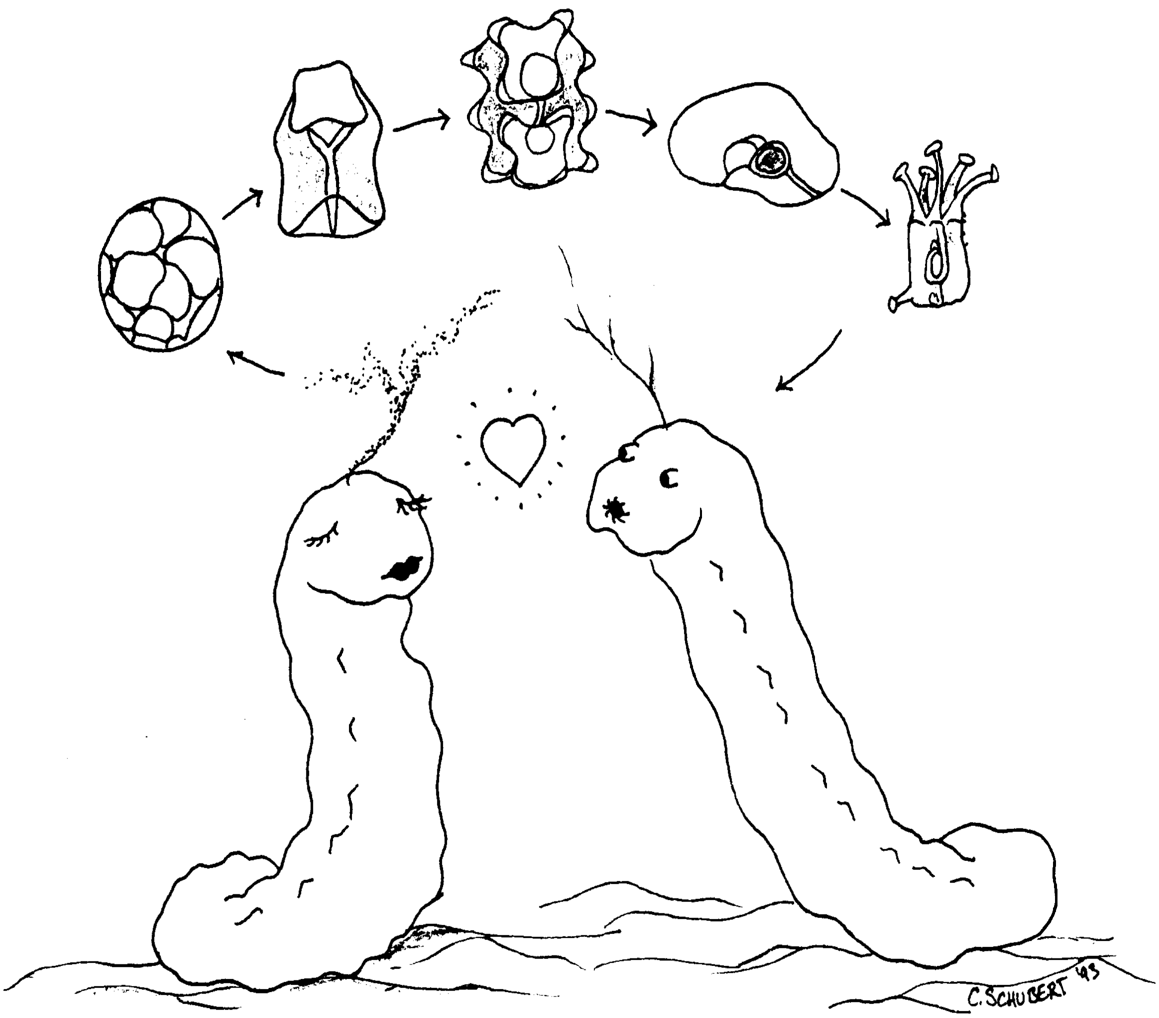
Suggestions for the Management of Sea Cucumber Resources in Micronesia

Results of the Workshop
"A Regional Management Plan for a Sustainable Sea Cucumber Fishery for Micronesia"

R.H. Richmond, Editor



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Cover: "**Sea Cucumber Love**" by Cynthia M. Schubert. Sketch illustrates the life cycle of the sea cucumber. The male (on the right) is releasing sperm from his gonopore (situated a few centimeters from the mouth, on the dorsal surface), while the female releases eggs. This upright position is typical of spawning sea cucumbers, and may be observed during the day or at night. Most tropical sea cucumbers have separate sexes (gonochorism) and exhibit spawning behavior with external fertilization and development of planktotrophic (feeding) larvae. From fertilization, the stages include (left to right) the fertilized embryo, the early auricularia stage, the late auricularia stage, the doliolaria stage and finally, the pentacula larval stage. The pentaculae settle, metamorphose and develop into the juvenile sea cucumbers.

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Foreword

The islands of Micronesia possess a wealth of marine resources. As funds provided under the Compacts of Free Association dwindle, there is increasing pressure to exploit these resources to provide much-needed capital. Due to the relatively small size of the coastal areas within Micronesia, there is justified concern that resources can and will be fished out without adequate management efforts. Sea cucumbers, with present values as high as $22/lb have been exploited for centuries throughout the Pacific, and the fisheries are expanding into Micronesia. Historically, sea cucumber fisheries have been "boom and bust," with few efforts at sustainable management. In most cases, resources have been depleted, and the financial return to the islands has been only a fraction of their true value. Sustainable resource development depends on a number of factors including an understanding of the biology of the organisms, knowledge about the efficiency of the fishing techniques and the size of the populations being exploited, and the will of "participants" (fishermen, buyers, reef/resource owners and governments) to balance the benefits of short-term financial gain with sustainability and long-term returns through management plans and regulations.

A group of individuals with shared concerns and responsibilities, yet diverse experience and expertise, met to discuss suggestions for sustainable management of sea cucumber resources in the region. The resulting report presents summaries of the ecology, fisheries biology, and economics of sea cucumbers as well as alternatives for managing the developing fisheries. The ultimate success of the meeting can only be evaluated in the future, if the knowledge shared is put to use. However, participants felt this meeting that brought biologists, managers, fishery experts and an economist together was extremely worthwhile and served as a model upon which additional management efforts should be based. Local and regional cooperation are needed if resources are to be used in a sustainable fashion, and the members of the work group exemplified the value of such efforts. The Chair of the meeting and the Principal Investigator of the project are grateful to the participants for their efforts, and hope the knowledge shared here will assist in managing marine resources in a sustainable fashion.

Noah Idechong, Chair
Robert Richmond, P.I.

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Executive Summary

Sea cucumbers are both economically and ecologically valuable marine invertebrates that are easy to capture and, hence, overfish. Eighteen species have been identified from the waters of Micronesia that have substantial commercial value. Those species studied so far have separate males and females that release their eggs and sperm into the water column during limited spawning periods each year. Reductions in population densities can lead to decreased reproductive output and success.

The establishment of a minimum size for possession or sale is necessary to allow maturation and reproduction to support the abundance of future stocks. Larger female sea cucumbers typically produce more eggs and contribute more to future populations than smaller individuals. Size limits are relatively easy to enforce if regulations are established and regulatory agencies are given adequate support.

"Pulse fishing," or fishing every few years, permits an accumulation of larger individuals and bigger populations, both of which support higher reproductive output and success. Marine sanctuaries are another important tool to support population growth in harvested species. Quotas can be established based on either maximum sustainable yield (MSY) or maximum economic yield (MEY), and can be used to limit the amount harvested during a fishing season. Data on population size and distribution are needed as a basis for establishing regulations and for determining their overall effectiveness. Such data can be collected using few people and inexpensive gear. Initial population data and maintenance of harvest records are important to managing the resource.

Harvesting "undersized" individuals results in the loss of economic benefits as well as reproductive stock. The most economically sound means of harvesting is to limit collection to the larger individuals (size categories of 10 - 20 organisms per kg). Harvesting those smaller than 30/kg will result in revenue loss.

Regional cooperation in resource harvesting and marketing allows for maximizing gain by rotating harvesting pressure among species and areas, providing larger individuals worth more money, maintaining reproductive stocks and providing larger numbers for obtaining a higher price in the marketplace.

Suggestions for the Management of Sea Cucumber Resources in Micronesia

Results of the Workshop

"A Regional Management Plan for a Sustainable Sea Cucumber Fishery for Micronesia"
March 3 - 5, 1993

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This is Technical Report 101 of the University of Guam Marine Laboratory
Robert H. Richmond, Editor

Objective: To develop suggestions for a regional management plan for an economically feasible and sustainable sea cucumber fishery for Micronesia.

Rationale: A substantial amount of fisheries data and biological information exists on commercially valuable sea cucumber species. This meeting was organized to bring the technical expertise on sea cucumber biology, fisheries management, and fisheries economics together with the regional fisheries experts for discussions of how to approach sea cucumber fisheries development to maximize the economic benefits to the islands of Micronesia.

Goals:

1) To formulate guidelines and provide technical information to support the development of a sea cucumber fisheries management plan for Micronesia.
2) To provide a forum for regional fisheries officers to express their ideas and concerns, promote interactions, and approach the feasibility of regional cooperation.
3) To discuss plans for future possibilities, coordinating research efforts with regional needs and goals.

Introduction and Overview

Robert H. Richmond
University of Guam Marine Laboratory

In response to expressed and perceived needs for scientists to perform research in support of the development of sustainable fisheries for Micronesia, a grant proposal was submitted to the Salstonstall-Kennedy Program (S-K) to study sea cucumbers as a potential candidate for fisheries development and cultivation. Sea cucumbers have a number of characteristics which make them of particular interest. There are over a dozen species that are commercially valuable within the waters of Micronesia, they are easily caught, they can be dried and hence do not require refrigeration, and they are not an important part of the subsistence diet within the region. Four years of funding were received, and a substantial amount of information gathered. A fifth year of funding was granted to bring together the scientists, the regional fisheries experts and an economist to determine what steps, if any, could be taken to develop a management plan that could be applied to the sea cucumber resources within the region. Considering that Micronesia is composed of a number of different political entities, each with unique social and reef tenure systems, there was a full understanding that such a "plan" would only contain suggestions that could be used by the various islands as seen fit by local leaders and resource managers. There was also the hope that a workshop such as this could lead to further regional cooperation and collaboration among the islands as well as among those having expertise to apply to regional problems and concerns. This report presents the results of the workshop, including technical information that can be applied to a variety of fisheries, not only sea cucumbers.

Sea cucumbers have several characteristics which make them commercially valuable. They are edible, and considered a delicacy by several Asian cultures, including Chinese, Japanese and Koreans, and in some instances, by Pacific Islanders as well. The edible portion of the organism varies among species. In most cases, the body wall is used in soups and vegetable dishes in the same manner one would use chicken, pork or beef. In certain species of *Stichopus*, the five paired longitudinal muscles bands are eaten, while in other types, the intestine is preferred. Palauans like to chew the body wall of a small seagrass associated *Actinopyga* species, known locally as erumrum. The large *Stichopus variegatus* is eaten as "sashimi" in several Pacific islands.

In addition to their value as a food item, sea cucumbers are believed to have medicinal properties, and are sold as an aphrodisiac in several Asian markets. There are also chemicals of biomedical interest in species of sea cucumbers, notably saponins (holothurin) which are toxic to gram-negative bacteria as well as fish (Standaert, et al., 1960; Bingham and Braithwaite, 1986). The common Pacific reef-flat species *Holothuria atra* is used by artisanal fishermen for tide pool fishing and to remove octopi from small caves and crevices. The reddish pigment that is released from the skin of this species is highly toxic to fish. Additionally, the collagen found in the body wall and Cuvierian tubules of holothurians is of commercial interest in the production of glues and adhesives.

The greatest threat to sea cucumber resources is overfishing. These organisms are slow moving, conspicuous, with no defenses against human "predators." Overfishing has already occurred in a number of islands including the Solomon Islands, the Cook Islands, and Fiji. Overexploitation is largely the result of the present fishery system, which usually involves foreign buyers offering a low price to indigenous fishermen for valuable species. The goal of foreign buyers is to get into an area, get as much resource as possible as cheaply as possible, and get out. The goals and interests of indigenous fishermen appear to be quite different; buyers focus on the largest profit in the shortest time period, while indigenous fishermen are usually more concerned with sustainable resource utilization. There is no example of a buyer encouraging sustainable resource utilization in the historical records of sea cucumber fisheries. Once an area is overfished, buyers look for new sources.

The quality of the product, greatly influenced by size, affects the price paid to the fishermen. The relationship between size and price is not linear, meaning a 10% - 25% reduction in length can translate to a 50% reduction in the price paid. This relationship, as applied by foreign buyers, encourages overfishing. As an example, a fisherman may receive $1 for a 20 cm black teatfish. Once the largest specimens are fished out, smaller size classes are captured. Teatfish 15 cm in length may only fetch $0.50, meaning a fisherman must capture twice as many smaller sea cucumbers to match the income produced by selling the larger individuals. As the size drops, so does the price. There are two problems that result: a larger number of individuals are taken for a lot less money, and pre-reproductive individuals are collected, reducing the reproductive stock. Such free-market systems without controls inevitably lead to resource depletion.

Data are sketchy, however there are several reports which document the effects of overfishing: reduction in the number of individuals, a decrease in the population size distribution, and the disappearance of certain species (Gentle, 1979; Trinidad-Roa, 1987; Anon., 1988; Johnson, 1990; Dalzelle, et al., 1993). Data from Micronesia collected during the Japanese Mandate years 1922 - 1936, indicate that approximately 5,124 tons of sea cucumbers were removed from these reefs in the 14 years preceding World War II (South Sea Bureau, 1937; Takehisa, 1940). At an average of 6.6 animals per kg, this equals approximately 30,743,460 sea cucumbers. The recorded values are almost certainly underestimates based on present data recording efforts, and do not include critical periods during World War II, when large numbers of Japanese soldiers were left without food. A survey of eight sites around Chuuk Island performed in 1988 found only 16 species overall, and only two individuals of the black teatfish, *Holothuria nobilis*. These data, in light of the records and anecdotal information on the large number of sea cucumbers exported from Chuuk in particular, suggest that present populations may not have recovered from the heavy exploitation levels from the 1920's - 1940's. Considering the reproductive biology of the commercially valuable species, once population densities are below a certain level, the probability of fertilization of spawned eggs is low to negligible. If an over-exploited area is beyond the distance that allows for the immigration of larvae from source areas, it is conceivable that populations may never recover unless artificial resource enhancement is performed. Knowledge of larval competency periods and oceanic circulation patterns are important for making local as well as regional management decisions.

Ecological problems may also result from overfishing sea cucumber populations. Holothurians are important agents of bioturbation and recycle nutrients in coral reef, lagoonal and reef flat communities. Recent studies have shown that while coral reefs are among the most productive biological communities, this productivity is based on the tight recycling of nutrients starting with the animal-algal coral symbiosis. A high standing stock or biomass occurs on coral reef ecosystems, but high export levels are not sustainable. The export of massive quantities of sea cucumbers (and fish) leads to rapid depletion, and may remove an important source of “raw materials” from a system based on efficient recycling. Sea cucumber larvae and juveniles may also be important links in reef food chains.

One of the most interesting and unfortunate examples of the negative ecological effects of sea cucumber fisheries occurred in the Galapagos Islands. During a four to five month period in 1991 and 1992, the sea cucumber *Isostichopus fuscus* was commercially harvested in the Galapagos Islands, Ecuador. Due to the illegal nature of this activity within the National Park, violations of marine resource regulations and related impacts on the marine and terrestrial environments associated with the fishery, harvesting of sea cucumbers was prohibited in August of 1992 by presidential decree. At the request of the Charles Darwin Foundation and the Government of Ecuador, the World Conservation Union (IUCN) funded an assessment of the situation. A team was organized, including scientists from the University of Guam with expertise in sea cucumber biology and fisheries, and representatives of Ecuador’s National Fisheries Institute (INP), the Charles Darwin Foundation (CDF), The

Universidad San Francisco de Quito and IUCN to perform a preliminary assessment of the sea cucumber resource and implications of its exploitation.

The population surveys showed a highly significant difference among sites. This is attributed to level of exploitation based on interviews with fishermen, park service officials, and Darwin Station scientists who identified the sites where cucumbers were commercially collected. The highest density observed was 183 individuals per 100 m^2 (1.83 per m^2) which occurred in a site not fished. Densities ranging from 0 - 4 individuals per 100 m^2 were encountered in areas which were reported to have had heavy fishing pressure.

Since the fishery was closed in 1992, the research team was unable to visit the camps established on Isabela and Fernandina Islands to observe the land-based activities and impacts first hand. However, a report by Sandra Abedrabbo and Edgar Munoz of the Darwin Station, dated July 30, 1992, summarized the impacts they observed. These included the possibilities of introduced plants, mammals (rats) and insects (ants and cockroaches) to Fernandina Island, which was pristine, and was probably one of the only islands in the world with no introduced species. Protected animals within the National Park, including penguins, boobies, pelicans and sea lions were undoubtedly disturbed by the establishment of villages on these pristine sites. Mangroves were cut to provide fuel and building materials. The fishermen who originally came from the mainland to harvest sea cucumbers began finning sharks and cutting off the penises of male sea lions for the lucrative Asian market. These are serious impacts which may be irreversible in the case of introduced species and may further impact the ecotourism industry which is the backbone of the Galapagos economy.

The density data indicate sea cucumber populations had been completely fished out in certain areas. The long-term ecological effects are not presently quantifiable. At the reported level of exploitation, 130,000 to 150,000 sea cucumbers per day, populations of sea cucumbers would be devastated within a 3 - 4 year period. At the reported price of 100 sucres (ca. US 5.6 cents) each to the boat owner, of which 20 sucres (1 cent) was paid to the diver, the resource was being exploited at a non-sustainable level, and at a fraction of the actual worth. This will lead to the collapse of the fishery, depletion of the resource, and the ecological consequences of species loss.

In a second recent example of unregulated sea cucumber fisheries, the University of Guam Marine Laboratory was contacted by the Government of Yap to comment on a fishery that had commenced in early 1995. As in the Galapagos, a foreign agent had found economically valuable species in the shallow waters surrounding the island, and had begun an “experimental” fishery. While a promise was made of sustainable resource use, no data were collected or recorded on species captured, sizes taken, quantities or locations. There were no pre-exploitation surveys of species abundance, and no information on reproductive timing of species, nor on size of first reproduction. A workshop was held on Yap using a draft of this report, and the suggestions offered by the regional fisheries officers for methods of resource management. The outcome of this workshop was the immediate closure of the fishery until the Yap Marine Resources Management Division was able to put a management plan into effect. The difference between the outcome in the Galapagos Islands and Yap State are attributed to the traditional nature of fisheries knowledge in Micronesia, and the leadership which values marine resources for their cultural as well as economic value. The reef tenure system of Yap State lends itself to management at the village level.

Sea cucumbers are a resource that can be easily overfished. They are conspicuous, slow-moving, and lack defenses against human collectors. Their biology is such that populations can be extirpated quickly, with little to no chances for recovery. In light of these concerns, the regional meeting of Micronesian fisheries officers, biologists and an economist was held. The results of this meeting including suggestions for a regional management plan that could be adopted in part or in whole by the jurisdictions involved are presented here. The expertise and experience of the fisheries personnel were the basis of these suggestions, which are summarized in this report and in the appendix.

Sea cucumbers are both economically and ecologically valuable marine invertebrates. Regional management plans are vital for protecting this important resource.

Section 1

THE BIOLOGY AND ECOLOGY OF SEA CUCUMBERS

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A. Introduction

Sea cucumbers, also known as holothurians or holothuroids, are exclusively marine, benthic (bottom-dwelling) invertebrates. Many species are commercially valuable as a food item in Asian markets, where they are often referred to as Beche-de-mer (beast of the sea) or trepang. Taxonomically, they belong to the Class Holothuroidea, and join their close relatives, the starfish, brittlestars, sea urchins, and crinoids, in the Phylum Echinodermata. This seemingly unlikely combination is based on the shared characteristics of deuterostome embryological development, a secondarily derived radial or bi-radial symmetry (round body plan), a water-vascular or ambulacral system, the presence of tube-feet, and a skeleton which includes calcified ossicles.

Holothurians are globally distributed from the Arctic region, through temperate and tropical waters, to Antarctica. They are found from the intertidal zone to the deep abyss and can be either epifaunal (on top of the sea floor) or infaunal (living buried in the bottom sediments or within cracks and crevices of hard material). Some species are exclusively nocturnal (active at night) or cryptic (hidden), with a pronounced negative phototaxis (avoidance to light), while others are quite conspicuous and actively feed in the open during the day. Species in this latter category often have defenses against predation including toxins in the skin (saponins), the release of sticky threads known as Cuvierian Tubules, and evisceration, a reaction which includes release of the respiratory tree, intestine and gonads through the anal opening (Figure 1-A).

Special adaptations to a particular habitat are often seen, especially in the tube feet, outer skin and feeding tentacles. For example, species such as *Actinopyga mauritiana*, distributed in high energy reef zones, have a well-developed sole or trivium with tube feet adapted for attachment. Species of *Ophiodesoma*, common in sea grass beds, have reduced podia, and use longitudinal muscles for movement. Sea cucumbers can range in size from a few centimeters to over two meters in length. The mouth is surrounded by 10-30 feeding tentacles, which are really modified tube feet. The pharynx, which serves as the passageway into the gut, is surrounded by a circum-oral ring composed of 10 plates: five radial and five inter-radial (Figure 1-A). Besides the microscopic ossicles imbedded in the body wall, the plates in this ring are the only hard-parts within the sea cucumber body. The temporary hardness of some species is caused by the cross-linking of proteins in the body wall, resulting from the activity of the nervous system. In most of the commercially valuable species, the body wall is composed primarily of collagen protein.

Holothurians are predominantly detritivores, passing sand and associated material through a long intestine, although some are suspension feeders, extending their branching feeding tentacles into the water column. Sea cucumbers are ecologically important as agents of bioturbation (bottom mixing), aerating sediments and recycling nutrients, and are believed to be important links in food chains, with their larvae providing a food source for planktivores, and the juveniles supporting a variety of crabs, snails and worms.

B. Reproduction

Sea cucumbers are predominantly gonochoric, having separate males and females, although some species are hermaphroditic, with both male and female gonads found within the same individual. Most sea cucumbers are spawners, with distinct reproductive cycles. Typically, there is a single gonad attached near the base of the respiratory tree (Figure 1-A). Usually, eggs and sperm are released into the water column, where fertilization and subsequent larval development occur, although a few cold-water species have been found to brood their young. Spawning can occur during daylight hours or at night, with individuals raising their front ends up into water column while releasing their gametes from a small pore located almost directly above the mouth, a short distance from the anterior tip. Such spawning behavior can be induced by increased temperatures, and is often seen in tide pools and lagoons during low tides.

While it is important that males and females are synchronized for spawning to be successful, males can be observed to release sperm in the absence of females. The density of sea cucumbers, and the distance between males and females are important factors affecting reproductive success. Migrations and clustering of sea cucumbers have been observed prior to spawning in some species. While eggs do contain a sperm attractant, if the distance between males and females is great, as in populations at low densities, fertilization is not likely to occur. Data from Chuuk Atoll, Federated States of Micronesia, for example, indicate some populations may not have recovered from the over-exploitation that occurred prior to and during World War II, due to insufficient population densities to support successful reproduction.

B.1. Reproductive Timing

Two parameters are considered for the determination of reproductive activity: egg diameter, and gonadal index (the proportion of gonad weight to whole body weight). The first of these has proven to be useful only for the prickly fish (*Thelenota ananas*) which undergoes a period where no gametes can be located, and a period of development in which egg diameters can be observed to increase over time. Both the black teat fish (*Holothuria nobilis*) and the red surf fish (*Actinopyga mauritiana*) frequently possess full-sized eggs throughout the year, thus, egg diameter is not always a predictive tool for determination of reproductive activity. The use of a gonadal index is probably the most practical tool for determining spawning periods for the three species studied.

B.2. Collection of Specimens for Reproductive Analysis

In order to determine reproductive state of a population of sea cucumbers, it is necessary to collect between 20 and 30 animals to ensure an adequate number of males and females. The animals should be placed in large containers filled with seawater immediately following their collection. Thirty to 50 quart, plastic, insulated coolers are ideal. The containers should be covered to reduce direct exposure of the organisms to the sun. The sea cucumbers should be transported in at least four times their volume of water to prevent additional stress due to over-crowding. Agitation of the containers should be avoided as much as possible, since the release of saponins (toxic proteins) from the animals can act as an additional stress factor. The shorter the period from collection to examination, the better. Prolonged periods in transit can result in premature gamete release or evisceration (expelling of the viscera). Individuals that have spawned should be removed from the sample for gonadal index. A running seawater system is recommended for storage after transport.

B.3 Dissection and Data Collection - Oocyte Diameters and Gonadal Index

Since sea cucumbers respire by “inhaling” and “exhaling” seawater through their anal opening, it is necessary to allow all of the water contained in their body cavity and respiratory tree to empty prior to weighing. The animals should be removed from water and allowed to drain for 10-20 minutes to remove this additional weight.

Values for the gonadal index have been reported either using the whole wet weight or the drained weight of the animal. The first of these utilizes the whole weight of the animal after respiratory water has been allowed to drain from the anus, but before it has been dissected. The drained weight is the weight of the animal and all of its internal organs after the internal body fluids have been allowed to drain from the dissected specimen. The value of the latter of these two methods has been most frequently reported in the literature since the weight of body fluids may vary considerably among individuals.

After respiratory water has drained from the animal, the sea cucumber is weighed using a balance or scale accurate to 0.1 g. The animal is then cut open length-wise, mid-dorsally. The gonads are located behind the mouth, adjacent to the polian vesicles and tentacular podia on the right or left hand side (Figure 1-A). The gonads (both testes and ovaries) of *Holothuria* and *Actinopyga* are made up of long tubules, averaging around 50 mm long and 3 mm wide at maturity. These tubules may be singular, joined at their base, or may branch. Color ranges from opaque white or grey to light pink for the ovaries, while the testes are creamy to dirty white. The gonads of the prickly teat-fish (*Thelenota ananas*) are made up of small grape-like clusters which originate from a long gonad with multiple branches. The entire gonad may be in excess of 100 mm in length. Walls of both the ovaries and testes are deep purple in color.

The ovaries are removed and weighed separately from the rest of the body wall musculature and viscera. While the internal body fluids are allowed to drain, all sand should be removed from the gut. The musculature and viscera should then be weighed together. The combined weight of the musculature, viscera, and gonads constitutes the drained weight. The gonadal index is then calculated from the following formula:

$$GI=(G/G+V\&M)100\%$$

Where G is the gonad weight, and V&M is the combined weight of the viscera and musculature. The value is expressed as a percentage. Values are averaged from each sample period to be used as an indicator of the reproductive state of the population. Mean values for animals at their peak typically range between 3-5% for the black teat-fish (*H. nobilis*), 9-14% for the surf-fish (*A. mauritiana*), and 2-3% for the prickly teat-fish (*T. ananas*). Low values for the mean gonadal index are less than 2%, 2%, and 0.5% for the three species respectively (Figures 1-B - 1-F).

Gonads are placed in separate containers and can be refrigerated until they can be observed under a compound microscope. Sperm activity is noted by cutting a length of testes and blotting it on a microscope slide. One to three drops of seawater are added and mixed with the sperm. After sitting for 1-2 minutes, a cover slip is placed on top of the sperm and the sample is observed at high power (~40X). Sperm activity can be noted at this magnification. Egg diameters are obtained by cutting ovaries perpendicular to their length, placing the ovary on to a flat, smooth surface, and gently forcing out the eggs by running a blunt object along its length toward the cut. Ripe or near ripe ovaries will readily yield intact eggs for analysis. Measurement of egg diameter is made using an ocular micrometer and should be done on a depression slide at a lower magnification (~10X). A depression slide is used to prevent distortion due to pressure of the cover slip. As with analysis of the gonadal index, it is necessary to obtain a sample size of 30 to arrive at an estimate of egg diameter (30 or more eggs from an individual is recommended). The diameter of mature eggs is generally around 135 µm for the black teat-fish, 125 µm for the surf-fish, and 165 µm for the prickly teat-fish, although all may vary by as much as 20 µm (Figures 1-G - 1-J).

These studies of the three most commercially valuable species in Micronesia, *Actinopyga mauritiana*, *Holothuria (Microthele) nobilis*, and *Thelenota ananas* found variable reproductive cycles. *A. mauritiana* was found to spawn during the period from April through August, while *H. nobilis* has reproductive peaks throughout the year. Data for *T. ananas* indicates reproductive readiness peaks during the summer months and December, but attempts at induced spawning with this species have been unsuccessful (Figures 1-B - 1-F).

In collections of *H. nobilis*, a sex ratio of approximately 8 males:2 females was observed, while in *A. mauritiana* the sex ration was close to 1:1. Ripe males were observed to release sperm within 20-30 minutes of collection or when stressed with elevated temperatures. Females took an additional 10 minutes to one hour prior to the release of eggs.

B.4. Maturity and Fecundity

The age or size of first reproduction is an important parameter for management of any marine resource. The age-size relationship in sea cucumbers is somewhat confused by the elasticity of the organisms. For regulatory purposes length or circumference are practical, while weight can be converted for a number of species.

Conand (1981) reported the length/drained weight at which 50% of the organisms sampled were mature as 300 mm/1,150 g for *T. ananas*, 227 mm/580 g for *H. nobilis*, and 324 mm/900 g for *H. fuscogilva*. Hopper (1990) found *Actinopyga mauritiana* becomes mature at a size of approximately 153 g. These numbers indicate some sea cucumbers may reach sexual maturity as early as two years of age, and as late as five.

Fecundity estimates for female sea cucumbers indicate large numbers of eggs are released during spawning events, and that as expected with most spawning species, one female 25% larger than another has an increased fecundity of an order of magnitude or greater. Coefficients of fecundity (mean weight of the ripe ovary/cube of the oocyte diameter) were reported as 4,750 for *T. ananas*, 22,800 for *H. nobilis*, 7,350 for *H. fuscogilva*, and 31,000 for *A. mauritiana* (Conand, 1981; Hopper, 1990). Hopper, 1990, estimated ripe females of *A. mauritiana* contain approximately 6.2×10^5 eggs per gram of ovary wet weight.

C. Fertilization and Development

Fertilization in spawning species takes place in the water column. Fertilized eggs undergo numerous cell divisions, typically passing through the blastula and gastrula stages within 24 hours (Figures 1-K - 1-O). Within 48 - 72 hours of fertilization, the embryos develop into a boat-shaped feeding stage called the auricularia, complete with ciliary bands, a mouth (located in the center of the body), and an anus (Figures 1-P - 1-S). At this stage, the larvae are free swimming, and can be observed to feed on phytoplankton, which gives the stomach a green color. As the auricularia continues to feed and grow, small glass-like spicules can be seen developing throughout the body, as well as extensions or lobes containing spheres (Figure 1-T). These spheres, previously believed to be solely lipid, may possess additional structural features (Strathmann, pers. comm.). The late auricularia stage is usually reached in 14 - 20 days, depending upon the species, water temperature and food availability. Three weeks after fertilization, the lobes of the auricularia begin to shrink inward, as the larvae become more cylindrical, developing five or so ciliated bands which encircle the width of the organism. This stage, which includes movement of the mouth and anus to opposite poles and straightening of the gut, is called the doliolaria (Figures 1-U,V). Four to six weeks after fertilization, the larvae become negatively buoyant, and develop tube-feet and oral tentacles. This pentacula stage metamorphoses into the juvenile, which will eventually become a mature adult, completing the cycle.

The larvae produced by tropical and sub-tropical sea cucumber species are planktotrophic (plankton feeders), with indirect development, and must feed, grow, and undergo these several metamorphic changes prior to being able to settle. This period, which lasts approximately 5 weeks in several tropical Aspidochirote species, affects dispersal and distribution of individuals. Knowledge of this period is important for resource management, especially in determining the areas where critical population densities must be maintained in order to seed local sites.

D. Recruitment and Growth

Juvenile sea cucumbers are rarely found, preferring a cryptic existence until a refuge-in-size from predation is attained. Growth rates are initially slow, and depending on species, individuals may take three years to reach maturity and/or a commercially valuable size. Sea cucumbers are reported to live to ages of 15 years or more. While they have substantial regenerative powers, and some smaller species possess the ability to reproduce asexually via fissioning (splitting into two pieces), experiments performed to determine if cutting could be used as a tool for propagation found larger commercially valuable species usually died when “fissioning” was induced.

Relatively little is known about settlement cues in tropical sea cucumber species. Data for other marine invertebrates demonstrates many are sensitive to specific chemical cues found in coralline algae (corals), specific prey species (nudibranchs), or adults of the same species (polychaete worms). Research on settlement cues in sea cucumber larvae is still in progress, and may be an important step in the successful cultivation of commercially valuable species.

E. Biological Diversity and Biogeographical Distribution

The holothuroids are a relatively diverse group, with an estimated 1,100 - 1,200 tropical species, of which approximately 300 are distributed in shallow-waters above 20 meters depth (Feral and Cherbonnier, 1986. Deichmann (1941, 1958), identified 69 species from the Panamic region of the eastern Pacific, including Mexico, Panama, and the Galapagos Islands. Twenty-eight species have been identified from the reefs of Kosrae, Federated States of Micronesia, 15 from Chuuk (Truk), while the holothuroid fauna of Guam includes 30 species (Kerr, 1994; Richmond, 1988; Rowe and Doty, 1977). Greater biological diversity has been found elsewhere: Madagascar has 122 species

(Cherbonnier, 1988), while the tropical to temperate waters of Northern Australia support 126 species (Cannon and Silver, 1986). The commercially valuable sea cucumbers are a subset of the above, with 16 species identified from the waters of Micronesia.

Table 1. Commercially Valuable Species of Sea Cucumbers from Micronesia

Actinopyga echinites
Actinopyga lecanora
Actinopyga mauritiana
Actinopyga miliaris

Bohadschia argus
Bohadschia marmorata
Bohadschia vitiensis

Holothuria atra
Holothuria edulis
Holothuria fuscogilva
Holothuria fuscopunctata
Holothuria nobilis
Holothuria scabra

Stichopus chloronotus
Stichopus variegatus

Thelenota ananas
Thelenota anax

For visual reference, please refer to The South Pacific Commission Handbook no. 18 (revised edition, 1994) "Sea Cucumbers and Beche-De-Mer of the Tropical Pacific: A Handbook for Fishers" ISBN 982-203-381-8.

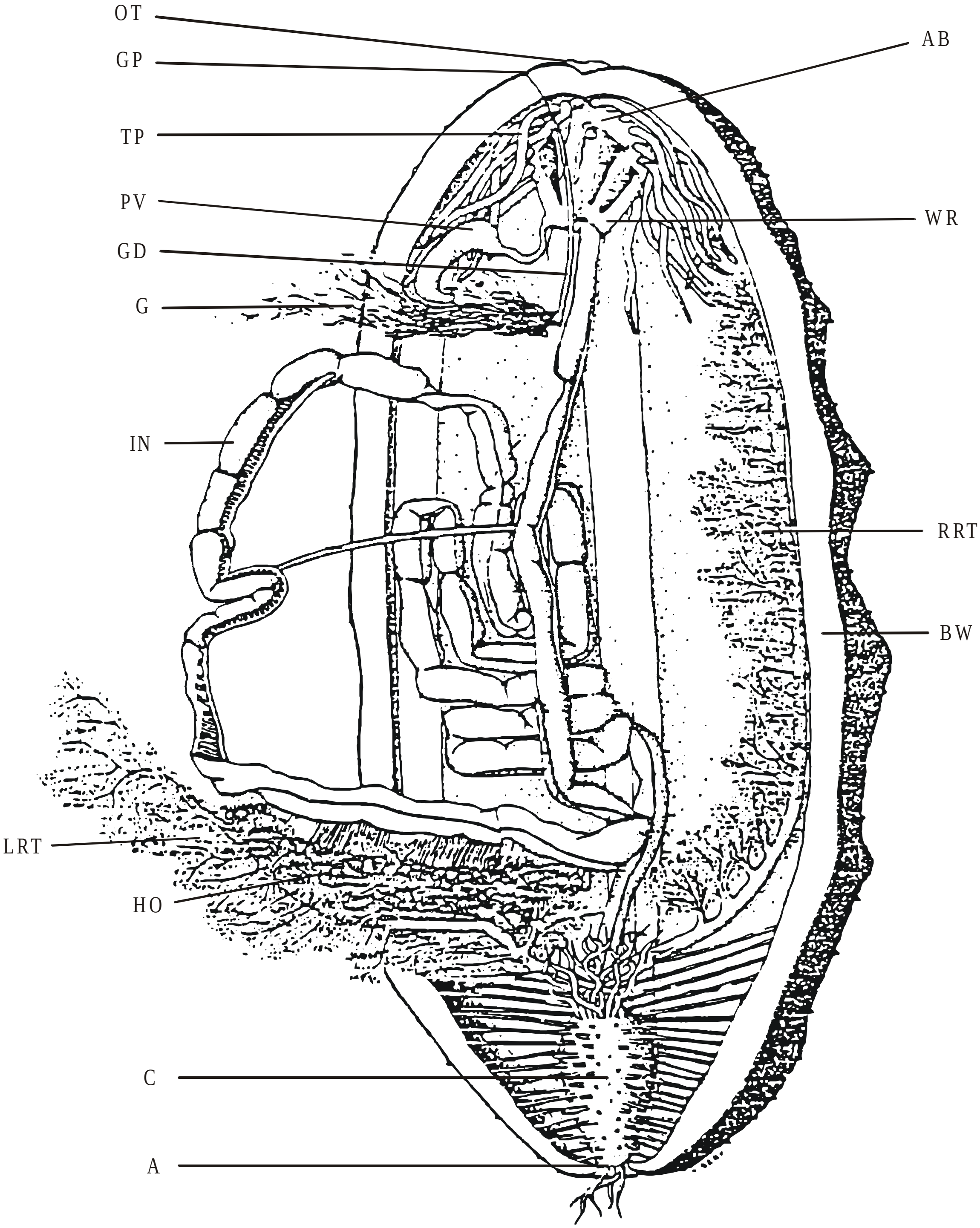


Figure 1. Holothuria nobilis depicting the internal anatomy. OT: oral tentacles; GP: gonopore; AB: aquapharyngeal bulb; TP: tentacular podia; PV: polian vesicles; WR: water ring; GD: gonoduct; G: gonad; IN: intestines; RRT: right respiratory tree; BW: body wall; LRT: left respiratory tree; HO: hemal organ; C: cloaca; A: anus; (modified from Conand, C. 1989. The Aspidochirote Holothurians of New Caledonia Lagoon. ORSTOM. Paris, France.).

Figure 1-B

GONADAL INDEX SUMMARY FOR

ACTINOPYGA MAURITIANA (1988–1990)

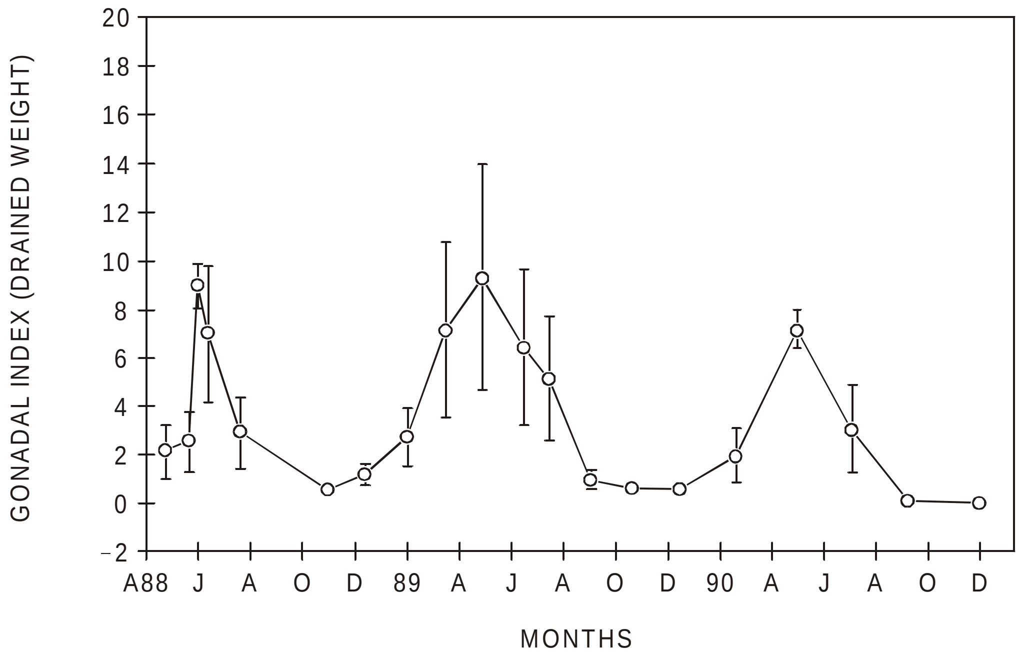


Figure 1-C

GONADAL INDEX SUMMARY FOR

HOLOTHURIA NOBILIS (1988–1990)

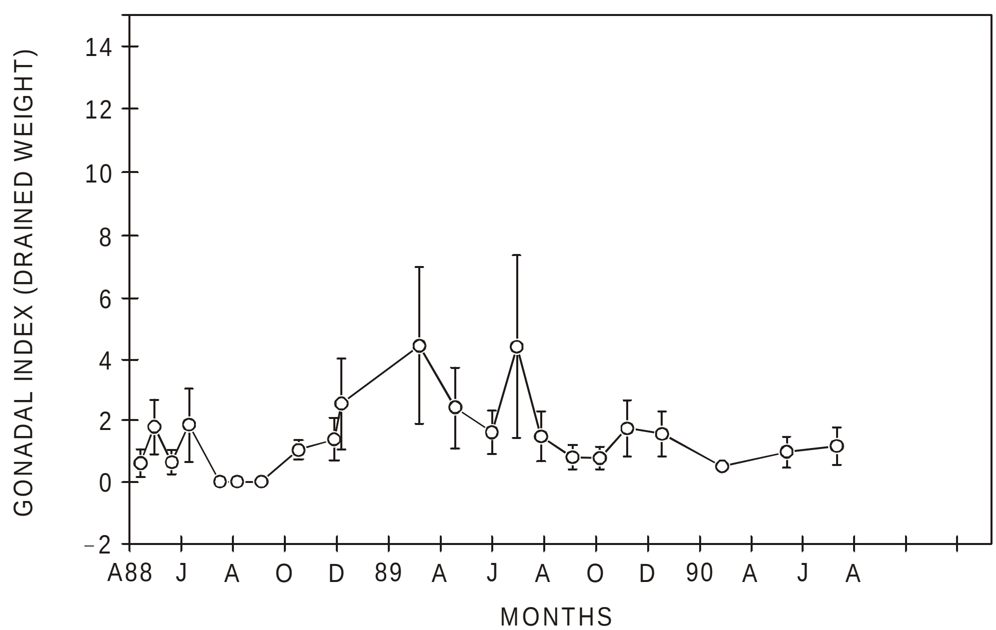


Figure 1-D

GONADAL INDEX SUMMARY FOR

THELENOTA ANANAS (1988–1990)

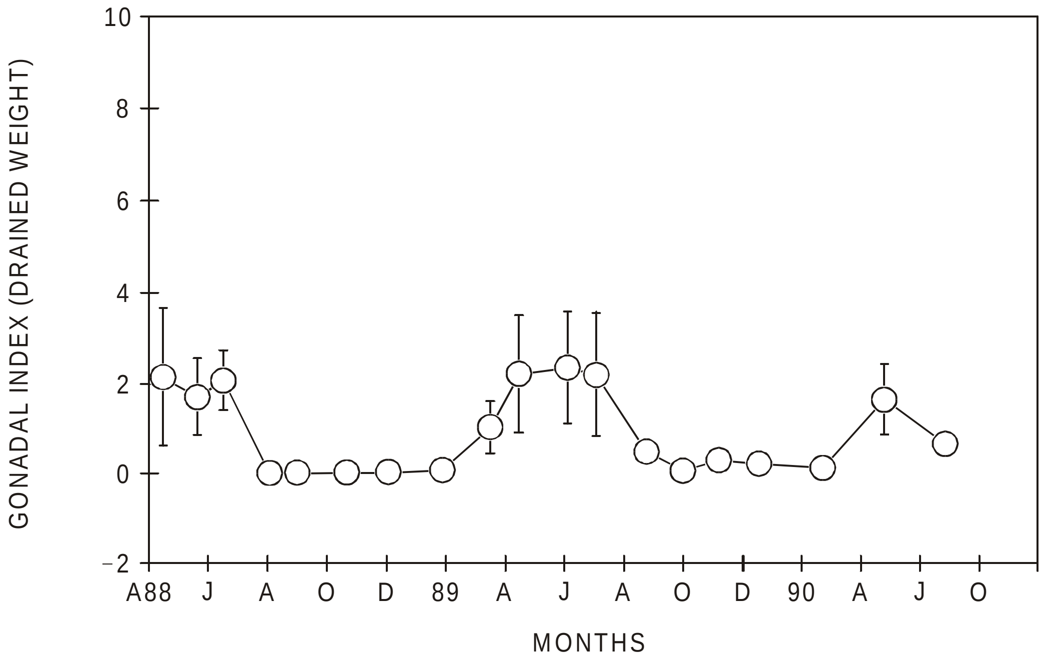


Figure 1-E

GONADAL INDEX SUMMARY FOR
THREE SPECIES OF GUAM HOLOTHUROIDS
1988–1990

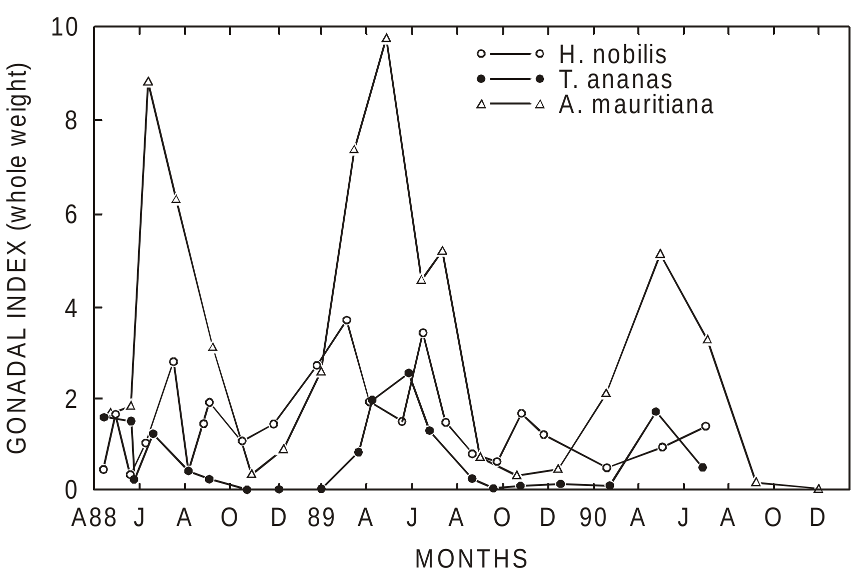


Figure 1-F

GONADAL INDEX SUMMARY FOR
THREE SPECIES OF GUAM HOLOTHUROIDS
1988–1990

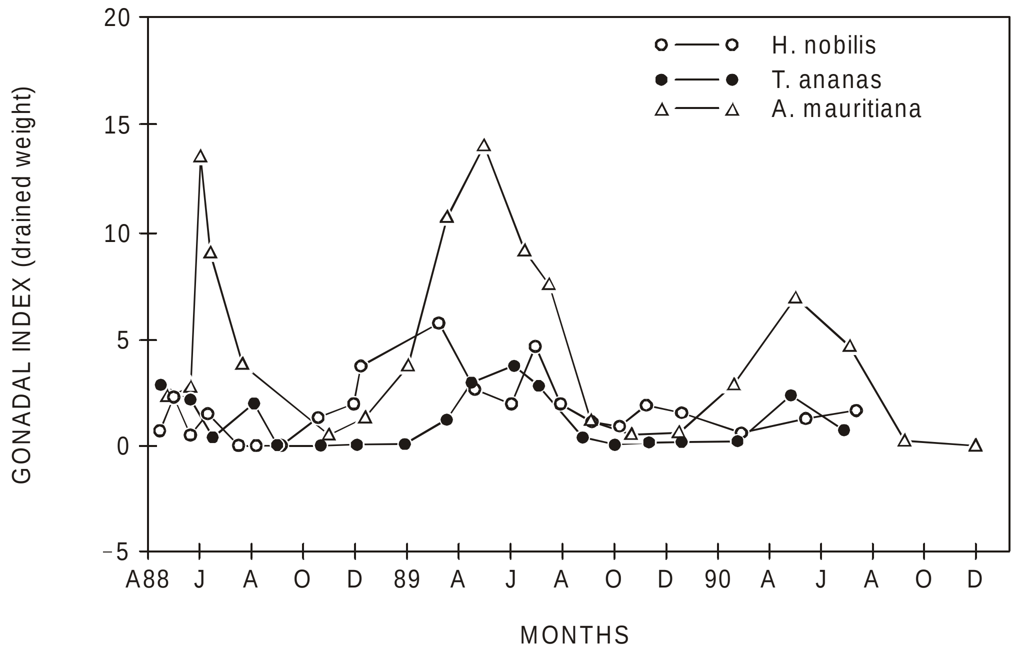


Figure 1-G

OOCYTE DIAMETER SUMMARY FOR

ACTINOPYGA MAURITIANA (1988–1990)

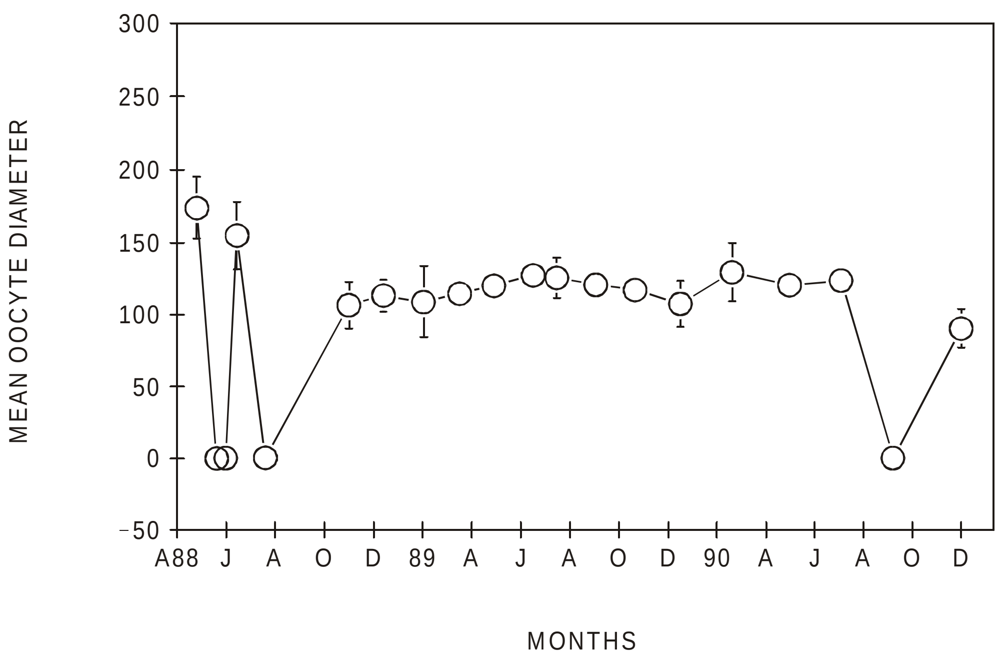


Figure 1-H

OOCYTE DIAMETER SUMMARY FOR

HOLOTHURIA NOBILIS (1988–1990)

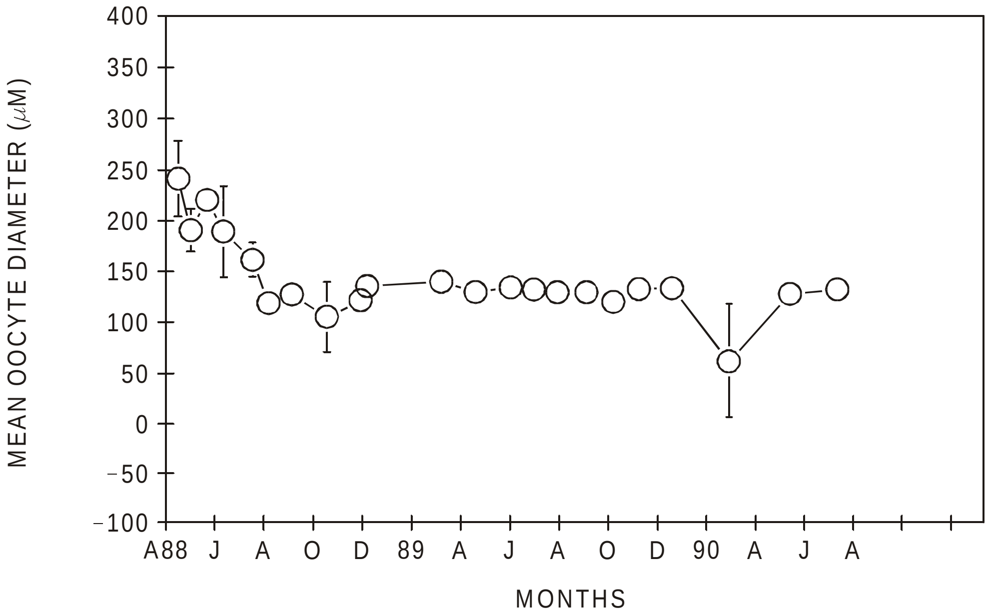


Figure 1-I

OOCYTE DIAMETER SUMMARY FOR

THELENOTA ANANAS (1988–1990)

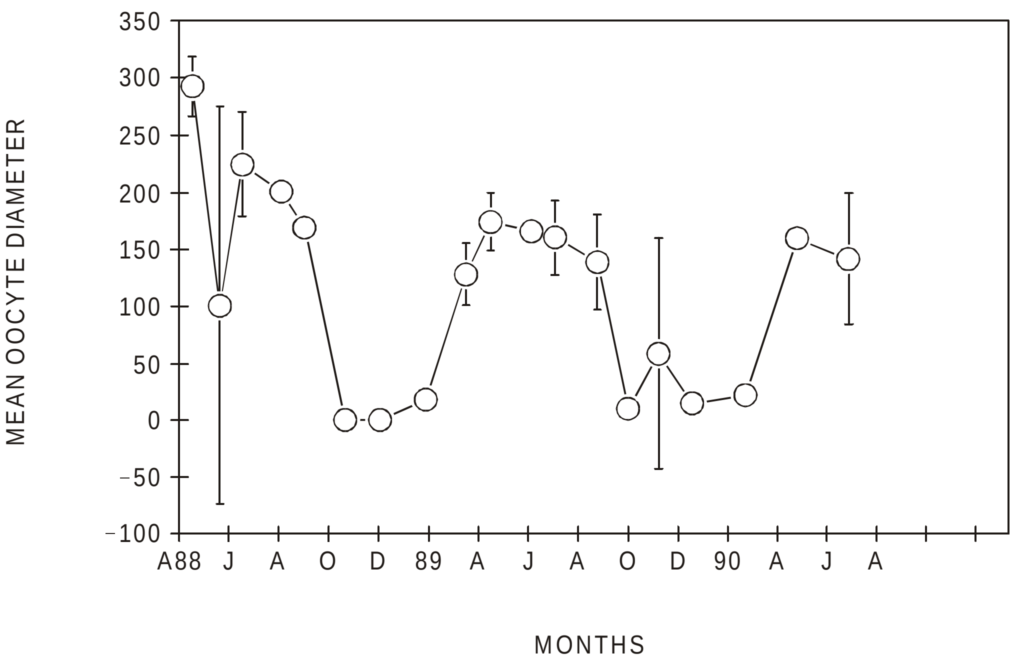


Figure 1-J

OOCYTE DIAMETER SUMMARY FOR
THREE SPECIES OF GUAM HOLOTHUROIDS
1988–1990

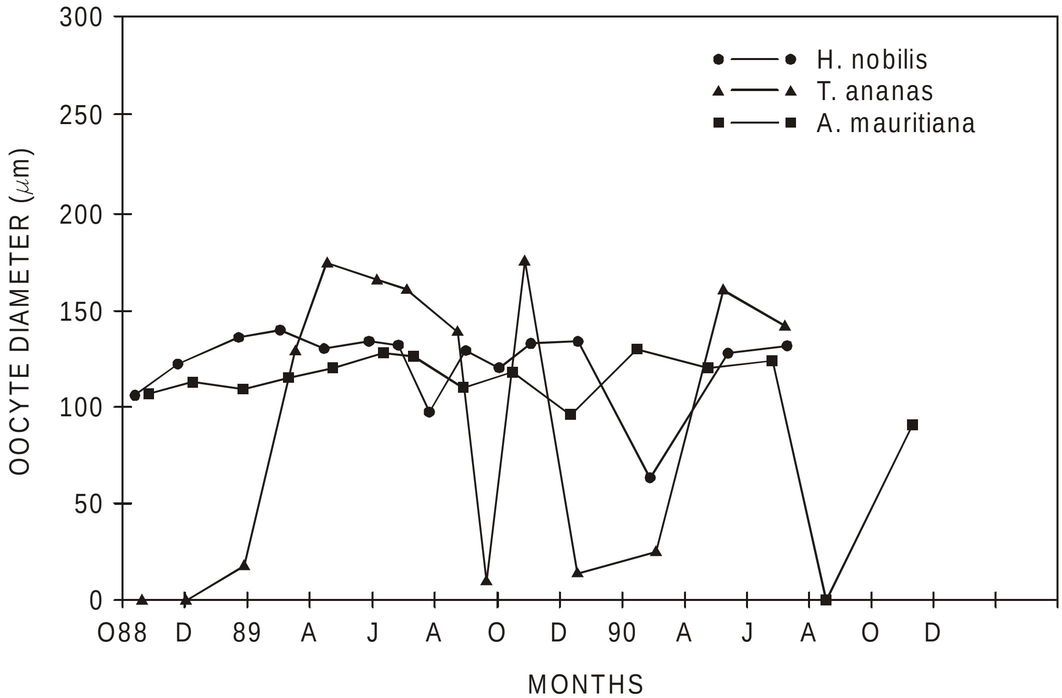


Figure 1-K.
Holothuria nobilis 4 hours after fertilization. (diameter ~.14 mm)

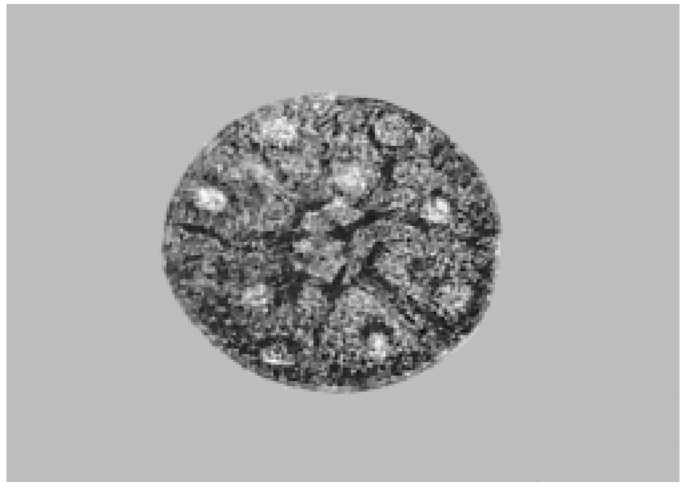


Figure 1-L.
Holothuria nobilis 6 hours after fertilization. (diameter ~.14 mm)

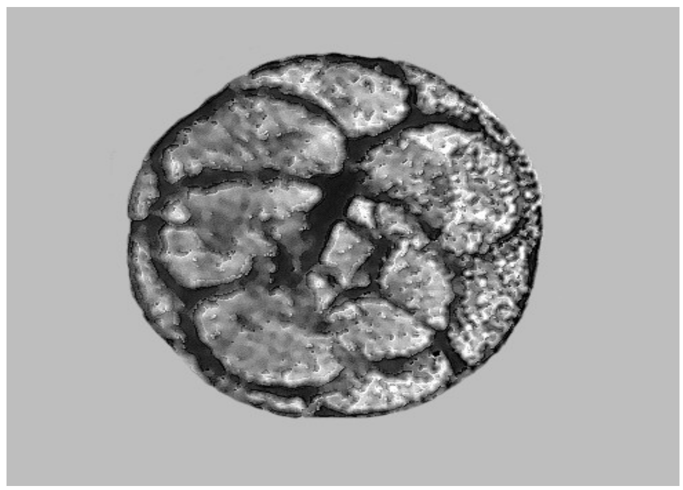


Figure 1-M.
Holothuria nobilis 10 hours after fertilization. (diameter ~.14 mm)

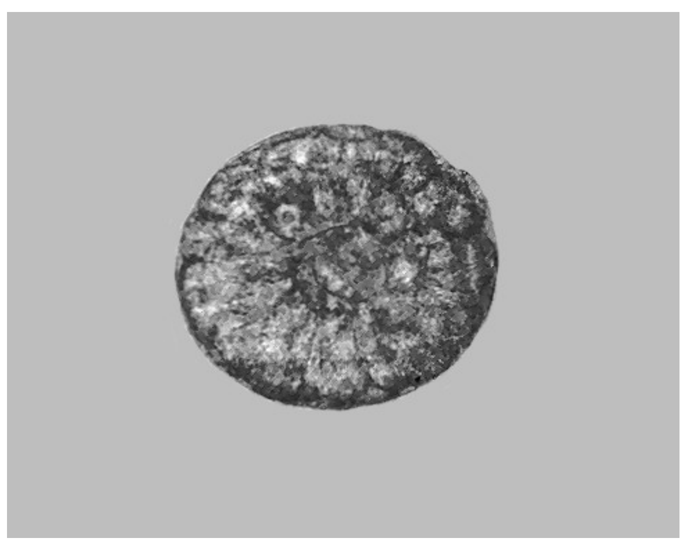


Figure 1-N.
Holothuria nobilis 20 hours,
blastula stage.
(length ~.18 mm)

Figure 1-O.
Holothuria nobilis 30 hours,
gastrula stage.
(length ~.18 mm)

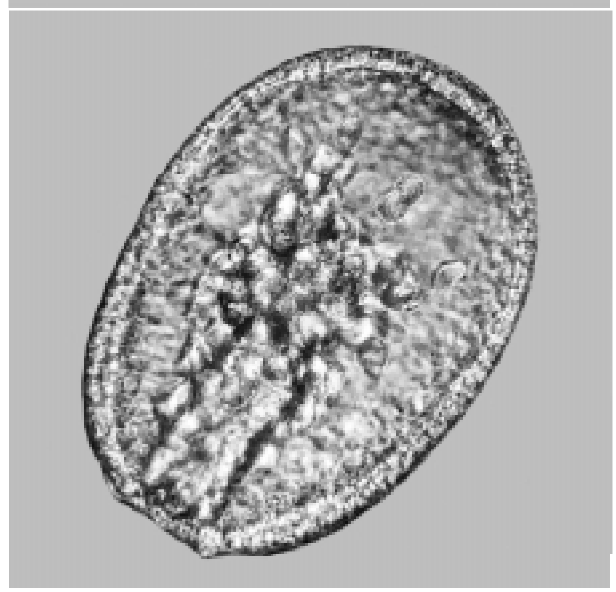


Figure 1-P.
Holothuria nobilis 40 hours,
pre-auricularia.
(length ~.30 mm)

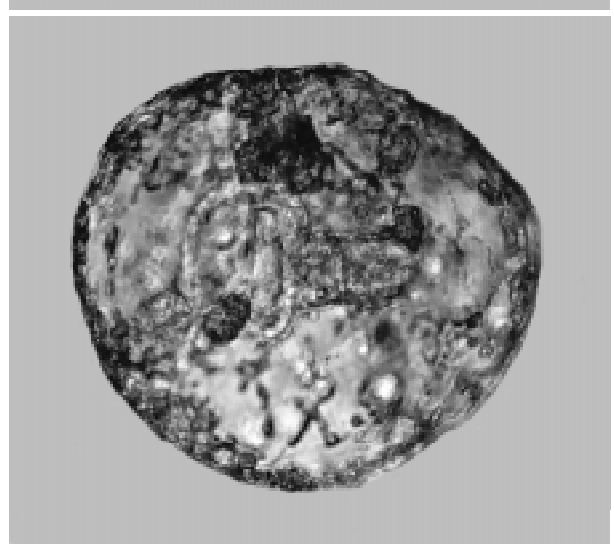


Figure 1-Q.
Holothuria nobilis 50 hours,
early auricularia.
(length ~.40 mm)

Figure 1-R.
Holothuria nobilis 60 hours,
auricularia.
(length ~.45 mm)

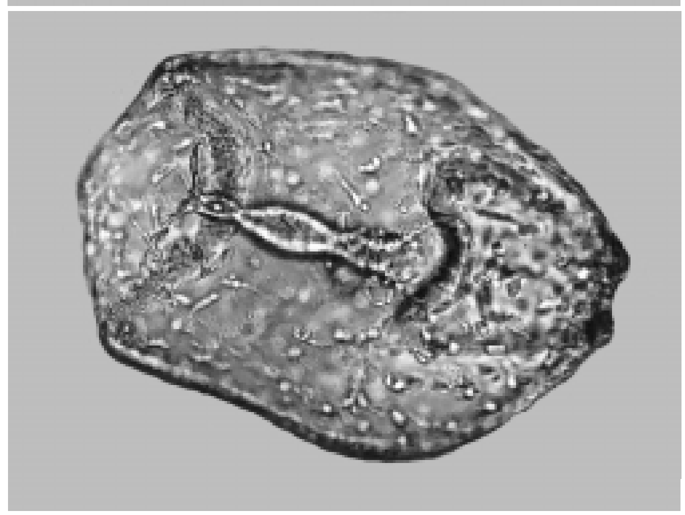


Figure 1-S.
Holothuria nobilis 72 hours,
primary stage auricularia.
(length ~.45 mm)

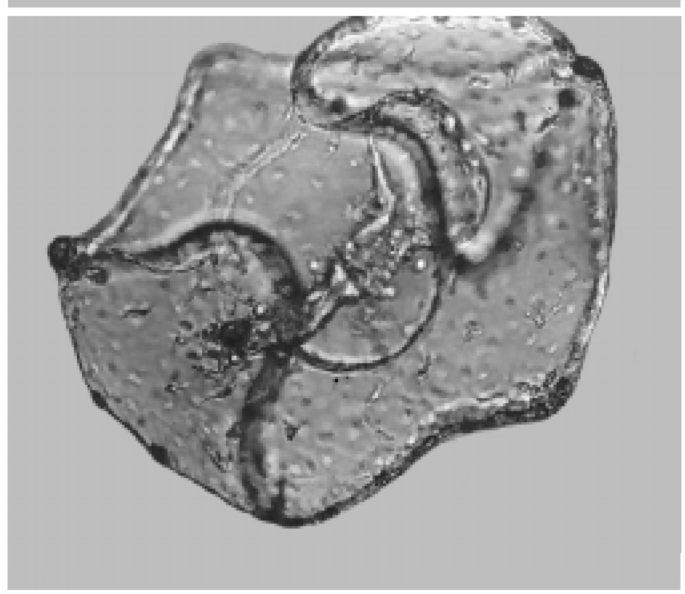


Figure 1-T.
Holothuria nobilis 14 days,
secondary stage auricularia.
(length ~.55 mm)

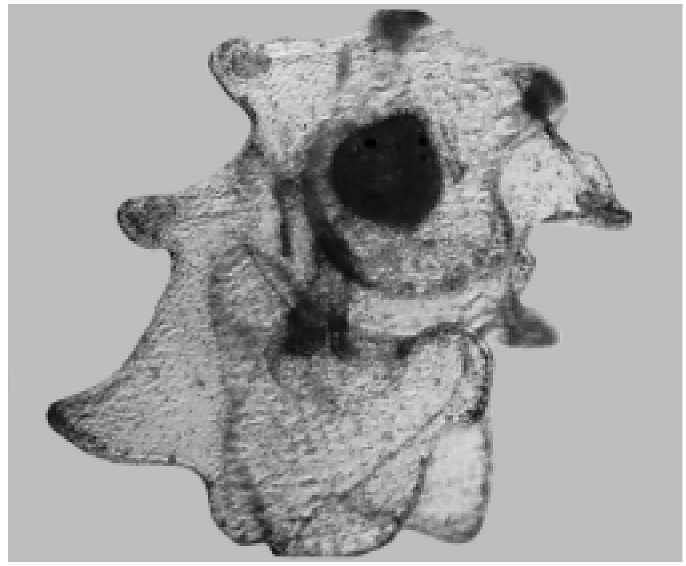


Figure 1-U.
Holothuria nobilis 20 days,
early doliolaria.
(length ~.25 mm)

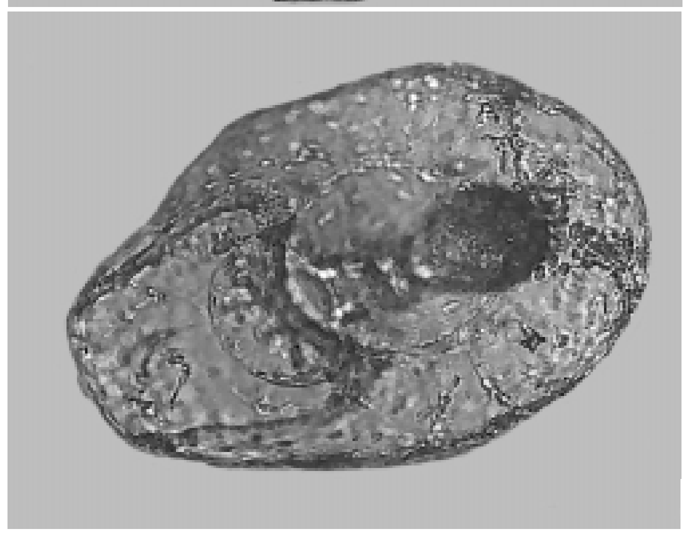
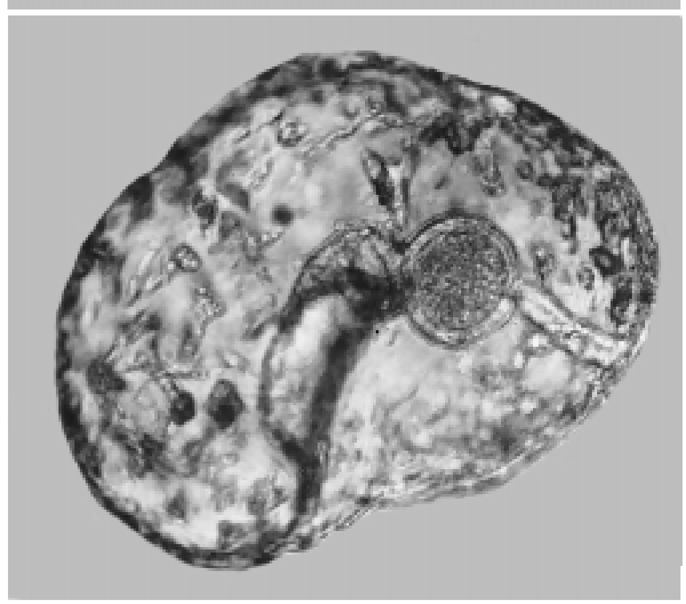


Figure 1-V.
Holothuria nobilis 25 days,
doliolaria.
(length ~.25 mm)



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Section 2

MANAGEMENT OF BECHE-DE-MER RESOURCES IN MICRONESIA

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A. Introduction

Developing management strategies for an exploited fishery resource is more like custom tailoring than cooking from a recipe book. A number of specific details of the biology of the resource species, harvesting, processing, and marketing methods, and the social and economic context of the fishery must be considered. Frequently information on these details is not immediately available, and provisional management decisions must be made before all the necessary information is in hand. Additionally, management strategies must be modified over time as new information becomes available and as technological and economic changes affect the fishery.

Perhaps the most important consideration in the design of a fishery management strategy is deciding on the objectives of management: What do we want to achieve in managing this fishery? Objectives may be economic (e.g., maximizing profits), social (e.g., maximizing recreational opportunities), or biological (e.g., preventing the collapse of stock productivity), and, of course, more than one objective may be pursued.

The various management options discussed in this chapter focus on preventing stock collapse as this, at least, must be assured before other objectives can be sought. There is some mention of other objectives (maximizing sustainable fishery yields and maximizing economic yields) in the chapter, and conceptual methods for achieving these goals are discussed.

As will be seen, choices among management options depend to a large extent upon the availability of information about the fishery and the stocks. In the Micronesian beche-de-mer fisheries, which are the focus of this discussion, little data are immediately available for management purposes. Thus the subject of a subsequent chapter is methods for gathering appropriate data which can provide the basis for better management decisions.

B. Minimum Size

A management strategy which is primarily aimed at maintaining the reproductive capacity of a stock is the establishment of a minimum size for possession or sale. This is a commonly used fishery management technique which is generally acceptable to harvesters and which is relatively easy to enforce. The rationale for the measure is to protect younger animals from harvesting until they have grown and matured sufficiently to reproduce and to contribute to the abundance of future stocks of the resource species.

Most simply a minimum size regulation would be set so that the minimum size was somewhat larger than the size at first reproduction for the stock, which would give each individual an opportunity to reproduce before it was susceptible to capture. However, with a bit more data on the ecology of the resource species, it is possible to adjust the minimum size more precisely to achieve any specific desired level of reproduction for the stock.

The types of data that are needed for establishing an appropriate minimum size for a harvested stock are the following:

1) the size-frequency distribution of a virgin (unharvested) stock;
2) size-specific sex ratios of the stock;
3) size-specific rates of female sexual maturity;
4) the relationship of body size to egg number among females of the stock; and
5) species-specific conversion factors among various relevant size measures (e.g., live length, drained weight, processed weight, etc.)

> The establishment of a minimum size for possession or sale is necessary to protect sea cucumbers from harvesting until they have matured sufficiently to reproduce and contribute to the abundance of future stocks.

B.1. Size-Frequency Distribution

A size-frequency distribution is a graph or table that shows what proportion of the population is contained within different size classes. An example of such a size-frequency distribution for the sea cucumber *Actinopyga mauritiana* on Guam is shown in Figure 2-A. The "size" used in this figure is drained weight, but could have been length or processed weight or some other convenient measure of size. This graph is based on drained weight measurements of 214 animals ranging in size from 100 to 510 g; individuals are lumped into 10-g size categories, and the percent of the total 214 animals that fall in each 10-g category is shown.

For subsequent analysis it is necessary to convert the size-frequency distribution into a cumulative size-frequency distribution (Figure 2-B), which, by adding the percentage of a given size category to the percentages falling in all smaller size categories, gives a graph that shows what percent of the population is of a given size or smaller. In Figure 2-B, for example, 20% of the population is 230 g or less in drained weight; 100% of the population is 510 g or less.

To acquire the data necessary for constructing these distributions, it is necessary to identify an unharvested or virgin population of the resource species. If that is not possible, then select a population which has been subject to little fishing pressure.

The individual animals which are measured must be selected in some representative, unbiased way. The bigger the sample size the better. Usually length is the easiest measurement to make, but weight may be more consistent. Sea cucumbers are somewhat flexible (and some species are very flexible); thus length measurements are subject to a certain amount of variability. Wet weight is variable, too, depending on the amount of water retained in the body cavity. Dry weight is probably the most repeatable size measurement, but requires considerably more labor to determine and of course cannot be used in the field on live animals.

A recommended procedure for collecting data for constructing the size-frequency relationship is presented in section 3 on data collection.

B.2. Size-Specific Sex Ratios

Because the reproductive capacity of the stock in this analysis is determined by female reproductive output, it is necessary to determine the percentage of females in the population at all sizes. If the female:male sex ratio remains the same at all sizes (as it does with *Actinopyga mauritiana* in the example) then the cumulative percent of individuals in the population at different sizes will be the same as the cumulative percent of females in the population at different sizes. If the sex ratio changes with size, then the cumulative population size distribution must be converted to a cumulative female size distribution by multiplying the number of individuals in each size category by the proportion of females in that size category. Once this is done for all size categories, the numbers are readjusted to produce a cumulative percent size distribution of females (Figure 2-C).

To establish the size-specific sex ratios for a species of sea cucumber, it is necessary to secure specimens over a range of sizes and to dissect them to determine their sex on the basis of their gonad type (holothurians do not have external indications of their sex).

B.3. Size-Specific Female Sexual Maturity

The procedures for determining the size-specific sex ratios, described above, will also provide data for determining size-specific rates of sexual maturity among females.

Typically among sea cucumbers, as among other animals, there is some size at which females begin becoming sexually mature; by the time some larger size is reached, virtually all females are sexually mature (Figure 2-D). Since only sexually mature individuals are able to contribute offspring to future populations, the cumulative size distribution curve for females must be adjusted to produce a cumulative size distribution curve for sexually mature females (Figure 2-E).

B.4. Egg Number/Female Body Size Relationship

Typically, larger females produce more eggs than do smaller ones; thus larger females make greater contributions to the abundance of subsequent generations. To factor this relationship into the cumulative reproductive contribution curve, it is necessary to determine the relationship between female size and egg production. In the simplest case, it can be assumed that the number of eggs produced is directly proportional to the weight of the sexually mature female, without actually knowing what that proportion is. In the case of the holothurian *Actinopyga mauritiana* in Guam, it has been determined that on the average 14% of the drained weight of the female is made up of ovary, and 1 g of ovary contains 6.2×10^5 eggs (Figure 2-F). When this relationship is incorporated into the cumulative reproductive contribution relationship, the graph of Figure 2-G is produced. This graph shows the cumulative production of eggs by females of a given size or smaller. For example, 20% of the eggs produced by this stock are produced by females with drained weights of 275 g or less; 50% of the eggs are produced by females with drained weights less than or equal to 330 g; and 80% of the eggs come from females of 375 g or less drained weight.

> Larger female sea cucumbers typically produce more eggs than small females and thus, contribute more to the abundance of future generations.

B.5. Selection of Minimum Size

The graph of Figure 2-G provides the basis for selection of a minimum size which will protect some desired proportion of the reproductive capacity of the stock. A prudent, perhaps conservative, goal would be to preserve 50% of the reproductive capacity of the stock. This could be achieved by enforcing a regulation which prohibited the harvest of *Actinopyga mauritiana* individuals which have drained weights less than or equal to 330 g.

Other minimum sizes could be selected if protection of other reproductive capacities were to be the goals of management. Some fishery scientists have suggested that maintenance of 20% of virgin spawning potential is an appropriate goal (although there is little empirical data to support this suggestion). In the present example, 20% of the reproductive capacity or spawning potential would be provided by individuals with drained weights of 275 g or less.

A phenomenon known as the Allee effect has been proposed for various echinoderms wherein spawning becomes less effective when animals are at low densities because the animals are broadcast spawners and at low densities eggs may not encounter sperm and be fertilized before they are carried out to sea by water currents. If the Allee effect is a significant factor in fertilization success among sea cucumbers, then it would be safer to select a somewhat larger (more conservative) minimum size.

> A phenomenon known as the Allee effect occurs when the number of reproductively mature sea cucumbers is low, resulting in low fertilization and low reproductive success.

B.6. Expression of Minimum Size in Appropriate Form

Because the reproductive analysis of *Actinopyga mauritiana* used in the example was based on drained weight of animals, the minimum size to protect a given spawning potential, shown in Figure 2-G, is expressed as drained weight. Although convenient for the biologist, drained weight is not a useful measure for the harvester who sees the animals alive in the field and does not often have a scale available. Nor is it useful at the marketplace where cucumbers are most frequently marketed eviscerated and dried. Therefore it is necessary to determine conversion factors so that minimum sizes can be expressed in appropriate form for different users. This can most conveniently be done by measuring and weighing a group of animals at various stages of the fishery process: at the time of harvest, after draining, after eviscerating, and after drying. Regression formulas used to express the relationships among these various measurements can be used to calculate appropriate equivalent minimum lengths or weights for the various stages of the process.

There is a natural range of variability among sea cucumbers in these various size measures and some problems may be anticipated. Some sea cucumbers which appear to be “keepers” when compared with a minimum live length measure, for instance, will prove to be underweight when finally dried and processed. There is no real practical remedy for this except to prohibit sale of the undersized product, even though the harvester was innocent of any wrongdoing in retaining the animal originally. Compromises such as allowing a certain percentage of undersized individuals to be marketed would seem appropriate, but these compromises ultimately make enforcement of minimum sizes unworkable.

The method used for measuring the minimum harvesting size of sea cucumbers should be convenient for both enforcement personnel and harvesters.

B.7. Evaluation of Minimum Size as a Management Tool

The principal advantage of using a minimum size for managing an export sea cucumber fishery is that all the enforcement can be done at the marketplace. There is no need to patrol for poaching or to intercept harvesters while they are fishing. Since the prices of sea cucumbers are based on size, the cucumbers will have to be weighed at the market anyway, providing an opportunity to detect undersized animals.

The principal disadvantage is that rejected undersized animals are already dead, and so they represent a loss to the reproductive capacity of the stocks as well as an economic loss to the harvester/processor. There can develop a tendency under this situation to go ahead and allow the sale of undersized animals since they are of no use to anyone otherwise. This practice, however, will undermine the effectiveness of the management effort and should be resisted.

Because the management measure is based on details of the life history of specific species of sea cucumbers, the appropriate minimum size will be different for different species. This makes enforcement somewhat more complex, but since market prices also differ from species to species, the identity of the sea cucumbers will have to be determined anyway. The primary burden is on the harvester who must determine the species being harvested and then determine whether the animal meets the minimum size requirement for that species. Ideally, harvesters could be provided with some sort of plastic ruler or template with the minimum size for each commercial species (as live length) indicated on it. The harvester could determine whether the animal was a “keeper” with little expenditure of time or handling of the sea cucumber.

Although minimum size regulations are rather simple to enforce, a significant amount of data, as described above, are required to determine what the minimum sizes for the different species should be. The collection and analysis of these data need be carried out only once, however (although updates may be desired from time to time), unlike annual quotas or similar measures which require constant data collection and analysis.

A further disadvantage of relying on minimum size for management is that this method does not guarantee that the maximum sustainable yield will be harvested nor does it predict how many sea cucumbers will be harvested in any given year. The expected course of events in a fishery managed solely by minimum size is that harvests will be large in the initial years of the fishery as all individuals larger than the minimum size will be subject to harvest. In time, "legal-sized" individuals will become scarcer and scarcer, and the annual production of the fishery will depend on how many animals grow from less than legal size to legal size in a year. Thus the harvest will come to consist almost completely of animals right at the legal size and the catch will stabilize at a level equal to the number of undersized ones reaching legal size in a year.

> Minimum size regulations are rather simple to enforce, but require a substantial amount of data to determine what the minimum size for each sea cucumber species should be.

B.8. Minimum Size and Pulse Fishing

The concept of "pulse fishing," harvesting a stock heavily, letting it "lie fallow" for a few years, and then harvesting it heavily again, has often been associated with a "rape and run" style of exploitation. However, when the heavy fishing during the pulse is controlled, as with a minimum size, this fishing strategy offers some advantages to a beche-de-mer fishery.

If fishing is allowed during every fifth year, for example, then there will be a five-year accumulation of legal-sized individuals available for harvest. In addition, there will be individuals who have grown to sizes considerable greater than the minimum size which will be more valuable in the marketplace. By having a larger harvest, containing larger individuals, it may be easier to attract buyers for the product as shipping and handling costs are proportionally reduced by economies of scale.

There are disadvantages for the harvesters in that they cannot fish four years out of five and would need to seek alternative employment during years when the fishery was closed. In an archipelago large enough, it may be possible to establish five fishing areas and open a different one each year. This would provide continuing employment for the harvesters and also provide the pulse fishing advantages: more abundant legal-sized individuals of larger size.

One approach to pulse fishing would be to design a system whereby different island states would rotate harvesting closures among species and states so that when the harvest of a particular species was closed in one state, it would be open in others. This would allow each species to enjoy a respite from harvesting in each island area, but by having each area on a different schedule, there would be continuing availability of that species from somewhere in Micronesia. With this system there would always be some beche-de-mer species to harvest at each island state.

It would be relatively easy to enforce closed fishing years, particularly if there were a central processing location. Rotating closed areas is more difficult to enforce, particularly when remote areas are involved.

In the absence of major disturbances, such as typhoons or poaching, the harvest should remain relatively constant from pulse to pulse once the initial "fishing down" of the virgin stock has occurred, making it possible to reasonably predict the catch once a record has been established.

> "Pulse fishing", or fishing only every few years, permits an accumulation of larger, legal-sized sea cucumbers available for harvest

C. <u>Sanctuaries or Refuges</u>

A management approach which has gained in popularity in recent years is the use of marine sanctuaries or refuges to protect a portion of the spawning stock, with the idea that larvae produced by spawners within the refuge will be carried by water currents to other areas of the reef where they will settle and ultimately become harvestable individuals. However, there is as yet no widely accepted body of principles for designing sanctuaries to adequately serve this function. Factors fundamental to the design of effective sanctuaries are size, shape, and number of sanctuaries, their locations relative to larvae-dispersing currents, and the type of activities that can be allowed in them without compromising their function as recruitment sources.

Establishing refuges for beche-de-mer may quickly lead to a situation where the abundance of sea cucumbers is very high within the sanctuaries and very low elsewhere in areas open to harvest. This situation could be practically irresistible to poachers, and it would require constant, vigilant enforcement to prevent the destruction of the spawning stock within the refuge.

Enforcement could be made more effective by locating the refuges near population centers where enforcement personnel could more easily monitor harvesting activities, but these areas are generally ones that are more subject to pollution and may already have low beche-de-mer densities from previous harvesting. Refuges located in outlying areas may be in better locations for the conditions of the stocks, but are, of course, much more difficult to protect from illegal harvesting. And, in any case, the refuges should be located in areas which will permit their larvae to be distributed to the rest of the reef.

If sanctuaries are established to protect a variety of marine life, as for example sanctuaries set up to be recreational diving and snorkeling areas, these will provide some protection to the spawning potential of beche-de-mer stocks, but, with our present state of knowledge, sanctuaries by themselves do not appear to be effective tools for managing sea cucumber fisheries.

> Establishing marine sanctuaries to protect a portion of the spawning stock, together with other management tools, may be an effective method for managing sea cucumber fisheries.

D. Quotas

A quota is a set limit to the amount of resource that can be harvested during any year or fishing season. Quotas are usually established so that some desirable level of harvest, such as maximum sustainable yield (MSY) or maximum economic yield (MEY) will not be exceeded. When the quota limit is met, then harvesting ceases until the next fishing year. To be useful, then, a desired maximum catch (MSY, MEY, or some other value) must be established so that the quota can be set, and continuous monitoring of the catch must be carried out to determine when the quota is reached. There must then be a way to inform harvesters that the fishery is closed for the rest of the fishing year.

The following diagrams and discussion explain the concepts of maximum sustainable yield and maximum economic yield. Methods for estimating these values will then be discussed.

Figure 2-H shows the course of events (highly idealized) in a hypothetical beche-de-mer fishery. The graph shows the changes in the amount of catch (in kg) as harvesting effort (measured in man-hours) increases from 0 to 500 man-hours. What happens is that total catch increases, but the rate at which it increases decreases over time; that is the 50 person-hours of harvesting effort between 0 effort and 50 person-hours of effort results in a catch increase of almost 500 kg, while the 50 person-hours added from 400 to 450 person-hours only adds about 100 kg of catch. This is a typical characteristic of any limited fishery resource.

The consequence is that additional fishing effort becomes less and less effective as the fishing effort increases. This is illustrated in Figure 2-I which shows the catch per unit effort (CPUE) in kg per person-hour decreasing as the harvesting effort increases. The consequence of this relationship is that the catch will increase from 0 when there is no fishing to some maximum point (here when fishing effort equals 500 person-hours) and then will decrease if fishing effort grows beyond 500 (Figure 2-I). The highest point on the catch curve (where the curve reaches 2500 kg) is the maximum sustainable yield

(MSY), and in theory it would be possible to harvest 2500 kg every year if the harvesting effort were kept to 500 person-hours annually.

If we had the data from a beche-de-mer fishery necessary to do the analysis just described, we could set an annual quota of 2500 kg in order to achieve the maximum sustainable yield from this fishery.

Figure 2-J illustrates a further refinement of this analytical technique to achieve maximum economic yield (MEY) which is the catch that will provide the greatest economic yield, i.e., profits, over a long period of time. In this analysis we determine the value of the catch at each catch level by multiplying the catch in kg times its value in $ per kg. This gives the value of the catch curve which has the same arc shape as the catch curve of Figure 2-I but now is expressed as $. Then we determine the cost of the harvesting effort by, in this case, multiplying the person-hours of effort times the hourly rate of labor. This produces the upwardly slanted "cost of harvesting" line. The difference between these two lines (value of catch minus cost in harvesting it) represents the profit made. As long as the value curve is higher that the cost curve, the fishery is making a profit, but where costs exceed value (when harvesting effort exceeds 900 person-hours in the example), the fishery is operating at a loss.

In Figure 2-J, the profit is also graphed and rises to a maximum at a harvesting effort of 450 person-hours and then drops beyond that. Thus the maximum profit or MEY is at the point where harvesting effort is 450 person-hours and catch is about 2475 kg (slightly less than the MSY). Thus, if we had cost and value (price) data in addition to the catch and effort data we could set the quota at 2475 kg per year to achieve maximum economic yield.

> Quotas are established based on either the maximum sustainable yield (MSY) or the maximum economic yield (MEY) and set a limit to the amount of resource that can be harvested during any year or fishing season.

D.1. Determining MSY

There are a number of ways for determining (or estimating) MSY in a fishery, and the method used depends primarily on the kind and quality of the data available on the fishery. One technique is the use of the Schaefer Model which requires data on the total catch and total fishing effort in the fishery over a number of years. These data are used as described in Figures 2-H and 2-I in the above discussion to determine a value for MSY. Data of this type are not presently available for any beche-de-mer fisheries in Micronesia, but it would be extremely helpful to begin collecting these data for future use.

Other techniques require data on various biological parameters of the harvested stocks, such as beche-de-mer growth rates, natural and fishery mortality rates, stock sizes, and, if possible, recruitment rates. Determining these rates, in turn, requires data on size and age structure of the population and research into patterns of growth. In the long run these techniques can probably produce the best estimates of MSY for beche-de-mer species, but, realistically, it is unlikely that the necessary data and biological studies necessary will be forthcoming any time soon.

A somewhat simpler, perhaps simplistic, approach involves the following steps: 1) estimate the size of the stock being harvested (in numbers or weight); 2) determine the average age (in years) of individuals in the exploitable size classes; and 3) set the annual harvest quota at a value equal to the stock size divided by its average age. The rationale for this procedure is that if the size of the harvestable stock is, for example, 10,000 animals, and these harvestable individuals are, on the average, 10 years old, then you could harvest the whole stock (10,000 animals) every 10 years and 10 years later the stock would have rebuilt itself to the original condition; or rather than taking the whole stock every 10 years, you could harvest one-tenth of it (1,000 animals) every year with essentially the same outcome.

Estimates of the total harvestable stock size of beche-de-mer species can be made by measuring animal density (number/m^2) in different types of habitats and multiplying these values times the areal extent (in m^2) of the various habitat types as determined from aerial photography. Determining the average age of a stock of beche-de-mer presents some difficulties and would require well conducted biological studies; growth rate parameters for some species in some locations have been published (Conand, 1986, 1989), but there are significant differences among species and even among different studies of the same species.

All of these techniques for determining appropriate values for fishery quotas for beche-de-mer require data which are not presently available. Thus management will, of necessity, need to be of the “seat of the pants” type until the required data are available. And to be sure that needed data do eventually become available, it is necessary to initiate data collection programs as early as possible.

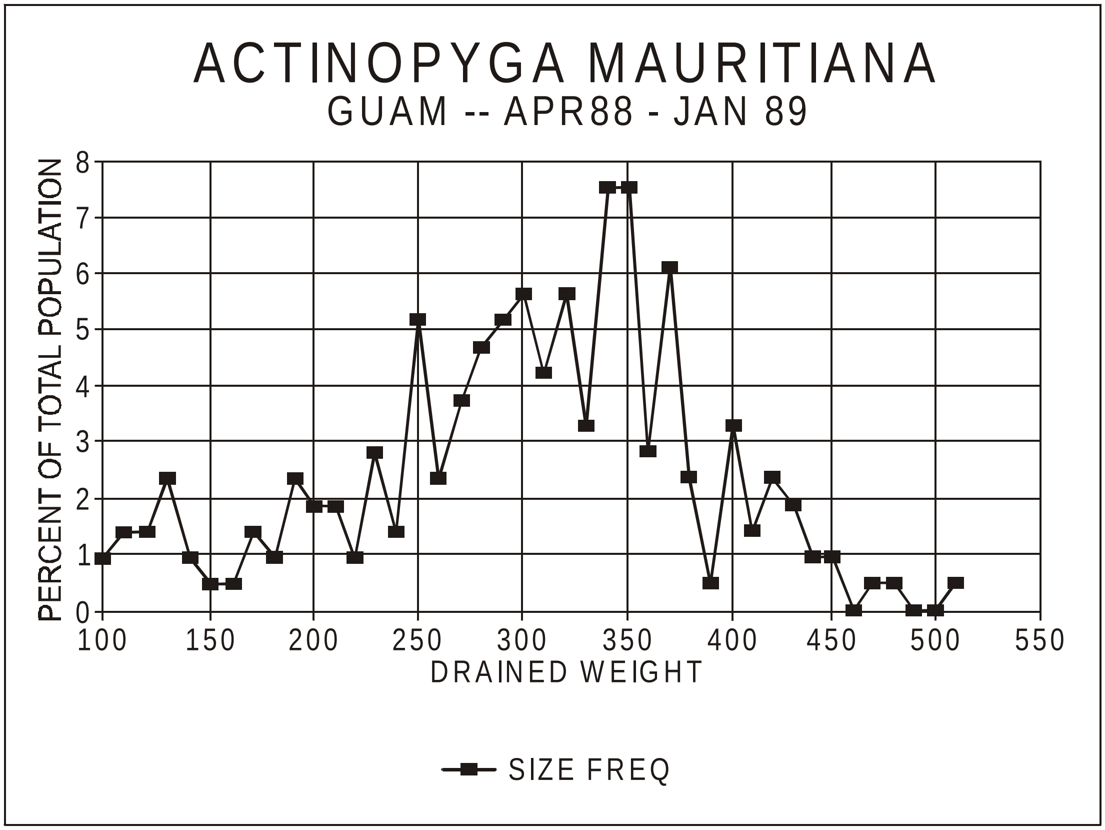

Figure 2-A. Size-Frequency distribution.

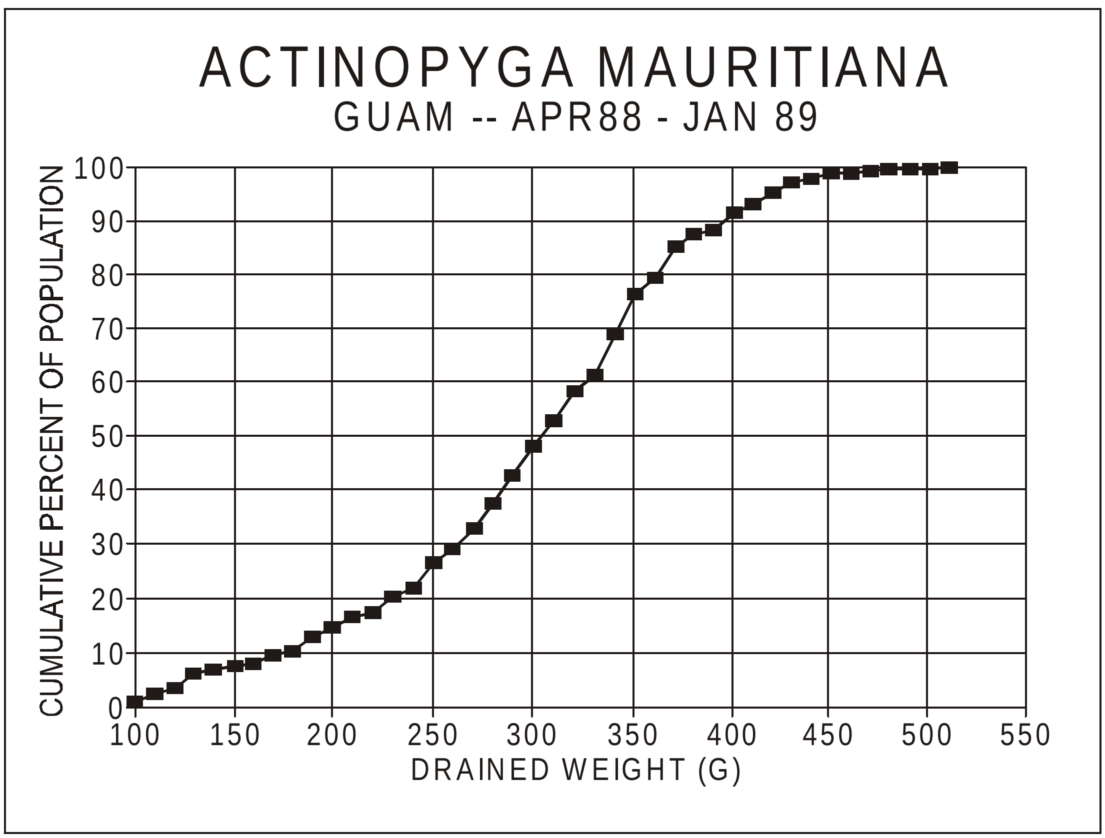

Figure 2-B. Cumulative percent size-frequency distribution.

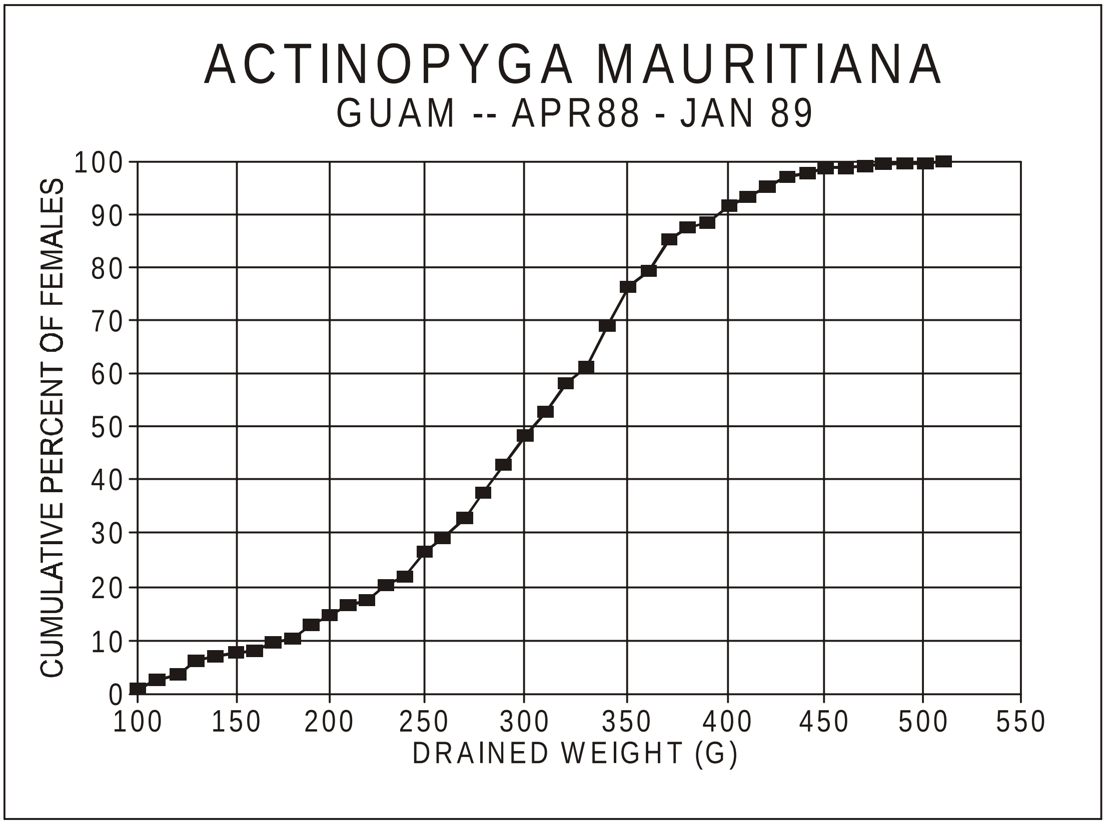

Figure 2-C. Cumulative percent size-frequency distribution of females.

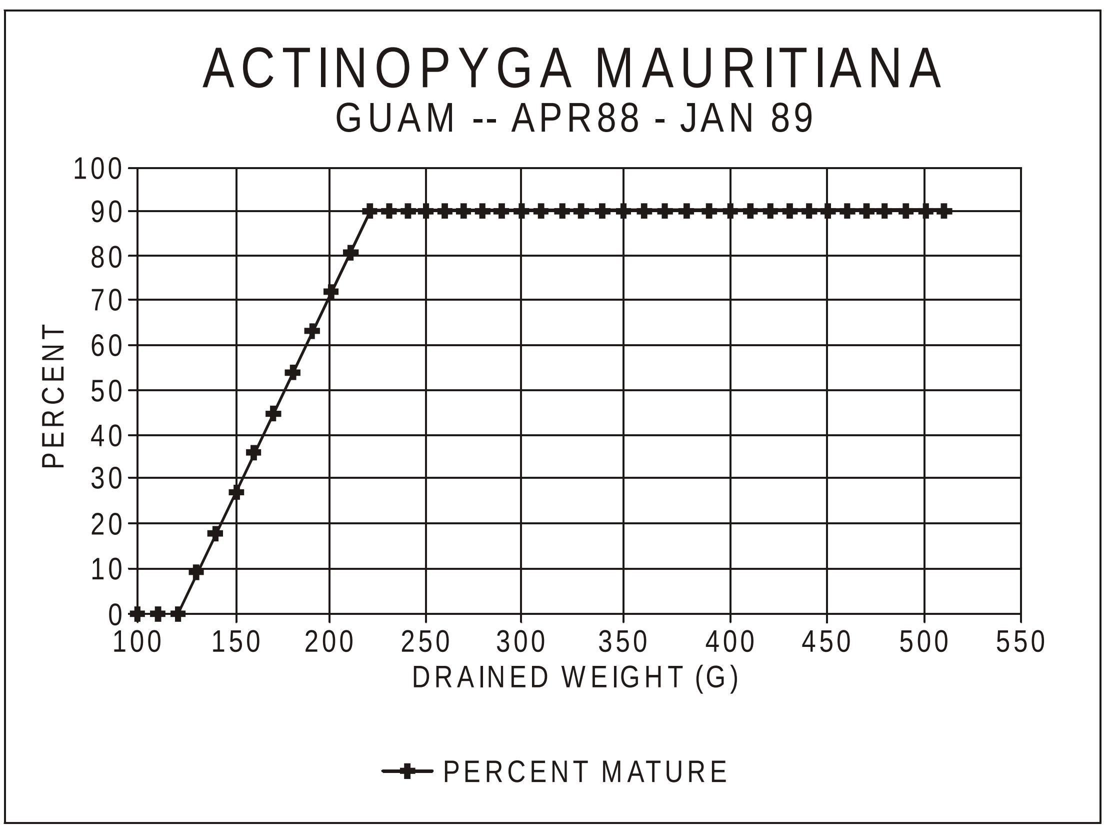

Figure 2-D. Percent of females sexually mature at various sizes.

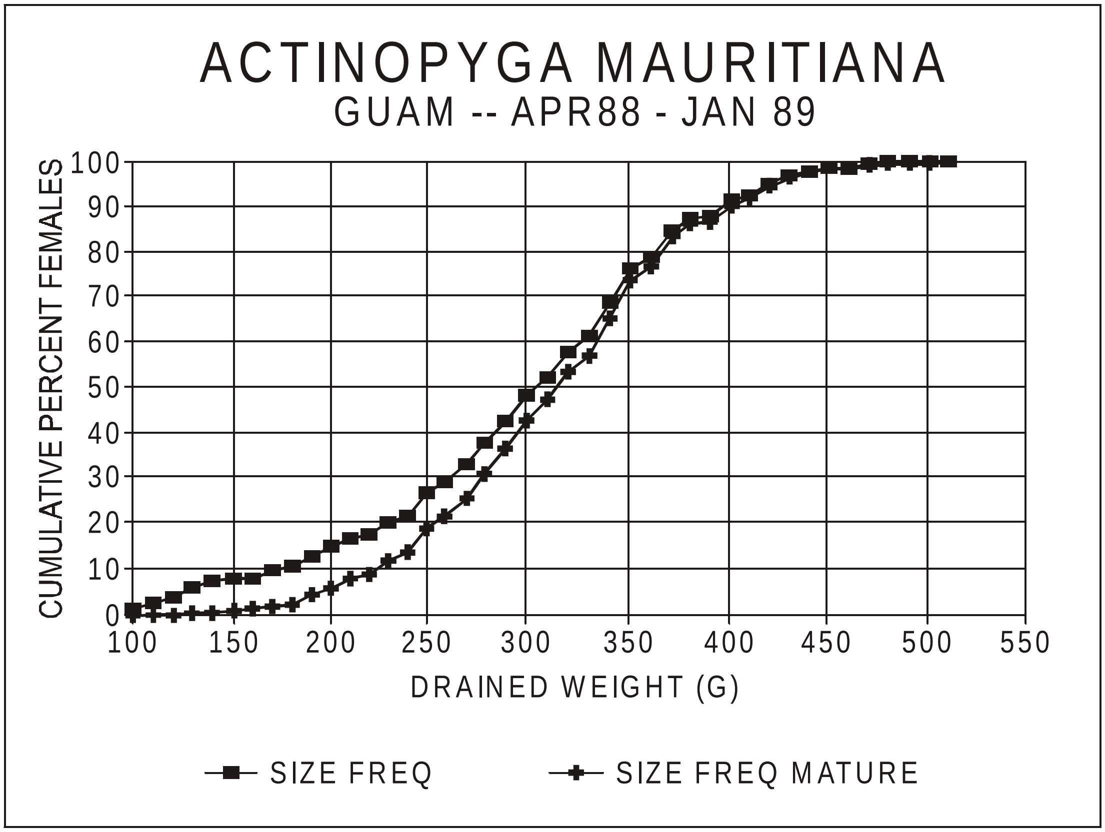

Figure 2-E. Cumulative percent size-frequency of all females and of sexually mature females.

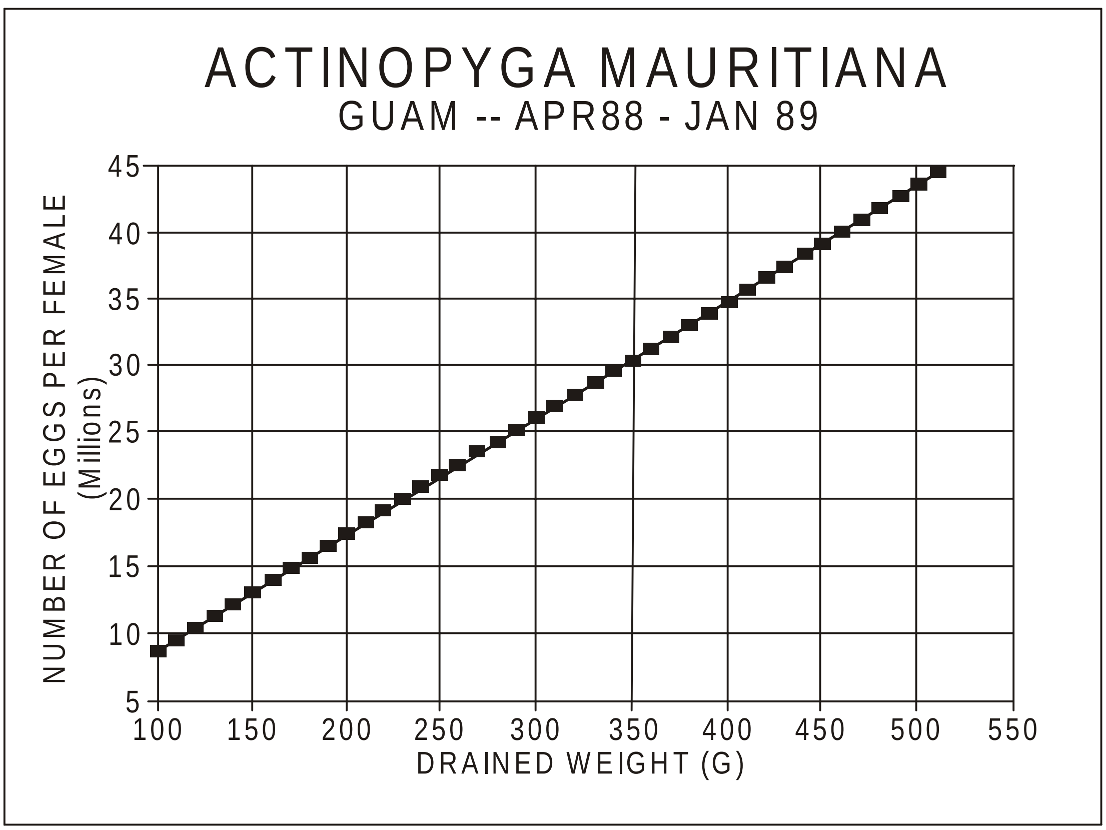

Figure 2-F. Number of eggs per female of various sizes.

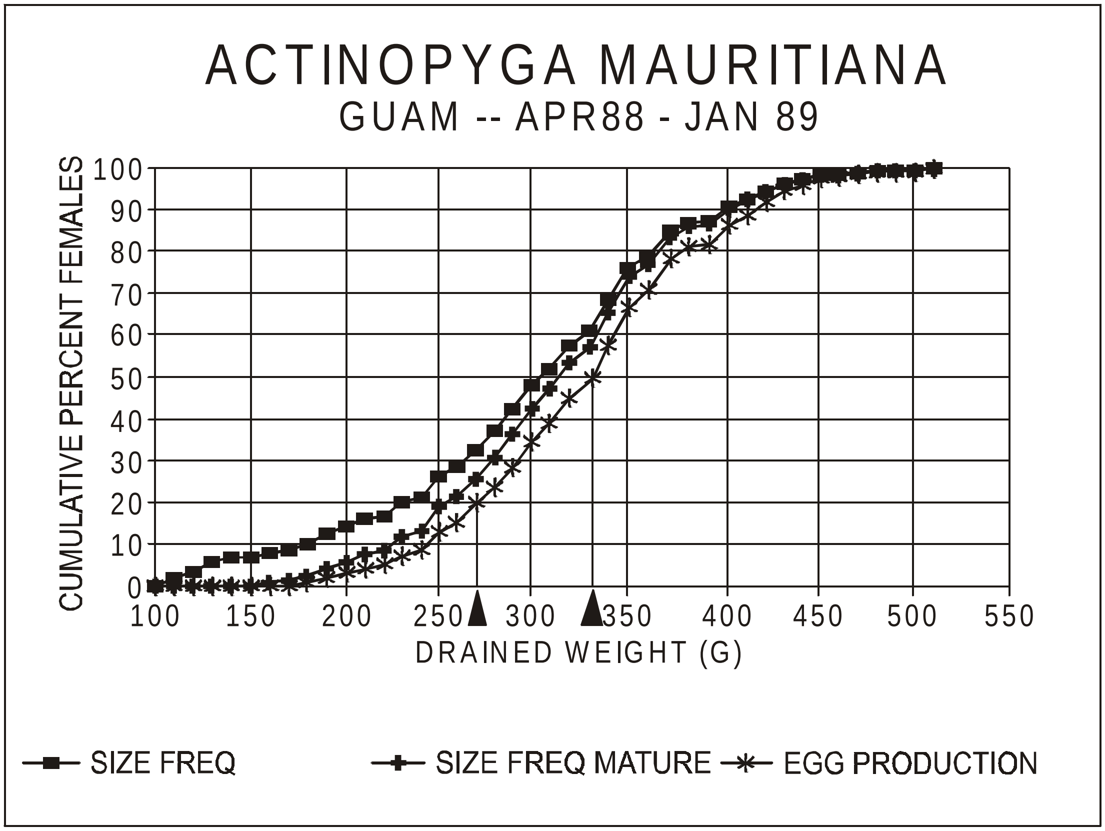

Figure 2-G. Cumulative percent production of eggs by female of various sizes.

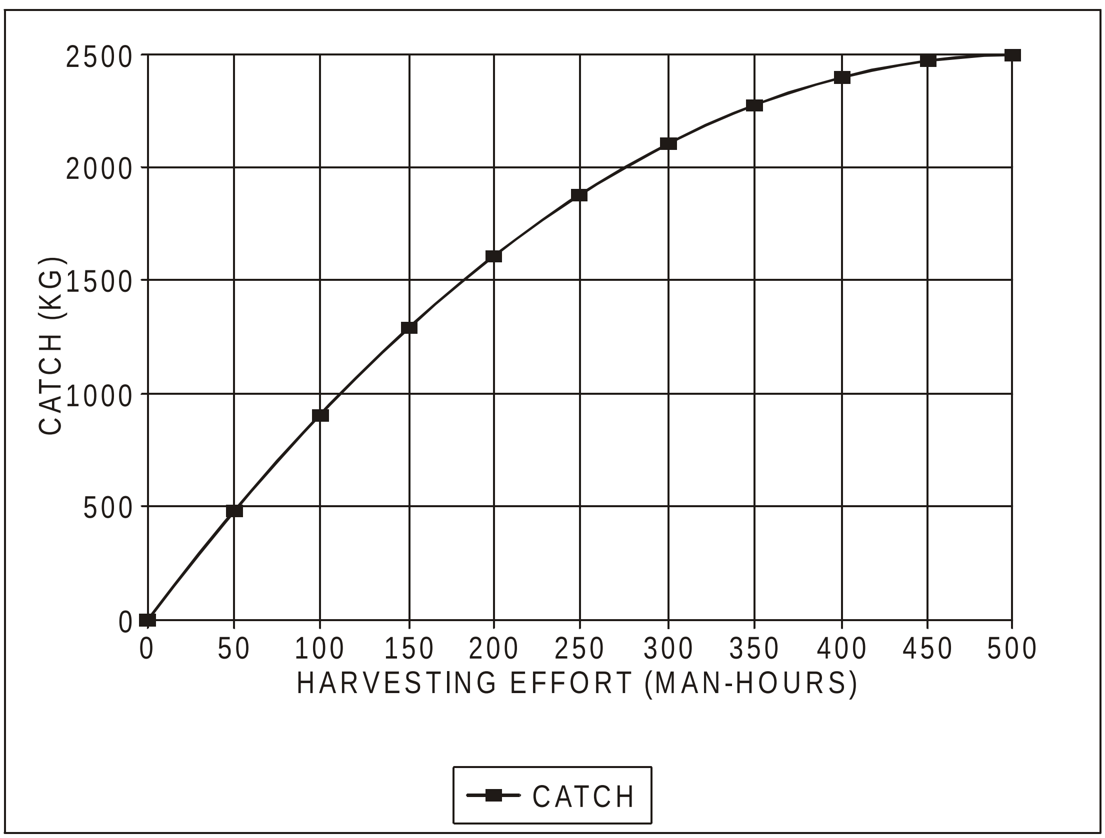

Figure 2-H. Relationship between total catch and harvesting effort in an idealized fishery.

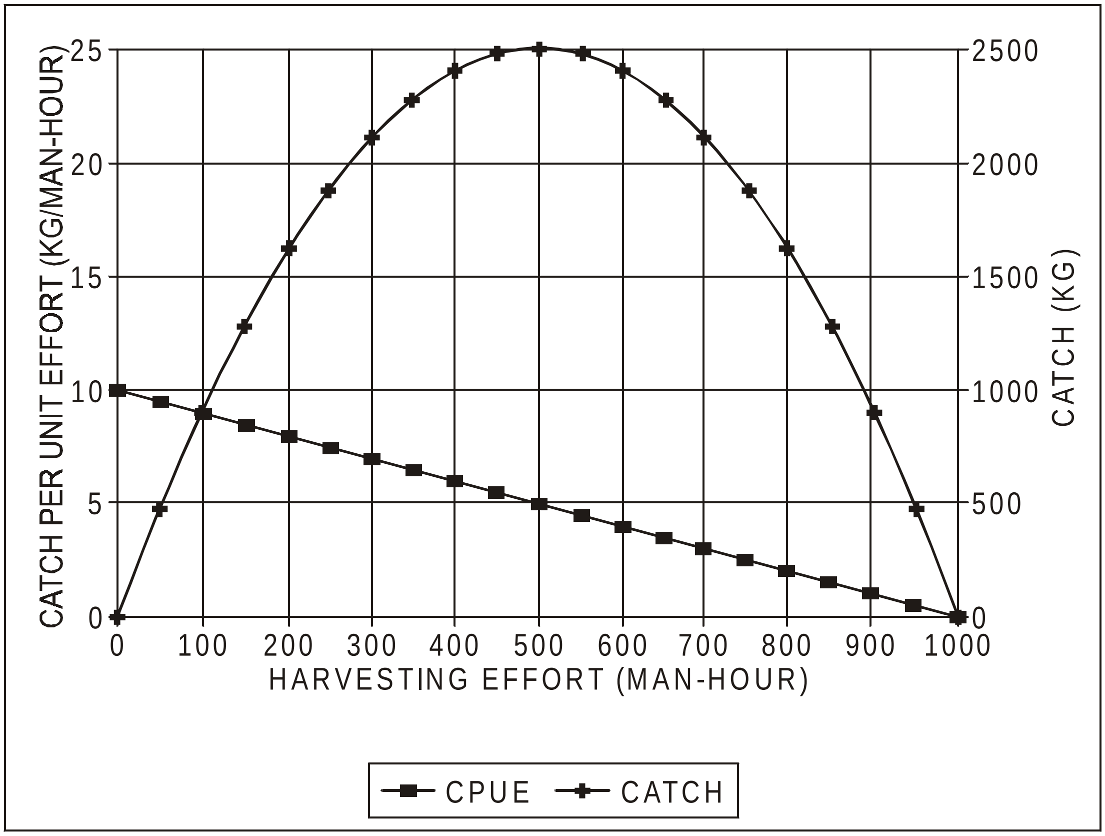

Figure 2-I. Relationship between total catch, catch per unit effort, and harvesting effort in an idealized fishery.

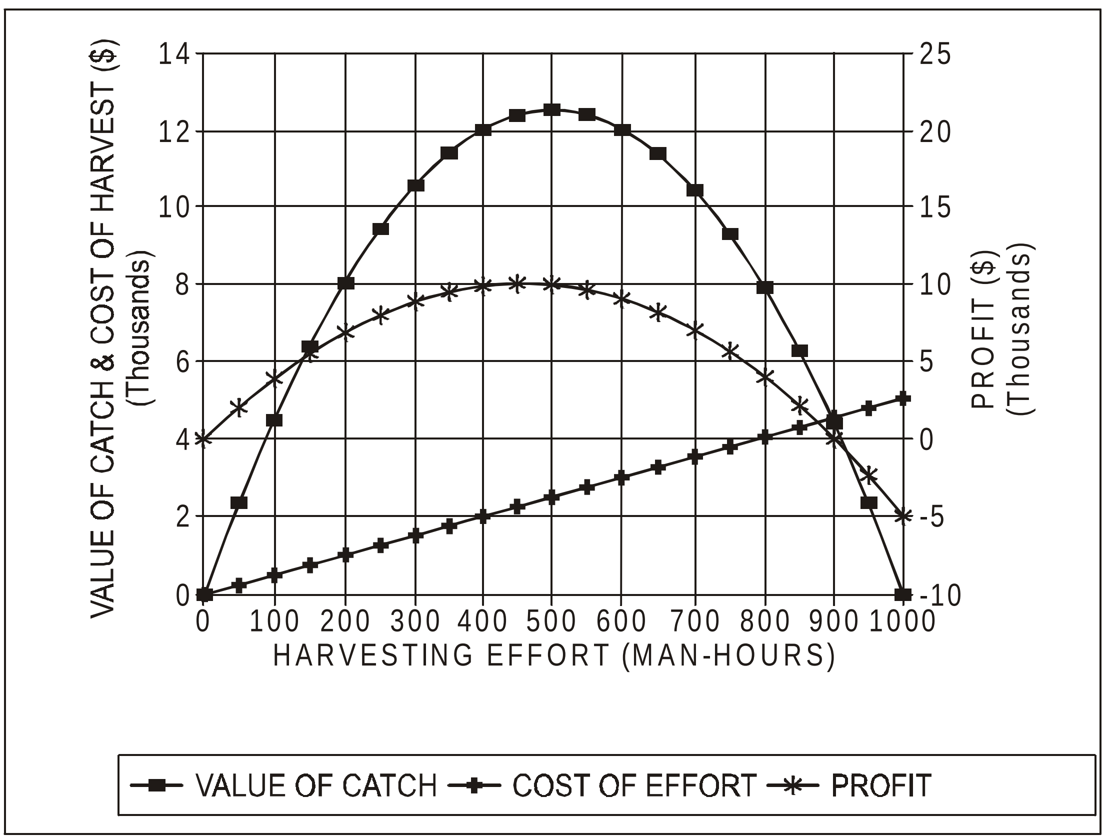

Figure 2-J. Relationship between value of catch, cost of harvesting, and profit in an idealized fishery.

E. Literature Cited

Conand, C. 1986. Les ressources halieutiques des pays insulaires du Pacifique. Deuxieme partie: Les holothuries. FAO Doc. Tech. Peches, 272.2, 108 p.

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Section 3

DATA COLLECTION METHODS FOR BECHE-DE-MER RESOURCE MANAGEMENT IN MICRONESIA

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A. Introduction

The preceding chapter outlines several strategies for the management of beche-de-mer resources in Micronesia. An important criterion for selecting among these (or other) options is the quality and availability of the data which are needed to implement them. In some cases, particular data are needed prior to implementing a management scheme (such as data required to set minimum size limits or quotas); in other cases data must be gathered on a continuous basis during the operation of the fishery (such as timely catch data so that managers can determine when quotas have been reached). There is little data presently available for managing Micronesian beche-de-mer fisheries, and so one of the first priorities is to initiate data collection efforts in support of resource management.

B. Beche-de-Mer Field Assessment Techniques

Three important characteristics of beche-de-mer stocks, their density, species composition, and size structure, can be measured with the following procedures. The method requires two workers and the equipment needed is simple, consisting of the following items:

1) a 5.64 m long polypropylene rope with a 2- to 3-kg weight at one end;
2) a slate for recording data underwater;
3) a plastic measuring tape marked in 1-cm increments;
4) a conspicuous, weighted marker such as a 1-kg dive weight with flagging tape tied to it; and
5) snorkeling or scuba equipment.

The rope is used to define the limits of a 100-m^2 survey area by placing the weighted end on the substrate within a habitat to be surveyed. One worker, equipped with snorkeling or scuba gear depending upon water depth, stretches out the rope until it reaches its full length (5.64 m) from the weight, places the marker at that spot, and then slowly rotates the rope, keeping it at full length, around the weighted end (Figure 3A). A second worker, similarly equipped, follows the rope as it is being rotated and records the identity and measures the length of each beche-de-mer individual which is located between the weight and the end of the rope. By the time the rope has been rotated completely around the center weight (when it is back at the location of the marker) it will have circumscribed a 100-m^2 circle. The buoyancy of the polypropylene makes it relatively easy to manipulate the rope over coral heads or other obstructions as it is moved around the circle.

The counts of the various beche-de-mer species made by this surveying technique are a measure of the species' densities in number per 100 m^2. By performing several of these counts in an area, mean densities and their standard deviations can be obtained through standard statistical manipulations of the data.

The measurement of the lengths of the sea cucumbers encountered during the survey process will provide the basis for construction of length-frequency distributions for the various species stocks. The length measurement should be made along the dorsal surface of the animal, following its natural curves so that the length measurement is the same as it would be if the animal had been straight. In a size-frequency analysis, measurements are aggregated into size classes; for economic beche-de-mer species, 1-cm size classes are appropriate, and so the field length measurements need be no more precise than this. A tape measure clearly marked off in 1-cm increments could be made for rapid use in the field.

Experience with this procedure indicates that, even in areas where beche-de-mer are relatively abundant, a two-person survey can be conducted in approximately 10 to 20 minutes, although this will vary with visibility, habitat complexity, and other factors.

By conducting a large number of these surveys within beche-de-mer harvesting areas, it is possible to determine the distribution of stock densities within the area and the length-frequency distributions of the various harvested species. Table 1 is a proposed data form upon which survey data can be transcribed for analysis.

The beche-de-mer density data can be used for estimates of total stock size and for monitoring changes in density over time which can serve as an index of harvesting pressure. The length-frequency data can be used in several ways: for analyses leading to minimum size limits, for several length-based techniques for stock assessment, and, again, for monitoring harvesting impacts of the status of the stocks.

Sea cucumber density data and length-frequency data can be collected by two people using simple, inexpensive equipment.

C. Habitat Mapping and Stock Size

To convert sea cucumber density measurements into estimates of total stock size within an area, it is necessary to estimate the area (in m^2) of the various habitats within which the beche-de-mer species are found. One way do this is to obtain aerial photographs which show details of the reef habitat in the area of interest. By field checking, it is often possible to determine what types of habitats correspond to various patterns and shades of color in the photographs. Lines can then be drawn on the photos to indicate the boundaries of the various habitat types, and a planimeter can be used to determine the area of the various habitats. For deeper habitats where aerial photography does not penetrate, maps showing submarine topography can be used to estimate areas falling between different depth contours. Knowing the area of the habitats and the density of the beche-de-mer species within the various habitat types, estimates of total stock size can be calculated.

> It is necessary to know the area of the habitats and the density of beche-de-mer species in order to estimate total stock size.

D. Minimum Size Determinations

The steps for determining appropriate values for minimum size limits are described in the previous chapter on stock management, and the chapter on sea cucumber biology describes procedures for gonad analyses which are needed. The size-frequency distributions of the beche-de-mer species under virgin stock conditions are the final data requirements, and these can be determined with the survey methodology described above.

E. Data from the Fishery

The two most important types of data that characterize the fishery are 1) the total harvest and 2) the fishing effort which was required to obtain that harvest. If there is a centralized processing location or if all export product is centrally handled, total harvest (or at least total processed harvest or total export harvest) can be determined for each commercial species through a centralized data collection effort.

Determining total fishing effort (in person-hours or even person-days) is a considerably more difficult undertaking. In most fisheries, effort data are gathered either by requiring some sort of reporting by fishermen or by effort surveys carried out by fishery agency personnel. We do not feel that a fisherman reporting system is currently realistic for beche-de-mer fisheries in Micronesia. Nor do we feel that the cost and difficulty of carrying out effort surveys are justified for these fisheries unless the harvesting period was a very limited one so that a short period of intense data gathering could characterize the fishing effort patterns of the whole fishery for a particular year.

> Total harvest and the fishing effort to acquire the harvest are the two most important types of data that characterize the fishery.

F. <u>Growth Data</u>

Knowledge of growth patterns of economically important sea cucumber species is exceedingly useful in a variety of fishery management models. Conand (1986, 1989) presents values for growth parameters for several beche-de-mer species which have been studied and reported in the literature. These values show wide differences among species, and, wide differences within species which have been studied in more than one location. Studies of growth rates of beche-de-mer in Micronesia would, therefore, be of value.

Determining growth rate parameters for beche-de-mer is technically complex and would most likely require specific research projects carried out by persons with training in this area. Perhaps the most accessible method is the analysis of size-frequency data using computer programs such as ELEFAN (Pauly, 1982). The data requirements for this approach are sets of size-frequency data for each species; these data can be collected using the survey methods described above.

> Growth patterns can vary among beche-de-mer species and within species studied in different locations. Determining growth rate parameters, while technically more complex, is valuable for calculating management models.

G. <u>Recommended Data Collection Priorities</u>

We recommend that a comprehensive survey program using the 100 m^2 circle survey method, as described above, be initiated as soon as possible. The data from these surveys can be applied in a variety of ways in assessing and managing harvestable beche-de-mer stocks.

Efforts should also be initiated to obtain aerial photos of reef areas where beche-de-mer are harvested and to do field checks so that habitat areas can be discriminated.

Finally, a data collection program at the point of export should be established which will provide data on the species, sizes, numbers, and weights of beche-de-mer exported.

Table 3-A. Proposed data form for field beche-de-mer surveys.

Date of Survey:
Names of Personnel:
Location of Survey:

Habitat Type:
Tide Condition:
Other Information:

	SPECIES							
LENGTH(cm)	A. maurit.	A. echinit.	A. obesa	H. nobil.	T. ananas	T. anax		
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
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47								
48								
49								
50								
>50 (WRITE IN LENGTH)								
TOTAL NO.								

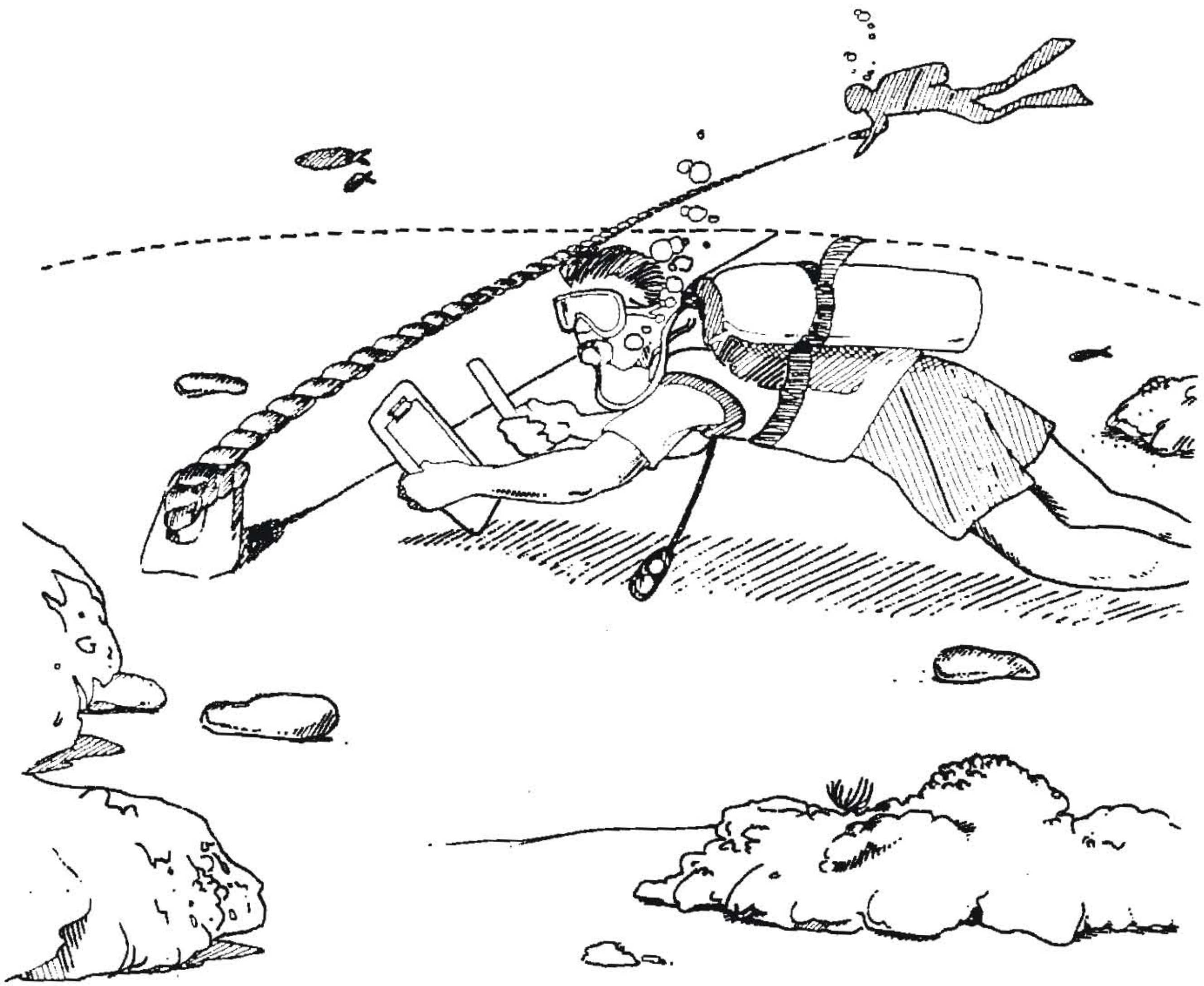

Figure 3-A. Method of surveying beche-de-mer by circular transect. (Illustration by Robert Amesbury).

H. Literature Cited

Conand, C. 1986. Les ressources halieutiques des pays insulaires du Pacifique. Deuxieme partie: Les holothuies. FAO Doc. Tech. Peches, 272.2, 108p.

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Pauly, D. 1982. Studying single-species dynamics in a tropical multispecies context. In: D. Pauly and G. I. Murphy, Theory and management of tropical fisheries. International Center for Living Aquatic Resources Management, Manila, pp. 33-69.

Section 4

AN ECONOMIC MODEL OF SEA CUCUMBER EXPORT IN MICRONESIA

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A. Introduction

This section attempts to address the following questions: (1) Is an indigenous small-scale (subsistence/artisanal) export fishery for sea cucumbers economically feasible in Micronesia? (2) If the fishery is feasible, what management/regulatory measures would insure maximum long term benefit from the sea cucumber resource?

One of the first socio-economic considerations relevant to the export of any resource should be attention to the following question: "Does this resource have a domestic function or use which provides a greater net value to society than the value which could be received from export sales?". With respect to the sea cucumber resources in Micronesia the answer to this question appears to be a clear "no". There are only a very few species which are eaten or otherwise used by Micronesians, and this occurs in only a few localized areas. The social customs in these areas can be safeguarded by local regulation. Sea cucumbers are known to have some ecological importance in recycling nutrients; however, experts present at The Regional Sea Cucumber Fisheries Meeting, University of Guam Marine Laboratory, March 3-5, 1993, felt that these recycling functions can be adequately accomplished by the remaining non-commercial and unharvested commercial species. Generally speaking the sea cucumber resources in Micronesia appear to have their greatest social value as an export commodity.

Whenever resources are exported there is a second socio-economic consideration which arises, "Which group in society should receive what portion of the net value of the export?" For example in the case of sea cucumbers which group should receive most of the net revenue (profits) -- the fishermen, the owners of the harvesting location, the government, the exporters or the processors? A complete resolution of this question is well beyond the scope of this study. However, the reader should constantly be aware that choices of resource export and management/regulatory measures often carry with them major implications about which groups in society will receive the most benefit from sale of the resource.

B. Procedures and Methodology

B.1. Derivation of Costs Per Fishing Trip

The Regional Sea Cucumber Fisheries Meeting held at the University of Guam Marine Laboratory, March 3-5, 1993, provided an excellent opportunity to construct assumptions and parameters necessary for formulation of a simple cost and earnings feasibility model of sea cucumber harvest in Micronesia. Participating in this Meeting were fisheries officers from the Territories of Guam and American Samoa, the Federated States of Micronesia, the Republic of the Marshall Islands and the Republic of Palau, as well as fisheries experts from the South Pacific Commission, the University of Guam and several interested Federal Agencies.

During a two hour workshop session the Meeting participants were asked to consider the potential costs, time, and effort involved in a hypothetical sea cucumber fishing trip. This hypothetical trip was to be undertaken by indigenous islanders (subsistence or artisanal fishermen) in waters and under circumstances familiar to those at the Meeting. Participants were told by the Meeting facilitator to assume that this hypothetical fishing trip would result in the capture of 100 (size 10 per kg.) sea cucumbers, and that the trip would be undertaken by two fishermen using a 16-18 foot outboard powered vessel. Since conditions differ throughout Micronesia, this exercise generated a spirited and informative discussion. Despite their differences participants were able to arrive at a general consensus regarding the costs, time, and effort involved in such a fishing trip.

Next the participants were asked to evaluate the hours of work necessary to prepare, package, store, and ship the catch of 100 sea cucumbers. Again lively discussion lead to a general consensus as well as a much better understanding on the part of participants as to the intricacies of sea cucumber preparation, storage, and shipment. Finally the participants were informed by the facilitator about the concept of labor opportunity cost (the amount which workers might earn in the best available alternative employment), and participants were asked to estimate the opportunity cost of fishermen who might normally be involved in sea cucumber fishing activities.

The consensuses of meeting participants were noted by the facilitator and then used to formulate the assumptions and parameters used in a simple fishing trip cost and earnings model. The assumptions, resulting parameters, and estimated total costs per fishing trip are presented below in Table 4-A. It should be noted that whenever the general consensus of participants reflected a range, the session facilitator made every effort to use the lower cost assumptions. Therefore the estimated total cost per trip presented in Table 4-A should be viewed as the minimum cost per trip which could be expected under the best of circumstances.

Table 4-A
SEA CUCUMBER HARVEST/EXPORT
COST AND EXPENSE PROJECTIONS PER FISHING TRIP

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Assumptions Regarding Harvest and Processing Costs:

Opportunity Cost of Workers (per hour)	$1.00
Vessel & Fuel Costs (per hour)	$3.50
Drying Fuel Costs (per hour)	$0.50
Drying Time (hours per 100 sea cucumbers)	48 hrs.
Packing Materials Costs (per 100 sea cucumbers)	$3.00
Storage & Other Expenses (per 100 sea cucumbers)	$10.00

Assumptions Regarding Labor Effort (per 100 sea cucumber trip):

Activity	No. of Workers	Hours Worked	Costs Per Trip
Travel & Collection	2	8	$16.00
Gutting & Washing	2	4	$8.00
Cooking & Cooling	1	10	$10.00
Preparation	1	3	$3.00
Drying/Smoking	1	10	$10.00
Grading & Packing	1	3	$3.00
Estimated Labor Costs Per Trip			$50.00
Estimated Equipment Costs Per Trip (vessel & fuel)			$28.00
Estimated Miscellaneous Costs Per Trip (drying fuel, packing, storage, and other			$37.00
ESTIMATED HARVEST AND PROCESSING COSTS PER TRIP			**$115.00**

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B.2. Derivation of Revenue Per Fishing Trip

The Hong Kong market is by far the largest and most influential market for sea cucumbers in South East Asia. Published prices for this market are generally higher than those for other markets. The "Infofish Trade News" and "Infofish International", both published in Kuala Lumpur, Malaysia, provided the source for the 1993 Hong Kong sea cucumber prices. These prices are quoted on a c.f. (cost of freight) basis. This means that the seller pays the cost of shipping the sea cucumbers to the buyer. After considerable discussion among Meeting participants as well as consultation with local shipping agents it was decided that $3.00 per kg. represented a conservative estimate of shipping costs from most points in Micronesia to Hong Kong.

The assumptions, resulting parameters, and estimated total revenue per fishing trip are presented below in Table 4-B. It is important to note that the price assumptions used in Table 4-B reflect those paid for premium species of highest quality delivered to the buyer in Hong Kong. Therefore the estimate of gross revenue per trip in Table 4-B should be viewed as the maximum revenue which could be expected under the best of circumstances after shipping costs have been paid.

B.3. Derivation of Estimated Net Revenue Per Fishing Trip

As stated previously the estimate of gross revenue per trip in Table 4-C is based on available published price information (see Table 4-B) and reflects maximum expectations under the best of circumstances. The estimated costs in Table 4-C are based on a consensus of Meeting participants (see Table 4-A) and represents the minimum expectations under the best of circumstances. Therefore, the estimated net revenue per trip in Table 4-C rests upon the assumptions (model parameters) developed by Meeting participants and reflects the highest expectation under the best of circumstances, for a fishing trip that is carried out by two fishermen in a 16-18 foot outboard powered vessel and results in the capture of 100 (size 10 per kg.) sea cucumbers.

It should be further noted that the net revenue estimates in Table 4-C are likely to be biased on the high side because the model does not make allowance for depreciation, cost of capital, or tax liability. It is implicitly assumed that the vessels and equipment already exist in the hands of fishermen and that if fishermen were not fishing for sea cucumbers they would be using the same equipment to fish for something else.

The estimated net revenue per fishing trip (profit to the artisanal fishermen) is determined by subtracting the estimated harvest and processing costs (Table 4-A) from the estimated gross revenue (Table 4-B). This calculation is presented in Table 4-C.

Table 4-B
SEA CUCUMBER HARVEST/EXPORT
REVENUE PROJECTIONS PER FISHING TRIP

Assumptions Regarding Revenue Per Trip:	
Number Harvested Per Fishing Trip	100
Size of Sea Cucumbers Harvested (number per kg.)	10
Shipping Costs to Hong Kong (per kg.)	$3.00
Prices (1993 est. c.f. Hong Kong, dry weight):	
10-21 pieces/kg.	$42.35
22-35 pieces/kg.	$35.60
40-55 pieces/kg.	$32.50
60-80 pieces/kg.	$26.40
ESTIMATED GROSS REVENUE PER TRIP	**$394.00**

Table 4-C
SEA CUCUMBER HARVEST/EXPORT
ESTIMATED NET REVENUE PER FISHING TRIP

Estimated Gross Revenue Per Trip (From Table 4-B)	$394.00
Estimated Harvest and Processing Costs Per Trip (From Table 4-A)	$115.00
ESTIMATED NET REVENUE PER TRIP	**$279.00**

C. Sensitivity Analysis

As evidenced by discourse at the Sea Cucumber Fisheries Meeting, economic, social, and ecological conditions differ greatly throughout Micronesia. Because of these differences an analysis was undertaken to determine the impact of changes in model parameters on estimates of net revenue received by Micronesian fishermen.

C.1. Size and Abundance

The estimated net revenue per fishing trip in Table 4-C is based on an assumed capture rate of 100 size 10 per kg. sea cucumbers per eight hour trip. This assumption represents a consensus of Meeting participants as to what might normally occur on average in their respective fisheries. However, suppose that a particular fishery has a greater or smaller abundance and/or size of sea cucumbers. Table 4-D provides a set of expected net revenues per fishing trip which would result from various combinations of abundance and size distributions.

TABLE 4-D
SEA CUCUMBER HARVEST/EXPORT
ESTIMATED NET REVENUE PER EIGHT HOUR FISHING TRIP
BY SIZE AND CAPTURE RATE

Number Harvested Per Trip	Sea Cucumber Size (Number of Sea Cucumber Per Kilogram of Dry Weight)						
	10	20	30	40	50	60	70
25	**$11**	($38)	($60)	($69)	($73)	($78)	($79)
50	**$100**	**$2**	($42)	($60)	($67)	($77)	($80)
75	**$189**	**$42**	($24)	($50)	($62)	($77)	($81)
100	**$279**	**$82**	($6)	($41)	($56)	($76)	($82)
125	**$355**	**$109**	($1)	($45)	($63)	($88)	($95)
150	**$432**	**$137**	**$5**	($48)	($70)	($100)	($108)
175	**$508**	**$164**	**$10**	($51)	($77)	($112)	($122)
200	**$585**	**$192**	**$15**	($55)	($84)	($124)	($135)
225	**$662**	**$219**	**$21**	($58)	($91)	($136)	($149)
250	**$738**	**$246**	**$26**	($61)	($98)	($148)	($162)
275	**$815**	**$274**	**$32**	($64)	($105)	($160)	($175)
300	**$892**	**$301**	**$37**	($68)	($112)	($172)	($189)

As one would expect, Table 4-D shows that net revenue per trip will fall as the size of harvested sea cucumber falls, and also that net revenue per trip will fall as the number of harvested sea cucumbers falls. In addition note that the net revenue remains below zero for all sea cucumber size categories below 30 per kg., and further note that substantial net revenue occurs only in sea cucumber size categories of 10 and 20 per kg.

C.2. Export Prices

Prices paid for sea cucumbers in Hong Kong will likely continue to fluctuate over time as they have in the past. In recent years the general price trend has been upward, but the future is difficult to predict. There are many influencing factors. As mainland Chinese markets become increasingly open to foreign imports it is expected that the demand for sea cucumbers will continue to grow. This growth in demand, coupled with natural limitations on the supply, should cause continued upward pressure on sea cucumber prices. Rising prices will (as they have in the past) encourage greater fishing effort and potentially the harvest of smaller animals. It is possible that prices may rise to a level which makes cultured production an economically viable alternative source of supply. The growth of cultured production would exert a stabilizing or perhaps a negative influence on prices paid for sea cucumbers caught by Micronesian fishermen. In the near future, however, mariculture of sea cucumbers is not a promising option and measures must be taken to effectively manage existing stocks.

In addition it must be remembered that Micronesian fishermen are paid in U.S. dollars while the sea cucumbers are sold in Hong Kong for Hong Kong dollars. Variations in the rate of exchange between Hong Kong dollars and U.S. dollars will impact the U.S. dollar prices received by Micronesian exporters. If the U.S. dollar becomes stronger relative to the Hong Kong dollar, the Hong Kong c.f. prices will translate into less U.S. dollars received by Micronesian exporters. Conversely if the dollar becomes weaker relative to the Hong Kong dollar, the Hong Kong c.f. prices will translate into more U.S. dollars received by Micronesian exporters. International, political, and economic forces can cause very sudden and drastic changes in currency exchange rates. These exchange rate fluctuations will be reflected in prices received by Micronesian exporters. Whether or not price fluctuations are passed on to Micronesian fishermen or absorbed by the middlemen/processors depends largely upon the degree of competition among middlemen/processors and the extent of Micronesian government regulation. In the absence of middleman competition and government regulation it is likely that export price fluctuations would be largely passed on to the fishermen.

Tables 4-E and 4-F provide some insight regarding the impact of sea cucumber price changes on the expected net revenue of Micronesian fishermen. In Table 4-E the Hong Kong prices for all size categories are reduced 20% below those assumed in Table 4-D. As a result net revenue falls across the board, and positive net revenue occurs only in the size categories of 10 and 20 per kg. In Table 4-F the Hong Kong prices for all size categories are increased by 20% above those assumed in Table 4-D. As a result net revenue rises across the board, but negative net revenues continue to occur in all size categories below 30 per kg. Once again substantial net revenue occurs only in sea cucumber size categories of 10 and 20 per kg.

In other words harvesting sea cucumbers of a size smaller than 30 per kg. is not profitable over a fairly wide range of export prices. Irrespective of export price fluctuations, substantial profits are likely to occur only in catches which contain a high percentage of sea cucumbers in the size 10 and 20 per kg. categories.

TABLE 4-E
SEA CUCUMBER HARVEST/EXPORT
ESTIMATED NET REVENUE PER EIGHT HOUR FISHING TRIP
BY SIZE AND CAPTURE RATE
(Assuming a 20% Decrease in c.f. Hong Kong Prices)

Prices:
10-21 pc./kg. (c.f. Hong Kong) $34
22-35 pc./kg. (c.f. Hong Kong) $28
40-55 pc./kg. (c.f. Hong Kong) $26
60-80 pc./kg. (c.f. Hong Kong) $21

Number Harvested Per Trip	Sea Cucumber Size (Number of Sea Cucumbers Per Kilogram of Dry Weight) 10	20	30	40	50	60	70
25	($10)	($49)	($66)	($73)	($76)	($80)	($81)
50	**$58**	($19)	($54)	($68)	($74)	($81)	($84)
75	**$126**	**$10**	($42)	($63)	($71)	($83)	($86)
100	**$194**	**$39**	($30)	($58)	($69)	($85)	($89)
125	**$249**	**$56**	($31)	($65)	($79)	($99)	($104)
150	**$305**	**$73**	($31)	($72)	($90)	($113)	($120)
175	**$360**	**$90**	($32)	($80)	($100)	($127)	($135)
200	**$416**	**$107**	($32)	($87)	($110)	($142)	($150)
225	**$471**	**$124**	($33)	($94)	($120)	($156)	($166)
250	**$527**	**$141**	($33)	($102)	($131)	($170)	($181)
275	**$582**	**$157**	($34)	($109)	($141)	($184)	($196)
300	**$637**	**$174**	($34)	($117)	($151)	($198)	($211)

TABLE 4-F
SEA CUCUMBER HARVEST/EXPORT
ESTIMATED NET REVENUE PER EIGHT HOUR FISHING TRIP
BY SIZE AND CAPTURE RATE
(Assuming a 20% Increase in c.f. Hong Kong Prices)

Prices:		
	10-21 pc./kg. (c.f. Hong Kong)	$51
	22-35 pc./kg. (c.f. Hong Kong)	$43
	40-55 pc./kg. (c.f. Hong Kong)	$39
	60-80 pc./kg. (c.f. Hong Kong)	$32

Number Harvested Per Trip	Sea Cucumber Size (Number of Sea Cucumbers Per Kilogram of Dry Weight) 10	20	30	40	50	60	70
25	**$32**	($27)	($54)	($65)	($69)	($75)	($77)
50	**$143**	**$23**	($30)	($52)	($61)	($73)	($76)
75	**$253**	**$74**	($6)	($38)	($52)	($70)	($75)
100	**$363**	**$124**	**$17**	($25)	($43)	($67)	($74)
125	**$461**	**$162**	**$29**	($24)	($47)	($77)	($86)
150	**$559**	**$200**	**$40**	($24)	($51)	($87)	($97)
175	**$657**	**$238**	**$51**	($23)	($54)	($97)	($109)
200	**$754**	**$276**	**$63**	($22)	($58)	($106)	($120)
225	**$852**	**$314**	**$74**	($21)	($62)	($116)	($132)
250	**$950**	**$352**	**$86**	($21)	($66)	($126)	($143)
275	**$1,048**	**$390**	**$97**	($20)	($69)	($136)	($155)
300	**$1,146**	**$428**	**$108**	($19)	($73)	($146)	($166)

C.3. Wage Rates

There are differences in wage rates and available employment opportunities throughout the Micronesian region. In some areas very cheap foreign labor can easily be imported. In other areas it can not. In some areas there are growing opportunities for alternative employment. In other areas the alternatives are almost nonexistent. The results presented in Table II reflect an assumed labor opportunity cost of $1.00 per hour. This was the consensus labor opportunity cost arrived at by Meeting participants; however, some participants were interested in the impact on the fishery of changing labor opportunities.

Table 4-G presents some insight into the impact of changes in the "opportunity wage" on the economic viability of sea cucumber fishing. As one would expect the net revenue to fishermen falls as the wage rate increases; yet, even at wage rates as low as $.25 per hour, harvesting sea cucumbers of a size smaller than 30 per kg. is not profitable. Irrespective of the wage rate substantial net revenue occurs only in sea cucumber size categories of 10 and 20 per kg.

TABLE 4-G
SEA CUCUMBER HARVEST/EXPORT
ESTIMATED NET REVENUE PER EIGHT HOUR (100 ANIMAL) FISHING TRIP
BY SIZE AND ALTERNATIVE WAGE RATE

Alternative Hourly Wage	Sea Cucumber Size (Number of Sea cucumber Per Kilogram of Dry Weight) 10	20	30	40	50	60	70
$0.25	**$316**	**$119**	**$31**	($4)	($19)	($39)	($44)
$0.50	**$304**	**$107**	**$19**	($16)	($31)	($51)	($57)
$0.75	**$291**	**$94**	**$6**	($29)	($44)	($64)	($69)
$1.00	**$279**	**$82**	($6)	($41)	($56)	($76)	($82)
$1.25	**$266**	**$69**	($19)	($54)	($69)	($89)	($94)
$1.50	**$254**	**$57**	($31)	($66)	($81)	($101)	($107)
$1.75	**$241**	**$44**	($44)	($79)	($94)	($114)	($119)
$2.00	**$229**	**$32**	($56)	($91)	($106)	($126)	($132)
$2.25	**$216**	**$19**	($69)	($104)	($119)	($139)	($144)
$2.50	**$204**	**$7**	($81)	($116)	($131)	($151)	($157)
$2.75	**$191**	($6)	($94)	($129)	($144)	($164)	($169)
$3.00	**$179**	($18)	($106)	($141)	($156)	($176)	($182)

C.4. Vessel Operating and Shipping Costs

Two other model parameters which were of interest to Meeting participants were vessel operating costs and shipping costs. Both of these costs are likely to vary from area to area within Micronesia. Tables 4-H and 4-I indicate the expected impact on net revenue to fishermen of changes in these two parameters. Of course as shipping costs and vessel operating costs rise net revenue falls; yet, once again, over a fairly large range of hourly vessel costs and shipping costs, the only substantial net revenues result from harvesting sea cucumber of sizes 10 and 20 per kg.

TABLE 4-H
SEA CUCUMBER HARVEST/EXPORT
ESTIMATED NET REVENUE PER EIGHT HOUR (100 ANIMAL) FISHING TRIP
BY SIZE AND HOURLY VESSEL & FUEL COSTS

Hourly Vessel Costs	Sea Cucumber Size (Number of Sea cucumber Per Kilogram of Dry Weight) 10	20	30	40	50	60	70
$1.00	**$299**	**$102**	**$14**	($21)	($36)	($56)	($62)
$2.00	**$291**	**$94**	**$6**	($29)	($44)	($64)	($70)
$3.00	**$283**	**$86**	($2)	($37)	($52)	($72)	($78)
$4.00	**$275**	**$78**	($10)	($45)	($60)	($80)	($86)
$5.00	**$267**	**$70**	($18)	($53)	($68)	($88)	($94)
$6.00	**$259**	**$62**	($26)	($61)	($76)	($96)	($102)
$7.00	**$251**	**$54**	($34)	($69)	($84)	($104)	($110)
$8.00	**$243**	**$46**	($42)	($77)	($92)	($112)	($118)
$9.00	**$235**	**$38**	($50)	($85)	($100)	($120)	($126)
$10.00	**$227**	**$30**	($58)	($93)	($108)	($128)	($134)
$11.00	**$219**	**$22**	($66)	($101)	($116)	($136)	($142)
$12.00	**$211**	**$14**	($74)	($109)	($124)	($144)	($150)

TABLE 4-I
SEA CUCUMBER HARVEST/EXPORT
ESTIMATED NET REVENUE PER EIGHT HOUR (100 ANIMAL) FISHING TRIP
BY SIZE AND SHIPPING COSTS
(Per kg. c.f. Hong Kong)

Shipping Costs Per Kg.	Sea Cucumber Size (Number of Sea Cucumber Per Kilogram of Dry Weight) 10	20	30	40	50	60	70
$0.50	**$304**	**$94**	**$2**	($35)	($51)	($72)	($78)
$1.00	**$299**	**$92**	**$0**	($36)	($52)	($73)	($79)
$1.50	**$294**	**$89**	($1)	($38)	($53)	($74)	($79)
$2.00	**$289**	**$87**	($3)	($39)	($54)	($74)	($80)
$2.50	**$284**	**$84**	($5)	($40)	($55)	($75)	($81)
$3.00	**$279**	**$82**	($6)	($41)	($56)	($76)	($82)
$3.50	**$274**	**$79**	($8)	($43)	($57)	($77)	($82)
$4.00	**$269**	**$77**	($10)	($44)	($58)	($78)	($83)
$4.50	**$264**	**$74**	($11)	($45)	($59)	($79)	($84)
$5.00	**$259**	**$72**	($13)	($46)	($60)	($79)	($84)
$5.50	**$254**	**$69**	($15)	($48)	($61)	($80)	($85)
$6.00	**$249**	**$67**	($16)	($49)	($62)	($81)	($86)

D. Conclusions and Recommendations

It appears that under the “best case” conditions an indigenous small-scale export fishery for sea cucumbers would be economically feasible in Micronesia so long as significant quantities of high quality species in the size categories of 10 and 20 per kg. remain available.

E. Resource Management

Based on the preceding analysis the greatest net revenue (profit) will result from the harvest of sea cucumbers in size categories 10 and 20 per kg., and the harvest of sea cucumbers in size categories smaller than 30 per kg. will almost certainly result in small, if not negative, net revenue. As shown in the section on model sensitivity this conclusion remains valid despite significant variations in assumptions about export prices, wage rates, shipping costs, or vessel/fuel costs.

Management/Regulation of the sea cucumber fishery in Micronesia is warranted because of the following concerns: (1) As discussed above there is reason to believe that sea cucumber prices, although subject to fluctuations, may continue to rise over time. The rising prices will encourage increased fishing effort. Past experience with sea cucumber harvest in Micronesia and in other parts of the world has demonstrated that under normal conditions the biomass is unlikely to produce large numbers of size 10 and 20 per kg. sea cucumbers over extended periods of time in the face of increased fishing pressure. (2) Fishermen/Processor/Exporters are unlikely to perceive the unprofitable nature of harvesting small animals until after the harvest has taken place, and even then the lack of profit on small animals will be masked by the substantial profits made on large animals. Unrestricted harvest of small animals will ultimately lead to reduced availability of large animals and the collapse of profits in the fishery.

In view of the implications resulting from the cost and earnings model, it appears that some combination of size restrictions and fishery closures would provide the most economically viable regulatory approaches for consideration by resource managers. From an economic perspective it would be advisable to only allow harvest of sea cucumbers larger than 30 per kg. Fishery closures (seasonal, annual, or multi-year) should be employed to the extent that these closures maximize the availability of sea cucumbers in the size categories of 10 and 20 per kg. There may be considerations of biology (size of first reproduction, etc.) which argue for even larger size restrictions and/or special regulations for particular species. Considerations of biology and stock dynamics might also necessitate multi-year fishery closures. In fact after consideration of the biological aspects the sea cucumber fishery might best be regulated as a “pulse fishery” where harvests are undertaken only once every several years.

The enforceability of fishery closures is to some extent complicated by the fact that processed sea cucumbers can be stored for some time without deterioration. Size regulation is complicated by measurement difficulties (wet vs. dry, processed vs. unprocessed, etc.). However, there has been a long and fairly successful history of size and season regulation for the trochus fishery in Micronesia. Trochus shells can easily be stored, and measurement difficulties have not proved insurmountable. There seems to be no reason why this same type of management cannot be applied to the sea cucumber fishery. Since few sea cucumbers are consumed domestically, enforcement at the point of export may prove to be the most effective approach. When exporters cannot export animals smaller than a specified size, they will be unlikely to purchase such animals from fishermen. If fishermen cannot sell animals of a certain size, they will be unlikely to harvest them. In any case, if there is a community willingness to overcome management obstacles, the most efficient methods for doing so will likely be suggested by the fishery participants themselves.

F. Economic Regulation

Actual economic conditions faced by fishermen/processor/exporters in Micronesia are likely to be somewhat less hospitable than the "best case scenario" (highest prices and lowest costs) assumed for the cost and earnings model used in this study. The overall size of potential Micronesian sea cucumber fisheries is not large enough to allow significant competition among processor/exporters. This condition will naturally result in one, or at best a few, processor/exporters handling most of the sea cucumber business.

As the volume of sea cucumbers handled by any one monopoly processor/exporter grows, product quality will improve, processing and shipping costs will be reduced, and the marketing power of the exporter/processor will increase. Since Micronesia can supply only a small fraction of the world supply, the benefits accruing from marketing power with respect to foreign buyers will probably be minimal; however, the economies of scale (cost savings associated with "bigness") and benefits of better product quality control should be significant for a monopolist. Therefore the benefits of efficiency provide a strong economic argument in favor of government regulation which severely limits the number of exporter/processors (and perhaps fishermen) allowed to do business in Micronesia. In other words the government should license only a single "monopoly" (or at most two) processor/exporter.

The additional profits resulting from monopoly status can either accrue to the exporter/processor, his employees, the fishermen, or the government. Of course without some type of government intervention there will be no natural tendency on the part of a sole exporter/processor to share the monopoly gains with fishermen, employees, or the government. Additional government intervention may be necessary to achieve a socially desirable distribution of benefits. One method of insuring that the monopoly profits are distributed in a socially acceptable manner might be for the licensing authority (the government) to conduct an auction (or require closed bidding) for all firms that are interested in acquiring the right to become the monopoly processor/exporter. The firm which makes the most socially acceptable offer would then be granted the exclusive license for a set period of time.

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Appendix

The following appendix is a compilation of the comments and ideas presented in a round-table discussion among meeting participants. A central theme throughout the meeting was the need for recognizing that differences exist among the Pacific Island nations in terms of reef and resource tenure systems, culture, traditions, governance, and hence appropriate methods for management. The outline is meant to offer alternatives that could be used for the management of sea cucumber and other marine resources.

Sea Cucumber Regional Management Plan
Alternatives for Micronesia

I. Management
  A. Regulation possibilities
    1. size
      a) length - circumference probably least variable
      b) weight - not appropriate
    2. season - if appropriate circumstance, very short season solves a lot of problems.
    3. area - need to look at larval dispersion and recruitment patterns - scope for regional project?
    4. species - different species have different ecological role & will sustain different harvesting rates. Heavier restrictions on locally consumed species are desirable.
    5. quantity - probably the most important and effective means of managing the fishery.
    6. a combination of several of the above may be needed.
    7. permits - need to know how many fishermen & useful way of getting some information on general effort, but some national fishermen won't accept licenses. Palau gets invoices from buyers instead. Licensing is not a tool for regulating local fishermen generally. It is better used as a carrot (with associated privileges) than as a stick. "Registration" is a better word.
    8. export license - probably a good idea. Enforcement is easier. Sea cucumbers are usually 100% exported, so export license data gives good idea of total harvest. Suggest common system across region. Can be used to limit entry and to generate government revenues to finance other management measures. If dept. of commerce already issues permits, fisheries management body should still be able to control the certificate of origin. (regional cooperation on enforcement by getting certificates of origin & signatories is recognized).

9. gear/fishing method restriction - illegal to use SCUBA for trochus in Pohnpei. Koror banned SCUBA fishing. Chuuk & Kosrae have not. Use of underwater breathing apparatus generally undesirable - (Scuba and hookah) basically to maintain a reserve in deeper water. Probably not necessary to worry about other methods. (SPC always recommends ban on SCUBA and hookah when advising governments on sea cucumber fisheries - Tonga, Solomons, Fiji. Any ban has to be pre-emptive. No point in introducing it when people have already bought the gear.)
10. limited entry - Only a limited number may participate in the fishery.
11. quota systems - If based on number, not weight, fishermen will seek out the big ones. Possible wastage, unless required to bring in live, but quotas difficult to introduce & difficult to decide
12. industry villages - rural centers for processing. Note: price is very sensitive to quality in this trade & processing is not trivial or traditional. Has to be learned & practiced. Especially if no foreign companies teaching people processing. economies of scale - drying sheds, fuel etc. Sites can be clearly identified and controlled.
13. final product - see export licensing, which can guarantee access to final product for checking.
14. processing control
15. investment guidelines

B. Resource Protection/Enhancement
    1. reserves
    2. aggregation
    3. controlled spawning
    4. larval rearing
        a) mariculture facilities
        b) lagoon farming
    5. seed production

C. Regional Cooperation
    1. sharing expertise and experiences
    2. sharing data
    3. regional regulations
    4. pooling resources
    5. regional marketing

6. cost/profit sharing
    a) shipping
    b) marketing agent
7. regional seed production
8. sole-source contracts

D. Role of Government and Private Sector
1. government control
2. government regulation
3. joint ventures
4. limited entry
5. privatization

Several major points came out of the discussions. First, that none of the islands or political entities in the region have sufficient resource to be both profitable and sustainable. Markets require large numbers of organisms to be worthwhile. Competition among islands has had the effect of decreasing the price, and increasing the amount of resource that has to be exported to be profitable. Regional cooperation would allow fixing a minimum price, and to set standards for size and quality. Cooperation would also allow the management of species by rotating pressure to meet the conditions of the populations that exist. Additionally, Micronesia has preferred trading status with the U.S., where retail markets exist in several "Chinatowns." By direct marketing rather than working through middlemen, more profit goes to the producers.

Size limits that reflect the biology of the organisms are needed. Collecting pre-reproductive individuals leads to eventual population collapse. Larger individuals are worth more than an equal weight of smaller sea cucumbers, hence, there is an additional advantage to size restrictions. The economic analysis has proven that collecting smaller individuals results in a net loss of revenue.

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