Physical alteration of the environment during construction and the resulting physical structure of aquaculture ponds can cause a lasting effect on the biological community by altering water flows and circulation, especially in estuary areas where blockage of large sections can prevent flushing (Odum, 1970; Copeland, 1968). Effective planning to allow for natural circulation is needed or the addition of an artificial circulation. Alteration or destruction of estuary areas, that may serve as a nursery for numerous species, may secondarily affect sport or commercial fisheries by reducing the natural stock. As with any construction envolving the grading or moving of earth the potential for sedimentation is increased.

Pollution Parameters

Water pollution is defined by Warren (1971) as any impairment of the suitability of water for any of its beneficial uses, actual or potential, by man-caused changes in the quality of the water. A more workable definition, limiting effluent discharge, is used by the Guam Environmental Protection Agency as the water quality below the discharge point must be equal to or better than that above the discharge.

Parameters and their effects contributing to water pollution of the receiving waters of fish pond effluent are as follows:

Nitrates

Nitrates are the most highly oxidized phase in the nitrogen cycle. They can reach high concentrations during biological oxidation. High concentrations are indicative of organic pollution. Nitrate concentration in natural waters usually ranges from 0.5-5.0 PPM (Hutchinson, 1957). Nitrates are the most usable form of nitrogen for plant growth. Generally an increase in nitrates is followed by an increase in algal production and an increased productivity of the whole ecosystem. However, an increase of nitrate level beyond 20 PPM has detrimental effects for fish culture (Spotte, 1970).

Nitrite

Nitrite is an intermediate of the nitrification process (ammonia-nitrite-nitrate). It can accumulate during the development of nitrifying activity, due to elevated ammonia levels, or when the normal nitrification path is interrupted, for example, by addition of chemotheraputics to the water. Nitrite can be toxic to fish by means of reducing oxygen transport efficiency of the blood resulting in hypoxia in extreme cases. The nitrite oxidizes hemoglobin to methemoglobin which is incapable of releasing oxygen on demand (Smith and Russo, 1975). Lethal levels for nitrite range from 0.14-0.55 mg NO_2-N/l (Forster et.al., 1977). Concentrations as low as

0.096 mg/l NO_2 showed a small, but significant increase of methemoglobin in trout which were exposed for 8 days (Smith, 1975). A LC 50 of 0.23 mg NO_2-N/l was found for trout (Brown and McLeay, 1975).

Ammonia

Ammonia originates from mineralization of organic substances by bacteria and from excretion by fish. Unionized ammonia is very toxic to fish and should not exceed 0.1 PPM. Toxicity varies by the concentration of undissociated ammonium hydroxide in the water, which in turn is a function of the pH and temperature. Spotte (1970) notes that even at sublethal levels ammonia will have four adverse effects to fish populations: (1) increased susceptibility of fish to other unfavorable conditions such as low oxygen, (2) inhibited normal growth, (3) decreased fecundity, and (4) decreased resistance to disease. High levels affect the gill tissues and reduce the ability of hemoglobin to combine with oxygen. High, but nonlethal, ammonia concentrations will cause extensive proliferation of eithelium which prevents normal respiration (Smith, 1972). Spotte (1970) sites chronic ammonia levels as the most serious problem that the fish culturist must deal with.

Settleable and Suspended Solids

Settleable solids and suspended solids can be organic or inorganic in origin. They have a greater effect on fish populations in a natural environment than in fish ponds where artificial feeding occurs. Light penetration would be limited, thus reducing algal growth which is the basis for the food chain. In aquaculture, the suspended solids may cause a buildup of sludge on the bottom, consisting mainly of the remains of plankton which decompose and increase the BOD in the pond. High loads of suspended solids may cause gill tissues to be affected and should remain below 80 PPM for optimum health in fish culture (Wedemeyer and Wood, 1974). The composition of suspended particles in surface waters are important because of their effects on light penetration, temperature, soluble products, and aquatic life. The mechanical or abrasive action of particulate material is of importance to the higher aquatic organisms, such as mussels and fish. Gills may be clogged and their proper functions of respiration and excretion impaired. Blanketing of plants and sessile animals with sediment as well as the blanketing of important habitats, such as spawning sites, can cause drastic changes in aquatic ecosystems. If sedimentation, even of inert particles, covers substantial amounts of organic material, anaerobic conditions can occur and produce noxious gases and other objectionable characteristics, such as low dissolved oxygen and a decrease in pH. Odum (1974) sites the increase of sedimentation under rafts, mainly due to feces and pseudofeces, in the case of oyster culture.

Biochemical Oxygen Demand

Biochemical oxygen demand is the quantity of oxygen required for the biochemical oxidation in a given time at a given temperature of organic matter. The introduction of effluent with a high BOD into a stream puts an excess burden upon it. This type of pollution can be very destructive when relatively large amounts of putrescible organic materials, which require oxygen for their decompostion, are introduced into the waters. The oxidation is dependent upon the availability of dissolved oxygen in the waters and the ability of the body of water to maintain this oxygen level above the BOD through exchange with the atmosphere and the photosynthesis of algae.

If the dissolved oxygen falls below that required by the BOD loading, anerobic conditions arise.

Toxins

Since we are dealing with the culture of organisms, the use and occurrence of toxins are avoided. Usually the only time a toxin is introduced into a pond is after drainage. However, a class specific toxin may be used during culture to rid the pond of pest species (e.g., fish from prawn culture ponds). A fish toxin may be introduced to eliminate undesirable species that may remain in small bodies of water or the mud/water interface. This should be held in the pond for the prescribed period of time for deactivation of the toxin before refilling or further discharge. The addition of chemical oxidants can speed up this process. Careless use of the toxins with its entry into the receiving waters can cause large fish kills. Trained personnel should be available for supervision during the administration of toxins. Toxins from tank culture systems can include algacides, and chemicals used in cleaning the tanks.

Coliform

The quantity of coliform bacteria is a standard means of indicating pollution levels. Coliform bacteria (*Escherica coli* and similar gram negative bacteria) are normal inhabitants of fecal discharges from warm blooded animals. Total coliform counts can be misleading since certain coliform bacteria occur naturally associated with various vegetation. The Guam Water Quality Standards specifies fecal coliform counts as a standard testing of Guam's waters for pollution. The presence of fecal coliform is used to indicate a degree of pollution (possible presence of human pathogenic organisms) in waters; however, since fecal coliform is restricted to warm blooded animals this is not relevant as a pollution indicator from fish ponds. As previously mentioned, the use of a total coliform count also is not a reliable indicator of pollution since certain species of coliform bacteria occur naturally in the environment. Certain coliform bacteria are part of the natural nitrification process, and most likely due to the increase in ammonia (metabolic waste) within fish ponds, the presence of this coliform bacteria will increase.

If it were possible to monitor a common intestinal bacteria restricted to fish, this would be more suited as a pollution indicator from fish ponds than fecal or total coliform counts. The monitoring of other parameters (e.g., ammonia, nitrate, phosphate) will be a more useful guide to the degree of pollution a fish pond contributes to the receiving waters.

Study of Hatchery and Pond Effluent

A study conducted at six hatcheries in the United States showed a degradation due to hatchery effluent of the receiving waters (Hinshaw, 1973). Of the parameters tested, ammonia (major nutrient contributing to the effluent), BOD, MPN coliform, and suspended solids were the factors contributing significantly to a change in the receiving waters. A correlation was found with the water quality above the discharge point to that below. A high quality water showed degradation less than in water of lower initial quality. Waters with a high degree of enrichment prior to use resulted in hatchery effluents that were considered a possible public health problem. Contrary to this, waters of high quality, prior to hatchery use did not significantly degrade receiving waters below the discharge point. In general, hatchery effluents showed a significant increase in MPN coliform counts, which could pose a potential public health hazard (Hinshaw, 1973). BOD levels were increased significantly, which were mainly attributed to the use of animal offal or wet feeds that were not consumed. The enrichment of the receiving waters by hatchery activities has increased the growth and propagation of many fish food organisms and supplementally increased the fish population supported by the waters. This could be considered a desirable affect depending if the species of fish were of use to a sport or commercial fisheries. However, the number of pollution intolerant benthic species tended to decrease. In contrast, the organic enrichment from a water quality and public health stand point may not be desirable.

Data recorded by Aquatic and Wildlife Resources (FitzGerald, 1975) for the parameters of nitrate and phosphate sampled from their demonstration ponds and the water supply source (Talofofo River) indicate a significant ($p = 0.05$) increase in phosphate in the pond waters over the river water supply source (Table4). However, nitrate levels showed no significant increase, and actually a slight decrease (not significant) in pond 2 as compared to the river. This lowered nitrate level reflects its uptake by the phytoplankton and macroalgae populations within the ponds. Pond 2 illustrates to a certain extent the efficiency of the use of a stabiliaztion pond in pollution abatement. The operational proceedure of Aquatic and Wildlife Resources personnel was to supply pond 2 with sufficient water to maintain the water level by siphoning water from pond 1. Occassionally, when additional water was needed or adverse conditions arose within pond 2

Table 4. Nitrate and Phosphate Values from Aquatic and Wildlife Resources Experimental Ponds and Talofofo River (FitzGerald, 1975).

Date	Pond 1 mg/l Nitrate	Pond 1 mg/l Phosphate	Pond 2 mg/l Nitrate	Pond 2 mg/l Phosphate	River mg/l Nitrate	River mg/l Phosphate
10/1/74	0.200	0.300	0.140	0.240	0.430	0.192
10/8/74	0.360	1.200	0.260	0.330	1.230	0.470
10/17/74	0.150	0.730	0.120	0.310	0.170	0.320
10/21/74	0.140	0.290	0.060	0.240	0.210	0.190
10/30/74	0.330	0.800	0.070	0.340	0.330	0.640
11/4/74	0.940	1.390	0.210	0.410	0.820	0.530
11/20/74	0.222	0.258	0.249	0.444	0.167	0.228
12/3/74	0.610	1.529	0.249	0.944	0.167	0.159
12/20/74	0.360	0.241	0.167	0.797	0.222	0.228
1/3/75	0.332	2.133	0.277	1.084	0.250	0.334
3/10/75	0.332	1.588	0.222	0.419	0.111	0.119
4/4/75	0.279	0.719	0.580	0.211	0.049	
5/4/75	1.387	2.280	1.218	0.419	0.775	0.089
n	13	13	13	13	13	13
$\bar{x}$	.434	1.035	.294	.476	.384	.273

water was pumped directly from the river. The data illustrates a reduction of nutrients (nitrate and phosphate) in pond 2 as compared to pond 1.

Pollution Abatement

Various means of minimizing the impact of aquaculture effluents on the environment are by trickle filters, sand filters, stabilization ponds, irrigation and spraying of crops.

Advanced waste treatment may be physical, biological, chemical or a combination of these processes. Wastes from aquaculture can be treated by the same means as sewage waste water is handled. Biological secondary treatment is the most economical and most satisfactory means of processing waste water (Parker, 1975). Disposal sources of waste water include fresh water, oceans, underground injection, land surface, and reuse.

Trickle Filters

Utilization of trickle filters would be restricted by economics to sophisticated compact aquaculture systems such as hatcheries, raceways, and systems where recycling is used. A trickling filter makes use of a natural cleansing system in which nitrification occurs by biological means (biological oxidation process). It consists of a bed of inert material (oyster shells, gravel, plastic material) on which an aerobic growth of organisms (algae, fungi, bacteria, protozoans, worms, and insect larvae) grow. Waste effluent is trickled from above through the filter. Wastes are removed by the biological community within the filter. This type of filter does not mechanically strain the effluent since the space between the filter media is relatively large (45% of total filter volume) to allow gaseous exchange and rapid flow. Factors influencing the ability of the organisms in the film to assimilate the organic matter depends on the flow rate, organic loading aerobic conditions, and temperature.

Sand Filters

Sand filters, especially slow sand filters, can be used in improving the water quality of pond effluent. A sand filter consists of a layer of sand 2-5 ft deep of 0.25 to 0.35 ml in effective size, underlain by gravel. Drainage is usually be perforated pipes laid under the gravel bed. Flow of the water through the filter is by gravity. Mechanical and biological cleansing of the effluent occurs within the filter. Flow rate is approximately 2.5 million gallons per acre of filter area per day. Higher flow rates can be obtained with pretreatment of the effluent such as sedimentation. The upper layer of the filter after a period of operation (varying with the effluent) must be scraped off to prevent excessive clogging and reduction of the filter efficency. The filtered water can then be recycled to the pond, which reduces its total requirement from the water supply, or it can be drained to the receiving waters if reuse is not desired.

Rapid sand filters require pretreatment of the pond effluent with coagulants (e.g., aluminum sulfate, ferric chloride, ferric sulfate, ferrous sulfate, and sodium aluminate) and sedimentation. Flow rates are 125 million gallons of water per acre of filter surface per day (Ehlers and Steel, 1965). The filter media consists of a gradation in size of sand (0.4-0.8 ml effective size) 20 to 30 inches (50 to 76 cm) thick underlain by 16 to 24 inches (41 to 61 cm) of gravel (1/8 to 2 1/2 inch diameter). The sand filter consists of a tank, the inlet, the underdrain system (perforated collecting pipes) filtering medium, rate of flow controllers, and loss of head gauges.

Spray Irrigation

Spray irrigation systems are designed so they can take primary treated waste water. The water can be taken directly from fish ponds or a stabilization pond. This means of disposing of the effluent is most suitable where agriculture crops and aquaculture are done together. The nutrient enriched waters from the fish ponds serve as fertilization to the agriculture crops with no additional costs thus, best utilizing the resources. This would be a highly preferred method of effluent control from fish ponds. Canal irrigation can be used to augment the spray irrigation for crops for which this method would be preferable.

Stabilization Ponds (Oxidation Ponds)

The employment of stabilization ponds to effluent from fish ponds, prior to its discharge back to the receiving waters, can be an effective means of reducing BOD, nutrient levels, and suspended matter to acceptable EPA standards. The stabilization pond basically consists of an impoundment of water (less than 5 ft deep) that is held for a period of time to allow the breakdown of waste materials through biological processes and a final uptake of nutrients by algae. The period of holding varies with the BOD loading. A decreased holding period can be obtained by added aeration (mechanical) to the waters. Tsai (1975) points out the efficiency of using a final pond for effluents in general. In periods of water shortage this water can then be recycled to the fish ponds.

The basic concept behind the stabilization pond is that it allows the suspended matter to settle; waste material is decomposed and fed upon by bacteria and zooplankton; sludges produced are degraded by faculative anaerobes, including bacteria, protozoa, insects, and worms; nitrification of ammonia wastes products, uptake of nitrates, carbon dioxide and other plant nutrients is done by algae. The further addition of suitable fish species can convert the algae and benthic fauna into a final marketable product (helping to defer construction costs).

In areas where a large quantity of flat unutilized terrain, adjacent to the ponds, exists; it can serve as a simplified evapotranspiration system along with a leaching field of the effluents. However, since land is usually at a premium on Guam this would be an uneconomical use of the land.

Wastewater Addition To Fish Ponds

The use of fish ponds in the purification of sewage water has been noted by numerous authors (Schuster et.al., 1954; Schroeder, 1975; Schroeder and Hepher, 1976; Woynarovich, 1976). Light loads of either organic-rich raw sewage or nutrient-rich biological treatment (secondary) effluent can be channeled through aquaculture systems which would essentially be an extension of the waste treatment process and simultaneously derive an economic benefit. Limiting factors to the use of aquaculture in waste treatment would be the presence of toxic chemicals, petroleum, metals, and pathogenic organisms above an acceptable level. Properly treated (filtered, settled, and diluted) sewage water that does not contain significant poisonous industrial pollutants is a suitable medium for fish culture. Fish culture associated with duck, chicken, and pig rearing as the source of fertilization is common in countries throughout the world, and is an effective solution to domestic animal waste management problems. This is mainly an Asian fish culture practice, but is also a long practiced method in Europe (Bardach et. al., 1970; Woynarovich, 1976) and Israel (Schroeder and Hepher, 1976); and is used on experimental bases in the United States (Buck et.al., 1976). Odum (1974) also sites a study in Israel; fish ponds serve as nutrient traps where most of the organic compounds are either precipitated, lost to the atmosphere, bound by the sediments, or tied up in fish flesh so that a minimum amount of nutrients leaves the ponds. The amount of sewage that can be put through a pond is determined by maintaining the BOD level at a safe point to prevent oxygen depletion. Daily rates of sewage addition can be inexcess of 1.5 tons/ha. These sources of nutrients serve to enhance primary prodution along with a fauna associated with eutrophic conditions. The mineralized portion of the manure provides nutrients to the phytoplankton while the non-mineralized portion serves as a food base for zooplankton. This food source is in turn utilized by the stocked fish population (usually *Tilapia* or carp). Utilization of carp in the treatment of nutrient-enriched waste waters is practiced in Indonesia and Germany (Bardach et.al., 1970). The carp feed on the natural productivity of the waters. Recent studies (Carpenter, 1974; Coleman et.al., 1974; Goldschmidt, 1970; Schroeder, 1975) have indicated that fish improve the waste treatment capacity of pond systems. Utilization of fish ponds for this purpose on Guam is feasible. They also have been used in effluent wastes from dairies, sugar mills, slaughterhouses, and starch mills. Part of pond ecology and proper management is the use of species to utilize excess food thus affecting reduction of pollution, improvement of pond environment, and greater production. Yields of fish grown in such ponds, with no supplemental feeding, have been as high as 4000 kg/ha/year (Schuster et.al., 1954; Schroeder and Hepher, 1976).

Public Health

Fish may serve as a passive carrier of infectious human diseases such as *Salmonella*, *Vibrio parahemolyticus*, *Shigella*, or other enterobacteria (Janssen, 1970; Guelin, 1962; Buttiaux, 1962). The occurence of these diseases from fish caught in polluted waters was noted by Shewan (1962). However, the pathogens are confined to infecting the gut of fish (Allen, Busch, and Morton, 1976), so that with proper precaution in preparation of the fish this possible hazard could be eliminated. There is danger of introducing *Schistosomiasis* as had happened in the Caribbean (Odum, 1974). With rapid air transport of live aquatic species from tropical areas the survival chances of waterborne stages of flukes and other pathogens has increased (Courtney and Robins, 1975). The limited knowledge in this area (Sonstegard, 1975) will require further research as aquaculture expands.

Exotic Species

The introduction of exotic species for the purpose of aquaculture is often a necessity in establishing a viable aquaculture industry; however, candidate species for introduction should be carefully examined in regards to their ecology, behavior, reproduction, and marketability. Indescriminate introduction can lead to the detriment of the endemic species and possibly their elimination in addition to threats to established culture species (Allen, 1949; Frankenberg, 1966; Lanchner et.al., 1970; Buckow, 1969;

Idyll, 1969).

Some detrimental effects that may result from the introduction of exotic species are; reduced growth of introduced species due to less favorable environmental conditions than those found in their indigenous area, a population explosion of the introduced species leading to competion with, and possible elimination of native species, introduction of new pests, diseases, and parasites harmful to resident species, and destructive activitities of the introduced species affecting other fields of economic interest (e.g., common carp in the U.S.) (Rosenthal, 1976).

ROLE OF AQUATIC AND WILDLIFE RESOURCES

The Division of Aquatic and Wildlife Resources should continue to play an instrumental part of the development and support of an aquaculture industry on Guam. Aquatic and Wildlife Resources initiated investigation into the prospects of aquaculture on Guam in 1973. The initial phase of the program dealt with the investigation into feasible species for culture on Guam with experimental-demonstration ponds located on the Talofofo River. The second phase consisted of assisting in the establishment of commercial ponds with extension service provided to the entrepreneur. This is continued into the present program with the addition of the pursuit in establishment of a hatchery on Guam, so that Guam can become self-sufficient in production of the major cultured species juveniles.

All importation of live fish (including crustaceans and turtles) requires a permit which is issued by Aquatic and Wildlife Resources. Shipment of species from foreign countries (outside U.S. and T.T) requires, in addition to the Aquatic and Wildlife Resources permit, a permit issued by the Federal Fish and Wildlife Service for some species. This system is intended to screen out the introduction of undesireable species and species originating from countries that have a high disease occurence or the presence of a disease that does not occur on Guam that might be carried by the introduced species. This also can restrict importation of species that might be detrimental to established aquaculture species.

The introduction of a large number of exotic species to Guam would be ill-advised; however, the major species that will be most suitable for aquaculture will be exotic to Guam. The utilization of species which have proven their success as a culturable species should have priority for examination of their potential on Guam. This usually involves an extensive degree of technical and practical knowledge available on a species culture and careful selection weighing all the pro and con arguments both concerning its economic and biological impact. This regulatory and research function will have to be mainly fullfilled by the Aquatic and Wildlife Resources Division. However, an interagency screening committee consisting of the Guam Environmental Protection Agency, University of Guam Marine Laboratory, and Aquatic and Wildlife Resources, should be formed to review all new introductions.

For the aid in inforcement of an affective environmental protection program the Aquatic and Wildlife Resources should keep the Guam Environmental Protection Agency aware of scheduled large discharges (e.g., during harvest). This allows for the proper monitoring of effluents. In addition, Aquatic and Wildlife Resources should oversee application of toxic substances to fish ponds for the purpose of elimination of pest species. Potential farmers should be advised of requirements and permits required from other agencies. The construction of the aquaculture facilities should be observed by Aquatic and Wildlife Resources along with other appropriate governmental agencies to assure that excessive abuse of the environment does not occur.

Aquatic and Wildlife Resources in conjunction with the Public Health Department, should screen all imported aquatic species coming from areas that infectious diseases can be carried by fish (fish or human pathogens). This could consist of impounding in concrete tanks and treating with proper prophylatic drugs. Specimens that are obviously diseased should be destroyed.

If local facilities were available for the propagation of these preferred culture species then this would eliminate the need for importation and its possible accompanying health problems.

CONCLUSION

Guam has the climatic and physical conditions for the development of a diverse and productive aquaculture industry. This potential, needs to be recognized by both governmental agencies and private entrepreneurs, so that proper and well-planned development can proceed.

A state program should be drawn up to cover the development of aquaculture and its supportive facilities (laws, policies, and administrative procedures) to encourage its development. In addition, the over-seeing of environmental protection measures should be realistically enforced to prevent abusive use of Guam's waters. Decisive effort is needed to put into operation a viable aquaculture program that is consolidated into a workable industry that will attract the businessman/farmer into this new industry on Guam.

The governmental agencies involved in this formation of a state program should be limited to those directly concerned with the functional operation of an aquaculture industry, thus preventing an over diversification of authority, which would hinder development.

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Figure 1. Map of Guam showing areas having suitable terrain and soil type for aquaculture. The uncircled number indicates the soil type, while the circled number corresponds to the paticular site listed in Table 1. Major marine sites suitable for mariculture are also indicated. Refer to text for further details.

Legend: Soil Types (Tracey et.a.., 1959)

2 - Toto Clay: Brown to pale-yellow, firm plastic, slowly permeable, acid clay with reddish stains (Grumusol); ranges 5 to 30 feet in depth and averages 10 to 20 feet; has very high shrinkage and expansion (large cracks in dry season; depressions ponded in wet season); prevailing surface gradient 1 to 8 percent.

3 - Chacha-Saipan Clays: Yellowish-brown, firm clay (Chacha), and red, firm clay (Saipan); neutral to acid reaction; Latosolic intergrades. These soils with concave survaces they are 10 to 60 feet deep; prevailing surface gradient 1 to 8 percent.

6 - Atate-Agat Clay: Remnant benches or small mesas of an old red, granular, porous, acid Latosol (Atate clay) with deep, reddish, mottled, plastic to too hard clay C horizon, pale yellow, olive, or gray in lower part; and its truncated counterpart (Agat clay) with similar C horizon of saprolitic clay, ranging in depth from a few feet to about 100 feet and averaging about 50 feet; prevailing surface gradient of Atate clay is 1 to 8 percent, and of Agat clay 8 to 15 percent.

9 - Pago Clay: Brownish, granular to firm and plastic Alluvial clay, with gray mottling to within 24 to 30 inches of the surface; generally alkaline to neutral; soil depth is generally more than 10 and less than 150 feet; moderately well drained; subject to occasional flooding; prevailing surface gradient 1 to 3 percent.

10 - Inarajan Clay: Similar to Pago clay but lower, wetter, and shallower (thins out on coastal sands and bedrock); water table at or near the surface (within 30 inches) most of the time; poor drainage mottlings (gray) within 6 to 12 inches of the surface; depth to sand or bedrock ranges from 3 to 25 or more feet; reaction is alkaline in water saturated zone; poorly drained; frequently flooded; prevailing surface gradient 0 to 1 percent.

11 - Muck: Black to brown, soft muck and peat, with some clay and silt; depth to underlying material (chiefly limesand or shelly clay) ranges from 3 to 20 feet, averages 5 to 10 feet; alkaline reaction below the water table, which is generally at or near the surface; prevailing surface gradient is level or very nearly level.