TOPIC REVIEWS IN

INSULAR RESOURCE DEVELOPMENT AND MANAGEMENT

IN THE PACIFIC U. S.-AFFILIATED ISLANDS

Edited by

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PREFACE

This technical report consists of five review papers commissioned in 1985 by the Office of Technology Assessment of the U. S. Congress as part of a broader study of renewable resource management for U. S. insular areas of the Pacific and the Caribbean. A synthesis of 50 commissioned papers, the OTA final report, by necessity, omitted much of the detailed information provided in these documents. After OTA terminated their "embargo" of these papers upon publication of their final report in 1987, the contributing authors revised and updated their reports for publication in this volume.

Because of the terms of the OTA contracts, there is considerable overlap among these five review papers, and the authors have developed different, sometimes opposing, conclusions and recommendations based on their knowledge of and experience with a particular subject area. It is hoped that these reviews will stimulate further discussion and that they will assist policy-makers in making sound judgments regarding future programs of development and management of insular resources. It is noteworthy that some of the recommendations suggested by the authors have already been set in motion.

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THE ROLE OF MARINE RESOURCE TENURE SYSTEMS (TURFs) IN SUSTAINABLE NEARSHORE MARINE RESOURCE DEVELOPMENT AND MANAGEMENT IN U. S.-AFFILIATED TROPICAL PACIFIC ISLANDS

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ABSTRACT

In contrast to western traditions, many Pacific Islanders have traditionally maintained the right to restrict or control fishing activities in their waters. Where these customs remain in force today, an awareness of their mechanics and their social and biological implications is essential for sound marine resource management. Traditional sea rights can function either as a means of fisheries conservation or as an impediment to optimum exploitation of marine resources. Either way it is often politically unacceptable to ignore them.

INTRODUCTION

Managing a resource involves regulating the behavior of the people whose activities affect that resource. In order to do so effectively, it is necessary to study not only the resource itself, but also the local customs and institutional arrangements associated with its use. Conservation laws and resource management schemes that are compatible with local practices will gain more public acceptance than those perceived by users as alien. Public support is especially important in developing tropical countries because money and personnel available for enforcement are generally minimal.

Here I describe a millennia-old system of allocation of marine resources found in many of the U. S.-affiliated tropical Pacific Islands (USATPI). In contrast with western tradition, Pacific islanders have traditionally owned the right to restrict or control fishing activities in their shallow water fishing grounds. Such fishing rights are sometimes referred to today by fisheries researchers as TURFs, an acronym for "traditional use rights in fisheries." A belated recognition of the importance of TURFs in the context of contemporary marine resource management has emerged only within the past few years. Before developing this subject I will first describe the specific characteristics of TURFs operating on USATPI.

DESCRIPTION OF SPECIFIC TENURE SYSTEMS

Caroline Islands

In the Caroline Islands it is useful to consider separately two types of island society:

1) administrative and population centers, typically on larger islands and with populations of several to tens of thousands; and 2) small outlying islands, typically with populations of a few hundred people.

Main Population Centers

Yap

Yap is a high island of 216 km^2 with a population of about 7,000 people living in numerous small coastal villages as well as in the district center of Colonia. Yapese customs pertaining to traditional fishing rights are probably more complex than any other among USATPI. A comprehensive study of Yapese fishing rights would probably take several years and fill a large book.

Yap is divided into a number of ranked districts and villages, the inhabitants being ranked accordingly (Falanruw, 1968). According to Sudo (1984) the inshore waters of Yap are divided by each village boundary, which extends directly from the village through the lagoon and reef to the open ocean. Boundaries inside the reef are defined by passages or channels through the fringing reef. Outsiders are strictly prohibited from exploiting the resources of this area. Villagers may seize the catch and gear of any trespasser. Falanruw (pers. comm., 1981) says that even trespassers' boats may be seized. In earlier times trespassers were sometimes killed.

Sudo (1984) states, "a Yapese estate usually consists of one or more houses, several taro patches (maut), yam gardens (milay), coconut palms (niw), grassy uplands (tayid), forests (egaragar), tracts of sea inside the reef (daay) and stone fish weirs (ech). The eldest man of a patri-lineage heads the estate and has nominal control over all estate land. The Yapese consider these associated land and sea resources as a single unit.

"There are three well-defined status levels among chiefs, each with definite roles in controlling marine resources. The "Chief of the Village," the highest rank, has important rights to exercise general control over inshore waters. His supreme rights are acknowledged by gifts from the catch obtained by communal fishing and fish trapping.

"The "Chief of Fishing," of second rank, is the status which leads communal fishing in the open sea. The statuses to lead fishing and to exercise magical ritual in fishing are appendant to the privilege to receive a portion of the catch. And the "Overseer of Fishing" has the right to direct communal fishing inside the lagoon. He has the privilege to take more shares than the other participants. It is interesting that those statuses are assigned to particular estates.

"On the other hand the right to use inshore waters is sub-divided. The fishing rights in reef flat areas are controlled by particular families. Small-scale fishing is allowed to every villager but for communal fishing permission must be obtained from the "Overseer of Village Sea Land." The tracts inside reefs are parcelled out and owned by particular families."

The lowest Yapese class, the pimelingai, owned no fishing grounds and were restricted from using all but the most primitive fishing gear (e.g., pointed sticks). They were allowed to gather seafood only in streams and estuaries. They could eat only eels, octopus, sharks, rays, and other fishes which could not be eaten by the higher classes. They had to report any "high class" fish they caught to the appropriate higher class authority (Falanruw, 1968; pers. comm., 1975).

In Raang Village, where fishing rights were studied in some detail by Sudo (1984), certain extended families, usually of high ranking estates, "own" and oversee all fishing grounds within the reef. Fishing rights are parcelled out to various estates, and careful distinction is made among the methods of fishing permitted and prohibited.

In principle each family is supposed to own one fish weir, but because of depopulation some families in Raang village have inherited several weirs. However, many, if not most, weirs in Yap have fallen into disuse.[1]

According to Sudo (1984), "The catch obtained by small-scale hand net fishing in the lagoon is considered the fisherman's own and is consumed by his family. For stone weirs a particular family who owns the rights to them may also take all the catch. On the other hand, communal fishing inside the reef is led and directed by the suwon e fita ("Overseer of Fishing"). He is also responsible for the distribution of the catch and is privileged to take several big fishes as his portion. Some pieces of those fish are presented to the chiefs. Each participant in this activity receives an equal share of the catch. Men engaged in fish trapping or use of bamboo fish weirs are obliged to present three pieces of fishes to the suwon e madaay, "Chief of Village".

"The fishes received by the "Chief of the Village" are redistributed to the villagers who did not participate in the communal fishing, in exchange for traditional Yapese money, nganefita (lit. "food for fisherman")."

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[1]The annual rebuilding of such weirs was an arduous community activity. Throughout much of Oceania, Westernization has brought with it a trend away from communal activities to individual enterprise and weakened the authority of traditional leaders to organize and control communal activities. This, plus the greater ease with which fish can be caught by individuals using modern devices (spear guns, gill nets, outboard motor boats, cheap fishhooks, etc.) are generally believed to be the main reasons for the virtual demise of stone fish trips that are found today in various states of disintegration throughout the tropical Pacific islands.

Falanruw (pers. comm., 1981) states that fishing areas are sometimes put off limits until fish populations increase. Other restrictions were more subtle. For example, an individual making an especially large catch did not go fishing again right away as it was considered bad to harvest too much at once. Luck in fishing should be shared rather than used for one's own benefit.

Accounts of Yapese fishing rights customs, whether it be those of fishermen whom I have interviewed or of the writers cited above, shift confusingly from past to present tense. It is clear that some relevant customs have died out. But it is not always clear just how strong the various customs are today. It does appear, however, that overall village fishing boundaries are still upheld vigorously.

Destructive fishing using dynamite or bleach is sometimes carried out on Yap reefs. One Yap municipality reacted by advertising on the local radio that anyone found doing this in their waters would have their boats confiscated (Falanruw, pers. comm., 1975). The Yap newspaper also occasionally mentions disputes over fishing rights. At least one dispute reached the High Court, Yap District (Yangruw and Giltaman vs. Manggur and Fenam, Civil Action No. 23 (1961).

Palau

Palau is an archipelago consisting of limestone and volcanic islands—most of them within a large lagoon—plus two atolls. The population is about 14,000. I carried out research on traditional fishing rights in Palau in the early 1970s.

Each of Palau's village clusters, called municipalities, exercises the right to limit access to its adjacent fishing grounds. Within at least one municipality (Ngaraard) further subdivisions were made in this century so that individual villages have control of adjacent fishing grounds. These fishing rights are still maintained, in most municipalities, to just beyond the outer reef dropoff. The lateral boundaries of municipal fishing grounds are shown in the endpapers in Johannes (1981a). Until the turn of the century, when the custom of shark fishing miles offshore died out, fishing rights extended in theory to the outer limit of foraging seabirds resident on Palau, or about 75-150 miles (Nakayama and Ramp, 1974). The need to defend this vague outer boundary arose rarely if ever.

Traditional fishing rights are controlled by the chiefs for the benefit of the villagers they represent. A municipality concerned about poachers will sometimes broadcast a warning to them over the local radio station. Continued poaching can lead to the chief of a poacher's village being fined by one of Palau's traditional high chiefs. The fined chief thereby loses face, and the clan of the fisherman who caused this embarrassment is made to pay for it—usually in the form of a substantial amount of cash. Formerly, hostilities between neighboring districts often precluded the observations of these niceties, and the offenders, if caught, forfeited their lives.

The system was not inflexible however. The use by others of marine resources surplus to the needs of the owners could be arranged. Fisherman were sometimes allowed to fish in the neighbor's waters providing they asked permission and agreed to pay a portion of the catch. Today some municipalities forbid outsiders to fish commercially in their waters but allow visitors to fish there for their own needs.

Sharing of fishing resources sometimes went beyond temporary fishing permits to the outright gift of fishing grounds to less well-endowed villages. For example, about 1930 the municipality of Ngeremlengui ceded fishing rights to two reef and lagoon areas surplus to their needs to the neighboring district of Ngatpang.

McCutcheon (1981) provided another example of the flexibility (and vicissitudes) of the traditional reef and lagoon tenure system in Palau: "[The municipality of] Melekeok never had any shortage of trochus-rich reefs, but its southern neighbor, Ngchesar, had none. Through a long-standing agreement, the reef off Ngchesar's shores belonged to Melekeok. According to legend, the hamlet of Ngerang in Melekeok once came to the military aid of Ngaruingel village in Ngchesar. To repay Ngerang for this help, Ngaruingel gave up its reef as teliakl payment—payment of land or money in compensation for service in war. The reef became known as Idimes ("southern") as affirmation of its ownership by Melekeok.

"As trochus became more and more valuable a trade item, the residents of Ngchesar began to help themselves to the wealth that Idimes reef harbored. The poaching began during the Japanese administration, but created a real annoyance to Melekeok in the 1950s. There were some insults exchanged by the chiefs in power, and a payment of money to a chief of Melekeok was made to acknowledge wrong doing and indebtedness and to assure future use rights. In this way, title by Melekeok has been confirmed, and use rights in perpetuity by Ngchesar were acquired." McCutcheon (1981) pointed out that had trochus not been a valuable resource, such a problem would never have resulted in the explicit definition of the villager's respective rights.

Fishing grounds may be shared by two districts. For example, Kossol and Ngerael reefs have traditionally been jointly fished by the people of Kayangel and Ngercherong. Also, fishermen from Ngeremlengui and Ngardmau may exploit one another's trochus resources commencing three days after the opening of trochus season (Kaneshiro, 1958).

Formerly, subsidiary fishing rights within TURFs, to stone fish traps, and to particular fishing areas were owned by individuals or corporate kin groups (Johannes, 1981a;

McCutcheon, 1981). These subsidiary rights are rarely taken seriously today and often not even remembered.

Truk

Truk is a complex of volcanic and coral islands in a lagoon encircled by a barrier reef. Fourteen islands are permanently inhabited by a total population of about 35,000. According to Sudo (1984), "The reef flat and seaward margin are the most important fishing grounds, and are strictly subdivided into several named sections. Each section is owned and controlled by a particular lineage. Although such property as sand or rock is owned exclusively by lineages, fishing rights in those sections are open to all villagers. Women gather shellfish and carry out hand net fishing. On the other hand, the fishing rights to the seaward margin are limited to members of the lineage owning that section. If men obtain a catch in the reef sections owned by another lineage they are obliged to present several fishes to the owner of that section."

Pohnpei

Pohnpei is a high island with associated small islands surrounded by a barrier reef. The total population is about 20,000. The following description of traditional sea rights comes from Fischer (1958). Each of five municipalities had exclusive fishing rights in adjacent waters. Trespassing sometimes led to warfare. At certain times in the history of Pohnpei, municipalities' sea rights were so severely enforced that travel by water was virtually impossible.

In aboriginal times the municipal boundaries were marked all the way out to the outer reef. On the outer reef, piles of coral showed the traveller or fisherman when he passed from one municipality to another. These customs died out around the turn of the century, apparently because of suppression by German colonists, although the former lateral boundaries of municipal fishing grounds are still described in each municipality's charter (Johannes, unpubl.).

Although many Pohnpeian fishermen and municipal leaders I talked to in 1978 favored the reintroduction of some form of fishing rights, subsequent deliberations by Pohnpei fisheries authorities led to the conclusion that 20th century changes in Pohnpeian society and demography made the practicality of such a move doubtful.

Kosrae

I have never come across anything of value written concerning traditional fishing or fishing rights on Kosrae. Gawel (pers. comm., 1983) stated, "lack of the old traditions of reef tenure and of fishing taboos in Kosrae makes it more important there for the government and communities to develop new management techniques to protect marine resources."

Outlying Caroline Islands

Information on TURFs exists for only a few of the outer Caroline Islands.

Ulithi Atoll

Ulithi lies 160 km northeast of Yap. A total of 710 persons inhabit five of the 30 islets on the atoll. According Sudo (1984) the atoll is divided politically into eight districts, each composed of several villages and one or more islets. Districts are ranked and Mogmog is the senior district. The paramount chief of Mogmog has some jurisdiction over the entire atoll. Districts were reportedly apportioned among the chiefs of each clan by the paramount chief, who set aside several reefs, lagoons, and islands for each clan. The chiefs of each district control marine resources on behalf of the paramount chief (Ushijima, 1982).

The lagoon and reef areas of the atoll are divided into 14 lagoon and 18 reef sections. Sudo (1984) provided a map showing these subdivisions as drawn by Ushijima (1982). Members of clans in any district or island have fishing rights in those reef and lagoon areas belonging to their clan. The authority of the paramount chief is acknowledged by periodic gifts of specified fish. No one may partake of the catch until the proper presentation has been made (Lessa, 1950; Akimichi and Sauchoman, 1982).

Satawal

Satawal is an isolated, small, raised coral island with a population of about 500. The people are grouped into eight clans. The chiefs of the three highest-ranking clans share the responsibility for planning and controlling resource use. One of these, the "Chief of the Sea," takes most of the responsibility for regulating fishing activities.

In the vicinity of Satawal, men are usually free to fish anywhere, whereas the women are limited to fishing within the reef (Sudo, 1984). Occasionally the "Chief of the Sea" will prohibit the use of spears in an area.

Fishing activities on more distant fishing grounds are more strictly regulated. Fishing on Wenimong Reef is restricted to special occasions, for example. In general, men who wish to visit uninhabited islands or remote reefs must obtain prior approval from the "Chief of the Sea." The latter has proprietary rights to certain species in these ares as well as the authority to determine how and when fishing shall be carried out (Sudo, 1984).

Woleai

Woleai is a small atoll lying about half way between Truk and Palau. According to Alkire (1968), "The lagoon is a controlled area. Boundaries conceptually divide it into segments, each of which is under the stewardship of one of the chiefs of the atoll. The chief, as a guardian of the lagoon divisions, has the right to restrict certain kinds of fishing in the area he controls as in the case of a funeral ceremony, for example, where he can prohibit fishing altogether for a specified period of time ...

"In many ways an atoll dweller considers reef areas as more important than the lagoon itself ...

"Large coral heads which protrude from the lagoon floor, independent of the encircling atoll reef, are termed moto. These too are individually named and they are usually owned by the clan or sub-division thereof that has stewardship over the area of the lagoon in which they are found. The controlling lineage, sub-clan, or clan of specific moto has the right to restrict the number of fish-traps placed in their vicinity. There are about 30 moto within Woleai Lagoon."

Etal Atoll

Etal Atoll in the Mortlock Islands had a population of 446 in 1980. Sudo (1984) described the regulation of fishing. The reef flats and reef slopes are divided into small named tracts owned by one of the eight clans or subclans, who have exclusive fishing rights to them. Five fish weirs are owned by particular clans. The catch from these weirs is usually distributed to all clan members by the clan chief. Permission by one clan to use a section of reef or a weir owned by another is sometimes granted upon request. A portion of the subsequent catch must be given to the owners.

According to Sudo (1984), "Since the paramount chief of Etal holds proprietary rights over the lands and inshore waters, he can place a taboo over one section of the reef off Etal Islet in times of food scarcity or to commemorate the death of a prominent man. The chiefs of each district also possess proprietary rights to place taboos on particular reef sections within each district. These taboos are designed to conserve marine resources."

Namonuito Atoll

Namonuito Atoll comprises five inhabited islands 230 km northwest of Truk. Sudo (1984) has described briefly the regulation of fishing on one of them, Ulul, which had a population of 276 people in 1976.

All islanders are permitted to fish anywhere, using any method, with the exception of one area which is exclusively owned by the chief's clan. Members of this clan use it mainly to catch octopus for bait, but the area is sometimes opened to all islanders for a communal fish drive. The chief is responsible for controlling marine resources and directing communal fishing.

Nothing has apparently been recorded concerning fishing relations between the populations of Ulul and the four other inhabited islands of the atoll.

Lukunor Atoll

During German colonial occupation of Lukunor Atoll traditional fish rights lapsed. I do not know the reason—perhaps as a result of a German governmental edict, as in Pohnpei (see above). In any event, at the beginning of the American administration a chief set out to restore the fish trapping and reef fishing areas to those who had formerly controlled them.

According to Tolerton and Rauch (1949), "This was not popular with the people, who in the last generation and particularly during the war had become accustomed to considerable freedom in the use of the lagoon, and particularly of the reef area adjacent to the islands. Also while not everyone had trapping grounds, their ownership was sufficiently widespread through "companies" so that all shared more or less equally in their produce. However, only 12 people controlled the reef area, and five the great majority, three of whom were closely related to the chief. Re-establishment of control meant that one must go through the routine of asking permission before using it and render a token tribute of one's catch. The order was particularly resented because the area is that utilized most intensely by the women and boys whose contribution was important during the scarcity induced by wartime dynamiting and people wished no restriction on gleaning. Yet this was precisely the reason, and undoubtedly a just one, given by the chief for the order restoring the former ownership pattern, for he felt the young men particularly were not giving the fish a chance to rest and multiply, and that they and the women were taking too many of the shellfish, which are the only readily available food after a typhoon. It is also true that traditionally the chiefs have felt identified with the reef areas, it is "their" land and it hurts to see it being abused by careless people. But those without an interest in such property charged that the chiefs and other owners were interested in obtaining a monopoly and that the people could then only buy fish in "cafes", and appealed to the Civil Affairs Office in Truk, upon which the chief rescinded the order."

Mariana Islands

Only the barest outline of the traditional culture of the original inhabitants of the Mariana islands is known because Spanish colonizers reduced the population by more than 90% and shifted the remainder, mostly women and children, to Guam. There is no recollection today in these islands of a tradition of sea rights. Unless certain modern de facto sea rights customs have evolved (I am unaware of any after having interviewed fishermen on Guam, Saipan, Tinian, and Rota) any form of limited entry for the purpose of fisheries management would have to be formulated without reference to local tradition.

Marshall Islands

The Marshall Islands consist of 29 atolls and five raised coral islands spread out over an area of about 750,000 km^2. The total land area is only 120 km^2 and the population was about 30,000 in 1980.

According to Tobin (1958) reefs throughout the Marshalls were claimed as personal property by the paramount chief if fishing was good around them. After this taboo was instituted, no one else was permitted to fish the particular reef on penalty of death or expulsion from his land. Otherwise, property rights extended out into the water to the area where people stood, usually waste deep, in order to fish with a pole. These rights belonged exclusively to the lineage whose land holding bordered the marine area (Tobin, 1952).

Certain unpopulated islands and the reefs around them were set aside as reserves for the protection of seabirds and their eggs (both eaten by the Marshallese), nesting turtles, coconut crabs, and crayfish. Harvesting was allowed only on occasions designated by the chiefs (Kramer, 1906; Tobin, 1952).

These customs continued until 1934 when Japanese authorities declared that all marine areas, up to the high water mark, belonged to the Japanese government. According to Tobin (1952), "this break with tradition has continued under the American trusteeship and is apparently accepted by everyone today." Nevertheless, "the concept that the right to exploit the marine resources of an atoll is the prerogative of the inhabitants of that atoll still persists" (Tobin, 1958).

American Samoa

The only description we have of traditional fishing rights in Samoa was published in an obscure German paper (von Bulow, 1902). He reported that all Samoan fishing grounds have their owners. Reefs and portions of reefs were variously owned by communities, chiefs' families, or other individuals. Trespassing was punished by the "local assembly".

According to von Bulow (1902), "Fishing rights are generally considered as nonsaleable in Samoa. Nevertheless in the 1870s it happened that native fishing grounds were surrendered to strangers; this however, in part without obtaining the assent of the state ...

"These fishing grounds make up part of the wealth of the owner and therefore should be protected by law today just as much as any other possession—something which until this day has actually been the case in the villages.

"Fishing rights entitle the owner to every kind of fishing on his fishing ground, to the piling up of coral and stone heaps as hiding places for fish, and to setting up any number of fish and crab traps.

"The duties of an owner of a fishing ground are in general the following:

1. If he catches certain large species of fish (the turtle, laumei, is also considered as "fish" - ia) he has to turn them over to the village assembly or in some villages to particular chiefs or to particular speakers (translator's note - "talking chiefs?").
2. In addition he has to follow the orders of the village assembly if for a certain period it forbids the catching of atule (South Sea Herring) in order for the assembly to gain time to prepare to catch this fish in the lauloa (a large drag-net), or
3. If the assembly declares the ocean "forbidden" - sa - because a high chief has died, or because during the transfer of the remains of a long-deceased person from the present grave to a new grave his bones were "bathed" by the sea.
4. The owner has to allow his own village or neighboring localities to cast their large drag-net, but to do so without searching through the stone heaps he has set up himself,
5. As well as to allow everyone to cross his fishing ground while dragging a fishing lure, pa, any time of day or night."

Although the impact of westernization has fallen especially heavily on American Samoa, some elements of traditional sea rights apparently continue to function. Thus, Wass (1983) stated, "Village councils occasionally limit fishing on the reefs fronting their village through a temporary ban on fishing or by prohibition of fisherman from other villages. Several villages do not allow fishing on Sundays and most prohibit the use of dynamite and poison—especially chlorine bleach. Management regulations instituted on the village level are much more effective than those of the territorial or federal governments because they are promulgated within the cultural context by traditional leaders and, consequently, are more likely to receive the approval and fealty of the villagers."

DISCUSSION

My task here is to try to describe the role of TURFs in contemporary marine resource management. It would be nice to be able to set out a list of relevant conclusions and recommendations for each island or island group. But this is not practical; our knowledge of these systems is too fragmentary.

Needed, along with better information on the contemporary status of traditional sea rights practices, is more detailed local knowledge of the relevant aspects of marine resource use (locations, species, quantities harvested, methods used, distribution of the catch, the relation between the size of the fishery and of the resource base, the effects of adjacent or overlapping commercial fisheries, etc.). Also needed is more information on contemporary use of these rights on a day to day basis. Published information has focused heavily on theory rather than on practice.

In addition, the knowledge we do possess is not sufficiently up to date; conditions are changing rapidly in these islands as a consequence of Westernization and political reorganization. Even studies conducted as little as eight or ten years ago (e.g., Johannes, 1981a; McCutcheon, 1981) cannot be assumed to reflect adequately the state of affairs today.

There is, thus, no substitute for detailed, locale-specific studies of the current state of traditional sea rights and how they fit into the complex and varied sets of biological, political, economic, cultural, and geographic factors relevant to marine resource management. Nevertheless a variety of useful lessons and helpful general guidelines emerge from what we do know about these systems.

Some writers have described how TURFs provide a means for maintaining or improving the welfare of small fishing communities by facilitating sound marine resource management (e.g., Cordell, 1974; Johannes, 1977; Christy, 1982; and many others). These researchers point out that where TURFs exist it is in the best interests of those who control them not to overfish. The penalty for doing so—reduced future catches—accrues directly to the owners. Self-interest thus dictates conservation. In contrast, where such resources are available to everyone, it is in the best interests of fisherman to catch all they can. Since they cannot control the activities of other fisherman, the fish they refrain from catching will most likely be caught by someone else. In a fishery open to all self-interest dictates overfishing.

Pacific islanders anticipated the west's discovery of this principle by many centuries. This is almost certainly because, firstly, the islanders, unlike continental peoples, depended upon the sea for something like 90% of their animal protein and, secondly, the sea's productivity around small isolated islands is limited largely to a narrow fringe of coral reefs. Thus, the marine resources associated with small oceanic islands are much more liable to overexploitation than those of continental shelves. As Brower (1974) has said, "Islanders perceive their limits more easily than do continental peoples."

In the west, recognition that there were practical limits to the sea's productivity developed only around the turn of the last century (e.g., Nielsen, 1976). An awareness of how unrestricted entry to a fishery contributed to stock depletion did not gain momentum until fifty years later when Gordon (1954) clearly described the benefits of limited entry. Hardin (1968) extended this analysis to all renewable resources, terrestrial and aquatic, and described the depletion resulting from unlimited access to limited natural resources with the now familiar phrase "the tragedy of the commons."

For the past 25 years a gradually expanding campaign has been waged by western economists and biologists to introduce limited entry in western commercial fisheries. For the past ten years a growing number of economists, anthropologists, and marine biologists has been pointing out that nonwestern systems of limited entry to fisheries, i.e., TURFs, have existed for centuries, but that many of these have, ironically, been destroyed or are under threat today because of the impacts of westernization.

In the past five years several fisheries biologists have argued that TURFs can pose an impediment to fisheries management and development; traditional owners may lock up underutilized marine resources, excluding the outside capital and expertise needed for their more effective exploitation (Haines, 1982; Polunin, 1984; Wright, 1985).

These contrasting views might be perceived as fundamentally contradictory and thus confusing to fisheries managers who look to researchers for advice on the subject. This would be unfortunate and unnecessary. The two points of view are based much less on differing interpretations of the facts than on different sets of facts. Systems of traditional fishing rights are very diverse. Some, accordingly, are more useful in fisheries management than others.

Whether TURFs are, in general, a boon or a bane for fisheries managers should thus not be an issue. The real question is, how can a specific system of traditional fishing rights contribute usefully to contemporary fisheries management?

The number of disputes over access to fishing grounds increases as populations grow, fishing technology improves, and pressures on resources push their potential for sustained yields to the limit. This is the case in many shallow water fisheries of the USATPI. Where TURFs exist in this setting the fisheries manager must determine where they fit in the contemporary management structure.

Here I suggest: 1) how to go about answering this question for a particular system of traditional fishing rights, 2) why TURFs cannot simply be ignored or eliminated by legislative fiat, and 3) how these considerations pertain to the fisheries of USATPI.

ASSESSMENT

There are four basic questions that must be answered in order to assess the role in contemporary fisheries management of a system of traditional fishing rights.

1. Can or does the TURF contribute to fisheries conservation?

As discussed above, the limited entry afforded by TURFs can facilitate fisheries conservation, but it cannot guarantee it. TURFs are not always seen by their owners as a means of facilitating conservation. Carrier (1981), Haines (1982), Polunin (1984), and Wright (1985) have pointed out that TURF owners in areas of Papua New Guinea and Indonesia often appear to employ these rights not as means of conserving scarce resources, but for political or social ends having little to do with conservation. They point out that, indeed, marine resources were not generally limited in these areas; population densities have been comparatively low and/or terrestrial sources of animal protein comparatively high. These authors find little evidence for the existence of a strong traditional ethic of marine conservation among these peoples. We are presently finding a similar state of affairs among the Torres Strait Islanders (Johannes and MacFarlane, unpubl.).

Perhaps a conservation ethic cannot be expected to flourish in a society where the supply of renewable natural resources greatly exceeds the needs of the population. This situation does not apply in the great majority of oceanic islands in the Pacific, however. And in contrast to the findings of researchers in Papua New Guinea and Indonesia, there is plenty of proof of the existence of a well articulated traditional conservation ethic in Polynesia (e.g., American Samoa) and Micronesia (e.g., Chapman, 1985). In fact, most basic marine conservation measures developed in the West in the past century have been practiced for centuries in these islands—closed seasons, closed areas, gear restrictions, size restrictions, etc. (see Johannes, 1978, for review).

This should not be taken to imply that Pacific islanders enjoyed a perfect relationship with nature and that all their actions were governed by wisdom and restraint. Environmentally destructive practices coexisted with efforts to conserve natural resources (Johannes, 1978) as they do in Western societies. But the existence of the former does not diminish the significance of the latter. TURFs, therefore, contribute to fisheries conservation in USATPI.

2. Does the TURF facilitate equitable allocation of the resources?

Pacific Island TURFs seem generally to have resulted historically in villages or districts getting reasonable access to adjacent fishing grounds. Furthermore, these systems have proven flexible in the past, as discussed above, so that changes could be made in TURF boundaries or ownership to accommodate changing needs. This is not to suggest that warfare and power politics have never resulted in departures from equitable allocation of TURFs, but to my knowledge this has not generally been a serious problem, at least in recent times.

3. Does the TURF facilitate sound economic management of the fishery?

It is often stated that "overcapitalization and thus economic waste is inevitable in a fishery in which there is unlimited entry" (Marr, 1976). In the absence of limited entry in a capitalist economy fishermen crowd onto the fishing grounds, investing in boats, gas, and gear (often paid for in USATPI with precious foreign exchange) to catch the fish that far fewer fishermen could have caught with a much lower expenditure of money and effort.

Maximizing profits may not always be an option which island governments choose, however. Government policy in Southeast Asian countries, for example, increasingly favors employment over economic efficiency in the artisanal sector. One cannot maximize for both where unemployment is high and natural resources are limited relative to demand. Pacific Island governments do not all seem to have clearly worked out their priorities in this regard as yet. TURF owners who exclude others from fully-exploited fishing grounds help to prevent overinvestment and resource depletion. On the other hand, TURF owners who exclude others from underexploited fishing grounds reduce the economic yield. An example of this problem and suggestion for responding to it will be the subject of a latter section of this report.

TURFs work against maximizing employment in the short term. But, in the absence of TURFs or some other form of limitation on effort, resource depletion may limit employment much more severely in the longer term.

4. How strong is the TURF system?

TURFs continue to play a major role in some island cultures (e.g., Yap, Palau, the outer Caroline Islands), a diminished but not insignificant role in others (e.g., Truk, Samoa), and have lapsed in others (e.g., the Marianas, Pohnpei, Kosrae).

Where TURFs are an impediment to the full exploitation of marine resources it would be politically unacceptable to abolish them if they retain strong community support. Other means of solving the problem must be sought (see below).

Where TURFs are an impediment to full exploitation but are weakly held, the fisheries manager may, in consultation with TURF owners, try to: 1) strengthen but modify them so that they facilitate fuller exploitation, or 2) hasten their demise. In my opinion the latter option will rarely be justified in any of the USATPI, at least in the near future.

The Roles of TURFs in Contemporary Resource Management

Incorporating traditional resource management in contemporary resource management programs is receiving growing attention in developing countries, but it is important not to underestimate the difficulties. These customs evolved in subsistence economies. Some of their features are not always consistent with market economies towards which Pacific island nations are in various stages of transition.

Pressures from Outsiders in TURFs

Perhaps the single most widespread problem faced by those charged with fisheries development in areas in Oceania where TURFs are found concerns the use of tenured fishing grounds by commercial fishermen to obtain the bait fish necessary to support offshore pole fisheries for tuna. For example, the crew of a Korean tuna boat licensed to operate in Palauan waters relied for bait on schools of small fishes netted in tenured lagoon waters. Whenever they sought bait fish they had to land and ask permission to fish. The formal presentation and granting of such requests takes considerable time and ceremony in Palau, as elsewhere in the Pacific. The tuna fishermen were so hampered by this problem that they finally left and valuable resources were left unharvested as a consequence (Johannes, 1981a). Tuna are perhaps the single most important renewable marine resource for Pacific island nations and such problems must not remain unresolved.

One response has been to arrange some form of royalties paid to the TURF owners for bait caught on their fishing grounds. When this was tried in Papua New Guinea unforeseen problems arose. Arguments developed over just where the traditional TURF boundaries lay. This may not be a major problem in USATPI because boundaries seem generally to be pretty well known and accepted. But a second problem also developed, which might also emerge in USATPI. Just who had the right to share in the royalties became a very contentious issue because of the increasing mobility of the villagers and the growing number of intervillage marriages. In one such case in Papua New Guinea the royalties derived from bait fishing were directed by the court to be held in trust until the disputants settled their differences (Johannes, 1982). I do not know the final outcome.

When the influx of outsiders reaches a certain point it becomes impractical to defend TURFs and they lapse. For example, in Koror Municipality, the seat of Palau's district center, migrants from outer villages and foreigners coverage, overwhelming the traditional order with new economic and social pressures. Immigrants from other districts greatly outnumber traditional residents in Koror, and it is almost impossible to determine (or even define) which fishermen are true residents. In consequence, traditional fishing rights are no longer exercised.

The disappearance of fishing tenure in the vicinity of district centers may be inevitable in Oceania. It has already occurred in many places. It is perhaps even desirable insofar as some portions of the coastline must often be set aside for receiving domestic and industrial wastes on one hand and for visitors seeking recreational fishing on the other. Both are often incompatible with good fishing. But if they are confined largely to waters around district centers, local deterioration in fishing conditions is perhaps not too large a price to pay.

<u>TURFs within TURFs</u>

Within a fishing ground associated with a single village or district, fishing rights are sometimes subdivided. The rights to use certain fishing techniques, to fish in certain areas, or to catch or consume certain species have been owned, for example, by particular individuals, families, or clans (e.g., Yap, Palau (formerly), Ulithi, Etal, American Samoa). I have little personal experience with such systems in USATPI, but I believe that my observations in Papua New Guinea have some relevance.

Traditionally such rights could be employed in a flexible manner so that those without formal rights to a fishing area or technique could obtain access upon request. Often the most highly valued right of property in Oceania has been the right to give it away (e.g., Sahlins, 1974). But problems may develop when villagers begin to channel their fish into a cash economy. Just as disputes <u>between</u> villages increase when cash is involved, so do disputes <u>within</u> such villages. As one Papua New Guinean testified in a court case concerning intravillage fishing rights, "Before in customary times we had no trouble....But when *Trochus* became a business the disputes over the controllers of the reef started."

In Papua New Guinea such disputes have sometimes dragged on for years. Local councils, now often divided among themselves on the issue, find it difficult to come to terms with such problems. Government intervention is sought, but the government is hampered by conflicting village testimony and the absence of any written records of who owns what.

Fine subdivisions of fishing rights appear in general not to serve conservation functions of overriding importance. Where they are reduced or absent, the potential for village disputes—especially in the context of developing cash economies based on fishing—is lessened. Those responsible for fisheries development in USATPI should keep this in mind when targeting development projects. The scope for internal village friction appears great, for example, in some of the outer Caroline Islands where fine internal subdivisions of TURFs exist and where, according to the first Federated States of Micronesia Development Plan, efforts will be made to develop commercial fishing for export to the district centers.

TURFs and Mobile Stocks

Limited entry systems, including TURFs, do not facilitate the conservation of stocks which move beyond the system boundary. For example, some species move through different tenured fishing grounds during their spawning migrations or feeding movements. Since fishermen cannot pursue migrating fish beyond the boundaries of their tenured fishing grounds, they will not invest in the gear necessary to exploit them adequately.

In 1972, in an unpublished fisheries "progress report", fisheries biologist R. Powell described such a problem on Truk. When he asked fishermen why they did not buy nets to catch abundant mackerel which travelled in schools in the lagoon, he was told that the ownership of fishing grounds prevented fishermen from exercising sufficient mobility to pursue the schools.

Powell stated, "They say that every shoal of fish which schools in close to a village is claimed as the property of that village. This is not a matter of isolated cases but is widely recognized in all islands in the lagoon.

"As a cultural problem in its simplest form, it is one where a community regards fish in front of their village as a natural resource. They can harvest a few as and when they need with inexpensive fishing gear. The fish are referred to humorously as "money in the bank."

"From the point of view of the tense administrator charged with making great changes and bringing a monied economy by fisheries to backward people who have not yet been motivated to develop a commercial fishery, such schools of fish are an untapped and wasted resource.

"It would take a brave (or stupid) man to attempt to harvest such fish from in front of any island village other than [that of] his own clan, without consulting the chief first. Anyone who does attempt this will bring a Pacific wide problem to a head. An administrator working as an Attorney would be forced into making a decision which will be a definite confliction of two cultures."

The "confliction" Powell refers to here is that between the Western tradition of "freedom of the seas" and the Pacific Island tradition of ownership of fishing rights, and between two different philosophies of marine resource management. Powell's frustration has since been felt by "tense" fisheries managers in various parts of Oceania.

One possible solution is to encourage representatives of different TURFs to work out cooperative arrangements. For example, a single net could be purchased and used cooperatively to harvest the migrating fishes, with portions of the catch or equivalent cash payments, going to owners of each TURF.

<u>TURFs and Aquaculture</u>

The issue of the relationship between property rights arrangements and the nature of aquacultural developments was first raised by Johnston (1977). Aquaculture is held by it proponents to be an important potential source of food and revenue in USATPI. Mangroves are the most common site for aquaculture development in the tropics, and mangroves form portions of TURFs in various USATPI. Of what significance are TURFs in relation to aquaculture development?

Unfortunately Johnston's (1977) deliberations were, of necessity, theoretical, because no one had studied the problem in the field. As far as I am aware, no one has done so yet in Polynesia or Micronesia. This seems unfortunate; Johnston made a very good general case for the importance of property rights in determining the nature and degree of success of aquaculture. He pointed out, for example, that "despite its efficiency, the salmon trap was outlawed in Alaska years ago to avoid control of the industry by the few firms who held strong property rights through ownership of the traps." One can easily imagine similar scenarios in connection with a subdivided TURF where one clan or family happens to own the fishing rights to the best location for an aquaculture development.

On the other hand, as Aristotle said, "that which is owned by the greatest number has the least care bestowed upon it." Aquaculture projects in which the proceeds are the property of a limited number of individuals may be pursued with greater vigor than projects where the access rights are spread over a large community.

I don't know enough about this subject to make any judgments concerning the merits of different TURF arrangements in the context of aquaculture, but like Johnston (1977), I do believe that the subject is important and deserving of serious study in connection with the USATPI. In particular, I recommend a study of the role that institutional arrangements such as TURFs have played in the success or failure of aquaculture projects in the Pacific Islands and Southeast Asia. The study should not be limited to the USATPI because there are probably not enough cases to study there as yet in order to produce useful general conclusions.

In the preceding discussion I have shown why TURFs are not an unmixed blessing in societies undergoing the transition from subsistence to cash economies. Because of the problems TURFs create, some efforts have been made to weaken or invalidate them. In Palau, for example, a bill was introduced in the legislature in 1976 that would permit "all residents of Palau to fish in any waters of the Palau Islands without the incumbrances of traditional right and ownership concerning reef and marine areas." It failed to pass.

Such efforts are understandable, but I do not believe they are justified, except, possibly, in some cases where TURFs are finely subdivided. Fishing grounds will almost certainly be chronically abused if they are thrown open to all. History provides innumerable examples. Furthermore, any legislation which weakens marine tenure laws also reduces the ability of the owners to police these resources—something they do voluntarily if their rights are secure. Such legislation would therefore increase the government's regulatory responsibilities and place serious additional burdens on already understaffed and underfunded fisheries departments. The government would thus be disposing of services it got for free and assuming new responsibilities it was ill-equipped to handle.

Consider, in the light of Western experience, what will probably happen if reef and lagoon tenure laws are invalidated in the USATPI. Fish catches, and profits where there are commercial fisheries, will dwindle as overfishing proceeds. In an attempt to reverse this trend the government will erect a complicated array of regulations—closed seasons, closed areas, size limits, gear restrictions, licenses, etc. It will be the only course open other than to invent a whole new system of limited entry to replace the abandoned system or to ignore the problem altogether. But it is an approach which has repeatedly proven both expensive and ineffective in the West. It will prove even less effective in the USATPI for at least five reasons.

1. There are far more species to deal with in the tropics. Thus, more regulations and more enforcement would be required to pursue the same objectives.
2. Biologists know much less about these species than they do about temperate marine food fishes and are thus poorly equipped to make useful decisions concerning their conservation. Furthermore, since the catch often does not go through a central market, catch data that are essential to sound scientific management are very difficult to obtain. They are, in fact, impossible to obtain at a cost commensurate with the economic gains achieved in small-scale island fisheries, except possibly in the case of a very few high-value export species (e.g., lobsters).
3. There are far more boats and far more fishermen to regulate per unit of catch than in Western commercial fisheries.
4. Government enforcement of environmental laws is notoriously lax in most USATPI and will be further impeded by fishermen who, initially at least, will resent the loss of their TURFs and the imposition of strange new laws.
5. USATPI have far less money per capita than most Western countries to try to cope with these problems.

In short, Western countries are quite unable to manage multispecies tropical reef fisheries on an efficient scientific basis, and it will be decades, if ever, before they are able to do so. In the meantime, management prescriptions are of necessity based largely on intuitions and good intentions. As a consequence our failures are legion; our successes rare. Traditional Pacific island management customs take on added appeal when we consider the West's dismal record.

If these arguments are not sufficient to persuade the reader that fisheries managers should generally work with TURFs and not against them, then let me reiterate a fact of life in many areas which makes the previous arguments academic. Whereas attempts to invalidate TURFs may sometime be greeted with the approval of commercial interests, they will create resentment within island communities on a scale that will often make such moves politically impossible in a democracy. In areas where TURFs have disappeared in Oceania and the causes were documented, I know of only one (Manus, Papua New Guinea) where undemocratic colonial governments of a bygone age were not responsible (except in areas around district centers, as described above).

Studies of TURFs and their roles in contemporary fisheries management are in their infancy. If the problems seem complicated now to the readers of this report, this is probably only a foretaste. The transition from subsistence to cash economies in the USATPI will create substantial difficulties in connection with marine resource management in general and with TURFs in particular. Here I have outlined some of the main problems that have come to light so far, but this report falls far short of a comprehensive guideline for management of TURFs in the USATPI. No one has sufficient experience to write such guidelines.

The USATPI and their constituent communities are situated at various positions along a continuum between a total cash economy and a total subsistence economy. Prescriptions for management of marine resources (and most other things) must differ depending upon the location of a particular society along that continuum.

Traditional authority remains relatively strong in the areas lying closest to the subsistence-economy end of the spectrum. An event occurring in the outer Caroline Islands provides an illustration. Turtles at Ulithi Atoll belong to some of the high lineages on the island of Mogmog. Neither turtles nor their eggs may be taken without the consent of the appropriate chiefs. In 1974 a Mogmog chief discovered the remains of a butchered turtle on a beach frequented by the people of Falalop. The Mogmog chiefs angrily issued an edict, "No one on Falalop may touch the sea water for three weeks; do not use the sea for cooling; do not catch any fish or anything from the sea; do not use the sea for `benjo' (toilet); do not swim in the sea; do not use, travel on or under the sea within or outside the lagoon in the vicinity of Ulithi Atoll; there is nothing in the sea which you can eat."

Failure to obey the order could have resulted in the destruction of personal possessions including crops and houses. Sixty traditional lava lavas (traditional skirts woven from vegetable fibers) were demanded in atonement and subsequently presented, along with abject apologies to the offended Mogmog chiefs. This proscription on any use of the sea applied even to U. S. government employees on the atoll, Peace Corps personnel, and a Jesuit missionary. Other government officials were warned by radio to stay away for the duration of the atonement. Never are U. S. or former Trust Territory conservation laws accorded such obeisance.

In Palau one comment I often heard in the remoter villages was, "We're not afraid of the courts, but we're scared of Palauan custom (laws). When you are punished Palauan style you are really punished!"

Thus, where traditional authority is still strong and the individuals in whom that authority is invested are concerned about maintaining their natural resources, the fisheries manager has a strong (and inexpensive) ally. Where such authority is faltering, one of the causes has been the gradual government assumption of the responsibilities of traditional leaders. The following statement by

Wass (1982) concerns American Samoa, but it applies generally throughout the USATPI: "Management regulations instituted on the village level are much more effective than those of the territorial or federal governments because they are promulgated within the cultural context by traditional leaders and, consequently, are more likely to receive the approval and fealty of the villagers.[2]

"Current management efforts by village councils are not as extensive as in the past. Councils should be encouraged to take a more active role in future management schemes as well as traditional religious beliefs and resource preservation for village use. A fisheries manager armed with ... some tentative management recommendations as a basis for discussion should meet with the councils and solicit their opinion regarding management objectives and the means for their achievement. ... Much or all of the enforcement responsibility would be assumed by the village if the councils firmly believed that the management strategy was beneficial," [emphasis added].

Where traditional authority over resource use has declined beyond the probable point of no return, e.g., in the vicinity of most towns, fisheries cooperatives are a possible means of using nontraditional authority, but authority nevertheless that still resides at the local level, to pursue management objectives. The Japanese took this route, gradually transferring TURFs from traditional village leaders to village-based cooperatives. Ruddle (1985) stated with reference to this system, "it is refreshing to also have [sic] in the Asia-Pacific region the example of Japanese nearshore fisheries, which, although by no means perfect in their administration and operation, stand in complete contrast to the dismal litany characteristic of most other countries in the Western Pacific."

This approach is no panacea however. Many fisheries cooperatives in various developing countries, including some in USATPI, have failed. The subject of cooperatives is complex. Space (and my limited expertise) prevents me from exploring it in detail here. But two caveats should be mentioned. First, Ruddle (1985) stressed that the Japanese system of nearshore TURFs cannot be assumed to be transferrable to other socioeconomic contexts. However, the principle behind it—that of allowing traditional TURF systems to evolve to meet changing circumstances rather than replacing them with alien (and not very successful) arrangements based on Western traditions—deserves to be tried. Second, a point made by Alexander (1980) deserves repeating. "It is easy to romanticize these social arrangements, to see peasant villagers as possessing a unique cooperative mentality. This is mistaken. Reciprocal labor relations persist because they perform vital economic functions, because debts are calculated in time if not in money, and because the

[2]They are also more liable to be appropriate to local conditions.

institutions are maintained not only by moral norms but by the abrasive force of envy and gossip. Attempts to introduce cooperatives which do not recognize this are doomed to failure."

CONCLUSIONS

It has been argued above that traditional use rights in fisheries should be integrated with contemporary systems of marine resource use in the USATPI where they are found, namely the Marshall Islands, American Samoa, and the Caroline Islands excepting Pohnpei and Kosrae. Whereas available information is sufficient to document the general features of TURFs in these islands, it is not sufficient to enable its use to generate specific practical island-by-island recommendations concerning how, precisely, this should be done.

A continent dweller is liable to assume that the environmental and economic conditions and the cultures of the mere 100,000 people that populate the USATPI are homogeneous and that their resource management problems are, accordingly, fairly standard and therefore amenable to standardized solutions. The foregoing discussion has hopefully demonstrated some of the errors involved in this assumption.

Resource management problems in USATPI are not only very complex at any one place or time, but they also vary greatly with space and time. Western resource managers are simply not in a position to solve them unilaterally. The biological and socioeconomic knowledge bases are much too slim.

There are two general responses to this problem; neither is novel: 1) obtain more information, and 2) support and encourage greater local involvement in marine resource management.

Information Needs

The management of biological resources is too important to be left to biologists. (In case readers think they detect a professional bias here, it should be pointed out that the writer is a biologist). Arguments have been advanced above for the importance of social science research in this context. There has been almost no direct input from social scientists concerning marine resource management in the USATPI. This should be remedied.

More information is needed about the current status of TURFs in the USATPI, especially American Samoa, Truk, and the outer Caroline Islands. The "right" kinds of individuals to carry out such studies could be biologists, geographers, or anthropologists, but there is probably a greater likelihood of finding such individuals among the latter two groups.

A study should be made of the implications of TURFs for aquaculture development in the islands. It should involve both a review of the literature pertaining to other areas (Southeast Asia in particular) and field research in the USATPI. One of the main objectives of the field research should be to determine whether past failures in aquaculture efforts can be traced in any significant degree to problems associated with traditional tenure systems. Unless things have improved recently, the social dimensions of successful aquaculture have received no explicit attention from researchers in the USATPI.

Undoubtedly other writers contributing to the report of which this report forms a portion will call for better education of marine resource managers in USATPI. A thorough examination of TURFs and their implications for managements should form a part of that training.

Legislation has been introduced in various Pacific island countries to protect traditional fishing rights. This is a laudable objective, but the effect of such legislation, unless very carefully conceived, is to freeze what traditionally were flexible systems of resource management and allocation. In the past, fishing boundaries and associated use rights changed as populations shifted or political or economic conditions changed. It would be valuable to the USATPI to have available for their consideration a study of existing relevant legislation throughout Oceania and its advantages and shortcomings as perceived by fishermen and marine resource managers. Although Fiji has considerable experience in this area, I do not believe such a study exists at present.

Traditional fishing boundaries and the nature of the associated TURFs should be recorded for all USATPI. However, because resources within island fishing grounds are becoming increasingly valuable as populations increase and export markets get functionally closer with improved transportation, the value of TURFs is increasing. Under the circumstances it is not surprising to find that villagers will invent "traditional" fishing rights. Information obtained from villagers on their fishing rights and customs is thus likely to be more reliable if it is elicited prior to the introduction of plans for commercial fisheries development in their waters. In other words, it should be gathered without delay.

<u>Encouraging Community Involvement in Management</u>

Efforts to reconcile government marine resource programs with TURFs, as well as with other local customs and aspirations, can only benefit from improved communication between resource users and resource managers. Lack of such communication in the past has resulted in some monumentally misguided government initiatives in the coastal waters of Oceania (e.g., Johannes, 1981b).

The current shift from expatriate to indigenous government resource managers will not necessarily always alleviate the problem. Indigenous resource managers have Western educations.

They are liable, in my experience, to have absorbed Western ideas and prejudices that render some of them almost as insensitive as many expatriates to their brethren in the villages.

The typical fisheries manager in Oceania is much too harassed and his responsibilities too numerous to enable him to spend much of his time in "extension" activities. I believe, therefore, that USATPIs should employ carefully chosen individuals whose sole responsibility is to serve as liaison between fishing communities and the government. Often such work would require living in fishing communities for weeks or months at a time (see Johannes 1981b) for discussion of some of the practical aspects of such involvements).

Such activities can be successful only if villagers are approached in a patient, relaxed manner by someone whom they have known long enough, preferably within their villages, to trust and with whom they feel at ease. It is hard to convey to someone who has never been involved in such situations the singular importance of this seemingly bland recommendation.

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THE DEVELOPMENT AND MANAGEMENT OF NEARSHORE FISHERIES IN THE U. S.-AFFILIATED PACIFIC ISLANDS

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ABSTRACT

During the 3000 years prior to western contact, Pacific islanders developed extremely efficient processes for marine resource harvest and management. These processes were based on a system of reef and lagoon ownership, a reciprocal distribution system, and a keen understanding of nature and of man's part in nature. Traditional management and conservation processes have been seriously disrupted by the introduction of modern fabrication, harvest, preservation, and transport technologies. This disruption has been accelerated by the economic pressures of commercialization which accompany rapid urbanization. The public-property, open-access philosophy embodied in U. S. marine law conflicts directly with traditional island conservation mechanisms. Thus, the effectiveness of modern conservation legislation has been constrained from the outset and diminished in effectiveness. Scientific information on the current status of inshore marine resources is fragmented and inconclusive, and generalizations about such a vast and diverse geo graphic area can lead to erroneous conclusions. It appears, however, that inshore marine resources are under significant stress near some urbanized areas. The degree of stress lessens with distance from urban centers. Reef productivity appears to be more than sufficient in the aggregate to meet the subsistence needs of island populations. However, such aggregate comparisons may lead to overoptimism because they fail to take into account the diversity of reef organisms and their dispersion among widely scattered islands. Subsistence harvests continue to make a major contribution to the standard of living even in the most urbanized islands. Commercial development potentials for inshore fisheries are limited to small-scale ventures. Species diversity and dispersion make economies of scale difficult to achieve. Opportunity costs of labor and wage rates in general are relatively high by world standards. Long term net social benefits will probably be maximized by concentrating inshore fisheries development on the improvement of small-scale local marketing and subsistence utilization. Offshore pelagic resources offer the best opportunity for the expansion of small-scale island fisheries—be they commercial, recreational, or subsistence. Unfortunately, the impact of U. S. law and policy regarding "highly migratory species" has been to place effective control of offshore pelagic resources in the hands of foreign nations and multinational corporations. These institutions often show only cursory regard for small-scale subsistence, recreational, and artisanal needs of Pacific islanders.

BACKGROUND AND SETTING

To the casual observer, what is pervasive and general among the U. S.-affiliated Pacific island peoples may be readily apparent, but an appreciation of the diversity and complexity of both the area and its inhabitants is required to understand regional fisheries issues. More than 2,100 islands and islets are scattered throughout a region as large as the United States mainland. The multiethnic character of its residents arose from numerous migrations over some 3000 years (Howells, 1973). More than ten different languages are spoken, and there is a wide variation in custom, stature, and temperament among the 272,000 residents.

The islands themselves can be divided into three general categories: large, high islands of volcanic and limestone uplift topography; low, coral atolls situated on the barrier reefs of associated lagoons; and small, raised islands with no lagoons and only fringing reefs

(Baines, 1982). Atolls are found throughout the American Pacific, but are most numerous in the Marshall Islands. Large, high islands are characteristic of the Caroline and Mariana chains and American Samoa. However, the high islands of the Marianas and American Samoa have only fringing reefs, while those in Truk and Palau are associated with large lagoons. In addition to geologic variation, there are differences in the amount and seasonality of rainfall, wind, and tidal conditions throughout the area. Cyclonic storms (typhoons) sometimes cause great damage in the Carolines and Marianas (Holliday, 1975), but are seldom experienced in the Marshalls.

Climatic and geologic variations have had a strong bearing on many of the differences which can be observed among island inhabitants, including the diversity of traditional fishing technologies and associated customs and laws. The high islands are blessed with abundant water and other land-based resources. Therefore, although fishing was an integral part of the traditional high island socio-economy, it was never as absolutely essential to life as it was on atolls and small, raised-reef islands which generally have a paucity of fresh water and arable land.

Although it is common for westerners to perceive traditional technology and way of life as simple, relaxed, and unsophisticated, nothing could be farther from the truth. Before western contact, the islanders fought wars, traded, fished, and colonized across thousands of miles of ocean, navigating by very accurate traditional methods in vessels of sophisticated construction and design (Gladwin, 1974). Fishing technology was also sophisticated in nature. The myriad of languages spoken by Micronesians in the Carolines, Marshalls, and Marianas and by Polynesians in American Samoa, Nukuoro, and Kapingamarangi, all reflect an unbelievably rich vocabulary for dealing with fishing and marine activities (Brower, 1981). In fact, this vocabulary is so rich and precise that in many locations it rivals western scientific nomenclature. However, translation often presents serious problems due to a poverty of appropriate English synonyms.

At times, there were elements of sport and competition involved, but seldom in traditional economics was fishing ever practiced for its recreational value alone. Those who attained great fishing skill were held in high esteem and were accorded significant social prestige. Their recommendations regarding ocean resource management were highly regarded by the community. Fishing knowledge, handed down from generation to generation, was a form of property of great personal value to the holder and, thus, not lightly shared with others in the community (Johannes, 1981). The "market system" as we know it did not exist. Profit in a monetary sense did not motivate fishermen. Fish were distributed through complex systems of reciprocal exchange and barter between and among large extended families (Hill, 1978). Even today, the majority of fish caught by island fishermen do not enter monetary markets (Knudson, 1985; Johannes, 1979; Milone et al., 1985).

Harvest methods, distribution patterns, and customs differed, but these patterns resulted in an apparently effective resource management system in all cases. Islanders understood and practiced the principles of property rights, resource ownership, and limited entry long before such concepts came to the attention of western scientists. Rights to harvest certain species or to fish in certain grounds were often held exclusively by particular families or other specific groups within the community (Sudo, 1984). Limited preservation techniques—primarily smoking, drying, and frequent reboiling—caused fishermen to avoid exploitation beyond what was currently needed for community food. The sea itself was the storehouse, the preserver, and the provider. Islanders also knew much about the life cycles of many organisms and their patterns of seasonal abundance (Johannes, 1981). In many cases, traditional harvesting techniques required a relatively large standing stock, or biomass. Therefore, stock depletion would automatically reduce harvests sufficiently to preclude long-term resource damage. Technologies were species-specific and not apt to damage other than the target resource. The efficiency of traditional resource management and distribution is supported by abundant evidence of relatively high pre-contact population densities on most Pacific islands—in many cases higher than densities which exist today (Vayda, 1968).

One central concept seems to pervade the complexity of all traditional island fishing technology and social structure: Man is a part of nature, not apart from nature. There is unity and interdependence among all creatures. Technological innovation is almost always viewed as a means for adjusting to the environment, rather than as a means of controlling or manipulating the environment. Attempts to outplan nature and change the inevitable are perceived as a foolish waste of time. Seldom are westerners cognizant of the conceptual differences which separate them from islanders and block mutual understanding regarding nature and conservation.

Such differences in thinking are best exemplified by the great island navigators who even today demonstrate their ability to travel accurately over vast distances without the aid of compass, sextant, or other modern devices (Gladwin, 1974). These navigators conceptualize their canoe as standing still while the rest of the world—stars, fish, birds, waves, and islands—goes past. The navigator makes adjustments to sail, speed, and direction in relation to what exists around the canoe at any point in time. He knows the significance of a change in wave pattern, which he detects by feeling the water with his hand or listening to the sounds of the canoe. He never has reason to ask why the waves change cadence as islands move by the canoe, or why the cloud patterns foretell the coming of an island far over the horizon. Western science with its own cultural bias toward the logic of cause and effect does not serve a practical place in the navigator's world. There is no need to know why; it is simply a need to know. Because of such conceptual approaches to life, islanders often have great difficulty embracing the western approach to fisheries management and conservation.

From the 17th through the 19th centuries, Spain, England, Germany, and Holland exerted varying degrees of influence on the U. S.-affiliated Pacific islands. These nations were concerned primarily with land-based resources, agriculture, and trade. Little commercial attention was paid to fisheries by any of these colonial powers. Fishing in a commercial sense began only in the 20th century with the arrival of the Japanese and the Americans. Some full-time commercial fishermen have evolved, but most are only part-time, and almost all contribute heavily to the nonmarket subsistence sector (Orbach, 1980; Johannes, 1979; Milone et al., 1985).

The semicommercialization of nearshore marine resources has had varying impacts on both the traditional subsistence harvest and the traditional management/conservation structure (Baines, 1982). The extent of this impact varies among islands depending upon resource abundance, population parameters, and degree of exposure to monetary markets. There seems to be little opportunity for large-scale commercial development of nearshore resources in most of the U. S.-affiliated Pacific islands. Lack of such potential should not lead the reader to discount the importance of these resources in the lives of island people. Fish provide a protein mainstay as well as a pillar of cultural heritage. Damage to these resources will have an extremely high opportunity cost in terms of food stamps, public assistance, and food imports, as well as the social costs of diminished self-esteem which accompany reduced self-sufficiency.

HISTORICAL TECHNOLOGIES

Much of what we know of indigenous island fishing technology is inferred from our understanding of methods presently used on islands with relatively little western contact. The people and customs of these islands offer a cloudy looking-glass into the past (Baines, 1982). The "generic" fishing techniques discussed in this paper were practiced throughout the U. S.-affiliated Pacific islands; however, there are literally hundreds of variations designed to fit the special environmental and resource characteristics of each unique island.

The importance of fishing to all Pacific islanders is underscored by the importance of fish in their diet. Recent studies in Tuvalu and Kiribati (Zann, 1983) indicate that finfish are served at 53-74% of all meals, and fish consumption averages 400 g $person^{-1}$ day^{-1}. Studies in the Marshall Islands (Milone et al., 1985) and in Guam (Callaghan, 1977) show similar high fish consumption patterns. In addition to finfish, hundreds of marine organisms are eaten, including algae, molluscs, crustaceans, and echinoderms. Based on other studies (U. S. Department of Interior, 1949), it seems reasonable to conclude that in the past, just as in the present, consumption of large quantities of marine organisms was essential to life throughout the U. S.-affiliated Pacific islands. Table 1 provides some recent data on fish consumption and harvest patterns which have changed little over centuries and are probably similar among most atoll or raised-reef islands.

The degree to which inshore and reef technologies dominate offshore technologies depends largely on the size of the lagoon and reef environment relative to the island's population size and to the extent of agricultural resources. Inhabitants of small, raised-reef islands, such as Satawal and Fais near Yap, and Tobi and Sonsorol near Palau, are very much dependent on the bounty of the open sea, and therefore, offshore technologies dominate (Gillett, 1984). These islands have little or no lagoon and reef area. Pelagic fish such as tuna, bonito, and especially flying fish, constitute approximately 70% of the finfish diet in these small, raised-reef islands (Zann, 1983).

Historically, tuna and bonito were caught by trolling from sailing canoes in the open ocean with lures constructed of wood, shell, feathers, and sennet (Johannes, 1981). The shape and glitter of the lures was provided by mother-of-pearl. Hooks were of wood or turtle shell. The lures were trolled using hand-lines of sennet. In some islands, the lures were attached by sennet and hibiscus fiber to a long pole which was used to flip the fish aboard the canoe (Gillett, 1984). Drifting logs, which tend to entice pelagic fish to aggregate, and feeding bird flocks provided signals that fish were present. Fishermen have long known that some seasons bring more logs than others and that the behavior of birds indicates the types of fish to expect. Johannes (1981) illustrated the complexity of knowledge possessed by Tobi islanders regarding current patterns and fishing locations around their reef island.

The harvest of flying fish was and still is practiced to a greater or lesser degree throughout the U. S.-affiliated Pacific islands. However, it seems to have been perfected by the small, raised-reef island and atoll dwellers. In most cases, fishing was carried out at night. Fishermen in canoes used coconut frond torches to produce artificial light to confuse

Table 1. Comparison of subsistence fishing in households during January 1980[1].

ISLAND	ONOTORA (KIRIBATI)	NIUTAO (TUVALU)
Description:	Atoll/Lagoon	Raised Reef
No. of Fish Species Eaten:	45-50	12
Species Eaten (% by Weight):	Rockcod (Serranidae), Reef Perch (*Lutjanus*), & Emperor (*Lethrinus*) ...50% Flying Fish ...10% Trevally (Carangidae) ... 5% Silversides (*Gerres*) ... 5% Mullet (Mugilidae) & Goatfish (Mullidae) ...10% Other Reef Fish ...20%	Tuna ...55% Flying Fish ...20% Wahoo (*Acanthocybium*) ...20% Other Reef Fish ...10%
Fishing Techniques (By Order of Use):	Gill Net in Shallow Water Handlining (Canoe) Skin Diving with Spear Spear Fishing Scoopnetting (Canoe) Reef Gleaning	Trolling (Canoe) Handline Deepwater (Canoe) Scoopnetting (Canoe) Handlining Shallow Water Skin Diving with Spear
Fishing Unit:	1-2 Fishermen, Small Canoe	3-4 Fishermen, Large Canoe
Average Fishing:	4.0 Days/Week	4.9 Days/Week
Fishing Effort:	27.7 Man Hrs./Week	33.0 Man Hrs./Week
Total Catch:	32.0 kg./Week	33.0 kg./Week
Catch/Effort:	1.15 kg./Hour	1.00 kg./Hour
Catch Distribution:	Household & Extended Family	30% - Canoe Crew 45% - Primary Fishing Household 25% - Extended Family and Community

[1]Source: Zann, L. P. 1983. Artisanal fisheries of the South Pacific. Univ. South Pacific, Suva, Fiji.

the fish and long-handled nets or spears to harvest them (Johannes, 1981). Flying fish were also harvested by trolling with crab-leg bait during daylight hours (Brower, 1981).

Inhabitants of large atolls or high islands with large lagoons were generally blessed with a wide selection and abundance of marine resources. These people were less dependent upon open sea fishes such as tuna and flying fish. Dietary patterns on large atolls reflect a marked reduction in the importance of pelagic species and a marked increase in the consumption of lagoon and nearshore marine resources. These differences in catch and consumption patterns are reflected in Table 1. Many of the traditional fishing methods used on atolls and raised-reef islands also were used by the people of large, high islands in the Carolines and the Marianas (Jennison-Nolan, 1979). Pelagic fishing was, of course, emphasized even less by these people since, in most cases, their islands have abundant terrestrial resources, rich mangrove swamps, tidal flats, and extensive reef ecosystems.

Despite a diversity of resource abundance and differing climatic conditions, the traditional fishermen of all islands, without exception, combined available physical natural resources with a keen knowledge of fish behavior, food preferences, spawning patterns, predator-prey relationships, and climatic and oceanographic influences (Johannes, 1978, 1979, 1981). One of the most commonly practiced techniques of fishing involved the herding of certain species into shallow areas or onto beaches. Large numbers of people formed a line some distance offshore. Often, a sennet rope with coconut fronds was stretched between them. The group would then move across several hundred yards of reef, splashing and herding the fish ahead of them. The idea was to form a semicircle around the fish, gradually reducing it in size until the fish aggregated near the shallows or a beach. This technique illustrates a precise understanding of fish behavior. Although fish could easily swim under the rope and through the legs of the fishermen, they do not. Thus, the fish actually cooperate in their own capture. Once aggregated, the fish are harvested by spear, dip net, or simply by hand. In some islands, similar aggregation was accomplished with a large surround net or beach seine made of sennet and hibiscus fibers with hibiscus floats and shell weights. The effective use of such nets required smooth sandy bottoms, not a frequent condition among Pacific islands.

Portable fish traps, lattice boxes with funnel or maze-type entrances, were used in almost all islands. The traps were constructed of local woods lashed together with sennet rope and weighted down with rocks. Considerable knowledge was required for proper trap placement on the reef. The fisherman must be familiar with the territorial and migratory habits of the targeted species. The trap was often camouflaged, and its entrance had to be situated properly with respect to the currents. Periodically the trap was removed, and the captured fish were brought to shore or placed in a canoe or bamboo raft. Alternatively, some traps were designed to remain permanently in place, and the fisherman dived to remove the fish either by hand or by spear (Johannes, 1981).

Handline fishing was a technique practiced throughout the Pacific islands during both day and night (Zann, 1983). The lines were made of sennet and hibiscus fiber. The hooks, or gorges, were made of wood, turtle shell, or bone. The bait used depended on the known food preferences and feeding behavior of target species. Rocks were used as weights to sink the baited hook to proper depths, and sometimes chum was distributed in association with the bait. Fishermen could tell from the feel of the line what type of fish was biting the hook. A knowledge of reef ecosystems and their dynamics, both day and night, was necessary to target specific species successfully. Handlining for sharks involved the dangerous task of enticing the shark to follow bait (usually hand-held) through an open noose beside the canoe. At the proper instant, the noose was closed leaving shark and fisherman to battle on the sennet handline. Quick reactions, calloused hands, and scars were undoubtedly the fisherman's trademark.

The use of fish poison was understood by most Pacific islanders (Johannes, 1981). Typically, the toxin was made from pulverized derris root or certain species of sea cucumbers. The toxin was then spread in the water, reef crevices, or potholes, often at low tide when water circulation in the area was minimal. Once anesthetized, the fish could easily be harvested by spear or hand. In most cases, unharvested organisms recovered from the stunning effects with the purging action of incoming tides.

On islands having large reef flats, fish weirs were commonly used (Hunter-Anderson, 1981). These are large, stationary walls made of piled stones or wooden stakes placed on the reef flat to form a large funnel or V-shaped stockade, with the narrow end toward the sea. The large open end may cover several hundred yards of reef flat. Many species of fish venture across the nearshore flats to feed during high tide; as the tide falls, they may find their retreat to deeper water blocked by the walls of the weir. As the tide continues to fall, the fish are channeled into a holding pen or trap at the bottom of the funnel. Fishermen periodically check the holding pen and remove the entrapped fish by spear, dip net, or hand.

Spear fishing was practiced both above and below water. Spears were made of woods with varying degrees of buoyancy and employed a wide variety of tip designs to suit specific uses. Harpoon type spear fishing was done both while walking in tidal flats and from the prow of a fast-moving sailing canoe. Throwing accuracy demanded good eyes, instant reflexes, and great muscular coordination. Adjustments had to be made for relative speed, distance, depth, and light refraction. Knowledge of swimming patterns and behavior of the target species during flight was critical to success.

Underwater spearfishing was also practiced. Again, a knowledge of fish behavior was crucial. Fishermen descended quietly, often using rocks for weight, and remained motionless for several minutes while holding on to a coral outcrop. Fish with inquisitive behavior patterns were frequently the victim since they were the first to investigate this new resident in their environment. During spawning, some species become virtually oblivious to the approach of a spearfisherman. Sounds made by certain target species were well known and duplicated by the spearfisherman to entice the prey to come within spearing distance. Night spearfishing by the light of the moon or by coconut frond torch light could be extremely productive since certain species of fish are easily speared while they sleep.

Foraging was also practiced, usually by women, throughout the tidal flats and mangrove swamps of the Pacific islands. A wide variety of invertebrates was regularly harvested and eaten. Tools usually consisted of wooden pries and coconut frond baskets, or creels. Seasonal patterns of abundance and behavior were well understood.

IMPACTS OF MODERN TECHNOLOGY ON FISHING

The management and conservation aspects of pre-contact fisheries were probably augmented by the inherent inefficiency of much of the gear used by traditional fishermen. Introduction of modern materials and construction has served to enhance considerably the productive efficiency and intensity of the old fishing technologies and, in many cases, served to undermine traditional management practices.

The underwater spear fisherman now has a steel shaft instead of wood, and "rubber bands" of surgical rubber to propel the spear over greater distances at higher speeds than was previously possible. Glass goggles and masks greatly improve underwater vision and increase the catch per unit of effort for several traditional fishing techniques. Battery-powered water-proof lights allow the spear fisherman to invade the heretofore undisturbed nocturnal resting places of many species.

Gas lights have replaced the old coconut frond torch and have significantly increased the efficiency of flying fish harvest and other nighttime reef-foraging activities. Fish traps are now made of galvanized chicken wire and welded steel reinforcing bars. Wire netting has now replaced the rock and wooden walls of the fish weir. Monofilament polymers, nylon, and lead weights replace the hibiscus fiber and shells in traditional nets. Steel hooks, wire and monofilament leader materials, and dacron lines have increased the working depth and catching capacity of handlines. Fish are now herded into large, fine-mesh monofilament gill nets which indiscriminately capture entire schools. The outboard motor has replaced the sail and greatly increased vessel maneuverability, speed, and reliability. Long-lasting, resilient fiberglass has replaced the wooden hull. The pearl shell lure has been redesigned with stainless steel, lead, and plastic in place of shell, wood, and feathers. Most damaging of all to the environment has been the substitution of chlorine bleach products in place of traditional fish poisons. These new chemicals cannot be directed at specific target species, and they destroy, rather than merely stupefy, all living organisms in the area of application.

In addition to the heightened effectiveness brought by these new materials, the introduction of entirely new methods created wholly new capabilities. Throw nets were probably first used in the Pacific islands by the Spanish in the 17th century (Jennison-Nolan, 1979). The nets are circular, sometimes up to 3 m in diameter. Lead weights ring the entire circumference, and the net is thrown into shallow water from a canoe or from a standing position on the reef flats. If thrown properly, the net opens to its full circumference before hitting the water, where it quickly sinks to envelop any fish under its scope. The net is then drawn from the center, forcing the trapped fish into pockets around the rim. Island fishermen throughout the Pacific have become very proficient in the use of the throw net.

In addition to throw nets, a wide variety of stationary and moveable surface and subsurface nets, traps, and weirs has been introduced. Of these, monofilament gill nets have probably had the greatest impact. Gill nets are designed to entangle fish which attempt to swim through the mesh. Fish with a girth smaller than the mesh size pass through unharmed. Those of larger girth pass only part way through and then attempt to withdraw. The limp monofilament entangles the fish's gill plate and the fish is entrapped. Further thrashing serves only to reinforce the entanglement. Gill nets are most frequently set in the reef passes or in the reef flats at high tide. When the tide retreats, fish attempting to move to deeper water are entrapped whether they are herded or not.

As with all other introduced innovations, it is the island fisherman's extensive knowledge of fish behavior that makes the new equipment so devastatingly efficient. With the sun coming over his shoulder, the throw net fisherman approaches a school at the edge of the reef just as the tide begins to flow. He knows the fish cannot easily see him and are intent upon feeding. At the same time, his ability to perceive them is greatly enhanced. The gill net fisherman knows that mullet in flight will jump when confronted by an obstacle. Therefore, he sets two rows of netting, one about 1 m behind the other. The school of mullet is herded toward the net, and when frightened, they tend to jump upon encountering the first net. As they reenter the water at a high rate of speed, they are trapped in the second net before they can evade it.

Fishing with explosives was contrived by islanders during World War II. After the war, there remained an ample supply of unexploded ordinance, and many fishermen became self-taught ordinance disassembly experts. There have been several deaths and maimings, but the practice of dynamiting continues with devastating results. Along with the use of chlorine poison, it ranks as the most environmentally destructive fishing method. The coral habitat on large parts of many reefs has been laid waste by explosives and chlorine. Recovery takes many years.

Modern mechanical and electronic innovations—echo sounders, loran, and hydraulics—have improved fishing efficiency immensely. Deeper and deeper resources are being tapped. Fish appear as colored blotches on the screens of electronic fish finders. Fishermen using dacron lines and lead weights can accurately place baited hooks in depths of 250 m or more. Even the swiftest schools are no match for the speed of a fiberglass hull and outboard motor. Production inefficiency no longer acts as it did in the past to control overharvest automatically. Traditional constraints are further eroded as traditional preservation techniques are supplemented with ice and cold storage.

PATTERNS AND CONSEQUENCES OF CHANGE

Contemporary fisheries in the U. S.-affiliated Pacific islands present a microcosmic cross-section of age-old fisheries problems—tragedy of the commons, overcapitalization, and habitat and resource degradation. These problems are made more complex as a market economy penetrates into the lives and cultures of traditionally subsistence peoples. A common pattern of events seems to be unfolding. The place of each island in this pattern is directly related to rates of urbanization, relative resource abundance, proximity to large markets, and availability of transportation.

Innovations mentioned in the previous chapter have brought about a re-ordering of community values and diminished social prestige associated with fishing. New materials have made it easier to construct durable fishing gear. As a result, traditional fabrication skills have fallen into disuse. It is now relatively easy to become a "fisherman". Consequently, the degree of respect and social status accorded fishermen has diminished. Their concerns regarding resource use receive less community attention. The modern fisherman can avoid a long apprenticeship, but then he misses its emphasis on the unity and interdependence of man and the environment. When the size of standing stocks diminishes, many traditional fishing techniques become less effective. In the meantime, the modern fisherman has become more and more dependent on imported materials to support his relatively high catch rates upon which the community has grown increasingly dependent.

Published research on the productivity of Pacific coral reef fisheries is diverse, inconclusive, and widely scattered. In an attempt to summarize existing information, Munro and Williams (1985) underscored the diversity of opinion and the immensity of remaining tasks in this area. Generally, coralline shelves with a good cover of actively growing coral reefs, sea grass beds, and algae produce around 3-5 mt km^{-2} yr^{-1} of neritic fishes (Munro and Williams, 1985). Coralline shelves are defined here as the horizontal and vertical marine environment between high water and the 200-m contour of the outer reef. Neritic species include all shelf-dwelling organisms, of which subsistence and commercially valuable species are a subset of unknown dimension.

If a conservative yield estimate of 3 mt km^{-2} yr^{-1} is applied to total lagoon areas and the results are compared with minimum daily protein requirements, the picture is not altogether encouraging for the potential commercial development of inshore marine resources. This comparison along with measures of population density, growth, and distribution is presented in Table 2. The implications of data presented in Table 2 were echoed in the Central, Western, and South Pacific Regional Fisheries Development Plan which stated that "...however extensive the present yield from reef and lagoon environments may be, there is probably little potential for expansion of inshore fisheries in most areas, other than that which will naturally occur as island populations grow" (Pacific Basin Development Council, 1983).

American Samoa, the Commonwealth of the Northern Marianas, and Guam are net importers of protein, as they have been for some time. Guam imports more than 350 mt of fresh and frozen whole fish each year (Myers et al., 1983). Palau, the Federated States of Micronesia (FSM), and the Marshall Islands appear to have a resource yield potential greater than current domestic protein requirements. However, several factors tend to diminish the true importance of these apparently underutilized resources. First, the excess inshore resources are distributed in small amounts among hundreds of islands scattered over thousands of miles. Second, urban populations are growing at such rates (Spoehr, 1970) that current excess yield potentials will not last long. Third, use of

Table 2. Population and inshore resource parameters for U. S.-affiliated Pacific islands. Topographic codes are HI = High Island, FR = Fringing Reef, B = Bays, A = Atolls, L = Lagoons. Estimates of reef productivity are derived by multiplying lagoon area by 3 mt km^{-2} yr^{-1}. Estimates of population protein needs are based on 300 g $person^{-1}$ day^{-1}.

Island Group	Population (x1,000)	Growth Rate (% yr^{-1})	Mean Pop. Urban Pop. (%)	Mean Rate of Urban Growth (% yr^{-1})	Land Area (km^2)	Pop. Density (n km^{-2})	No. of Major Islands	Lagoon Area (km^2)	Dominant Topography	Est. Reef Productivity (mt yr^{-1})	Est. Protein Needs (mt yr^{-1})
American Samoa	32.3	1.9	17.5	n.a.	199	162.3	5	24	HI, FR, B	72	3,537
CNMI	16.8	6.5	16.0	n.a.	471	35.4	13	35	HI, FR, B	105	1,837
Guam	106.0	2.5	39.5	9.3	541	195.9	1	28	HI, FR, B	84	11,603
Trust Territory	116.1	4.3	30.3	5.2	1,380	84.2	156	22,447		67,341	12,718
Palau	12.1	0.8	51.4	4.2	497	24.4	7	1,360	HI, L, A	4,080	1,327
Marshall Islands	30.9	3.5	47.8	2.1	181	170.6	33	11,676	A	35,028	3,381
FSM	73.2	n.a.	n.a.	n.a.	702	104.2	58	7,411		22,233	8,011
Kosrae State	5.5	6.8	n.a.	n.a.	109	50.4	1	n.a.	HI, FR, B	n.a.	601
Pohnpei State	22.1	4.5	25.1	11.0	347	63.6	9	859	HI, L, A	2,577	2,418
Truk State	37.5	n.a.	23.0	12.0	127	295.2	30	5,502	HI, L, A	16,506	4,105
Yap State	8.1	0.6	n.a.	n.a.	119	68.1	18	1,052	HI, L, A	3,150	887

Sources: U. S. Department of Commerce, Bureau of Commerce (1982a, 1982b, 1983c, 1983a, 1983b) and United States Commercial Company (1946).

explosives and chlorine, as well as siltation and pollution from terrestrial sources, may in some areas reduce coral, seagrass beds, and algae to levels which will no longer provide sufficient nutrient recycling to support yields of normal magnitude (Birkeland, 1984).

A rather consistent scenario of fisheries development and depletion seems to be emerging throughout the U. S.-affiliated Pacific islands. The scenario is in various stages of realization throughout the area. Table 2 provides some intuitive indication of the present position of various island groups in the scenario which is expanded upon below.

Urban centers are growing as rural, or outer island, dwellers immigrate in search of better education and employment opportunities (U. S. Department of Commerce, 1982a, 1982b, 1982c). Commercial fish markets—often cooperatives—are established to serve the emerging cash economies of these urban centers. Increased subsistence and commercial fishing, along with habitat degradation, put extreme pressure on urban center island reef resources (Hill, 1978). As marine products become scarce, the market prices are driven upward. Rising prices encourage even more intensive harvest efforts, and traditional reef tenure systems near the urban centers are gradually eroded. Traditional wealth and prestige are redistributed with little hope on the part of losers for satisfaction in court. The public-property, open-access philosophy embodied in the U. S. legal system conflicts directly with island conservation mechanisms and with islanders' convictions that lagoon, reef, and sea are no less ownable as private property than are houses, canoes, and coconut groves.

As the rural-to-urban migration proceeds, rural reef resources are impacted positively because rural subsistence needs are reduced. However, as the urban market demand grows, so does the pressure upon outer island resources. In the name of economic development and more equitable income distribution, governments subsidize the preservation and transport of outer island resource shipments to the urban center. Thus, the rural island subsistence fisherman is transformed into a part-time commercial fisherman. His harvest efforts now become responsive to rising market prices rather than to traditional distribution systems and subsistence needs. Because of well intentioned subsidies for vessel purchase, fuel, ice, freezing, and transport, he now finds it more profitable to harvest far more of the resource than he ever would have in traditional times or in a nonsubsidized environment. His modern, but often less selective equipment, aids the harvest. Those species most preferred by the urban dwellers command the highest prices and, thus, receive the greatest effort. Should a directed fishery be impossible or uneconomical, less commercially valuable resources may be unintentionally overharvested in the process of capturing the target species.

As urbanization continues, the reef resources are overharvested in an ever widening area emanating from the urban center (Munro and Williams, 1985). The radius of depletion depends largely upon the relative prices of fish in the district center markets and upon costs of harvest and transport from rural areas. As long as there is a profitable gap between market prices and costs (and fish are available), fish will continue to flow into urban centers from rural villages. Much of the economic rent is captured by urban businessmen and consumers rather than village fishermen and subsistence harvesters. To the extent that economies of scale are possible, fishermen will tend to invest in larger boats, larger nets, and ever more sophisticated technology. Governments, with the best of intentions, aid in this overcapitalization by subsidizing fishermen with low-interest loans, new vessels, and gear. When costs rise both fishermen and urban consumers have a vested interest in lobbying for increased subsidies. And so the problem intensifies.

As resources are depleted in the rural islands, traditional subsistence fishing becomes less and less productive. The old resource management and distribution systems are circumvented. Protein needs must be supplemented by canned fish imports (Wass, 1980). Islanders must increasingly make use of seasonally available offshore pelagic resources, which requires unfamiliar and costly imported technology, outboard motors, and fiberglass boats. The resulting upheaval of traditional roles and community value systems in rural islands is reflected in growing structural unemployment and loss of self-sufficiency which stimulates further movement to urban centers—food stamps, welfare, and canned imports.

As urban center fish prices continue to rise, less expensive foreign imports begin to flow into island fish markets. These imports exert a stabilizing pressure on local fish prices. Urban consumers benefit, but local fishermen are trapped between a fixed price for their product and ever increasing costs of harvest, storage, and transport. The only solution from the fisherman's viewpoint is to catch more fish more efficiently. Government-subsidized attempts to create further economies of scale simply serve to expand the circle of resource depletion and shift more of the rent into the hands of urban dwellers and out of the mouths of subsistence families. Fishermen search for high-priced foreign markets in the hope of improving their cost-revenue margin. In most cases, they are unsuccessful because of low volume and inconsistent quality, but even success brings with it a further loss of resource rent to foreign markets.

When the risk/reward relationship becomes unacceptable in terms of alternatives, full-time fishermen are attracted into other occupations. Part-time commercial fishermen with lower opportunity costs and second incomes take over the commercial fishing sector. These fishermen can afford to have lower returns while deriving some psychic value and subsistence benefits from their efforts. Ultimately, as the urban economy becomes more affluent, the part-time commercial fishermen is joined by the recreational fishermen who harvests common property resources, not for subsistence, not for monetary profit, but for the pure psychic value of the fishing experience. Because of time constraints and their willingness to accept lower catch per unit of effort, these part-time and sports fishermen are more likely to fish in already stressed grounds near urban centers.

The above scenario is in various stages of realization throughout the U. S.-affiliated Pacific islands. Guam (Amesbury and Callaghan, 1981), American Samoa (Wendler, 1980), and the Northern Marianas (Orbach, 1980) find themselves in the later stages of the scenario. Palau, the FSM, and the Marshall Islands seem to be in the earlier stages. Because of inshore resource depletion, more and more effort is being directed toward offshore pelagic fish.

Some western style conservation legislation has been passed in these islands in an attempt to conserve and manage the remaining inshore resources. In most cases, regulations involve net mesh-size restrictions, seasonal harvesting periods (primarily for trochus), and minimum size restrictions for some crustaceans and turtles. Water quality and environmental regulations exist in many islands. The use of explosives and chlorine is prohibited by law in most locations. However, both social and economic pressures work against successful enforcement of the few laws that are in existence (Birkeland and Grosenbaugh, 1984).

CONSTRAINTS, OPPORTUNITIES, AND POTENTIALS

The major constraints of economic development facing small Pacific islands have been noted (Fairbairn, 1971). Chief among these difficulties are isolation from large metropolitan markets, small and highly dispersed land masses with little mineral or industrial raw materials, and small but fast-growing populations with expectations rising faster than means of fulfillment. Other writers have shown how these constraints are reflected in the difficulties associated with developing inshore commercial fisheries (Kearney, 1979; Orbach, 1980; Gawel, 1981). Economic development of the immense diversity and seasonality of reef ecosystems requires great versatility of capital and labor. Seldom in Pacific islands can a fishery be developed for a single species alone. This need for versatility coupled with remoteness and small size results in high production, preservation, and distribution costs which are not easily reduced through economies of scale. Further difficulties are added by the fact that wage rates in the U. S.-affiliated Pacific islands are high relative to regional standards. Therefore, most islanders have high opportunity costs in terms of alternate employment and time required to fulfill social and cultural obligations.

The Japanese have been lauded for having achieved in many islands during the Mandate period, a sound degree of economic progress based upon indigenous island resources (Nishi, 1968). The Japanese administration used government subsidy and significant amounts of expatriate labor to encourage the production for export of trochus (topshell), pearl oysters, sea cucumbers (trepang), sponges, precious and semiprecious corals, turtle shell, assorted reef fish, and pelagic tuna products. Close examination of available records reveals that more than 90% of the exports by weight and value were composed of pelagic species, primarily tuna (U. S. Department of Interior, 1949). After more than two-and-one-half decades of Japanese fisheries development in Micronesia, exports from inshore fisheries were relatively small. In fact, inshore production was sufficient only for subsistence needs and supply of local markets for Japanese immigrants. Any significant fishery resource potential rests with offshore pelagic resources, not nearshore resources.

Most observers agree that the Japanese emphasis on commercial development of offshore pelagic fisheries was well founded. Proper management of these resources can provide opportunities for economies of scale, while at the same time allowing small-scale subsistence, commercial, and recreational participation (Kearney, 1979). One of the most promising technologies for augmenting small-scale pelagic harvests is the fish aggregation device (FAD), an anchored buoy placed adjacent to an island. Its effectiveness is based upon the long known fact that pelagic fish congregate around any floating debris in the open ocean. Substantial concrete anchors, along with chain and polypropylene line, are used to moor the buoy in depths exceeding 200 m (Boy and Smith, 1984). There are many theories for the aggregating powers of floating objects. One commonly accepted theory is that in the void of liquid space in the sea, floating objects present a reference point around which pelagic species congregate (Matsumoto et al., 1981; Shomura and Matsumoto, 1982). Sometimes, netting or short ropes are attached to the buoy and anchor line to provide a habitat for small marine organisms, which in turn provide food for the larger pelagic predators. The cost of fabrication and installation is high ($4,000-$8,000 per FAD). Life expectancy at present is 24 months or less, but placed in the right location, the FAD is extremely effective in increasing the "catchability" of pelagic fish. All FAD locations in the U. S.-affiliated Pacific islands are within the 3-mi territorial boundaries. Because of the high cost, short life span, and common property nature of FADs, most of them to date have been installed through government subsidy. Significant research efforts should be undertaken to increase longevity, to lower fabrication costs, and to standardize and mass produce FADs (South Pacific Commission, 1983).

There have been efforts, past and present, aimed at enhancing the productivity of reef flats through the introduction of artificial habitats (U. S. Department of Commerce, 1985). Old automobiles, ship salvage, and other scrap structures have been placed on reefs in an attempt to increase fish abundance. Generally these efforts have not provided long-run benefits primarily because of the short life expectancy of materials used. In most islands, outer reef slopes are very steep and have few substantial ledges. Violent wave action, currents, and silting have tended to remove or cover artificial habitats. There is no question that improved reef habitat can increase fish abundance and potential harvests (Artificial Reef Development Center, 1985). Research should be encouraged on reef enhancement devices which embody longer life expectancy and greater long-run net benefits.

Continued pursuit of some development ideas initiated by the Japanese Mandate administration (U. S. Department of Interior, 1949) is warranted. Breakthroughs in the spawning and culture of trochus (*Trochus niloticus*) and giant clams (family Tridacnidae) offer the possibility of reef reseeding (Heslinga and Peron, 1984; Heslinga, 1985). At present, trochus are harvested seasonally in some islands. The meat is eaten and the shells are exported for use in manufacture of buttons and other shell products (Carleton, 1984). Giant clams, sometimes reaching weights of 100 kg, have in some islands been overharvested to the point of extinction. Both the meat and the large shells represent a potential export if reseeding and grow-out techniques can be perfected (Munro and Heslinga, 1983).

Sea cucumbers (beche-de-mer) offer some export potential today, just as they did under the Japanese administration (Uchida, 1983). Several recent attempts to develop export markets have failed. Asian markets require a consistent, high-quality product of a particular species, dryness, size, shape, and color. As yet, it has not been possible to produce the required volume and consistency of quality. Natural abundance may have to be supplemented with mariculture to provide long-term economic viability. Continued efforts and research appear to be warranted.

All the U. S.-affiliated Pacific islands, with the exception of Midway, lie too far south to have extensive quantities of the highly valuable pink and gold corals (Western Pacific Regional Fishery Management Council, 1979; Grigg, 1982). Semiprecious black and red corals do exist in limited quantities. Extreme vulnerability to overexploitation requires harvest on a small-scale selective basis. Shells and corals in general offer some economic potential for small-scale local tourist-oriented sales. Sufficient resources for long-term, sustainable exports do not seem to be available (Uchida, 1983).

Pearl oyster cultivation and edible seaweed mariculture offer some export potential. The Japanese administration pursued both of these endeavors in Micronesia (U. S. Department of Interior, 1949). Japanese technology and marketing participation would undoubtedly be required for success in export markets today. Such joint venture approaches seem to warrant investigation. The mariculture of seaweed (*Eucheuma*) for industrial sales export has often been discussed (Doty, 1977). However, Asian nations seem to have an insurmountable advantage over small Pacific islands in terms of scale economies and labor costs. This advantage makes highly unlikely the long-term viability of industrial seaweed mariculture in U. S.-affiliated Pacific islands (McHugh and Lanier, 1983).

Two species of deepwater shrimp (*Heterocarpus ensifer* and *Heterocarpus laevigatus*) are fairly abundant in depths of 200-700 m throughout the U. S.-affiliated Pacific islands (Wilder, 1977). Rough terrain and the ecological concerns of habitat destruction make trawling unacceptable. To date, trapping has shown some success, but as yet, has not proven economically viable. Trap losses are high; productivity per trap night is low. Although the shrimp have an excellent taste, large-scale harvest and marketing problems have not yet been solved (Oishi, 1983). Further investigation of this resource is warranted; however, the highly competitive and volatile nature of international shrimp markets will probably always preclude small-scale, island-based participation (Rackowe et al., 1983).

The export of crustaceans such as lobsters, mangrove crabs, and coconut crabs offers very limited potential. Pacific island lobsters (genus *Panulirus*) do not seem to have a sufficient density on most island reefs to warrant other than small-scale harvest for local markets and subsistence use (Western Pacific Regional Fishery Management Council, 1980). Mangrove crabs (*Scylla serrata*) present many of the same problems. Although the product is of exceptional quality, the available habitat of mangrove swamps is simply insufficient to support other than meager, intra-regional shipments. Despite their high market acceptance, the mangrove crab and the land dwelling coconut crab

(*Birgus latro*) appear to be vulnerable to overexploitation and habitat degradation. Further intensive research on these species is certainly justified. Breakthroughs in the culture of mangrove and coconut crabs could be of significant economic importance.

Most Pacific islands have several marketable species of bottomfish living on the outer reef slopes and offshore banks at depths of between 20-300 m (South Pacific Commission, 1983; Taumaia and Gentle, 1983). The deeper dwelling species have become more vulnerable to harvest with the advent of echo sounders and hydraulic line pullers. There appears to be some potential for small-scale regional export of these bottomfish to higher priced markets (Howell, 1983). However, overfishing can easily take place because of somewhat limited habitat coupled with apparently slow recruitment and growth (Western Pacific Fisheries Council, 1985a). Improvements in the preservation, transport, and marketing of bottomfish products would certainly prove beneficial to many small-scale island fishermen.

Several of the U. S.-affiliated Pacific islands have relatively large baitfish stocks (Wilson, 1971; Muller, 1977; Lewis et al., 1983). Commercial pole-and-line fishing vessels capture and carry such live bait to sea, where it is used to attract schools of tuna and other pelagic species. The emergence of purse seine fishing as the dominant technology for pelagic tuna harvest has reduced the international importance of pole-and-line fishing. However, it is still viable, and live bait is essential to this harvest method. To the extent that the bait resource can be utilized by locally-based island pole-and-line tuna vessels or sold to foreign pole-and-line vessels, it represents a resource of some potential value.

RECOMMENDED FUTURE DIRECTIONS

Based upon past events, it appears that future development of inshore fisheries in the American-affiliated Pacific islands should be guided by five underlying concepts. First, growth must embody the idea of smallness and technical appropriateness. Economies of scale are not in most cases the answer to the success of island-based inshore fisheries (Bollard, 1978). Shoreside ice and freezing plants, as well as transport vessels, should be technologically uncomplicated, reliable, and culturally compatible with island communities (Baines, 1982; World Bank, 1980). Solar and wind technology offer some possibilities for outlying island.

Second, import substitution and long-run self-sufficiency should be the foremost development goals. Export of inshore marine products should be fostered only when it does not negatively impact upon present or anticipated future subsistence activities and only when such exports result in a significant local retention of resource rents (World Bank, 1980).

Third, management and conservation concerns are critical. The fragile inshore ecosystem is still an integral part of the social and economic fabric of island life. There is no hard evidence as to the present status of inshore resources, but circumstantial evidence leads to the strong suspicion of an ever growing sphere of resource stress surrounding population centers (Pacific Basin Development Council, 1983; Birkeland and Grosenbaugh, 1984). Inshore resources are the social security reserve and the unemployment insurance fund of island people. The preservation and enhancement of these inshore resources can do nothing but improve the quality of life for all residents.

Fourth, fisheries development and management should be carried out in as much harmony as possible with traditional social institutions. Cooperative organizations present a potential mechanism for accomplishing this harmony. However, considerable expertise—cultural, biological, and economic—will be required to adopt the western cooperative form of enterprise to the island social setting.

Fifth, care should be taken not to oversubsidize the commercialization of nearshore resources. These resources are fragile and finite. An overcapitalized inshore fishery will encourage depletion of stocks and add to the income of market participants while reducing the life style of subsistence participants. Such income redistribution may not lead to desirable long-run results (World Bank, 1980; 1981).

In the past, nearshore fisheries development and management in the U. S.-affiliated Pacific islands has emphasized commercial production and marketing. Resource assessments have pinpointed "underutilized resources." Government agencies have then encouraged commercial harvest of those resources. Development has been viewed as being synonymous with the commercialization of the subsistence fisherman. Little attention has been paid to either the long-or short-run opportunity costs of this "development." Management and conservation regulations have usually pursued species specific, gear specific, or seasonal formats. Enforcement costs have been high and results negligible. It has now become obvious that there are relatively few if any nearshore resources remaining "underutilized." The time has come for a more holistic approach which considers the long-run benefit of people as part of their environment. Management requires a new focus of attention on distribution of benefits as well as production. Nonmarket traditional production and distribution must become part of a management scheme which, when appropriate, incorporates traditional resource property rights.

Sea tenure and exclusive reef ownership form the foundation of traditional island fisheries management (Baines, 1982; Johannes, 1978, 1981). Artificial reef enhancement, FAD placement, and general fisheries management in many U. S.-affiliated Pacific islands could be greatly aided by legislation that would facilitate the incorporation of traditional reef and ocean tenure systems into management regulations. Unfortunately, island legislatures have tended to simply copy existing conservation statutes from mainland states for the sake of expediency and because of lack of alternatives. Legislative counsels have provided little help, either because they find it difficult to depart from the common property tradition of U. S. maritime law or because they are overburdened and generally unfamiliar with fisheries problems.

Incorporation of traditional customs and institutions into a western legal framework should be aided by federal initiative. Such an initiative could facilitate appropriate legislation by funding an interagency, interdisciplinary task force to assist islanders in drafting model area-specific laws. Peace Corps, ACTION, Sea Grant, and the National Marine Fisheries Service, as well as Pacific-based institutions of higher learning, would seem to be logical participants in such an effort. Task force components should involve the disciplines of fisheries biology, economics, law, anthropology, and sociology. Significant weight should be accorded to the latter two disciplines. Membership should be independent of vested federal agency interests which might influence recommendations. Ideally the project would take place over several years with little staff turnover. In this way, experience gained at one site could be used to speed work at subsequent sites. Liberal use should be made of indigenous island experts. In the end, a proper legal framework would greatly enhance local benefits from nearshore fisheries development. Families, clans, and communities would be much more willing to invest private funds in the protection and acquisition of marine resources if they could count on enforcement of regulations which are in keeping with traditional standards and "the island way of life."

Until recently, it had always been assumed by island governments that excessive pressure on nearshore resources could be relieved by shifting effort to offshore pelagic resources. Japanese Mandate administrators as well as subsequent investigators (Kearney, 1979; Uchida, 1983; and others) have realized that the only large-scale, commercially viable fishery resources in the Pacific islands are the pelagic species—tuna, billfish, and associated species. Unfortunately, U. S. law and policy regarding "highly migratory species" have served to place effective control of tuna and other pelagic resources in the hands of foreign nations and multinational corporations. In fact, the current state of affairs with respect to pelagic harvests provides some reason for concern as to whether residents of the U. S.-affiliated Pacific islands will ever be able to increase small-scale commercial, subsistence, and recreational harvests.

More than 100 large purse seine vessels from over a dozen countries are presently harvesting in waters of the western tropical Pacific (Petit, 1984). These seiners are not required to report their effort or catch to any U. S. government agency. Observers are not allowed on the vessels in the western Pacific. Purse seine technology is most effective when the net is set around drifting logs or other floating objects. Such sets indiscriminately capture many different species, but only the tuna and sometimes the larger billfish are retained. Unknown quantities (certainly in the thousands of tons per year) of non-tuna species of high value to islanders are discarded dead at sea. There is serious concern in the scientific community regarding the lack of verifiable scientific data on the pelagic fishery (Shomura, 1983; Western Pacific Fisheries Council, 1985b). At the present time there is no evidence as to how tuna seining activity might impact on small-scale island fisheries, and there appears to be little hope of acquiring such information in the near future. This potential loss of food fish, combined with data and management voids, may eventually result in serious abuse of the long-run self-sufficiency of island peoples. With the exception of American Samoa, where canneries are located, and to a lesser extent Guam, where refueling and transshipment takes place, most islands benefit little from large-scale tuna fishing.

Appendix A provides a list of agencies and organizations which impact upon fisheries in the U. S.-affiliated Pacific. Examination of this list makes it obvious that support for fisheries development and management is extremely fragmented. Often an agency's participation is simply dependant upon some administrator's interpretation of agency regulations. The quasi-foreign, quasi-domestic nature of some island governments makes such interpretations all the more difficult. The result is a patchwork of programs that frustrate planning at the local level and defy simple presentation. Past critiques of federal program disorganization have led nowhere (Harville, 1980). Complete enumeration and discussion of existing and potential programs would require an additional study of some length. Certainly such an effort is needed. Perhaps it would result in some reduction in the complexity of island life, but probably not.

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This paper represents only a small contribution to a much larger study of the economic potentials in U.S.-affiliated Pacific islands. The author is thankful for having been chosen to make such a contribution and would like to congratulate the Office of Technology Assessment and the Congress of the United States for undertaking this study. It is now forty years since the United States accepted responsibility for many of these islands. Such a comprehensive effort is long overdue.

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In the end, however, the author concedes that many of the positions taken in this paper reflect subjective appraisal and circumstantial evidence acquired during twenty years of personal involvement with fisheries of Micronesia. Hard data on many aspects of island fisheries are simply not available, and the author accepts full responsibility for the judgements presented in this paper.

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Appendix A. Executive agencies and independent government establishments with existing or potential fishery development, management, or conservation impacts on the U. S.-affiliated Pacific islands.

ACTION/VISTA

Skilled volunteer manpower

DEPARTMENT OF AGRICULTURE

Food and Consumer Services

1. Purchases of local marine products for school lunch and other food distribution programs

Cooperative Extension Service

1. Extension services and rural development
   - aquaculture

Cooperative State Research Service

1. Land Grant College
   - research
   - aquaculture

DEPARTMENT OF COMMERCE

Domestic and International Business Administration

1. International commercial information
2. Export trade promotion

Economic Development Administration

1. Technical assistance and development grants to economically depressed areas

National Oceanic and Atmospheric Administration

1. National Ocean Service:
   - Nautical charting
   - Research vessels and related support
2. Commercial fisheries natural disaster assistance
3. Fishery Cooperative Services
4. Sea Grant Support:
   - Research
   - Education
   - Training
   - Advisory services

5. Coastal Zone Management Program:
   - Funding for coastal planning
   - Insures state-federal consistency
   - Estuarine sanctuary assistance
6. National Marine Fisheries Service:
   A. Southwest Fisheries Center
      - Basic research
      - Resource investigation
      - Data collection and analysis
      - Habitat and conservation research
      - Management and development research
   B. Southwest Region
      - Marine mammal protection
      - Endangered species
      - Fisheries development (commercial)
      - P.L. 88-309
      - S-K Grants
      - Vessel loans
      - Infrastructure loans
      - Fisheries management
      - Enforcement
      - Education
      - Food product inspection
7. National Environmental Satellite, Data, and Information Service:
   - Oceanographic data
   - Weather service
   - Tsunami warning
8. Travel and Tourism Administration:
   - Marine tourist attraction development

DEPARTMENT OF DEFENSE

U. S. Army Corps of Engineers

1. River, harbor and waterway:
   - Design
   - Development
   - Construction
   - Maintenance
   - Associated environmental, economic, and cultural research
2. Preservation of navigable waters and wetlands
3. Disaster recovery assistance

U. S. Navy

1. Construction Battalion:
   - Community action services
2. Oceanography:
   - Fleet weather service
   - Typhoon warning

ENVIRONMENTAL PROTECTION AGENCY

Water quality
Pesticide control
Toxic, liquid, and solid waste control

DEPARTMENT OF THE INTERIOR

Fish and Wildlife Service

1. Farm fish pond management
2. Fishery research (freshwater)
3. Pesticides monitoring
4. Wildlife technical assistance
5. Marine environmental quality and biological resource programs
6. Habitat enhancement
7. Refuge management

National Park Service

1. Park and recreation technical assistance

Office of Territorial and International Affairs

1. Economic, social, and political development

NATIONAL SCIENCE FOUNDATION

Research funding

PEACE CORPS

Trained volunteer manpower

SMALL BUSINESS ADMINISTRATION

Management assistance and loans

DEPARTMENT OF STATE

Office of Pacific Island Affairs

Office of Oceans and International Environmental and Scientific Affairs

1. International fishery affairs
2. Fishery treaty negotiations and GIFAs

DEPARTMENT OF TRANSPORTATION

U. S. Coast Guard

1. Search and rescue
2. Navigational aids
3. Pollution control and port safety
4. Training and licenses
5. Maritime law enforcement
6. Fisheries management law enforcement
7. Commercial vessel safety
8. Boating safety
9. Vessel registration and documentation

OTHER BOARDS, COMMITTEES, COMMISSIONS, COUNCILS, QUASI-OFFICIAL AGENCIES, AND MULTILATERAL ORGANIZATIONS

Agency for International Development (AID)

Endangered Species Committee

Forum Fisheries Agency (FFA)

Marine Mammal Commission

Northern Marianas Islands Commission on Federal Laws

Pacific Basin Development Council (PBDC)

Pacific Fisheries Development Foundation (PFDF)

Smithsonian Institution - Tropical Research Division

South Pacific Commission (SPC)

South Pacific Regional Environmental Program (SPREP)

United Nations Trusteeship Council
- Economic and Social Commission for Asia and the Pacific (ESCAP)
- United Nations Development Program (UNDP)
- Food and Agriculture Organization (FAO)
- FAO/INFOFISH

Western Pacific Regional Fishery Management Council

DEVELOPMENT OF AQUACULTURE IN THE U. S.-AFFILIATED ISLANDS OF MICRONESIA

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ABSTRACT

The climate and traditions of the tropical Pacific islands are well suited to many types of aquacultural development although the economic potential for such development remains largely unrealized. The U. S. Pacific insular areas of Micronesia encompass a wide geographic range which consists of an expanse of ocean dotted with small land masses. The island cultures of the region are quite diverse and differ greatly in the levels of technological and economic development attained or desired. The ocean's resources are important in all of the Pacific island cultures. Although fishing is the primary means of obtaining food from the sea for these people, there is a high level of interest in the development of aquaculture within the region. This method of food production is appealing as a result of the traditional reliance of the islands on the resources of the nearshore waters. Most of the island groups have oper ated experimental or pilot-scale culture operations of one form or another. There are indications that some forms of traditional aquaculture existed in Yap, Pingelap (Pohnpei district), Kapingamarangi, and Kosrae, but these traditions were not well developed in the region in general. The island nations of Kiribati and Nauru also practiced traditional methods of fish culture. Modern interests in aquaculture derive from the desire to increase income and from concern over the decreasing fish catches in many areas. Species which have been identified as having particular potential for aquacultural development in the region include freshwater prawns, marine shrimp, giant clams, pearl oysters, rabbitfishes, milkfish, mullets, tilapia, and economic seaweeds. The major constraints to aquaculture development include the limited land areas, the lack of local sources of juveniles and postlarvae, restrictive shipping costs, the lack of aquaculture extension programs and marine advisory services, the lack of regional planning and coordination, the limited database available concerning aquatic and marine species of the region, and the lack of information on aquacultural economics.

INTRODUCTION

The islands of Micronesia have an unrealized potential for subsistence and commercial aquaculture. The warm, stable climate of this region provides conditions capable of sustaining high rates of aquatic productivity. This is evidenced by the fact that the nearshore marine ecosystems characteristic of this area are among the most productive in the world. The realization of this potential, however, presents some interesting problems since the cultural settings and the levels of technological development vary greatly between island groups. Special problems in relation to markets, transportation costs, and isolation have all contributed to the lack of major aquacultural development at present.

All of the islands share the problems associated with a limited land area and have a strong traditional reliance on marine resources (Johannes, 1977, 1978). As a result of their intimate association with the sea, the people of the Pacific Islands possess a vast knowledge of the marine organisms of importance to their daily lives. The extent of this knowledge has only recently been appreciated by the scientific community (Johannes, 1981). The tasks of obtaining food from the surrounding oceans have traditionally focused on fishing, the capture of terrestrial crabs, and the gleaning of shallow-water benthic invertebrates from the surrounding reefs. Today, the island cultures of Micronesia range from the highly Westernized and technologically sophisticated society of Guam to the essentially non-moneyed economies of the outer Caroline Islands. The technical capabilities of specific sites are major determinants of the nature of the technologies targeted for development. Also, sociological factors, such as the nature of extended family systems, will play major roles in the identification of technologies appropriate for the region.

It is the purpose of this paper to examine and assess the potential for development of a variety of aquacultural schemes for the U. S.-affiliated islands of Micronesia including the island groups of Palau, the Federated States of Micronesia (Truk, Yap, Pohnpei, and Kosrae), Guam, the Marshall Islands, and the Northern Mariana Islands. I hope to identify particularly promising opportunities for aquaculture development and to examine the constraints to such development.

ENVIRONMENTAL SETTING

The geographic region of Micronesia covers an area larger than the continental United States but possesses a combined land mass smaller than the state of Rhode Island. The marine ecosystems of Micronesia and Samoa are among the most diverse in the world and are highly productive in spite of the low levels of dissolved nutrients.

The islands may be roughly divided into two major categories 1) high islands of volcanic origin and 2) low islands, or atolls, of biogenic origin. Habitats associated with high islands include fringing reefs, barrier reefs, lagoons, mangrove swamps, bays, rivers, and small lakes (freshwater, brackish, and marine), whereas atolls are limited to lagoon and outer reef habitats. Nutrient inputs are higher around high islands as a result of periodic run-off during heavy rains (Birkeland, 1984). The input of nutrients can have profound effects on the nearshore marine communities as evidenced by the sporadic outbreaks of the crown-of-thorns starfish which occur primarily in association with high islands in this region (Marsh and Tsuda, 1973). In addition, some marine organisms are found only near high islands or are rare near low islands (Birkeland, 1984). Presumably, this is a result of the reduced nutrient availability near atolls.

Some islands, such as those of the Mariana Archipelago, are subject to the disruptive, and unpredictable, influences of tropical typhoons. These meterological events are characterized by high winds, at times in excess of 200 miles per hour, and destructive waves. The frequency and intensity of storms within the region constrain the development of aquaculture, as coastal structures may be destroyed, ponds may flood, and electrical power may be disrupted for days.

The general environmental characteristics of the region affect the strategies for development of aquaculture in a variety of ways. For example, the shortage of land area often prohibits the large-scale development of pond aquaculture. The intensity and frequency of tropical storms make the use of pen or cage aquaculture technologies impossible except in protected lagoons and large bays. The generally low levels of dissolved nutrients and the subsequently low standing crops of phytoplankton greatly reduce the feasibility of culturing such filter feeding marine organisms as oysters.

ISLAND TRADITIONS RELATIVE TO AQUACULTURE DEVELOPMENT

The people of the Pacific employ a variety of fishing techniques including trolling, fish traps, poisons, and spears (Lewis, 1967; Johannes, 1981; Hunter-Anderson, 1981; Sudo, 1984; Amesbury et al., 1986). Ocean fishes are held in high esteem and, in general, they are of greater value than freshwater fishes. Some exceptions occur, however, such as the desirability of freshwater eels to the people of Kosrae (A. Edward, pers. comm., December 1985). On some islands, certain species of marine fishes are particularly favored, and the distribution of the catch of these fishes may be limited to, or controlled by, the village chief. For example, the distribution of grouper (Serranidae) catches in the Caroline Islands is limited to the village chief; other such cases are cited by Sudo (1984).

In spite of the importance of marine fishes to the daily lives of the island people, there are few documented traditions of aquaculture in the region. Evidence exists, however, that there was some degree of fish culture practiced in several areas of Micronesia, and stone structures used as fish ponds have been reported from a number of island groups. Ahser Edward (pers. comm., August 1985) reported that fish pens constructed of stone were used in the lagoon of Pingelap (Pohnpei district) to hold fishes which had been caught and then transported to the pens in loosely woven baskets. Only one of the three fish pens in the Pingelap lagoon is still operational. The fishes held there are fed daily with breadfruit and coconut meat. A stone fish-pond, 20 meters in diameter, has also been reported to exist near the entrance to the lagoon of Kapingamarangi (Leach and Ward, 1981). In addition, stone structures found on Kosrae were reportedly used to hold turtles which were used by priests of a particular (Nosrunsrap) cult in special ceremonies (Cordy, 1983). The elaborate and diverse traditions of fish cultivation reported to have existed in the Hawaiian Islands (Kikuchi, 1976; Summers, 1964) did not develop in Micronesia.

The nearby island nations of Kiribati and Nauru have traditions of fish cultivation. Both of these cases involve the culture of milkfish *Chanos chanos*. In Kiribati, especially in the southern islands, milkfish are harvested from a number of naturally occurring ponds. These fish apparently appear in the ponds without being artificially stocked and they are not fed by the pond owners (K. Knudson, pers. comm., December 1985). However, on Nauru the milkfish were stocked, fed and reared in an inland lagoon which was partitioned into a number of smaller, individually owned ponds. The Nauruans harvested the fish primarily for consumption on special occasions and for use as bait (Petit-Skinner, 1981).

In addition, shellfish, particularly pearl oysters, have been important items of commerce for centuries in some areas within the region. The pearl shell industry had a major impact on some islands as a result of the activities of the foreign traders and fishermen drawn to the islands to exploit the stocks of the Golden-Lipped (*Pinctada maxima*) and the smaller, Black-Lipped (*P. margaritifera*) Pearl Shell (Oliver, 1962). As stocks of pearl oysters were depleted, the topshell, *Trochus niloticus*, came to be used as a source of shell for buttons and other items (Oliver, 1962; Nishi, 1968) and continues today to be a major item of export from several island groups. In Micronesia, the topshell occurs naturally only in the waters of Palau, Yap and Helen Reef (McGowan, 1956), but this species has been introduced to several other island groups within the region.

The level of interest in aquaculture in the region today is quite high, and most island groups have done preliminary work to determine the feasibility of culturing a number of species of fish and shellfish.

RECENT HISTORY OF AQUACULTURE RESEARCH AND DEVELOPMENT

Most of the Pacific island groups have demonstrated an interest in the development of aquaculture. This, in part, reflects the growing interest in aquaculture in the continental United States and throughout the world (Weatherly and Cogger, 1977; Klausner, 1985). A Pacific Islands Mariculture Conference (Anon., 1973) was convened some years ago in order to advise the development of aquaculture in the region. The current efforts in this area have been presented in some detail by Uwate et al. (1984) and summarized by Uwate and Kunatuba (1984) for the Pacific islands in general and by FitzGerald and Nelson (1979) and FitzGerald (1982) for Guam. Numerous species have been examined with regard to their potential for aquaculture development in the Pacific islands (Uwate et al., 1984; FitzGerald and Nelson, 1979). Aquaculture in this region has been proposed for a variety of purposes including food production, phycocolloid production, water treatment, and baitfish production.

In spite of the long-term interest and previous work, there are few commercially viable aquaculture ventures in the region at present. Several have been developed on Guam which has a relatively large local market and a fairly sophisticated technological base. Efforts are currently underway to develop the cultivation of phycocolloid-bearing seaweeds (Pohnpei), freshwater prawns (Guam), giant clams (Palau, Pohnpei, Yap), and rabbitfish (Guam and Palau). Those which have been or are under commercial production in the region are presented in Table 1.

Table 1. Aquatic species which have been cultured on a commercial or subsistence basis in the U. S.-affiliated islands of Micronesia.

Species	Location	Culture System	Comments
Freshwater prawns	Guam, Palau	Freshwater ponds	Seed limited
Marine shrimp	Guam, Palau	Brackish and marine ponds	Seed limited
Milkfish	Guam	Brackish ponds	Fry obtained from Taiwan
Tilapia	Guam	Freshwater and brackish ponds	Commercial
Eels	Guam	Freshwater ponds	Discontinued
Asian catfish	Guam	Freshwater ponds	Commercial
Marine fishes	Pingelap	Stone enclosure	Subsistence
	Yap	Small ponds	Subsistence
Giant Clams	Palau	Protected reefs	Seed limited
Seaweeds	Pohnpei	Protected reefs	Developing

SPECIES WITH POTENTIAL FOR AQUACULTURE DEVELOPMENT

Several species with potential for aquaculture development in the region have been identified, and these are presented below, along with a summary of their characteristics. I have omitted discussion of the possibilities of baitfish culture although this has received considerable attention in American Samoa (Baldwin, n.d., 1974; Kearney and Rivkin, 1981; Lambert and Bryan, 1979; Vergne et al., 1978). Following is a discussion of the factors which contribute to the potential for development of culture systems for selected species, the constraints to this development, and specific technologies which would be appropriate and conducive to such development.

Freshwater Prawns

The culture of the giant freshwater prawn *Macrobrachium rosenbergii* has been recently practiced commercially on a small scale on Guam. This species has been cultured on an experimental scale in Palau (Blommestein, et al., 1977). This prawn occurs naturally in the freshwater streams of Palau (McVey, 1975) but is not found in the other Micronesian islands. The strain cultured on Guam was imported from hatchery-reared stock in Hawaii and originated from stock obtained from Malaysia. Hatchery techniques for this species have been well developed. There is interest in cultivation of freshwater prawns in several islands of Micronesia, including Guam, Palau, and Pohnpei.

The cultivation of *M. rosenbergii* on Guam was underway on a small commercial scale for several years. The major factor limiting freshwater prawn production was the availability of post-larvae for stocking the ponds.

The production of *M. rosenbergii* in the ponds of Guam has proven satisfactory (FitzGerald and Nelson, 1979). The water temperatures in the region allow growth all year round. However, suitable areas for pond construction on Guam are limited (FitzGerald and Nelson, 1979), as is the case on most of the Pacific islands. On Guam and many other islands of Micronesia, there is also a severely limited supply of freshwater during the dry season. Therefore, the culture of *Macrobrachium* is limited to areas near larger drainage basins with year-round water flow. Areas especially suitable for *Macrobrachium* culture occur on Pohnpei, Palau and Guam.

Although *Macrobrachium rosenbergii* is not found naturally on most islands of Micronesia, several, mostly smaller, endemic species of *Macrobrachium* occur in the freshwater habitats of the region. Among these is another large species, *M. lar*, which is found on Pacific islands from the Ryukyus to Tahiti (Maciolek, 1977). In several areas, work has focused on the development of *M. lar* for aquaculture (Villaluz, 1972; Maciolek, 1977; Ling and Costello, 1979) with the idea that ponds could be stocked with post-larvae and juveniles obtained from the local streams. Villaluz (1972) pointed out several problems with the strategy of stocking ponds from wild-caught juveniles. Principal among these was the potential introduction of predators and competitors along with the juvenile and post-larval prawns.

Attempts have been made to develop hatchery techniques for *M. lar* (Atkinson, 1977), but to date there is no source of the post-larvae of this species. The physiological requirements of the larval stages of this species are apparently quite different from those of the commonly raised *M. rosenbergii*. The larvae of *M. lar* require higher salinities than *M. rosenbergii*, which is not surprising given the apparent need for long range oceanic dispersal of the larvae of insular species.

Another problem with the culture of *M. lar* is its highly aggressive nature (Goodwin and Hanson, 1975; Donaldson, 1981). This species was introduced to the streams of Hawaii from Guam and apparently was able to displace an endemic *Macrobrachium* species (Kubota, 1972). However, it may be worthy of attention for cultivation on a subsistence basis in areas where the cultivation of *M. rosenbergii* is not feasible.

Marine Shrimp

Marine shrimp of the genus *Penaeus* also have potential for cultivation in this region, and preliminary culture trials have been conducted on Guam (FitzGerald and Nelson, 1979) and Palau. The major problem with the cultivation of marine shrimp in this region is that the juveniles for stocking the ponds are not available. Once regional hatchery facilities are developed the potential for the culture of marine shrimp will be enhanced.

One consideration in marine shrimp culture is the nearby market in Japan. While it may be possible to cater to this export market, it should be realized that such plans will involve competition with shrimp producers in the Philippines, Taiwan, and elsewhere in Southeast Asia where labor costs are low. In Japan the demand is for *Penaeus japonicus* whereas in Taiwan and the Philippines the production is primarily of *P. monodon*. Marketing studies are needed in the early stages of regional planning for the development of marine shrimp aquaculture.

Other crustaceans

The only crustacean, other than marine and freshwater shrimp, which may have potential for cultivation in the region is the mangrove crab *Scylla serrata*. This species has been examined for its potential for culture on Guam where natural stocks are very limited (Dickinson, 1977), but no sustained commercial development has been realized. This species has been cultured in Taiwan (Chen, 1976) although Bardach et al. (1972) reported that this was a matter more of harvesting the crabs which entered the ponds incidentally rather than a managed program.

Rabbitfish

Several species of siganids are found throughout the Pacific, and these are highly prized food fishes. Although there is presently no commercial production of siganids in the region, several species of rabbitfishes are attractive aquaculture candidates (Lam, 1974; Macintosh, 1982). The major reason for interest in this group is that they are herbivorous, and, in some areas the juveniles can be collected from the reef-flats in large numbers (Kami and Ikehara, 1976). Numerous researchers have focused attention on the development of siganid culture in Micronesia (Tsuda and Bryan, 1973; May et al., 1974; Bryan, 1975; Bryan et al., 1975, Bryan and Madraisau, 1977; Hasse et al., 1977; Tobias, 1976), and similar efforts are currently underway on Guam.

Although siganids are herbivorous, they will readily accept and thrive on commercially available pelletized diets. In nature, siganids feed primarily on fleshy macroalgae (Tsuda and Bryan, 1973; Von Westernhagen, 1973a, 1973b, 1974a; Lundberg and Lipkin, 1979). They have been reported to occur on the reef flats in such numbers during seasonal recruitment episodes that their preferred algae are decimated to the point that the stocks suffer mortality from starvation. They feed almost constantly in culture and will take a variety of food items including fish and poultry feeds (Von Westernhagen, 1974b; Tobias, 1976). Since rabbitfish will accept such a wide variety of items, feed development is not considered to be a major problem. However, diets and feeding schedules need to be developed which will provide optimum conversion and cost efficiencies.

Although the juveniles may be collected at predictable times from the reef flats of some areas, including Guam, stable supplies of juveniles will eventually depend on their mass production in hatcheries. The development of hatchery technologies for these species is underway and several species have already been spawned and reared in captivity (Popper et al., 1973; Von Westernhagen and Rosenthal, 1976; Juario et al., 1984; Bagarinao, 1986).

Generally, rabbitfishes can be induced to spawn by hormone (chorionic gonadotropin) injections (Bryan et al., 1975). The larvae can be reared through their planktonic larval stage on an initial diet of rotifers and brine shrimp nauplii (May et al., 1974; Bagarinao, 1986). Juveniles have been consistently produced on a small scale at the hatchery of the Micronesian Demonstration Center in Palau for several years. However, in order to achieve the mass production of juveniles, hatchery-related mortalities must be reduced.

The culture of siganids can be achieved either in ponds and natural enclosures or in cages (Tobias, 1976; Lichatowich et al., 1984). They can survive in brackish water as well as in seawater. Although siganids are small- to moderate-sized fishes, they are prized throughout the region. On Guam, siganids bring a good retail price ($4.47 to $5.24 per kg), and it has been estimated that the market demand can not be met by the local fisheries (Myers et al., 1983).

Research efforts toward the development of siganid culture are proceeding in several regions outside of Micronesia as well. Notable efforts have been undertaken in Fiji (Gundermann et al., 1983), French Polynesia, Tanzania (Bwathondi, 1981), Hong Kong (Tseng and Chan, 1982), Kuwait (Akatsu et al., 1984), and near the Red Sea (Popper et al., 1973, 1976, and 1979; Lichatowich et al., 1984).

Milkfish

Milkfish (*Chanos chanos*) are popular in markets on Guam and in other areas of Micronesia. Milkfish are hardy and can survive and grow under a variety of environmental conditions from seawater to freshwater. Most commonly, they are cultured in brackish water ponds. This species has been successfully cultivated on a commercial scale in several adjacent regions, notably in the Philippines and Taiwan, and milkfish are currently being cultured in ponds on Guam. Milkfish have also been cultured on Nauru (Petit-Skinner, 1981) and in Kiribati (Crear, 1980). Guam has begun exporting milkfish to Nauru where production has diminished. About 20 percent of the fishes imported to Guam from the Philippines are milkfish (Myers et al., 1983).

Previously, the major problem with cultivating milkfish was the acquisition of a suitable number of juveniles for stocking the ponds. Milkfish fry for stocking were primarily collected from the wild (Villaluz et al., 1982). Around Guam, and many other islands in Micronesia, the milkfish stocks are too small to support a fry fishing industry. Locations in the region with sufficient milkfish stocks, such as in Palau, have not developed milkfish culture since fish are low priced in these areas. The exportation of fry from the Philippines, where milkfish aquaculture is well developed, was banned by their government because of the importance of the milkfish industry to their economy (Smith, 1981). Thus, until recently it has been difficult to obtain fry for use in other areas which have an interest in milkfish cultivation. Recently, however, aquaculturists have been able to spawn pond-reared broodstock, and hatchery techniques have been developed (Duray and Bagarinao, 1984; Bagarinao, 1986; Lee et al., 1986a; 1986b). The availability of milkfish fry is expected to increase dramatically in the future, and this will remove a major constraint to development of milkfish culture in this region.

Mullets

Mullet culture has received little attention in the region, but several of these species have potential for development. Several species of mullet occur in the Micronesia, including species of the genera *Liza, Valamugil*, and *Crenilabrus*. These species have received some attention on Guam, since the juveniles are abundant in shallow waters around the island. The culture of mullets was also recommended for a sightly brackish lake on Pulusuk (Truk district) for use when the sea is too rough for fishing (Nelson and Cushing, 1982). Although these fishes readily accept pelletized feed, the limited data available (S. Nelson, unpublished) indicate that most of the local mullet species have growth rates that are slow relative to those, say, of milkfish. However, techniques for induced spawning and grow out of the larger species such as the grey mullet, *Mugil cephalus*, have been well developed (Shehadeh and Nash, 1980) and either the importation of fry or their production in a hatchery would allow the culture of this species.

Mullet culture in the region deserves further consideration. Sources of fry need to be identified as an initial step.

Tilapia

Two species of tilapia, *Oreochromis mossambicus* and *Tilapia zillii*, have been introduced to Micronesia. The former species has been established in wild populations on Guam, Saipan, and Pagan in the Marianas, on Christmas Island in Kiribati (Lobel, 1980), and in some mangrove areas on Yap proper (K. R. Uwate, pers. comm., 1987). On Guam, *O. mossambicus* as well as a red hybrid, are being cultured on a commercial scale. The fingerlings, probably a hybrid between *Oreochromis mossambicus* and *O. niloticus*, were originally obtained from Taiwan, and although the fish breed readily in the ponds, additional importation of Taiwanese stock has occurred periodically. The herbivorous *T. zillii*, which is cultivated in Africa, is not cultured on Guam, but it has become established in a man-made reservoir, Fena Lake, on Guam (Best and Davidson, 1981; Leith et al., 1984) where it was introduced in an attempt to control submerged vegetation (Brock and Yamaguchi, 1955; Brock and Takata, 1956).

Tilapia culture on Guam has been quite successful. The major problem is that of controlling the breeding of the fish in the ponds and the resultant overcrowding. The overcrowding leads to stunting of the fish's growth so that, even though production remains high, the fish are too small to market. Preliminary trials have been conducted on Guam in the use of an introduced predator, the peacock cichlid (*Cichla ocellaris*) to control tilapia populations. This method of tilapia population control is limited to freshwater ponds since *C. ocellaris* can not tolerate brackish water. The peacock cichlid was introduced to the Fena reservoir on Guam for use as a sport fish. Its native habitat is South America.

Tilapia culture will probably continue to develop on Guam to serve the local market. However, because of the problems resulting from the abilities of these species to become established in a variety of aquatic habitats, their introduction to islands where they do not already exist should be strongly discouraged (see the section below on problems resulting from introduced species).

Giant Clams

There is considerable interest in the region at present in the cultivation of Giant Clams (Tridacnidae). This interest largely stems from the recent development of technologies for spawning and larval rearing of these species (Beckvar, 1981; Gwyther and Munro, 1981; Heslinga, 1981, 1982; Heslinga and Perron, 1983; Munro and Heslinga, 1983; Heslinga et al., 1984; Heslinga and Watson, 1985). Interest in tridacnid clam cultivation has developed in many areas of the Pacific, and a large international research program on the biology and culture of tridacnids is presently underway in Australia (J. Lucas, pers. comm., June 1985).

Although recent breakthroughs have spurred much of the present activity, there has been a long-standing interest in the cultivation of these species for the replenishment and management of natural stocks (Yamaguchi, 1977). Other work on tridacnids in Micronesia and nearby areas includes studies of their larval biology (Jameson, 1976; Fitt et al., 1984), the status of natural stocks (Hester and Jones, 1974; Bryan and McConnell, 1975; Hirschberger, 1980; McKoy, 1980), their growth rates in natural habitats (Bonham, 1965), and reproductive biology (Braley, 1984b).

Pearl Oysters

Pearl oysters have been important items of commerce in Oceania for centuries (Oliver, 1962), and pearl culture continues to be a thriving industry in the Tuamotus and other islands of French Polynesia (George, 1968; Davy and Graham, 1982; Coeroli et al., 1984; F. Blanc, pers. comm., June 1985). There were pearl shell operations established at Palau and, on a smaller scale, in the Marshall Islands during the Japanese era prior to World War II (Smith, 1947; Nishi, 1968). The success of this industry in Polynesia and the research underway there indicate that the culture of pearl oysters may be the focus of developmental efforts in other areas of the Pacific, including Micronesia.

Research was conducted over a period of approximately three years by scientists at CNEXO (now EFRIMER) in Tahiti to develop technologies for the mass production of pearl oyster spat. However, the methods used in other, commercially developed, oyster hatchery technologies apparently were not successful when applied to the pearl oysters, so the research has been discontinued for the time being (D. Coatanea, pers. comm., June 1985). The research focus of the scientists in French Polynesia is now on the general biology and ecology of the pearl oysters (Intes, 1984; Intes and Coeroli, 1985a). Intes and Coeroli (1985b) have compiled a bibliography concerning the biology of pearl oysters.

Since hatchery techniques for pearl oysters have not been developed, seed stock must be obtained from natural spatfall. One problem with this method is that spat of the desirable pearl oyster, *P. margaritifera*, is often mixed with and, at a small size, indistinguishable from, spat of a smaller, undesirable, species (F. Blanc, pers. comm., June 1985). The development of this industry in Micronesia would require training in the techniques of inducing the oysters to form pearls. The Tahitian government is sponsoring experts to train culturists in these techniques so, presumably, the technology could be transferred to other areas as well.

The potential for cultivation of pearl shells in Micronesia should be explored in greater detail. This type of cultivation is especially suited to protected environments, such as those of atoll lagoons where the retention of detrital materials may significantly enhance productivity (Birkeland, 1984). Attempts at the cultivation of pearl oysters should be preceded by studies of natural stocks within the region. The abundances of natural stocks of pearl oysters are currently being evaluated in Pohnpei (M. Gawel, pers. comm., December, 1985).

Other Bivalves

Numerous attempts have been made to introduce the temperate Pacific oyster (*Crassostrea gigas*) to various Pacific islands (Bourne, 1979) as recommended by previous workers (Glude, 1972). Most of these have ended in failure; however, commercial production was achieved in Hawaii (Goldstein, 1984). There have also been studies of some the indigenous bivalves, and some of these have been suggested as possible candidates for aquaculture development (Walters and Prinslow, 1975; Day, 1977; Braley, 1982, 1984a; Kamura et al., 1979; Angell et al., 1984; Glude, 1984). These projects have not led to commercial or pilot scale developments, and there has been little interest in the development of bivalve culture apart from the previously mentioned work on giant clam and pearl oyster aquaculture. There is not much of a regional market for these other species, with the possible exception of Guam with its hotel markets. In addition, the areas suitable for commercial development, such as mangrove swamps, are limited in many areas, including Guam. Another problem is that the nearshore waters are low in both dissolved nutrients and in the standing crops of phytoplankton upon which many oysters feed. Detrital feeding bivalves, however, may have potential for small-scale development.

Research-scale projects on the fast-growing Philippine green mussel *Perna viridis* are now underway in Western Samoa (Bell et al., 1983; Bell and Albert, 1984) and while this species shows some promise, caution should be taken with regard to its introduction (see the section below on introduced species).

Economic Seaweeds

The islands of Micronesia do not share the traditions of seaweed use that have been reported for Hawaii and other Polynesian islands (Schonfeld-Leber, 1979). Only a few species of marine algae are used for food in the region. These edible macroalgae, primarily *Caulerpa racemosa* and *Gracilaria* spp., are collected either for family use or to be sold in the local flea markets.

There is considerable interest in the cultivation of seaweeds in the Pacific Islands. This interest has been the largely the result of the success of seaweed farming for phyco-colloid production in Taiwan (Chen, 1976), the Philippines (Doty, 1973; Parker 1974, 1976, Deveau and Castle, 1979), and other areas (Raju and Thomas, 1971). The phycocolloid industry is rapidly growing and, for the most part, it is still limited by the supply of raw materials (the seaweeds) (Doty, 1982a, 1982b). The economic situation and the growth of the phycocolloid industry have resulted in a world-wide interest in the cultivation of seaweeds. The cultivation of seaweeds for phycocolloid extraction may be an industry well suited to remote islands, since the thalli can be sun-dried and so stored for many months. This is important where boat visits are infrequent and, even though scheduled, somewhat unpredictable.

Several species of *Gracilaria* from this region have been examined with regard to the yield and quality of their agar extracts (Nelson et al., 1983). In general, these species have relatively low quality agar extracts compared to those of cultivated strains in Taiwan. However, an exceptional variety found in Garapan Lagoon at Saipan yielded extracts within the range of those commercially cultivated in Taiwan (Nelson et al., 1983). There have been some attempts to develop post-harvest handling procedures to increase the gel strengths of the agar extracts, but these have, thus far, met with only limited success (Wilkins, 1986).

Other work on *Gracilaria* in this region has focused on growth (Nelson and Tsutsui, 1982; Nelson et al., 1982), physiology (James, 1982; Nelson and Tsutsui, 1981; Nelson, 1985), genetics (Matlock and Romeo, 1982) and on the development of suitable culture technologies (Nelson et al., 1980). In addition, research on the potential of *Gracilaria* cultivation has been recently undertaken at Pohnpei.

Other species of economic seaweeds have received some attention for possible cultivation in Micronesia (Doty, 1981; Russell, 1982; Tsuda, 1982). Primarily these have been in the genus *Eucheuma*, species of which have been successfully cultivated in the Philippines. These macroalgae contain carrageenan, another phycocolloid in demand on a world-wide scale. This genus does not occur naturally in abundance in Micronesia, but there have been some preliminary attempts at the development of *Eucheuma* cultivation at Pohnpei. A similar project was established in 1980 at Kiribati (Russel, 1982; Why, 1985). The Kiribati project has produced and exported a limited amount, about 2 tons per month, of dried seaweed. The experimental cultivation of *Eucheuma* was also undertaken at Kosrae (J. Robinson, pers. comm., August 1985).

The edible green alga *Caulerpa racemosa* is popular as a fresh vegetable and is marketed on a small scale on Guam. There has been some cultivation of this species in the Philippines for export to Japan (Doty, 1981). The potential for cultivation of this alga in the region is limited, since it is difficult to preserve or store.

Another possibility for seaweed or aquatic plant cultivation in the region is for use in water treatment (Nelson and Tsutsui, 1981; Nelson et al., 1981). The use of aquatic plants for waste water treatment has considerable potential for use in the tropics, because of the stable environmental temperatures. Aquaculture systems for water treatment have been instituted in several areas of the continental United States (Haines, 1975; Ryther et al., 1975, for example) and this concept deserves more attention for application in this region.

There has been some attention given to the cultivation of seaweed as food for other organisms (FitzGerald, 1976). Although this is likely to remain a peripheral activity, it should be mentioned that a large portion of the *Gracilaria* production in Taiwan is apparently used as feed in the culture of abalone (Y. M. Chiang, pers. comm., 1984).

PROBLEMS WITH INTRODUCED SPECIES

One striking feature of an examination of species with at least a biological/technological potential for aquaculture production within the region is that quite a large number of such species exist. Virtually any tropical species, and several temperate species, cultured today have the biological potential for production in the Pacific islands. This has led to a number of aquatic and marine species being introduced to the region specifically for evaluating their aquaculture potential. These introductions are often made somewhat indiscriminately, and if this situation continues, regrettable ecological disturbances could result (Lobel, 1980; Simberloff, 1981).

Ecological problems, such as the displacement and extinction of endemic species, which have resulted from the introduction of exotic species into aquatic ecosystems have been well documented (Lachner et al., 1970; Courtenay and Robbins, 1973; Maciolek, 1984). Such disturbances are even more likely in the relatively fragile and little known inland aquatic habitats of these islands. Species which exist on islands generally are not faced with competitive pressures as severe as are those from continental regions; thus, species which are introduced to islands may displace, or even cause the extinction of, endemic insular species.

Another problem with the introduction of exotic species is the potential for the inadvertent introduction of pests or diseases. This problem is not uniquely associated with the introduction of exotic species, but is also a problem with such practices as importing fry or fingerlings for stocking aquaculture ponds, even when the species in question occurs naturally in the area. If juveniles are to be imported in order to sustain an aquaculture industry, then some quarantine facility is necessary to reduce the potential hazards of this practice.

Aquatic introductions should be undertaken with caution and only after thorough studies of the potential impact on the native fauna have been completed. Local species should be developed for aquaculture in preference to introduced species whenever possible. Regional or local governments should establish screening committees for the purpose of evaluating proposed introductions.

FUTURE

Interest in the development of aquaculture in this region is expected to increase in the future as the reefs become overfished as a result of population pressure, the use of modern fishing equipment, and the breakdown of traditional methods of conservation. Subsistence aquaculture could be developed in a some areas to enhance the quality of life. Also, small-scale commercial aquaculture could supplement food resources, aid in the replenishment of stocks of marine organisms, and stimulate the regional economy. The political situations of nearby countries should entice companies involved in aquaculture to consider investing in ventures within the region. Meanwhile, the needs of the island territories and nations of this region should not be neglected.

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DEVELOPMENT AND MANAGEMENT OF NONFOOD MARINE RESOURCES IN THE PACIFIC U. S.-AFFILIATED ISLANDS

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ABSTRACT

The marine environment has supplied most of the food and material needs of the inhabitants of the Pacific Islands for more than 3,000 years. Traditionally, nonfood marine resources provided raw materials for manufacture of fishing implements, weapons, ornaments, currency, and dwellings. Cultural taboos limited harvests of these resources, thereby providing for sustained yields. Nonfood marine resources became the currency of commerce following contact of the islanders with European explorers and merchants. Western political, legal, and religious institutions replaced traditional practices and led to overexploitation of these resources. Under U. S. administration, nonfood marine resources have not achieved the level of importance in island economies that was developed during the Japanese mandate. Since World War II, records of harvests have been poorly kept, and research on distribution and abundance of resources has been limited. Federal agencies with oversight responsibilities do not maintain personnel in the region to assist in development and management programs. Technologies for development of nonfood marine resources of U. S.-affiliated islands already exists. Transfer of these technologies would assist in creating employment opportunities in the islands and in stabilizing island economies. Island governments need assistance in research, extension, and education programs to develop strategies to use resources wisely.

INTRODUCTION

Since the arrival of the first inhabitants of the Pacific islands some 3,000 years ago, the marine environment has supplied most of the food and material needs of the islanders. From raw materials in subsistence cultures to sources of revenue in modern international commerce, nonfood marine resources have been an integral part of island economies.

For the purposes of this paper, nonfood marine resources include biotic and abiotic resources occurring between the mean high tide line and extending to and including coral-reef resources to an approximate depth of 600 feet. Thus, products of molluscs, cnidarians, macroalgae, mangroves, sharks, and turtles, as well as mineral deposits are encompassed in this definition. The commodities produced from these resources include jewelry, ornaments, pharmaceuticals, and building materials.

The U. S.-affiliated islands of the Pacific include the Mariana, Caroline, and Marshall Islands in Micronesia and American Samoa in Polynesia. Together, they number more than 2,000 islands and atolls, but only about 100 are inhabited. Scattered across some 3 million square miles of ocean, the islands have a total land area of about 1,000 square miles, half of which is on three islands (Guam, Babelthuap, and Pohnpei).

The islands may be roughly classified either as high islands of volcanic origin or as low islands, or atolls, of biogenic origin. High islands are characterized by the presence of a greater diversity of ecosystems, including fringing reefs, barrier reefs, lagoons, estuaries, mangrove swamps, and marine lakes. Atolls generally have only lagoons surrounded by barrier reefs. Nutrient input from terrestrial run-off is believed to account for greater productivity at high islands.

Each of the island groups is unique in history, language, culture, and politics. Far removed geographically from sources of development capital, the islands share a common need for economic development. Because of the limited land mass of the islands, the oceans must play a significant role in economic development. Development of nonfood marine resources of the region would contribute to increased stability of island economies by reducing their dependence on import of both processed and unprocessed materials, by increasing employment opportunities for island residents, and by generating revenue through export of locally produced goods.

The purpose of this report is to review and assess the development potential of nonfood marine resources of U. S. insular areas of the Pacific. Particular attention has been given to renewable natural resources which can be managed on a sustainable-yield basis. This assessment is organized into three parts: 1) historical resource exploitation and management, from precontact economies to World War II; 2) contemporary resource exploitation and management, from World War II to the present; and 3) potential resource exploitation and management.

HISTORICAL RESOURCE EXPLOITATION AND MANAGEMENT

Before contact with Europeans, Pacific island cultures relied primarily upon the ocean for their food, transportation, recreation, and spiritual well-being. Island cultures reflected a variety of geographical, social, political, and economic conditions, but groups were traditionally, and by necessity, self-sufficient. Although access to certain resources led to some specialization and trade, the traditional system of marine tenure in the Pacific was associated with the subsistence economy (Eaton, 1985).

Despite great differences in language and culture among island populations, each group evolved over the millennia a distinctive set of traditions which reflect a keen awareness of local ecological relationships. Rights to exploit marine resources were limited to a group claiming exclusive use of an area of sea and carefully controlled by taboos to ensure a sustained yield (Johannes, 1977). Ownership or use of adjacent land was generally regarded as the basis of rights to the beach, reef, and sea. Outsiders were excluded or could use the area only with permission, usually after making some form of payment or gift (Eaton, 1985).

Magellan's landfall at Guam in the 16th century marked the beginning of the era of European exploration and exploitation in the Pacific. Consequent to contact with Europeans was the introduction of iron. More easily worked and more durable than traditional materials, iron quickly replaced natural products as the raw material for everything from fishhooks to adzes. European merchants and whalers exploited the high value islanders placed upon iron and other goods to entice them into bartering for, among other things, natural products of the islands and their surrounding seas.

As the value of land- and sea-based natural resources in the Pacific became recognized, countries of western Europe strove for jurisdiction over island groups. Colonial rule weakened traditional authority as new political and religious institutions were imposed. Traditional tenure systems were modified or outlawed in favor of western concepts of ownership rights and practices. Thus, many Pacific countries evolved a dual system of tenure (Eaton, 1985; Pulea, 1985), which frequently resulted in a cancelling of authority, thereby allowing uncontrolled abuse of resources.

Nonfood marine resources exploited prior to World War II can be grouped into the following categories.

Pearls and Mother-of-Pearl

Pearl shell, or mother-of-pearl, was one of the most important sources of raw material for the manufacture of fishing tackle in traditional systems (Thompson, 1945). Fishhooks, gorges, and trolling lures were shaped from nacre produced by several families of gastropods and bivalves. Because of its iridescence, mother-of-pearl was also harvested as a resource for producing ornamental items.

Chief among the nonfood marine products in early trade were pearls and mother-of-pearl of shells of the bivalve Family Pteriidae. Although there are no accurate records of this trade in U. S.-affiliated islands, small-scale harvest of pearl shell began in Palau during the German administration (Smith, 1947). Such an industry was well-suited to the islands, because little equipment was necessary; divers collected the pearl oysters by hand.

Merchants eagerly sought pearl and mother-of-pearl for the European market where these products were highly valued for jewelry, buttons, and other ornamental objects. Because a monetary economy operated outside traditional systems, harvests of pearl shell were unmanaged and stocks were overexploited. The development of diving helmets further aggravated the problem, and by the 20th century, natural populations of pearl oysters were depleted throughout their Pacific range (Oliver, 1962).

During the Japanese mandate, four Japanese companies began to culture pearl oysters in Palau in the 1930s (Motoda, 1938). One of these companies purchased the black-lipped pearl oyster *Pinctada margaritifera* from Palauan divers for cultivation of pearls. The other three companies used pearl species introduced into Palau from other areas of the Pacific. Motoda (1938) reported that these companies were producing more of the gold-lipped pearl oyster *Pinctada maxima*, which they introduced, than any region in which natural populations of the species were exploited. However, pearl oyster culture operations were closed as World War II moved into the Pacific.

Trochus

Exhaustion of natural pearl oyster stocks and increasing demand for mother-of-pearl stimulated search for new resources. The commercial topshell *Trochus niloticus* was found to possess dense, firm nacre suitable for button material (Hedley, 1917; Nakajima, 1920). Because trochus grew rapidly and was found at shallow depths, an extensive fishery for this species developed.

Within a few years, topshell harvests began to decline in a pattern similar to that of pearl oysters. The Japanese administration attempted to sustain topshell populations at fairly constant levels of productivity in Palau by imposing regulations on the length of the harvest season and on the minimum size of shells that could be harvested (Motoda, 1938; McGowan, 1956, 1958).

By the 1920s, the declining populations of mother-of-pearl species and high market demand in fashion centers of Europe and North America prompted research into methods of improving productivity. Japanese scientists successfully transplanted topshells in the Caroline and Mariana Islands in the 1930s (Asano, 1937a, 1937b, 1937c). Truk, the only area that produced a commercial harvest before World War II, suspended the fishery following the outbreak of hostilities (McGowan, 1956).

Ornamental Shells

The shells of marine molluscs have been valued as ornamental objects since prehistoric times. Various cultures and societies have attributed powers of magic, religion, and virility to shells, as well as placing value on them as currency and curios (Dance, 1966, 1986; Abreu, 1979).

Marine shells generally were harvested as raw materials for the manufacture of tools, utensils, ornaments, and weapons in traditional island cultures. These items were sculptured by craftsmen using tools such as chisels and drills made of seashells and files of sea urchin spines (H. Kurashina, pers. comm.).

Shells of giant clams (Family Tridacnidae) were fashioned into adzes used to hew canoes and housing materials. Various gastropod shells were used as scrapers for removing the peel from food crops such as taro or for grating coconut. Colorful species were worn as ornaments or fashioned into beads for jewelry (H. Kurashina, pers. comm.).

When early European explorers returned home from the Pacific, they brought with them various colorful shells which piqued the interest of naturalists and wealthy collectors in their own societies. Shell collecting as a hobby reached a peak of popularity in western Europe and the United States in the nineteenth century, when many extensive collections were assembled (Dance, 1966, 1986).

Because calcium carbonate is the major component of molluscan shells, they have had a number of industrial uses, primarily as constituents of fine pottery glazes, toothpaste, and poultry food (Wells, 1982).

Precious Corals

Highly treasured by man for millennia (Grigg, 1977), precious corals were first discovered in the Pacific near Japan in the early nineteenth century (Grigg, 1971, 1974). Since that time approximately 95% of the world harvest of precious corals has come from the Pacific (Grigg, 1974).

Precious corals are those species whose skeleton is hard and dense enough to be polished to a high luster suitable for jewelry manufacture. Historically, precious corals referred to the red corals of the genus *Corallium*. More recently, the term has been applied to white and pink varieties of *Corallium* as well as gold (*Gerardia*), bamboo (*Lepidisis* and *Acanella*), and black corals (*Antipathes*) from the western Pacific (Grigg, 1984).

With the exception of the black corals, precious corals inhabit deep water (100-

1500 m). Therefore, harvest of these corals has been by means of dredges, or "coral mops", which entangle and break the coral (Grigg, 1971). Takahashi (1942) reported that *Corallium* of good quality was harvested off the southern coast of Peleliu Island in Palau and north of Pagan Island in the Marianas before World War II.

Other Nonfood Resources

A variety of other nonfood marine resources was harvested in the subsistence economies of the Pacific. Although marine turtles were caught primarily for food, turtle shell provided a resilient material for the manufacture of fishhooks and other items (McCoy, 1974). Among high islands, timber and leaves from various mangrove species were used in construction of dwellings and canoe houses. Shark teeth were incorporated in some weapons of war used by Micronesians. Experimental sponge culture by Japanese scientists in the Marshall Islands produced fine quality sponges, but commercial exploitation of the beds was prevented by war (Smith, 1947).

CONTEMPORARY RESOURCE EXPLOITATION AND MANAGEMENT

The end of World War II brought a new political order to the western Pacific. The Japanese-mandated Caroline, Mariana, and Marshall Islands became a United Nations trusteeship administered by the U. S. as the Trust Territory of the Pacific Islands. Guam and the eastern Samoa Islands had already been acquired by the U. S. in the last years of the 19th century.

Pearls and Mother-of-pearl

Disrupted by war, harvest of pearls and mother-of-pearl never regained its place of importance in island economies. The culture methods developed by Japanese scientists in Palau before the war were regarded as proprietary information, and few islanders were permitted to observe Japanese techniques of implanting pearl blanks (Smith, 1947). Without transfer of this technology, local inhabitants were unable to continue pearl culture operations, and the numbers of pearls produced by natural stocks of pearl oysters were not sufficient to support the industry.

Trochus

In the more urbanized district centers and ports, commercial exploitation of trochus resumed under U. S. administration. Because the war prevented commercial harvest, overexploited populations had recovered to some extent, and harvests were greater in the years following the war than they were just prior to its outbreak (McGowan, 1956). However, populations began to decline again by the mid-1950s, leading to establishment of reef sanctuaries where no harvest was permitted (McGowan, 1958).

Records of harvests in Micronesia have not been well maintained over the years (R. Rechebei, pers. comm.), but steady increases in market prices in the last decade (Heslinga and Hillmann, 1981) have resulted in the trochus harvest becoming an important sector of island economy. It is a principal source of subsistence income, especially in remote areas, and as one of the few natural products exports, it is an important source of foreign exchange for island governments. Concern for sustaining this resource generated further studies on growth (Smith, 1979; Heslinga, 1982), culture (Heslinga, 1980; Heslinga and Hillmann, 1981), and management (Heslinga et al., 1984).

Precious Corals

Because most precious corals inhabit depths beyond the range of scuba divers, detection of commercially harvestable aggregations has been a matter of chance. A two-man submersible developed to harvest precious corals in Hawaii (Grigg et al, 1973) overcame this problem to a certain extent, but it ceased operation after 8 yr (1971-1978) because of the combined effects of rising operational costs and a depressed coral market (Grigg, 1984). Most species of black coral occur in shallow water (30-70 m), enabling scuba divers to harvest them.

Although all known commercial concentrations of deep-water precious corals are found north of 19° N latitude (Grigg, 1984), their existence in Micronesia and throughout the South Pacific has been established (Grigg, 1975; Grigg and Eldredge, 1975; Eade, 1980; Grigg and Eade, 1981). While there has been no documented commercial harvest of deep-water corals in the U. S.-affiliated islands, there have been reports of *Corallium* collected in the waters of Palau (Takahashi, 1942) and of the CNMI and Yap Islands (Anon., 1980a). Japanese and Taiwanese coral-dredging vessels have also been sighted operating within the territorial sea of Palau and the CNMI (Grigg, 1975; J. Villagomez, pers. comm.).

Black corals, which are less dense, and therefore less valuable, than deep-water precious corals, occur throughout the Pacific. Occurring at depths which are within the range of scuba divers, black corals have been exploited on a small scale at Palau (Grigg, 1975), Guam (Hedlund, 1977), and American Samoa (personal observation, 1985). After being sawed off at its base by a diver, the coral is then cut or carved into jewelry or curios and polished to form the final product.

Harvest of precious corals in American Samoa and Guam is regulated by a fishery management plan under the Magnuson Fishery Conservation and Management Act of 1976. In other U. S.-affiliated islands, it is either governed by local laws or unregulated altogether. Enforcement of regulations is a difficult problem throughout the region because of the vastness of the area involved and because of the inadequate levels of funding and personnel for surveillance (Grigg, n.d.). Poaching of precious corals by foreign vessels continues to be a major concern, even in waters under federal jurisdiction (Anon., 1986).

Ornamental Shells and Shellcraft

Following World War II the shell trade began rising in esteem again, not only with specialists and amateur collectors but also with tourists as well (Platt, 1949; Wells, 1982). Shells, shell jewelry, lampshades, and other shellcraft are highly prized by souvenir hunters at resorts throughout the world.

Shellcraft production depends upon an abundant supply of shells that are readily available to artisans. A cottage industry for shellcraft exists among U. S.-affiliated islands. It is generally limited to individuals who both produce and market their own handicrafts to the local tourist trade. Colorful shells are often incorporated as decoration in woven items such as baskets, fans, and mats. Engraving, shell carving, and shell inlay are not performed among the U. S.-flag islands.

Although most of the island governments have regulations on the harvest of edible or other commercially valuable shells, few have enacted protective measures for species involved in the ornamental shell trade. For example, on Guam the only legal action currently possible against shell collectors is veiled in vaguely worded sections on habitat destruction. Monitoring of the ornamental shell trade among U. S.-affiliated islands is nonexistent.

Specimen Shells and Corals

Specimen shells and corals refer to items prized for their individual appeal to collectors rather than for any decorative use. Depending upon the degree of sophistication involved, equipment requirements for the specimen trade may be as simple as a jar and a pair of gloves for shell collecting or a hammer and chisel for coral collecting. Harvest of the more-valuable species which inhabit deeper water requires additional equipment ranging from scuba gear and air compressors to dive boats and trap haulers (Parkinson, 1982).

Hedlund (1977) found that the shell collectors in Guam operate as individuals or as family units. Shells are marketed in local tourists shops or exported to dealers in other parts of the world. With one exception, a similar pattern occurs in the other U. S.-affiliated islands.

A cooperative specimen shell industry was initiated in Truk under government sponsorship in 1983 (Cane, 1984). Still in operation, the cooperative sells shells to local tourist businesses, but exports to outside markets have ceased because contacts with specimen shell dealers were not maintained by new management. However, it is deemed a successful operation by its founder and former manager because it demonstrated that the specimen shell trade can be a viable industry for this region (B. Cane, pers. comm.).

Although they constitute only a fraction of the value of precious corals, stony corals or Scleractinia make up the bulk of world coral trade. Too porous to be polished for jewelry, stony corals are sold as curios and decorations in many parts of the world (Grigg, 1984), and they are used industrially for building material, road construction, and lime production (Wells, 1981).

The major coral exporters in world trade are the Philippines and Taiwan. The genera *Fungia, Acropora, Pocillopora*, and *Porites* contain the more popular species in coral trade. Nonscleractinian corals of the genera *Heliopora, Tubipora*, and *Millepora* are often exploited as well (McManus, 1980; Wells, 1981).

In Micronesia, traditional harvest of coral to produce lime for the custom of chewing betel nut still exists in the Western Caroline Islands. However, most island governments have enacted legislation restricting harvest of coral for commercial purposes. As a result, there are a few small-scale specimen-coral enterprises which cater to the tourist industry (Hedlund, 1977). There is currently no commercial export of specimen corals from the U. S.-affiliated islands.

Aquarium Fish

Colorful fishes from coral reefs are prized by aquarium hobbyists around the world. Several exotic species from the Pacific command high prices in the world market.

Fishing for the aquarium trade usually is a one-man operation. Small-mesh surround nets and dip nets are used to capture juvenile reef fish on the reef flat at low tide. The fisherman then either supplies the fish to a local pet store for retail sales or exports them to retailers in Hawaii or the mainland U. S. Some fishermen have provided contractual services for large aquariums in the business and tourism sectors.

On Guam, export operations in the aquarium fish trade have been relatively short-lived, except when the fisherman catches aquarium fish as a side-line to other activities. The major reasons given for these failures have been problems related to the airlines. Personnel handling airfreight do not regard live fish as requiring extra attention. Frequent flight delays aggravate the long distances and extended air times in transit to large U. S. markets, resulting in losses of entire shipments valued at $200-300. Rates for air cargo from U. S.-affiliated islands are based on international schedules rather than domestic rates, making shipping expenses extremely high. One fisherman reported difficulties with a Honolulu-based buyer who regularly reported that all of the rarer, higher-priced species died in transit while lower-priced species all survived. Guam fishermen have not been successful at entering the potentially lucrative aquarium fish market in Japan because similar or identical species are available from the Philippines Islands at prices below the profitable margin on Guam (R. Sakamoto, pers. comm.).

There is essentially no management of the aquarium fish trade per se. Fishermen on Guam must obtain a no-cost permit to use small-mesh nets, and there are certain area closures for aquarium fish collection (Anon., n.d.). However, enforcement has been sporadic because none of the government conservation officers is assigned exclusively to patrol reef areas. Therefore, it is a relatively simple matter to fish illegally with small-mesh nets or even mild narcotics to catch specimens for the aquarium trade.

The effects of the aquarium fish trade on stocks of reef fishes in Micronesia are not known. However, heavy fishing pressure for food fishes on Guam's reef flats was found to decrease populations of some preferred species, permitting an undesired species to attain greater densities on heavily fished reefs than on lightly fished reefs (Katnik, 1982). Similar results could be expected if fishing pressures for aquarium species were to increase significantly.

Pharmaceuticals from Marine Natual Products

Many marine organisms produce compounds that are pharmaceutically active. For example, extracts of some brown algae have been used as hypotensive drugs in Oriental medicine for centuries (Baker, 1984). Neurotoxins from other algae are being studied for their potential as anesthetics (Curtin, 1985).

Several new compounds were identified in preliminary studies of marine organisms from U. S.-affiliated insular areas (Schmitz et al., 1983; Gunasekera and Schmitz, 1983; Schmitz et al., 1984). Recently, a systematic program to collect and screen marine organisms from this region was established on Guam. Additional new, biologically active compounds have already been identified (Paul and Fenical, 1985, 1986; Paul and Van Alstyne, In Press; Paul et al., In Press), and investigations of their pharmaceutical properties will be conducted in cooperation with researchers at several institutions (Paul, pers. comm.).

Phycocolloids

Phycocolloids are complex mixtures of polysaccharides produced by certain marine algae. Agar and carrageenan are phycocolloids which have important markets as commodity food additives, pharmaceuticals, cosmetics, paints, and ink. Other nonfood products from marine algae include fodder for livestock and fertilizer (Waaland, 1981).

Of the numerous species of marine benthic algae reported from U. S.-affiliated islands, ten species may have the potential to yield harvestable commercial products (Tsuda, 1982). Two genera of the red algae or Rhodophyta have been studied for mariculture potential in Micronesia. The carrageenan-producing genus *Eucheuma* has been farmed successfully in Pohnpei (Doty, 1981) and Kosrae (M. White, pers. comm.), but no marketing has been conducted at this time.

The genus *Gracilaria* has been studied in some detail in the Mariana Islands. *Gracilaria edulis* from Guam produced higher yields of agar than similar species from Taiwan (Nelson et al., 1983), where commercial cultivation of seaweeds began in the late 1950s (Tseng, 1981). *Gracilaria lichenoides* from Saipan produced agar with greater gel strengths, and therefore potentially more economic value, than species from Taiwan (Nelson et al, 1983). Nelson et al. (1980) found that *Gracilaria* grew rapidly in both the field and laboratory on Guam. A major obstacle encountered in efforts to culture these species in the field has been browsing by herbivorous reef fishes (Nelson and Tsutsui, 1982).

Sand and Quarry Material

Any level of urban and industrial development creates strong demands for mineral resources, including construction minerals such as sand, crushed stone, and fill. For example, a concrete foundation for a 10 m by 15 m house or office requires about 80 tons of aggregate (Dehais and Wallace, 1981).

Dredging of sand and fill materials has been conducted for projects involving airport expansion, road construction, and harbor development throughout the islands. Dredging in navigable waterways is under the jurisdiction of the U. S. Army Corps of Engineers (ACOE) in Guam, CNMI, and American Samoa, and all applications for dredging are routed through government agencies for review before permits are granted by ACOE. However, the freely associated states provide their own regulations.

Mining of intertidal beach sand for construction is regulated by local laws in some U. S.-affiliated islands and is under traditional jurisdiction in others. There is only one commercial venture, that I am aware of dredging sand from coastal waterways in the American flag Pacific islands. This operation is in Palau, and although it has been in operation for some 10 years, little information is available concerning environmental impacts of this operation.

Shark Products

Requiem sharks of the family Carcharinidae are abundant in the U. S. Pacific insular areas. Uchida (1983) reported good catches of reef sharks in fish traps, and Bryan (1972) demonstrated that commercial species could be caught on Guam with small boats. Although sharks are viewed as a nuisance by local fishermen, all parts of a shark theoretically can be utilized (King et al., 1984). Unfortunately, some of the potential value of the sharks is wasted, as fishermen usually take just the meat, fins, and jaws. Shark jaws and teeth are the primary nonfood products now being harvested from sharks. They are used to produce novelties for the tourist industry.

Shark-fishing methods do not differ from significantly from other commercial fishing methods. Probably the best method of shark fishing is longlining. A longline is stretched out with droplines or leaders spaced at regular intervals and with buoys attached to maintain the proper depth throughout its length. Gill nets are also used to catch sharks, but the initial expense of the net and the amount of time required for repairing it would make this method uneconomical among the islands.

Mangroves

Mangrove formations are highly productive ecosystems associated with many of the high islands of the Pacific. They are typically found in areas of low, muddy seashores, quiet bays, deltas, and estuaries. Characteristic vegetation consists of small trees of the families Rhizophoraceae, Meliaceae, and Verbenaceae.

Mangrove trees are economically important in subsistence economies of the Pacific as sources of structural timber and firewood. An extensive list of additional nonfood products was reported by Lal (1984). They are also of great ecological importance because they provide food and shelter for a large and varied group of fish and shellfish (Odum and Johannes, 1975) and because they act as buffers to coastal erosion (Baines, 1981).

Marine Turtles

The two most common marine turtles among U. S. insular areas of the Pacific are the green turtle and the hawksbill turtle. These species have been declared "threatened" and "endangered", respectively, and are protected under provisions of the U. S. Endangered Species Act. Therefore, all harvest of these turtles is prohibited in the territories of Guam, the Commonwealth of the Northern Mariana Islands, and American Samoa. However, residents of the other U. S.-affiliated islands are permitted to harvest marine turtles on a subsistence and traditional basis as a protein resource. Pritchard (1981) recently reviewed the status of marine turtle populations in Micronesia.

Although there is no regular handicraft industry based on the use of turtle shell, ornamental items can be openly purchased in many of the district centers (personal observation). Combs, earrings, and bracelets of hawksbill turtle shell are especially popular among local inhabitants and tourists alike.

POTENTIAL RESOURCE EXPLOITATION AND MANAGEMENT

Many of the nonfood marine resources of the U. S.-affiliated Pacific islands, such as pearl oysters and trochus, have histories of overexploitation resulting from poor resource management. Most of these resources have been underexploited since World War II because there has been little effort made to develop their potential. Following is an account of those resources whose importance could be increased through improved research, development, and management.

Pearls and Mother-of-pearl

The success of Japanese entrepreneurs in Palau prior to World War II leads to obvious questions about why pearl culture has never been resumed in Micronesia. Several species of pearl oysters occur naturally in Palau (Motoda, 1938), Yap (Smith, 1978), Truk (Amesbury et al., 1979), Pohnpei (M. Gawel, pers. comm.),and Guam (Smith, 1985). Surveys of some atolls in Pohnpei State found black-lipped pearl oysters in high densities (M. Gawel, pers. comm.). The status of species introduced into pre-war Palau is not known.

Although attempts to mass culture pearl oysters in the laboratory have failed in French Polynesia, recent success with artificial spat collectors is expected to bring the harvest of wild stocks to an end by 1985, permitting recovery of natural populations (Coeroli et al., 1984). Technologies developed by Japanese scientists for grafting and implanting pearl nuclei (e.g., Mizuno, 1983) could be imported to the Central Pacific as they have been for French Polynesia, where pearl exports in 1981 were valued at about US$3 million (Coeroli et al., 1984). The nacre of pearl oysters is more highly valued for button manufacture than trochus shell (W. FitzGerald, pers. comm.), and the mother-of-pearl produced in a pearl culture industry would be an added value. Thus, the potential for pearl oyster cultivation in Micronesia and Samoa warrants further investigation.

Trochus

While trochus exports constitute a major source of income for island economies (Johannes, 1978; Heslinga and Hillmann, 1981; Carleton, 1984b), an examination of historical catch data indicates that the reefs are capable of sustaining far greater numbers of shells than are presently harvested. For example, the trochus harvest in Palau in 1916, 1918, and 1923 exceeded 300 tons (McGowan, 1958). Sharp declines in harvests immediately following those years (Fig. 1) suggest that such harvests amount to gross overexploitation. Parkinson (1980) estimated that Palau's reefs should yield sustainable harvests of some 200 tons/yr. However, the few records available for recent years indicate an average harvest of about 100 tons/yr (R. Rechebei, pers. comm.).

A comprehensive management and development program for trochus fisheries in the region might attain the figures given by Parkinson (1980). This would entail re-examination of sanctuary sites and stricter enforcement of size and season regulations (Heslinga et al., 1984). A ban on the use of scuba for trochus harvesting should be considered in areas where none exists (Johannes, 1978). An added measure to enhance yields would be a program for reseeding depleted reefs with hatchery-reared juveniles, similar to trout fishing enhancement programs in the U. S. The technology for mass culture of trochus has been developed at the Micronesian Mariculture Demonstration Center in Palau (Heslinga and Hillmann, 1981) and is currently being transferred to Pohnpei (E. F. Curren, pers. comm.).

Attaining the sustainable harvests postulated by Parkinson (1980) for Palau, Truk, and Pohnpei would generate about 500 tons yr^{-1}, or about 14% of the world harvests (Carleton, 1984b) from these islands alone. These figures do not include harvests that will be realized from a trochus transplantation program initiated in Yap in 1983 (K. Partridge, pers. comm.) nor the harvests of Kosrae and the Mariana and Marshall Islands.

Although the Samoas have been reported within the natural range of this species (Hedley, 1917; Motoda, 1938), no commercial trochus were sighted during a recent marine survey of Tutuila (Smith, unpubl. data). The apparent eastern limit of their natural distribution lies in the Wallis and Futuna Islands, immediately west of the Samoas (R. D. Gillett, pers. comm.). However, the presence of several noncommercial congeners of trochus in American Samoa (Smith, unpubl. data) indicates that suitable habitat exists for the commercial trochus. In light of recent efforts to transplant trochus to the Tokelau Islands north of Samoa (Gillett, 1986), transplantation to American Samoa could be considered.

Although plastic buttons still dominate the clothing industry and their wholesale value dictates price levels for mother-of-pearl, pearl buttons hold a strong and high value sector of the consumer market (Carleton, 1984b). The price of raw trochus shell to the fisherman has increased from about US$0.2825/lb in 1978 (R. Howell, pers. comm.) to US$0.445/lb in 1985 (J. Robinson, pers. comm.) to US$0.60/lb in 1987 (R. Uwate, pers. comm.). Thus, the value of the shell has risen some 112% in nine years. However, the trochus button factory constructed in the Marshall Islands by a Japanese firm has been plagued by numerous problems (P. Buckingham, pers. comm.) including vandalism (Anon., 1986b), and its future status is uncertain.

Ornamental Shells and Shellcraft

Ornamental shell industries already exists in some U. S.-affiliated islands, but most of the handicrafts sold in tourism centers are imported from the Philippines, where greater varieties of products are available at lower prices. Carleton (1984a, 1985) noted poor organization of handicraft industries in the Pacific. The major constraints identified were intermittent production and lack of business and financial advice to this sector of the economy. He noted that improvements in the production of handicrafts would increase the economic value of the industry and provide greater market power. Therefore, efforts such as the Small Industries Center in Truk should be encouraged through government assistance.

Precious Corals

Little is known of the distribution and abundance of precious corals in Micronesia and Samoa (Anon., 1980a). Most of the islands remain unsurveyed, and only preliminary data have been gathered in the Marianas and Palau (Grigg and Eldredge, 1975; Grigg, 1975). A recent survey of the Mariana Archipelago found dead specimens of precious corals at Pagan and Aguijan Islands but no live ones (L. G. Eldredge, pers. comm.). Poaching of precious corals by foreign vessels dredging near Micronesian islands provides further evidence of the existence of precious corals among the islands (J. Villagomez, pers. comm.). Therefore, based on these reports and on the vastness of the area involved, it is reasonable to assume that suitable habitat for precious corals exists in the region.

A temporary glut of precious corals depressed world markets after extensive new grounds were discovered on seamounts near Midway in 1980 (Grigg, 1982). However, the continued decline of other stocks and the rapid depletion of the Midway beds combined to raise world trade in precious corals above US$50 million in 1982. Retail sales in Hawaii alone have averaged US$20 million annually (Grigg, 1984).

In 1981 the value of unprocessed deep-water precious corals ranged from US$72 to $4850/kg depending upon species, color, and quality of the coral (Grigg, 1982). Thus, even small beds of precious corals could provide important revenues when harvested on a sustainable yield basis.

Black corals provide two alternatives for development within the islands. One option is to sell unprocessed corals to the industry in Southeast Asia. The other is to produce quality black coral products within the region. The latter alternative, which exists to some extent, is potentially more profitable, as it would create employment opportunities in the production, processing, and marketing sectors of the economy (Carleton, 1985). However, this course of action would require the acquisition of training and machinery for lapidary and jewel-setting arts (Grigg, 1977).

Specimen Shells and Corals

The islands of Micronesia and American Samoa lie within the Indo-West Pacific region which is characterized by having the most diverse marine fauna and flora in the world (Ekman, 1953). For this reason, Pacific islands are in a position to supply the specimen market with species of shells and corals that are not available from other sources. In addition, the islands would be supplying an expanding market (Carleton, 1984a). Bans on exports of corals and shells have resulted from reef destruction caused by overexploitation in some areas (McManus, 1980; Wells, 1981; Carleton, 1984a).

Although a certain degree of technical knowledge is required for the specimen trade, education programs have been developed for identification, selective harvest, and conservation of the resource (Parkinson, 1982, 1984; Cane, 1984). Grigg (1984) suggested that shallow water reef-building corals can be managed by using maximum sustainable yield models developed for commercial fisheries.

Islands remote from tourism centers would have to rely on exports of specimens to dealers and retailers abroad (Cane, 1984). Although there are some reports that population densities of shells have decreased where tourism has developed, it is not clear whether the reduction is caused by overexploitation or by increased runoff and pollution associated with urban development (Hedlund, 1977). Mass culture techniques developed for species such as giant clams, which have both food and nonfood values, could be used to replenish depleted reefs (Munro and Heslinga, 1983; Heslinga and Peron, 1983; Heslinga et al., 1984; Heslinga and Watson, 1985).

On Guam, a shell dealer who asked to remain anonymous indicated to me that his business is thriving. In addition to the many species he markets locally, he receives orders from specialists overseas who pay prices ranging from US$20 to $200 each for shells known only from the Marianas. He currently is filling an order for 45 specimens of a species that has a wholesale value of $25 each.

Aquarium fish

Current supply does not satisfy demand in the aquarium fish trade, particularly in the U. S. Demand worldwide is expected to increase by 10-15% per year in the future

(Carleton, 1985). Those islands with direct flights to Hawaii or Japan are suitably located to establish small aquarium fish businesses and take advantage of this situation.

When methods of collecting that do not damage the environment or harm nontarget species are used, small-scale fisheries of this kind can be developed without upsetting the ecological balance on the reef. However, Johannes (1978, 1979) recommended bans on export of certain species which play vital roles in the health of coral reef communities. He cited evidence that reef-fish populations can be drastically reduced when species such as cleaner wrasses were removed from the community.

Pharmaceuticals

Little economic reward can be expected to return to the islands as a result of novel natural products isolated from marine organisms from the region. Although some of these compounds have potential applications ranging from medicine to industry, their concentrations in the organisms are too low to permit detailed studies. Therefore, new products are quickly synthesized after their structure is identified, and any economic benefit derived from their development remains with the laboratory (S.G. Nelson, pers. comm.).

Phycocolloids

The phycocolloid industry is expanding rapidly, and natural crops of seaweeds are not sufficient to satisfy the demand for gels (FAO, 1983). Because of the complexity of the polysaccharide molecules making up phycocolloids, prospects for synthesis of these compounds are not good. Therefore, farming of seaweeds, or marine agronomy, is an industry of considerable potential for the tropical Pacific. The value of the world phycocolloid industry was reported to be about US$1 billion in 1978, and gel extracts were estimated to be essential to some US$2 billion of the U. S. GNP (Doty, 1982).

The cultivation of seaweeds for phycocolloid extraction appears to be well suited for remote islands because little infrastructure is required. Algae are grown on shallow reefs, and the harvested thalli can be sun-dried and stored for long periods. The parallel to copra production, which has been practiced in the islands since the mid 1800s, is striking (Nelson et al. 1980).

The experimental efforts to cultivate seaweeds in the central Pacific so far have met difficulties in marketing the dried seaweeds (S. G. Nelson, pers. comm.). This problem could be overcome by development of a gel extraction facility in one of the urban centers. The dried seaweeds could then be shipped from the production site for extraction, and the gels sold to industry.

Sand and Quarry Material

Except for a survey of Saipan, Tinian, Rota, and Pagan (Doan and Siegrist, 1979), the extent of deposits of sand and material for aggregates in nearshore waters of Micronesia and Samoa is not known. In the absence of such data, it is difficult to assess accurately the potential for development of these resources. Because islands have finite onshore mineral resources, the need to exploit marine deposits may arise in the future. However, the destruction of important fishing grounds and traditional fish pens has already occurred as a result of dredging and filling for airport expansion in the absence of thorough environmental assessments (Johannes, 1978; A. Edward, pers. comm.). Therefore, environmental impacts of such operations must be rigorously assessed.

Shark Products

Sharks represent a potentially important and virtually unutilized resource in the tropical Pacific. In spite of the seeming abundance of sharks, Pacific islands supply only a small proportion of the market. Sharks are harvested primarily as a by-catch of Taiwanese tuna longliners landing at Pago Pago, and the fins are the only product that is retained (Carleton, 1985).

Presently unexploited among the U. S.-affiliated Pacific islands are shark hides, which are coming into prominence because they can be processed into beautifully grained, strong, scuff-proof leathers that are suitable for many applications (Slosser, 1983; King et al., 1984; Preston, 1984). Sharks that are 1.5 m or more in length are preferred for producing hides, but experience is required to decide whether a skin is worth taking and curing (Slosser, 1983). In addition, sharks that are harvested for skins must be treated differently than sharks caught for human consumption (Anon., 1980b; King et al., 1984). Therefore, establishment of a shark skin fishery in Micronesia and Samoa would require training programs for fishermen.

The value of shark livers, which have high concentrations of vitamin A, is currently low, except for livers with a squalene content of at least 80 percent. Such livers are found only in a few species of deep-water sharks which are not well known (Slosser, 1983).

Markets for shark products are expected to continue a recent trend of gradual expansion (Slosser, 1983; Carleton, 1985). Market growth, particularly for shark leather, appears to be limited by the supply of hides (Preston, 1984; Carleton, 1984a). Novelty products such as jaws and teeth have a ready market in tourism, while new products such as artificial skin for burn victims (Anon., 1981) are still in the development stages.

Mangroves

The mangroves of the Caroline islands are more diverse and more extensive than in other U. S. insular areas (Stemmermann, 1981). This abundance has led to speculation that some islands of Micronesia have sufficiently well developed mangrove forests to support small scale timber cutting industries (Baines, 1981). However, Gillison (1981) urged caution on any expansion of harvesting activities in Palau and Pohnpei. He further emphasized a need for better resource data.

Cutting, clearing, and filling of the mangrove swamps should be carefully managed. In the absence of rehabilitation efforts, mangrove communities in clear-felled areas of Southeast Asia have not successfully regenerated. This lack of regard for the resource is analogous to mining rather than harvesting on a sustainable basis (Baines, 1981).

The ecological importance of mangrove formations cannot be overemphasized. Mangrove swamps provide habitat for many species of fish and shellfish. Fallen leaves of mangrove trees may be at the base of food webs for higher trophic levels in the swamp and out in the estuary as well. Roots of mangroves prevent coastal erosion by absorbing wave energy and protect corals reefs by trapping large quantities of sediments from terrestrial erosion. Mangrove communities also absorb dissolved nutrients from terrestrial run-off (Baines, 1981).

Marine Turtles

Commercial harvest of wild populations of marine turtles is prohibited under U. S. law. Thus, potential for exploitation of turtles lies with development of mass culture in turtle farms. A turtle hatchery is currently under development in Palau as a joint venture with Japanese scientists (S. G. Nelson, pers. comm.). If this project is successful, it is conceivable that a limited amount of turtle shell and skin for leather could become available.

Another source of reptilian leather with limited potential for development is the marine crocodile of Palau. Like turtles, they are protected under U. S. law, but farming techniques for crocodile would probably be similar to those for turtles.

NEARSHORE ECOSYSTEM STRESS, RECOVERY, AND MANIPULATION

While tropical coastal ecosystems are among the most productive in the world (cf. Birkeland, 1985), they are also vulnerable to a number of natural and man-induced disruptions. Some theoretical aspects of this vulnerability to disturbance in spite of high productivity and high standing crop on coral reefs were discussed by Grigg (1979). Because most of the nutrients in the system are accumulated in biomass, a high percentage is exposed to removal by exploitation. Thus, exploitation removes nutrients that would otherwise be recycled, and thereby reduces the potential for future production. Longevity of species exposes many year classes to exploitation, and long-lived species are generally characterized by low reproductive rates.

Because coral reef communities are disturbed by natural events at frequent intervals, the succession process is disrupted so often that few reefs develop a climax community (Connell, 1978). Further complications arise from interactions between natural and man-induced stress, which may be synergistic or superimposed (Grigg, 1979).

Natural Stresses

Tropical cyclones or typhoons are frequent events in the Mariana and the Central and Western Caroline Islands, but less common in the Eastern Carolines, Marshalls, and American Samoa (cf. Eldredge, 1983). High winds and rain cause destruction on land. Storm wave assault may cause coastal erosion, fragmentation of corals, slumping of reef framework, and abrasion and scouring of the reef. Structural damage to the reef framework was minimal after Typhoon Pamela passed Guam in 1976, but damage to living coral and algal communities was intense and widespread on the deeper forereef slope zone (Randall and Eldredge, 1977).

Episodic catastrophes have also been related to tidal phenomena. Mass mortalities of reef animals have been studied on Guam (Yamaguchi, 1975) and at Eilat, Israel (Loya, 1976). In both instances, recovery of benthic communities was incomplete after three years. Rainstorms coinciding with spring low tides killed up to 92% of reef invertebrates at Enewetak Atoll, Marshall Islands (Leviten and Kohn, 1980).

Large scale biological disturbances have been generated on coral reefs by population irruptions of the coral predator *Acanthaster planci*, or crown-of-thorns starfish. Initial outbreaks of *Acanthaster* are associated with high islands and are usually related to terrestrial runoff (Birkeland, 1982). Recovery of the coral communities requires about 10 years, but may be interrupted by secondary outbreaks (Colgan, 1981, 1982).

Other natural stresses are less common in Micronesia and Samoa. Although minor earthquakes are frequently recorded, the deep waters surrounding the islands preclude disruption by major tsunamis. Active volcanoes are limited to the northern Mariana Islands, where eruptions may cause severe disruption of intertidal and shallow-water habitats (Eldredge, 1983; Eldredge and Kropp, 1985). The relationships between the El Nin~o phenomenon and shifts in rainfall and storm distribution in the central and western Pacific are still not understood well enough to determine cause and effect (Rasmusson, 1984).

Man-Induced Stresses

Urban development has generally concentrated in coastal areas of Pacific islands. As these areas attempt to transform from subsistence to more diversified economies, they are experiencing fundamental problems associated with population, commerce, light industry, and tourism (Low, 1981). Accompanying this transformation are unprecedented levels and kinds of waste discharges (Matos, 1981). Dahl and Baumgart (1983) reviewed pressures bearing on the Pacific environment, and a comprehensive report on tropical marine pollution was published by Wood and Johannes (1975).

Discharge of raw or primarily treated sewage and dredge spoils causes increased inputs of nutrients, turbidity, and sedimentation in coastal waters (Johannes, 1975). Organic or nutrient enrichment favors growth of decomposer communities, lowering dissolved oxygen levels to stressful levels. Turbidity and sedimentation physically degrade ecosystems through shading and smothering effects (Amesbury, 1982).

Because the tropical environment is near the upper tolerance limits of temperature for many reef organisms, thermal effluent discharged from power plants has disrupted reef communities in some areas (Jones and Randall, 1973; Neudecker, 1976). Thermal effluent could alter the pattern of succession on a reef by changing growth and survival ratios of reef species (Neudecker, 1982). Chlorine, used to control biofouling in power plants, is also very destructive in tropical ecosystems (Best et al., 1982).

Since oil is imported by means of tankers, there is some risk of oil spills. Small spills from port accidents, leaks in pipelines and storage tanks, and shipwrecks occur sporadically, but most have affected only small areas (Dahl and Baumgart, 1983). The effects of oil on corals was reviewed by Johannes (1975).

The marine environment cannot be separated from terrestrial influence. Toxic chemicals such as pesticides and herbicides used in agriculture enter coastal ecosystems via storm runoff. All the urban centers of the U. S. insular territories have storage areas containing polychlorinated biphenyl (PCB)-contaminated electrical transformers, and some of these storage facilities have reported leaks (Golob and Egan, 1984). Japan developed a plan for low-level nuclear waste disposal in the deep ocean north of the Mariana Islands, but this proposal has been postponed as a result of protests from the Pacific community (Bacon et al., 1984).

Destructive harvesting practices such as the use of explosives and toxic subtances have caused small-scale stresses in some areas. The use of dynamite is a commonplace but illegal practice in Micronesia (Johannes, 1975), and intense use of explosives has devastated some reefs (Parkinson, 1980; Naughton, 1985). Fishermen on Guam believe that poachers using dynamite have annihilated a damselfish species popular in the aquarium trade and endemic to Guam (R. Saylor, pers. comm.). Long-term effects of explosives and toxic substances include loss of fish from the community and marked decreases of crustaceans, annelids, and molluscs, and the community structure may be altered by increases of other taxa (Campbell, 1977).

Concerns over man-induced stresses are growing. Marine communities in the tropics may respond differently to pollution than those at higher latitudes. Tropical species are rarely used in bioassays so tolerance limits to many substances have not been determined. Heavy metals and many of the new synthetic compounds cannot be broken down in biological systems. As a result, some toxic substances accumulate in higher trophic levels. Contamination of ecosystems such as estuaries and the deep ocean is a particular concern, because their renewal rates are unknown.

Manipulation

Marine habitat rehabilitation or manipulation to increase production of desired resources has been largely conjecture (cf. Pinchot, 1974). However, mass culture techniques have been developed recently for some species such as trochus and giant clams (Heslinga and Hillmann, 1981; Heslinga and Watson, 1985). Animals produced in hatcheries could be used to replenish overexploited reefs or to enhance natural production. Farming of giant clams in this manner has been compared to resource management in forestry (Yamaguchi, 1977). However, farming of trochus would require a decision which could conceivably lead to reductions in populations of herbivorous reef fish as a result of depletion of algal standing crops. Although trochus has been widely introduced without obvious disruptions, no data are available on interactions between populations of large herbivorous snails and herbivorous reef fishes. The work necessary to gather these data should be undertaken.

During the Vietnam conflict, mangroves were found to be especially sensitive to contamination with herbicides (Odum and Johannes, 1975). However, mangrove seedlings can be transplanted to sustain production in heavily exploited or disrupted areas. On Guam, a mangrove area damaged by an oil spill has been successfully rehabilitated through a replanting program (Bultitude and Strong, 1985). Mangrove trees killed by the oil discharge were removed, and the area was replanted with germinated seedlings that were harvested from an undisturbed area.

The success of Japanese scientists in Micronesia during the mandate period suggests that a great deal of potential for economic development of marine resources is presently unrealized. In spite of recent advances in mass culture techniques for some species, the basic knowledge remains scant for most tropical species having potential for commercial harvest. Research on distribution, abundance, growth, reproduction, energetics, predator-prey interactions, and diseases will be required to develop sound management programs for optimum sustainable yield.

RESEARCH, EXTENSION, AND EDUCATION

Marine biological research in the U. S.-affiliated islands is centered at the University of Guam Marine Laboratory (UGML). This facility has a faculty of seven full-time researchers working in various fields. Environmental impact studies, studies in aquaculture techniques and species potential, and resource assessment surveys have been performed by UGML personnel at various islands throughout the region. Cooperative research programs have been developed with Taiwan, Indonesia, and French Polynesia, and visiting scientists from around the world have conducted research at the facility. Contributions of the UGML are published in refereed international journals.

Additional marine research has been performed at the Micronesian Mariculture Demonstration Center (MMDC) in Palau. Although there are no resident scientists at MMDC, a number of important advances in mass culture of trochus and giant clams have been made by researchers visiting this lab.

Fisheries biologists of the U. S. National Marine Fisheries Service, Southwest Fisheries Center, Honolulu Laboratory conduct occasional resource surveys in the islands. However, their work has focused primarily on commercial food species, and there has been no continuity to their research.

Fisheries officers employed by local governments have also been involved in marine research. Generally these studies have been related to artificial reefs and resource assessment of edible marine organisms.

The only formal marine extension program in the U. S.-affiliated islands is the Sea Grant Extension Service at the UGML. This program is a cooperative project of the University of Hawaii Sea Grant College Program and the University of Guam. Staffed by a single agent, the program has concentrated on fisheries development, marine conservation, and public information and awareness. Sea Grant extension programs in Saipan and American Samoa have not been successful.

Local fisheries officers have been involved in extension efforts from time to time. A number of fishermen's training programs have been conducted through marine resources offices. If significant development of nonfood marine resources is to occur, especially in the more remote islands, marine extension and advisory programs throughout the region will need to be strengthened.

Marine education programs are included in the curricula of the University of Guam (UOG) and several community colleges in the region. UOG offers undergraduate and graduate level instruction leading to Bachelor of Science and Master of Science degrees in biology. The graduate program in biology is taught by the faculty of the UGML and is decidedly marine-oriented. A nondegree, certificate program, the Marine Option Program, was recently initiated at UOG to provide undergraduates the opportunity to gain a marine orientation to their major. The UOG faculty has also conducted workshops for high school science teachers to enable them to include marine topics in their curricula.

The College of the Northern Mariana Islands in Saipan and the American Samoa Community College offer courses in marine science, but no degree program in a marine-related area is available at these institutions. The Community College of Micronesia in Pohnpei has developed a two-year Associate of Science program in marine science that is primarily oriented toward fisheries personnel (S. James, pers. comm.).

SUMMARY: PROBLEMS AND OPPORTUNITIES

Considerable scope exists in the U. S.-affiliated Pacific Islands for commercial development of nonfood marine products. With markets for many of these products expanding, awareness of and interest in the resources is growing among the islands. Following is a summary of problems and opportunities to be encountered in developing sustainable economic benefits from exploitation of these resources.

Problems

1. Because of their geographic isolation, limited land area, small population, and few natural resources, the Pacific islands have been neglected in regard to economic development. Exploitation of natural resources has been opportunistic, involving export of raw materials or only the simplest of processed products.

2. Federal agencies with oversight responsibility for development of marine resources in the islands are not actually present. Instead, their representatives, often based in Hawaii, make infrequent visits to the islands. They have little understanding, and frequently less concern, of the needs of the islands. Budget constraints are cited as the rationale for not having a greater presence in the islands.

3. Federal laws governing marine resources hinder their development in contrast to traditional laws which fostered wise management of the resources. Open access to resources in navigable waterways encourages overexploitation of any valuable products ("If I don't harvest it, someone else will"). Traditional marine tenure, however, required conservation and wise management of resources to ensure sustainable yields for the ownership group and to prevent overexploitation by outsiders.

4. Concise information on resource distribution and abundance is lacking. In the absence of such data, the concept of optimum sustainable yield is mere technical jargon. Historically, efforts to manage resources have been applied after they have already been overexploited.

5. There is no formal market structure for the nonfood products of Pacific islands. Collection, analysis, and dissemination of market information are absent. This usually means that the islands receive less than fair market value for their resources.

Opportunities

1. The technology for developing nonfood resource industries already exists. Technological expertise developed in other regions could be imported to the Pacific islands and transferred to the islanders in a mode compatible with local lifestyles. Initially this would require government support, but with sufficient assistance, the islands could develop diversified, self-sustaining industries.

2. Development of the economic sector in remote islands through transfer of appropriate technology could help to reverse the trend of immigration to the urban centers. Considering the limited land area of the islands, this must become a priority.

Recommendations

1. Provide technical expertise to the region. There is a strong need for creation of full-time positions in marine resource development and marine geology for the Pacific islands. Employed through the National Marine Fisheries Service and the U. S. Geological Survey, respectively, these specialists should be associated with the University of Guam which is centrally located in the islands.

2. Earmark minority institution grant funds for the Pacific islands. Pacific islanders are, by definition, minority races. Therefore, they should receive minority assistance in education, extension, and research programs.

3. Establish regulations recognizing traditional marine tenure in the islands. To be successful, management schemes must be socially acceptable, and group ownership of marine areas has a long tradition. In addition, private investment in industries such as seaweed and giant clam farming, pearl culture, and even trochus fishing will require greater confidence in the chances for a reasonable return on investment, and marine tenure help can provide this.

4. Increase extension and advisory services in the islands. Federal matching funds should be made available through such programs as Sea Grant to establish marine extension agent positions in all district centers. Working closely with the islanders, the agents would transfer new and proven technical information from researchers to the harvest sector and facilitate research by relating problems encountered in the resource management sector to the appropriate researchers. To perform more efficiently, the extension agents should receive annual updates and training programs in technology and market developments. This effort could be coordinated on a regional basis through the University of Guam. The

coordinator would be responsible for collection, analysis, and dissemination of this information through the extension network.

5. More baseline research on marine resources is needed. Many federal granting agencies restrict research proposals to short timeframes that are unrealistic for establishing a database, developing management models, and transferring technology to industry.

6. Develop the capacity for secondary industries to process raw materials into commodities within the islands. Technology for processing nonfood marine products exists, but capital for development of this sector is lacking. If Pacific islanders can produce quality products at reasonable prices, they could compete in the world market. Such development would greatly diversify and strengthen island economies.

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CASE STUDIES OF THE IMPACTS OF INTRODUCED ANIMAL SPECIES ON RENEWABLE RESOURCES IN THE U. S.-AFFILIATED PACIFIC ISLANDS

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ABSTRACT

A wide variety of animals has been transported throughout the Pacific islands. Case studies of selected species, exclusive of insects, show that such introductions usually have negative impacts on the islands. There are virtually no examples of long-term beneficial impact from introduced animals. Fishery and aquaculture organisms are known to escape confinement and enter the natural ecosystem. Animals brought in for hunting have become pests, and biological control agents are known to have caused extinctions of native species. Among the examples with immediate negative effects are the giant African snail and the toad. Both of these animals have become public health problems, causing human deaths in extreme cases. Many introduced animals—snails, snakes, birds, cats—are known to have brought about extinctions of native species, including some that were endemic to particular islands. Vegetation has been altered by larger animals such as deer and goats. In this report, case studies of a number of introductions are detailed, including a history of the introduction, the organism's present situation, ecological impact, and lessons learned. These lessons are collated into a set of integrated guidelines for introduction of animals.

INTRODUCTION

The islands of Micronesia and American Samoa originally had few native land vertebrates other than a handful of bird species. The majority of the fauna has been either accidentally or intentionally introduced. Little documentation exists, and what is available is primarily anecdotal or drawn from local reports; however, there is some broad-based review literature.

Most introductions are known to have caused a number of disturbances; some have led to widespread extinctions. Man has been responsible for most of these extinctions. Of the approximately 4,200 mammal species recognized, 88 continental and 33 insular species have become extinct since 1600 A.D. Among the birds, 155 of the known 177 species extinctions have occurred within island populations (Diamond, 1984). Introduced predators are responsible for half of these insular extinctions. Rats are known to have caused the extinction of birds on some 26 islands.

Mammals have been taken to a wide variety of international locations. Along with rodents, feral species have carried a number of diseases and parasites (de Vos et al., 1956). Lachner et al. (1970) outlined the introductions of aquatic animals into North America and Hawaii. More specifically, Maciolek (1984) documented introductions of fish throughout all the Pacific islands, and Eldredge (1987) identified the introduction of marine species to tropical coral-reef areas of the world.

Introduced animals and their impacts have been reported for selected Pacific island areas southwestern Pacific (Wodzicki, 1973), New Zealand offshore islands (Knox, 1973), Fiji (Pernetta and Watling, 1978), Papua New Guinea (Pernetta, 1982), and southern oceanic islands (Holdgate and Wace, 1971). Concern has been expressed at a variety of governmental levels about the continued introduction of animals and their impacts. U. S. President Jimmy Carter signed Executive Order 11987 entitled "Exotic Organisms" on May 24, 1977 [Federal Register 42(101)]. The order was intended to "restrict the introduction of exotic species into the natural ecosystems of land and waters which they own, lease, or hold for purposes of administration...." The effects of this executive order are unknown.

More recently, the International Union for the Conservation of Nature (IUCN) drafted a statement in 1984 on the "Translocation of living organisms; introduction, re-introductions, and re-stocking." This document recommended the formulation of national policies on the movement of animal species. Further, it suggested international recognition of these problems and advised that existing international agreements be enforced. Development of regional plans was urged, and areas needing further research were noted.

For the Micronesian and American Samoan islands, little information about their introduced animals has been documented. The major species known are briefly discussed herein. Lessons learned from each situation are noted within each case study. Both beneficial and adverse impacts can be stated for some introductions. In general, most introduced species have had negative impacts on islands. The lessons which were noted individually are summarized at the end of the case studies in an attempt to explain the background behind the suggested guidelines.

GIANT AFRICAN SNAIL AND ITS PREDATORS

Initially considered to be an "edible snail," the giant African snail *Achatina fulica* was introduced to Taipei in April 1933. Twelve specimens were imported to initiate an escargot industry in Taiwan. From Taiwan, specimens were taken to Japan and then to Micronesia (Esaki and Takahashi, 1942). By 1935 importation into Japan was prohibited and restrictions were established in their commerce (Asami, 1943). Both Esaki and Takahashi (1942) and Asami (1943) documented one of the first introductions of *A. fulica* into Micronesia. A Mr. Shoichi Nishimura brought snails to Palau from Hiroshima in May 1938. In November 1938 a flood washed the breeding stock from along the Garumisukan (now Ngardok) River to the lowlands. Breeding was also being conducted in Koror. On February 13, 1940, the Mayor of Palau issued an order to stop rearing snails and encouraged residents to destroy them (Asami, 1943). In September 1940, 150 youths were recruited to exterminate snails.

Snails were introduced to Saipan, Tinian, and Rota between 1936 and 1938 (Mead, 1961). During the summer of 1939, T. Esaki found snails at Pohnpei (Esaki and Takahashi, 1942) and warned the district officers of the problem. Snails were taken to Pagan in 1939 where they were raised for medicinal purposes (Kondo, 1950). They were apparently also taken to Aguijan during this time, although no published record exists. The other Mariana Islands appear free of *A. fulica*.

The first specimens recorded from Guam were found in late 1945 (Mead, 1961). [Additionally, Baker (1946) reported that R.T. Abbott had discovered a small colony on Guam in 1945]. Mead (1961) quoted a long-term Guam resident as saying, "snails first made their appearance in Guam in 1943 when the Japanese shipped into Guam sweet potatoes from Rota Island."

As a result of the U. S. Economic Survey of Micronesia, Townes (1946) reported that *A. fulica* was abundant on Saipan, Tinian, Rota, Koror, Pohnpei, southern Babelthuap, Peleliu, and part of Truk (Dublon). He added that there were small colonies on Guam which should be eradicated. The addition of Truk to this list probably was a result of the health reports on that island. From Dublon, snails were taken (presumably by the Japanese) to Moen and Romalum prior to 1945. They were first recorded at Uman, Sapata, and Fefan in 1948.

Even though snails have been found at Yap, they have been successfully eradicated by careful control at entry and by collection of specimens. Yap remains free of snails (Falanruw, pers. comm.), as does the Yap outer islands, Kosrae, the atolls of Pohnpei and of the Marshall Islands, and many of the isolated islands of Palau (Mead, 1979).

In American Samoa, *A. fulica* was first seen in May 1977 near the fish canneries at Tutuila. They may have been brought as food by oriental commercial fishermen (Lauofa, pers. comm.). During 1977 and 1978, *A. fulica* had moved over much of Tutuila. In mid-1977 more than one million specimens were hand collected. Between January and August 1980, approximately 135 tons, or more than five million snails, were collected by

300 workers (Lauofa, pers. comm.). Specimens were found at Manu'a, but all were successfully destroyed. None has been reported from Aunu'u.

Predators: In an effort to control the giant African snail, the Pacific Science Board (U. S. National Research Council) began investigating biological control animals. A number of animals was suggested. These included the marine toad (*Bufo marinus*), a variety of insects and hermit crabs, birds, reptiles (*Varanus* sp.), and snails. Mead (1961) reviewed all of these, as well as control through chemical means, human uses, and legislative action. Predatory snails appeared to be the most promising biological control agent.

Experiments suggested that *Gonaxis kibweziensis* would be a good candidate for African snail control. In 1948, specimens were sent to Honolulu for laboratory testing. Meanwhile, a suitable release site was investigated. In 1950 the Insect Control Committee for Micronesia (ICCM) of the Pacific Science Board decided that Aguijan (Mariana Islands) would be the site for field testing. On May 27, 1950, some 545 predatory snails were received from east Africa (Abbott, 1951). Following examination at Guam, approximately 400 were released on May 31 of the same year at a site along the southwest coast of Aguijan (Owen, 1950).

In August 1951, Owen returned and determined that the snails had survived and had spread. A year later Kondo (1952) observed that *G. kibweziensis* was actually feeding on *A. fulica*. The original release had increased to 21,750 individuals. The giant African snail population was estimated to be 1,122,500. Kondo (1952) noted, however, that *Gonaxis* appeared to have little impact on *A. fulica*. Additional specimens were released on the top of the island (Mead, 1961). Two surveys were conducted in 1954. No living specimens of either species were seen along the lower levels. However, they were numerous at the upper level. *Gonaxis* was seen "feeding on *Achatina*, on other *Gonaxis*, and on native species" (Peterson, 1957, p. 2). Peterson thought that there was greater control exerted than previously suggested.

The second survey in July-August 1954 was intended to evaluate further control efforts (Davis, 1954). No living specimens of *Achatina* were found on the lower terraces, but some were seen 2 km southeast of the original release site. On the upper terrace, a total of 80,800 *Gonaxis* and 37,600 *Achatina* was estimated. Davis (1954) calculated approximately 60 percent effectiveness. More than 500 *Gonaxis* were collected for shipment to Hawaii. Additionally, Peterson (1957) took 88 specimens to Guam. During November 1955 more than 5000 *Gonaxis* were collected at Aguijan for introduction to other islands of Micronesia (Truk, Pohnpei, Palau), to Hawaii, and to California (Peterson, 1957).

Thirty years later, biologists from the University of Guam were granted a two-day visit to Aguijan in August 1984 (Eldredge, ms). The western end of the lower terrace was surveyed, and no living *Achatina* or *Gonaxis* was observed. No dead *Gonaxis* shells were seen, although most hermit crabs carried eroded and well worn *Achatina* shells.

Gonaxis kibweziensis was introduced to American Samoa from Palau during fiscal year 1976-77 (Lai and Nakahara, 1980). They were first released near the canneries and appeared to be doing well enough to be collected and further transplanted at Tutuila (Lai and Miyahira, 1981).

Because of the small size and slow growth of *G. kibweziensis*, another species, *G. quadrilateralis*, was considered as a control agent. First introduced to Hawaii from east Africa in June 1957, the species appeared to be slowly adapting (Mead, 1961) and becoming a promising predator (Mead, 1979). In 1967 the first *G. quadrilateralis* were released on Guam but failed. A second, previously unreported release of 200 specimens near Barrigada and Yona took place on February 19, 1968 (Spencer, pers. comm.). Mead (1979) added that this species had been released at Palau and Saipan but did not provide dates.

A third carnivorous snail, *Euglandina rosea*, was originally collected in Florida and introduced to Hawaii in 1955 (Mead, 1961). Within three years, these snails had so successfully multiplied that 12,000 specimens were collected for distribution outside Hawaii. The first *E. rosea* to be introduced to Guam originated from Hawaii and were released in November 1957 near Ylig Bay (Anon., 1961). A second group from Hawaii was released in October 1958. In January 1960 specimens collected at the Ylig River were transplanted to five additional sites around Guam.

In August 1980, 242 individuals of *E. rosea* originating from Guam were released near the community college at America Samoa. By 1984 they were considered to be well established. The controversy surrounding this introduction is discussed below.

The flatworm *Platydesmis manokwari* became the fourth predator of *A. fulica* after it mysteriously appeared at Guam during 1978. By 1980 *P. manokwari* was found throughout the island (Muniappan, 1981). A similar association had been noted previously in Hawaii (Mead, 1963) but was not known at Guam. Interestingly, the flatworm appeared on Saipan shortly afterwards. During a survey of flora and fauna at Tinian in 1984-1985, numerous individuals of this flatworm were found in the jungle some distance from human habitation or from agriculture fields. Was the worm brought by the Japanese to Tinian from its native range in Western New Guinea forty years ago?

Present Status: Natural population decline in *A. fulica* has been well documented (Mead, 1961). New populations are more vigorous than "older" ones. Mead (1961) discussed this phenomenon under a number of separate topics which included population senility, sterility, starvation, exposure, traumatic breaks, predators, genetics, and disease. Predation is only one contributing factor. Introduction of the predatory snail is, therefore, not the only or major factor for the decline of *A. fulica*. Thus, there may be a confused interpretation of the value of predatory snails.

In the Mariana Islands at present, *A. fulica* populations appear to be at a very low level. Following the large, noticeable population explosions of the flatworm *P. manokwari* at Guam in mid-1980, *A. fulica* virtually disappeared. At present, there are scattered aggregations of varying sizes found around the island. During a three-visit faunal survey at Tinian in late 1984-early 1985, no living *A. fulica* were observed, although local residents did report very rare sightings. In August 1984 during a trip especially designed to look for snails at Aguijan, no living forms were observed (Eldredge, ms). During two visits to Pagan in 1981, none was seen at the northern inhabited portion of the island. The volcanic eruption in May 1981 may have further assisted in extermination of *A. fulica* at Pagan (Eldredge, 1982). The current status elsewhere in Micronesia is unknown; snails do not seem to be causing problems.

In American Samoa, *A. fulica* populations have declined although the snails had dispersed to the western end of Tutuila by May 1984 (Lauofa, pers. comm.). The introduced carnivorous snail, *E. rosea*, is locally considered responsible even though natural population declines have been suggested.

Impacts and Lessons: In addition to a being general nuisance, *A. fulica* is an agricultural pest. Its economic importance is probably greatest in newly colonized areas or at the height of its expanding populations (Mead, 1979). Damage is thought to be localized.

A very important effect of the dispersal of *A. fulica* is its transmittal of human diseases. Among others, the African snail carries the rat lungworm *Angiostrongylus cantonensis* and the gram-negative bacterium *Aeromonas hydrophila* (Mead, 1979).

The rat lungworm produces symptoms diagnosed as eosinophilic meningoencephalitis. Alicata (1962) was the first to report this worm in *A. fulica*. He further reviewed this disease in Micronesia (Alicata, 1965). Incidence was high among rats, but land crabs, coconut crabs, and freshwater prawns also had the parasite. In 1979 the first case of eosinophilic meningitis was reported in American Samoa (Beck et al., 1980). The parasite was not found in local rats, but all of the ten African snails examined had the parasite. Infection was acquired by ingesting raw or improperly cooked snails or freshwater prawns. At least one death is known (Whitten, 1981).

Perhaps an even more important impact of *A. fulica* is the effect the introduced predatory snails have on native snails. These predatory snails have been responsible for the elimination or reduction in numbers of native snails in Hawaii (Hadfield and Mountain, 1981), Australia (Colman, 1977), and French Polynesia (Pointier and Blanc, 1984; Clarke, et al., 1984). Arguments have appeared about the value of the introduction of predatory snails (Hadfield and Kay, 1981; Christensen, 1984). Hadfield (1986) provided convincing evidence of the extinction of the Hawaiian endemic *Achatinella* species.

A recent controversy erupted concerning the introduction of *E. rosea* into American Samoa. Tutuila has 33 species of terrestrial snails; six are known to be endemic. With the knowledge of extinctions elsewhere, several biologists protested the American Samoa Government's recommending the introduction of *E. rosea* (Hadfield, pers. comm.; Christensen, pers. comm.). Regardless of these protests, *E. rosea* was brought to Tutuila where it is successfully spreading, following its release near the community college in 1980 (Lauofa, pers. comm.). Even though one story indicates that the predators have been collected, another proudly relates how the residents are spreading them throughout the island for African snail control. *E. rosea* had reached the mountains by May 1984. Only time will tell the fate of the Tutuila native snail fauna.

TROCHUS OR TOP SHELLS

One of the best documented introductions is that of the marine top snail *Trochus niloticus*. The snail, valued for its shell and for its edible meat, occurs throughout much of the southwestern Pacific (Gail and Devambez, 1958). The status of the trochus fishery in Micronesia was summarized in detail by McGowan (1958). The current annual harvest is about 5000 tons, having a value of about $4 million (Heslinga et al., 1984).

Between 1927 and 1931, 6724 individuals were transplanted from Palau to Truk (Asano, 1937), and between 1929 and 1939, to Pohnpei. In March 1938, 2974 individuals were released at four sites on Saipan (South Seas Government, Fisheries Experiment Station, 1939). All were placed at depths of about 30 feet. The transplantation was considered unsuccessful at the time because the death rate was 42 percent (Asano, 1938). However, a year later the remaining 2.5-inch-diameter shells had grown as much as one inch.

In 1955 Van Pel (1955a) suggested that trochus should be introduced to Guam from Saipan. He added that some had already been brought to Guam but urged that more be placed on the reefs. Information on mass transplant is nonexistent.

Individuals of trochus were taken to a number of central Caroline Island localities, but attempts were thought unsuccessful at most areas. Approximately 200 specimens were released at Kosrae in 1959 by the Economic Development Office (Gawel, pers. comm.). An unpublished 1979 survey indicated that the population was too low to support a fishery. Trochus are reported as fairly common at Ngatik, an atoll 90 miles southwest of Pohnpei (Zoutendyk, pers. comm.).

Van Pel (1959) also recommended that trochus be taken to American Samoa. This apparently never occurred; no individuals were seen during an extensive coral reef survey during April 1985 (Smith, pers. comm.).

Present Status and Impact: Nothing is known of the impact of trochus on shallow-water reef ecosystems. At Guam, Smith (1979) carried out extensive field studies on growth, abundance, and distribution of the snail. He found densities as great as 2.45 +_ 0.65 for 20 m^{-2} at the outer reef flat at Tumon Bay. Some reef flats are thought to have commercially harvestable populations (Stojkovich and Smith, 1978). Truk and Pohnpei are thought to have populations sufficient to support a fishery of 150 tons annually (Parkinson, 1980). The successful trochus hatchery at Palau has not exported juveniles snails (Heslinga, pers. comm.) The Micronesian Mariculture Demonstration Center has, however, planted young giant clams (*Tridacna derasa*) on the reefs at Yap (1984), the Marshall Islands (1985), and Pohnpei and Guam (1985). The status and impact of these potentially commercial animals is yet unknown.

MARINE TOAD

The marine toad *Bufo marinus* occurs naturally from southern Texas and western Mexico to central Brazil (Zug and Zug, 1979). This amphibian has been introduced throughout much of the Pacific area during the past 50 years. Because of their large size and their wide adaptability, toads were thought to be good biological control agents. Transplantation of marine toads has been reviewed most recently by Honeggar (1970), Tyler (1975), and Easteal (1981).

In the Pacific area, the first toads were brought to Oahu (Hawaii) in 1932 from Puerto Rico (Pemberton, 1934). The toad was later introduced to Guam originally for insect and garden slug (*Veronicella leydigi*) control. Some nineteen individuals from Hawaii were released at Agana Springs in July 1937 (Anon., 1937a). By September of that year, toads were found as far as Piti, several miles to the south (Anon., 1937b). [Easteal (1981) reported from unpublished Hawaii Sugar Planter's Association information that fewer than 39 individuals were released in 1937.] In January 1938, more than 5000 young toads were collected near Piti and were transplanted in lots of 500 each to Umatac, Merizo, Inarajan, Yona, Dededo, Talofofo, and Sumay (Anon., 1938).

The first record for Micronesia outside of Guam was that from Tinian in 1944 (Stohler and Cooling, 1945). Individuals, estimated to be approximately 4000, were found in cisterns and lily ponds. Original stock arrived from Guam (Townes, 1946) during the Japanese occupation, although Downs (1946) stated that he did not know their source. Townes (1946) further added that toads were found at Saipan and at Rota, having been introduced to Rota as recently as 1944. Fisher (1948) noted that toads were abundant on Pohnpei and Yap. Toads were taken up to Ulithi in October 1948 but were all destroyed upon arrival (Langford, 1948). [They were later introduced in 1973 (McCoy, pers. comm.).] A single toad was taken to Pagan in the mid-1960s (Aldan, pers.

comm.). Savage (1960) reported toads from Palau and studied larvae collected at Koror. Because of the many similarities between Palauan and Mexican specimens, Savage suggested that the Palau forms may have originated from the west coast of Mexico.

The toad was introduced to Tutuila, American Samoa, from Hawaii in 1953, although Simmonds (1957) had strongly advised against such action. Amerson et al. (1982) provided details about the original introduction and the present status of the species, indicating that they have done more harm than good. Their introduction to Aunu'u is not documented (Amerson et al., 1982; Lauofa, pers. comm.).

Present Status: Studies are available on the present status of *Bufo marinus* for Guam (Chernin, 1979) and for American Samoa (Amerson et al., 1982). At Guam, five sites—a spring with standing water, a swamp with fluctuating water, a limestone forest, a savanna, and an area of human habitation—were studied. Populations were greatest in areas of standing water and human habitation. Toads were excluded from the savanna and were found in low numbers in the limestone forest. Densities varied seasonally. During late 1978-early 1979, the population density was 185 per hectare in areas of human habitation and 225 per hectare for standing water at Agana Springs (Chernin, 1979). For human habitation this density is similar to that (184 per hectares for 1975 and 138 per hectare for 1976) found by Zug and Zug (1979) at Panama. However, they found many fewer—54 per hectare for 1975 and 84 per hectare for 1976—for areas of standing water in Panama.

On Tutuila the toad population densities were estimated at 121 per hectare (extrapolated from "per 100 m^2" data) for areas near human habitation and 110 per hectare along the coastal rock strand (Amerson et al., 1982). These authors added that toads were active only at night; hiding during the daylight. Adults and tadpoles were observed during each month of the study.

Impacts and Lessons: The consensus indicates the toad introductions have been more disastrous than beneficial. This is the direct implication for American Samoa (Amerson, et al., 1982).

Toads are a nuisance and have poisonous parotid glands behind the head which secrete toxins that can be "squirted in jets of a distance of at least one meter" (Tyler, 1975,

p. 3). Numerous cat and dog deaths are reported; human deaths have also been recorded (Tyler, 1975).

In American Samoa there is no direct evidence, but the high incidence of polluted drinking water and dysentery may be correlated with the high densities of toads in areas of human habitation (Amerson et al., 1982). Kourany et al. (1970) reported a high incidence of *Salmonella* associated with amphibians.

In a general assessment of the impact of toad introductions, Tyler (1975) noted that "in the long term the toad failed to live up to expectations." Beneficial insects were also eaten by toads, and the impact on native vertebrates is not known. In addition to contaminating drinking water, toads are known to have killed freshwater exotic fishes. The problem remains. TIME magazine (July 29, 1985, p. 49) highlighted the introduction to Australia, detailing the effects of this "cold-blooded killer."

Nearly twenty-five years ago, Mead (1961, p. 105) wrote:

> Who could have guessed that introducing *B. marinus* would, in addition to reducing the black slugs, aggravate the rat problem, kill the monitor lizard, reduce natural control of coconut pests and the giant snail, bring some relief to the poultry industry, kill pigs and house pets, and ameliorate a public health problem of cockroaches and flies brought on by the introduction of giant African snails? As a final ironic twist, the native peoples are convinced that their dogs and cats have died from eating the "poisonous" giant African snails!

Additional Amphibian and Reptile Introductions:

Several other herpetofaunal species are known to have been introduced into Micronesia and American Samoa. Unfortunately, little is known about the original introductions or about the current status of most of these species.

A small tree frog, *Litoria glauerti*, was first found in the central courtyard of the Old Guam International Airport in 1968 (Falanruw, 1976). The species is now found throughout Guam. This frog belongs to a complex of species which occurs in the coastal areas of southern Queensland to as far south as Sydney (Zug, pers. comm.). Speculation might lead one to wonder whether the frog's arrival at Guam might not have resulted from the escape of a child's pet during an airline layover.

The green anole *Anolis carolinensis* was brought to Guam in the mid-1950s by an engineer who thought the lizards would be good for insect control (Owen, pers. comm.). Brown (1956) reported in a footnote that Dr. J.L. Gessitt "states that *Anolis* is apparently established on Guam island" (p. 1481). Individuals are also known from Saipan (Aldan, pers. comm.) and from Palau and, in both localities, are assumed to have arrived from Guam (Owen, 1977b).

The green tree skink *Lamprolepis smaragdina* is found on Rota, Tinian, and Saipan. Attempted introduction of this species at Guam from Yap in the late 1960s was unsuccessful. Since this skink is common in the central Caroline Islands and since there is periodic traditional sailing canoe travel between the Carolines and the northern Marianas, it would seem most logical that the skink arrived by canoe.

Even one of the crocodiles at Palau is said to have been intentionally brought in (Motoda, pers. comm.).

The most disastrous animal introduction occurred on Guam with the arrival of the brown tree snake *Boiga irregularis*. This potentially large snake was first seen in the late 1940s or early 1950s. Individuals spread throughout most of the island by the 1970s at a rate of 1.6 km yr^{-1} (Savidge, pers. comm., and 1985). This snake is the major reason for the range reduction and extinction of the forest birds of Guam (Savidge, 1987).

SELECTED FRESHWATER FISHES: TILAPIA, MOSQUITOFISH, TOPMINNOWS

Numerous freshwater fishes are known to have been introduced throughout the islands of the Pacific. For the U. S.-affiliated islands, perhaps Guam has recorded the greatest number. A total of sixteen species has been introduced into the Mariana Islands; nine have become successfully established. Little is known of most of these introductions; however, some species are well documented. Both exotic aquarium fishes and those brought for aquaculture are now naturalized. Maciolek (1984) reviewed the introduction of fishes into Hawaii and other Pacific islands.

Three species are detailed herein, since these forms are probably among the best documented and most widely distributed.

Tilapia - Oreochromis mossambicus: Tilapia originated in Africa where they were considered to be a good species for farming. Individuals were first taken to Java in 1939 and were subsequently transported and grown extensively throughout southeast Asian countries. In late 1954 the first tilapia were brought to Guam from the Philippines (DeLeon and Liming, 1956). From a small cement tank several thousand were distributed throughout Guam. [A second species, *Tilapia zilli* may have been released in 1956 at Guam.]

In January 1955, 300 tilapia from Manila were released at Lake Susupe, Saipan (Anon., 1955a). A similar report indicated that the original 375 tilapia brought from the Philippines had increased to five thousand by September 1955 (Anon., 1955b). Some 200 specimens were taken to Pagan in October 1955 (Brown, 1955) and reported to have grown unusually large by March 1961 (Brown, 1961). By 1957 tilapia had also been taken to Tinian and Anatahan. Recently, tilapia have been reported from Yap (Nelson, pers. comm.); however, Palau apparently remains without them (Bright and June, 1981).

Tilapia were released in the brackish lagoon at Aunu'u, American Samoa, in early 1957. From this successful introduction, some 80 fish were released in the Leme Creek on Tutuila prior to 1959 (van Pel, 1959). There are apparently no tilapia on Tutuila at present (Sesepesara, pers. comm.).

Mosquitofish - Gambusia affinis: Individuals of this fish have been introduced throughout much of the world as agents for mosquito control. During World War II the U. S. military brought mosquitofish to several island groups in the Pacific, including the Mariana and Caroline Islands and Samoa (Krumholz, 1948). A breeding population was well established in Fena Reservoir, Guam, by 1955 (Brock and Yamaguchi, 1955). Additionally, individuals were taken to Pagan around 1955 and are now well established in both lakes. Maciolek also (1984) reported *G. affinis* from Pohnpei. Nelson and Cushing (1982) noted the fish from the brackish lake at Pulusuk, Truk State, and indicated that individuals were brought from Truk in the 1960s.

Topminnows - Several species: An undetermined species of topminnow was brought from Japan to Saipan and Palau in 1939. A total of 170 fish was purchased in Tokyo and carried in a small tub to Saipan. Only about 5 died en route; some 50 were further carried to Palau (Ikebe, 1939). A number of other fish were taken to Palau in 1939 (Kato, 1940). Among them, the "medaka" was used as an experimental example for fish transport.

At Guam, *Poecilia reticulata* was first introduced into Fena Reservoir in 1956 (Brock and Takata, 1956). *Poecilia latipinna* and *Xiphophorus helleri* were later introduced and are now established (Shepard and Myers, 1981). These authors listed a total of nine introduced freshwater fishes. Bright and June (1981) provided information on the freshwater fishes of Palau and noted that four species—*Poecilia reticulata*, *Xiphophorus maculatus, Puntius sealei*, and *Misgurnus anguillicaudatus*—were considered introductions.

At American Samoa, topminnows, presumably *Poecilia mexicana*, were originally introduced in the late 1920s by the Department of Health for mosquito control (Sesepesara, pers. comm.). In the 1930s topminnows (also called mollies) were considered to be a candidate for use as baitfish when natural baitfish populations were low (Baldwin, 1977). Additional species have been tested for baitfish use, especially *P. vittata*. Large-scale trials (Vergne et al., 1978) and live bait testing (Lambert and Bryan, 1979) have been attempted at American Samoa. In June 1979, some 12,000 baitfish held at the airport lagoon escaped following vandalism. None was recaptured. Both species are reportedly found in the streams on Tutuila (U.S. Army Corps of Engineers, 1981).

Marine species: There are few examples of marine fish introductions in the Pacific. Marquesan sardines were released in Hawaii during the late 1950s (Brock, 1960). Three species of jacks, a bonefish, a goatfish, and a mullet were accidentally introduced at the same time (Randall and Kanayama, 1972). This smaller mullet (*Chelon engeli*) negatively impacted the existing mullet (*Mugil cephalus*) fishery, comprising about 80 percent of the mullets collected in estuaries in Kauai between 1975 and 1978. The goatfish also appears to have become established.

Ten species of deep-water snappers (lutjanids) and groupers (serranids) were introduced to Hawaii from French Polynesia between 1956 and 1961. Three have become established (Randall, 1980), and ecological studies have been conducted (Oda and Parrish, 1982). The species have spread widely throughout the islands and are either displacing or competing successfully with the commercially more desirable native species.

Impacts and Lessons: Quantitative studies on the impacts of these fishes and others are virtually nonexistent. Introduced fishes are known to have some beneficial aspects. Reservoir water-weed control was successful at Guam. Mosquito control has also been successful in numerous island areas. Additionally, there has been limited success with introduced species for bait or human food. Unfortunately, in almost all these cases, individuals have "escaped" and become naturalized in local streams. Tilapia are now found in marine waters where they are known to breed at Fanning Island (Lobel, 1980) and where they have become the predominate fish at the Ala Wai Boat Harbor, Hawaii (Kinzie, pers. comm.).

In general, introduced freshwater fishes have had a major effect on streams. Native island stream animals spend part of their life cycle in the ocean, usually entering the stream during their postlarval stages. Maciolek (1984) suspected that predation on the native fauna was more significant than competition. Another problem of transporting fish to new areas is the potential for introduction of new parasites or diseases, although no examples are known for the Pacific islands.

Among the possible solutions to exotic naturalization are the introduction of monosex populations or sterile hybrids. The "cherry snapper" is a hybrid tilapia (*O. mossambicus* and *O. niloticus*) developed in Taiwan and introduced into Guam in 1973 (Anon., 1983). About 85 percent are male (Lovshin, 1982).

Although primarily written for North American fish, Lachner et al. (1970) discussed numerous species in detail and presented guidelines and recommendations for animal introductions. These will be discussed in detail later in relation to the overall problem of introduced species.

BIRDS

Birds are among the most commonly introduced animals. They have been influenced by man's activities since early times and have been intentionally and accidentally released in numerous locations. Recently, a major compilation outlined the records of birds introduced throughout the world (Long, 1981).

Fortunately, few foreign birds have actually become established in Micronesia and American Samoa. Unfortunately, little information exists about these species and virtually nothing is known of the effect of these birds. "No Micronesian bird has even been the subject of an intensive study" (Jenkins, 1983, p. 1).

Fourteen species have been introduced to Guam. Jenkins (1983) stated that seven were established. The red jungle fowl (*Gallus gallus*) is known to be established on other islands in the Marianas (Owen, 1977a). Intentionally introduced but unsuccessful species include the gray francolin (*Francolinius pondicerianus*), spotted tinamou (*Nothura maculosa*), and red-winged tinamou (*Rhynchotus rufescens*) (Aquatic and Wildlife Resources Division, 1977).

The Philippines turtle dove (*Streptopelia bitorquata dusimieri*) was introduced to Guam from the Philippines in 1771 (Baker, 19851). Populations are now found on Rota, Tinian, and Saipan and are considered to be the most important game bird of the islands (Perez, 1970). A two-year moratorium on hunting on Guam began during 1985. The drongo (*Dicrurus macrocercus*) was originally brought to Rota from Taiwan 1935 (Baker, 1951) and was first reported from Guam in 1960 (Hartin, 1961). The Java sparrow (*Padda oryzivora*) was once established but disappeared (following Typhoon Karen) in 1962 (Owen, 1977a).

Five exotic species are reported at Palau and two at Yap. Red jungle fowl and the scaly-breasted mannikan are known from both islands. Two species of psittacids—sulphur-crested cockatoo (*Cacatua galerita*) and eclectus parrot (*Eclectus roratus*)—are probably established and breeding at Palau (Ripley, 1951; Forshaw, 1973). The house sparrow (*Passer domesticus*) and the tree sparrow (*P. montanus*) have become established in the Marshall Islands (Temme, 1985), and the common myna (*Acridotheres tristis*) was once established at Kawajalein (Owen, 1977a).

Of the two introduced species—rock pigeon (*Columba livia*) and red-vented bulbul (*Pycnonotus cafer*)—in American Samoa, only the latter is well established (Amerson et al., 1982). The rock pigeons are the survivors of a small flock which originally lived in the Pago Pago Harbor area in the 1950s. The red-vented bulbul first appeared sometime after 1957 (1958 of Muse and Muse, 1982). The birds are common around villages on Tutuila (Amerson et al., 1982).

Impacts and Lessons: Birds are intentionally introduced for a number of reasons (Long, 1981). Among these are aesthetics, food, hunting, sport, and pest control. There are numerous record of birds escaping from cages or enclosures. Problems may be brought about through introductions. Exotic species can pose threats to native species through competition, predation, or the introductions of diseases and parasites. Newly introduced birds may hybridize with native species. Of major importance is the possibility of agricultural damage brought about by introduced birds.

For the Pacific islands few examples demonstrate each of the benefits or disadvantages of these introductions. The Hawaiian Islands record the greatest number of bird introductions. Approximately 162 species have been brought to the islands; more than 70 have become established (Long, 1981). Unless measures are taken to control further introductions, there will likely be greater problems in the future. Future bird introductions to Micronesia and American Samoa should be restricted.

MAMMALS

The only truly native land mammals on Pacific islands are bats. A number of other mammals has been taken to the islands both accidentally and intentionally, recently and historically. The colonizing islanders may have carried rats and pigs, and dogs were known at Pohnpei upon European contact.

Small rodents (Johnson, 1962) are among the most transported species. The Polynesian rat (*Rattus exulans*) is found commonly throughout Micronesia and American Samoa and is generally thought to have been introduced prior to European contact (Williams, 1973). This rat is sometimes a serious agricultural pest. The roof rat (*Rattus rattus*) is also widespread throughout Micronesia (Johnson, 1962) and thought to be a recent introduction to American Samoa (Amerson et al., 1982) where it is considered uncommon. The Norway rat (*Rattus norvegicus*) is also a fairly recent introduction to the entire area. Specimens were found on Saipan and Pohnpei and at Koror following World War II (Marshall, 1962a). The first record from Guam was the collection of specimens in May 1962 (Barbeheen, 1974). The Norway rat remains uncommon. No specimens were observed in American Samoa, although there had been previous records (Amerson, et al., 1982). Perhaps, the species no longer occurs there.

The house mouse (*Mus musculus*) has been found throughout Micronesia (Marshall, 1962b) and is rare at Tutuila, American Samoa (Amerson et al., 1982). Although Marshall (1962b) indicated they are absent from atolls, house mice are found at

Enewetak Atoll, Marshall Islands (Berry and Jackson, 1979). They suggest that escaped laboratory mice may have originated or contributed to the present population.

The musk shrew (*Suncus murinus*) was first collected on Guam in May 1953 (Peterson, 1956). Individuals probably arrived from the Philippines. Within two years specimens were found as far away as 20 miles from the original location. By 1956 the shrew had moved throughout the island and became relatively as common as the local rodents (Barbeheen, 1962). The shrew population continued to expand. Between 1958 and 1969 the number of trapped house mice declined, apparently the result of the shrew's introduction (Barbeheen, 1974). The musk shrew was first seen on Saipan in August 1962, Rota in September 1966, and Truk in September 1967 (Barbeheen, 1974). Two independent sightings on Palau, each of an individual specimen, have been noted (Barbeheen, 1974; Owen, 1977b). Specimens are reported herein for the first time from Tinian, and one was seen at Guguan in 1984. Shrews are known to kill baby chickens and were considered a possible problem for Guam's flightless rail, although no evidence has been presented. House mouse populations decreased during the expansion of the shew, but there is no direct evidence that shrews were the cause. Shrews can be a household nuisance.

The Sambar deer (*Cervus unicolor*) was introduced to Guam from the Philippines in 1771 by Governor Mariano Tobias (Safford, 1905). Although the original purpose is not known, deer were hunted within a few years. A breeding population was established by 1774, and by 1819 deer ranged extensively on the island (Quoy and Gaimard, 1824). Several were taken to Rota and fenced on the Taipingot Peninsula (Prowazek, 1913), and they were later taken to Saipan (Schnee, 1912). The deer were taken to Pohnpei at an unknown time but specimens were collected in 1939 (Shikama, 1942). At present the deer is found throughout Guam; however, the greatest numbers are found within restricted military areas. Information on distribution, population trends, and biology for the eighteen-year period between 1961 and 1978 were detailed by Wheeler (1979).

Several other mammals are known to have been brought to the islands. The carabao has been on Guam since the late 1700s. Documentation on the original introduction has not been located. Carabao are presently on Pohnpei (Gawel, pers. comm.) and are known from Palau (Owen, 1977b). Feral cats, dogs, and pigs are found throughout the islands. A monkey, the crab-eating macaque, was accidentally introduced to Angaur

(Palau) in the early 1900s (Owen, 1977b). The impacts of these mammals are not well documented. A goat introduction program has been initiated by the United Nations at Pohnpei (King, 1985), but nothing is presently known about this project.

LESSONS

Introductions of exotic animals into new environments can be broadly categorized as having either beneficial or adverse impacts. Additionally, there are a number of instances of unknown impact.

Within the U. S.-affiliated islands there are virtually no examples of long-term beneficial impact from introduced animals. Potentially commercial fisheries may result from the introduction of the marine animals—trochus and tridacna. Unfortunately, nothing is known of the impacts of these animals, and tridacna have only recently (during 1984 and 1985) been transported in Micronesia. Aquaculture potential has been demonstrated for certain fishes and crustaceans. However, no real economic benefit has been gained from them, and a number of examples of escapes of these animals is known. Baitfish raised at American Samoa were released and never shown to be economically viable.

The original reason for bringing the deer and the Philippine turtle dove to Guam is unknown, but hunting has been suggested. In the mid-nineteenth century the deer did contribute significantly to the food supply for the Spanish garrison. At present, deer hunting is a recreational sport controlled by the Government of Guam. The Philippine turtle dove was, at one time, the most intensely hunted game bird, but a two-year moratorium is now in effect at Guam.

Animals introduced as biological control agents were initially believed successful; however, long-term evidence has not substantiated this. The toad became a greater pest than benefit. The topminnows taken to American Samoa for mosquito control have now replaced local fishes in the streams. Nothing is known of the drongo brought to Rota for insect control and now found also at Guam. Fishes originally controlled aquatic weeds successfully in such places as Fena Reservoir, Guam, but later escaped into local streams.

Birds transported for aesthetics into Hawaii have not been particularly beneficial even though they have been reasonably successful. No similar examples are known from the U. S.-affiliated islands.

Most animals introduced to new geographic areas have brought about negative or adverse impacts. Prime among these were agricultural and public health problems. The

African snail is among the most important agricultural pests because of its severe economic impact on cultivated plants. In some areas the snail is known to denude large areas in very short periods of time. Additional agricultural pests include rats feeding on plants and processed foods and birds feeding on plants, especially fruits.

Foremost among public health pests are African snails and toads which, in extreme, cases have been known to cause human deaths. The rat lungworm parasitizes the African snail and has been recognized as the cause of cerebral angiostrongylosis in humans. The consumption of raw or improperly cooked snails is the transmission route. Human and animal deaths have been reported following the consumption of toads. Circumstantial evidence indicates that there are increased salmonella outbreaks in areas of large toad populations. Introduced rats, birds, and fish are known to transmit new human and animal parasites into new geographic areas.

Another important negative impact is the extinction of native animals by introduced ones. Predatory snails are known to cause the extinction of native snails in Hawaii, French Polynesia, and Australia. The brown tree snake is thought to be the cause of the extinction of a number of Guam bird species, and cats are thought to have caused similar bird extinctions, although there is no direct evidence.

Vegetation has been greatly altered by introduced goats and pigs. Although there have been no studies in the U. S.-affiliated islands, evidence from Hawaii and Fiji indicates potentially significant problems.

Many introduced animals are considered to be of a high nuisance level. Road-killed toads and snail droppings attract flies, shrews build small residences, and toads consume beneficial insects and biological control agents. Nuisance levels differ from locality to locality.

The impact of a number of animals is unknown. Unfortunately, studies have not been conducted on trochus or tridacna introductions. Nothing is known about the impacts of the anole, the green tree skink, or released freshwater aquarium fishes.

GUIDELINES

Great care should be exercised when any exotic species is being considered for introduction. The biology and life history of the species to be introduced must be known.

The individuals to be introduced should be examined to insure that parasites or diseases are not introduced. Each individual released should be identified as the species to be introduced so that undesirable species are not introduced inadvertently.

Introduced individuals should be held in quarantine or in observation tanks to prevent the further introduction of disease or pest species from being introduced. Only healthy organisms should be released.

Sterile hybrids should be considered for introduction. The "cherry snapper" is a hybrid (cross between *Oreochromis mossambicus* and *O. niloticus*) tilapia developed for pond culture and popular as a food fish in Taiwan. About 85% of the hybrids are male (Lovshin, 1982).

Large scale intentional introductions could alter natural populations in much the same way that Vermeij (1978) suggested could happen during biotic mixing. There might be no interaction; there might be hybridization and evolution.

Courtenay and Robins (1973) suggested that "good intentions provide poor grounds for introducing exotic animals" and presented seven steps to be considered in order to prevent disastrous results.

1. The reason for the introduction should be clearly stated and demonstrated.
2. A search for introduction candidates should be proposed, listing favorable and unfavorable aspects of each candidate.
3. An assessment of the alien species' impact should be considered. This would include impact on the overall ecology, edibility and catchability, and public health aspects. (For coral-reef associated fishes this should include background information on the species and its potential for ciguatoxicity). The impact of the introduced species which has become established in a non-native area should be most helpful.
4. The introduction should be widely publicized and should be reviewed by a panel of specialists.
5. Experiments with the species being considered should be conducted, especially in escape-proof systems.

6. The prepared report should be publicized and evaluated by all governmental and private groups involved, particularly regional (or international where multi-national islands are involved).
7. After favorable review the species could be released.

Additionally, Li and Moyle (1981) proposed screening "rules" developed by entomologists but modified for fisheries management. They added four criteria pertinent to the introduction itself. They illustrated their study with "loop analysis" case histories of two lake systems. Perhaps the same work is applicable to tropical insular studies.

Kohler (1981) proposed a protocol which included four evaluation levels. The goal of this "review and decision model" is designed to "ensure that exotics are used in the wisest manner." The feasibility of the introduction should be considered, and the habitat requirements should be known. If at a later time the introduction is considered undesirable, he added that some control methods might be implemented.

Even after following these proposed steps, monitoring should be continued in order to establish the degree of success of the alien species. Randall and Kanayama (1972) have aptly summed up the problem of alien species: "Once an organism has become established in the marine environment, the new locality will probably have to live with it for as long as man survives on this planet."

SUMMARY

Considering that almost all the vertebrates animals other than a few bird species were at one time introduced to the Pacific islands, it is amazing that there have not been greater and more devastating impacts. Probably the most significant effect on an island is the high rate of bird extinctions currently occurring at Guam. The recent accidental introduction of the brown tree snake is thought to be the cause. Another example is the potential extinction of native land snails in American Samoa brought about by the introduction of predatory snails.

Action should be taken to control the introduction of exotic species. Local legislation and its enforcement would be the most direct route to control the transportation of potentially disastrous species. The key would be local enforcement. Numerous examples could be given throughout the Pacific where legislation exists but is ignored. The local governments could be assisted by appropriate Federal government agencies, such as the Fish and Wildlife Service, Environmental Protection Agency, National Marine Fisheries Service, and the Department of Agriculture. Each agency has its own objectives which could be extended to the complimentary local office. Academic institutions and nonprofit organizations could assist as an information resource, but the basic "grass roots" approach would be local enforcement. This is best supported through extensive educational programs demonstrating the pros and cons of exotic organisms.

In order to achieve this, funds should be provided for basic research of local organisms and their ecology with and without the problems of introduced species. Inventories must be made prior to introduction to investigate native (endemic) species. Research needs to be conducted on exotic species in an attempt to understand their biology and their potential impacts on the native fauna.

Additionally, funds are needed for public education programs. Specific types of literature should be produced for different levels of instruction, from formalized schooling to newspaper advertisements. These will be required in a variety of languages.

Further support is needed for the organization of local screening committees to investigate and enforce proposed species introductions.

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