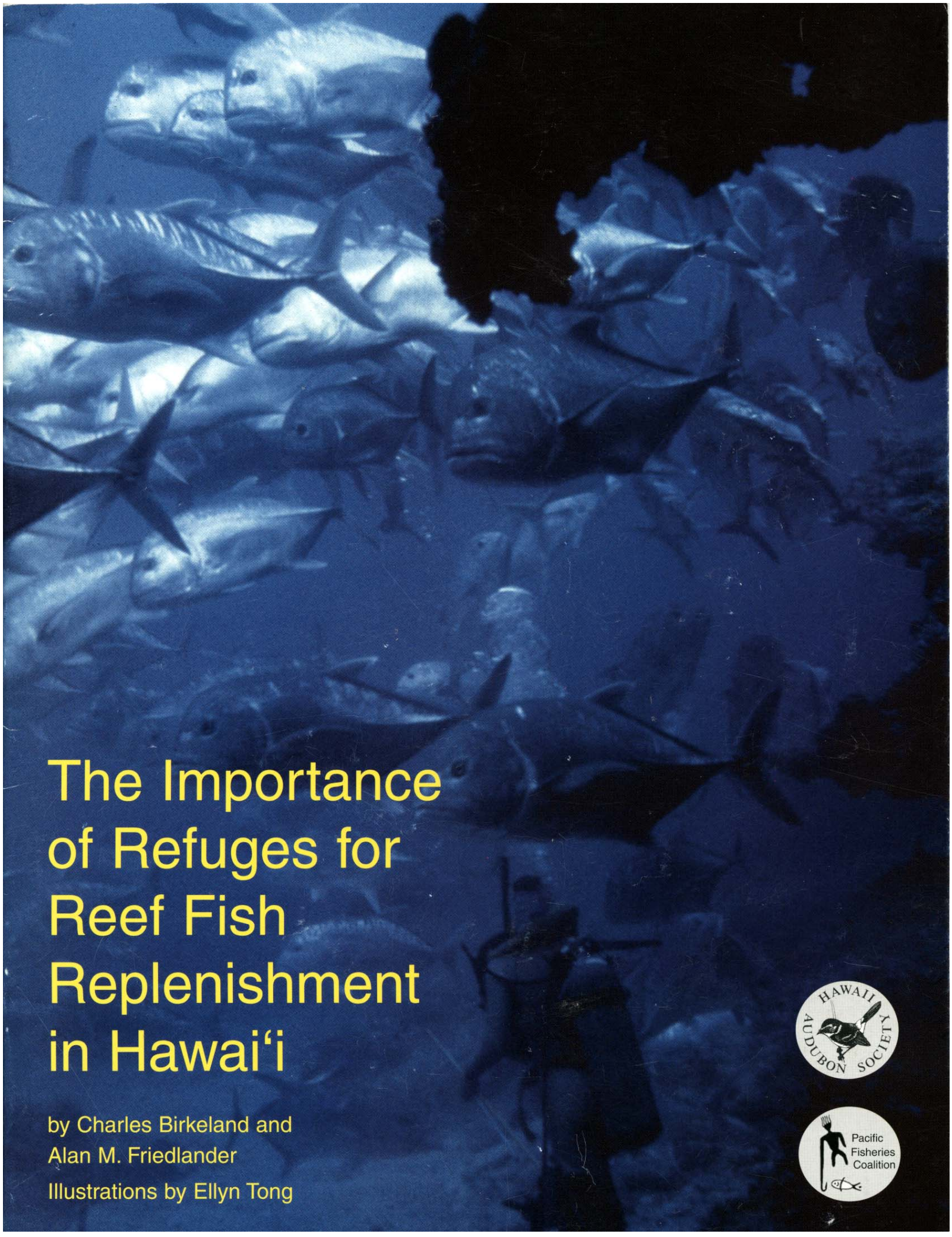

The Importance of Refuges for Reef Fish Replenishment in Hawai'i

by Charles Birkeland and
Alan M. Friedlander
Illustrations by Ellyn Tong

HAWAII AUDUBON SOCIETY
Pacific Fisheries Coalition

The Importance of Refuges for Reef Fish Replenishment in Hawai'i

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The Hawaii Audubon Society was founded in 1939 to foster community values that result in protection and restoration of native ecosystems and conservation of natural resources through education, science and advocacy in Hawaii and the Pacific. The Society is a member of the Marine Fish Conservation Network.

The Pacific Fisheries Coalition is a unique collaboration between conservationists and fishermen who have been working together since 1998 to promote the conservation and responsible use of living marine resources in Hawaii and the Pacific Basin.

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Cover photograph by John L. Earle "Apex predators (ulua) dominate the reef at Midway where Therese Hayes did a survey of reef fishes in 1992".

Illustrations by Ellyn Tong.

We would also like to thank Ellyn Tong for designing the cover and layout, and acknowledge Linda Paul for her editorial assistance.

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Executive Summary

- Abundant fisheries were maintained in the past by wise, traditional Hawaiian management practices based on a kapu system that protected spawning times and areas, and by the existence of natural refuges.

- Fish stocks were also abundant because traditional fishing gear was time-consuming to make, designed to catch just the targeted species, and biodegradable. Line was made from coconut fiber, hooks were carved from stone and bone, and rocks were used as weights.

- Hawaii's coastal fisheries have declined dramatically in the past 50 years because of the use of very efficient gear, wasteful fishing practices, and habitat destruction.

- Overfishing in the main Hawaiian islands has reduced many nearshore fish populations to levels below the capacity of the resources to replenish themselves.

- The failure of conventional fisheries management methods has led to the implementation of no-take refuges as a way to rebuild stocks by protecting large, highly productive fish.

- The number, size, overall weight and reproductive output of fish is greater in no-take refuges in Hawaii compared to other areas that are completely or partially open to fishing.

- The size and abundance of fish also increase in areas adjacent to no-take refuges. This is called the spill-over effect. It was demonstrated in the Philippines that nearly twice as many fish could be caught on 75% of the reef, if 25% was set aside as no-take refuges.

- No-take refuges may also replenish fish populations regionally via larval export.

- A network of large and small no-take refuges, which span long distances, provide insurance against overfishing and natural catastrophes.

- At present there are very few no-take refuges in Hawaii. Less than 1% of our coral reefs and essential fish habitat are protected in this way.

- There are also very few fish stocks that are managed in the traditional Hawaiian way. When fishing is controlled by some local communities, the catch is well over twice that of other areas that are only partially protected.

- The stocks of coral reef fish in the main Hawaiian Islands are at most 20-25% of what they were a hundred years ago. No-take refuges are needed to replenish fish stocks and replace natural refuges that have been lost to improved fishing technology.

- The Northwestern Hawaiian Islands is the last, large scale, pristine coral reef system in the northern hemisphere. These fragile natural refuges demonstrate what our reefs were like in the past and they should be designated pu`uhonua and protected for our grandchildren.

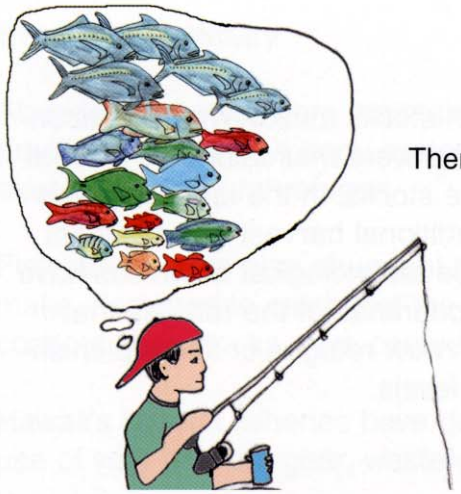
The Need for Fully Protected Marine Refuges

In ancient times, Hawai`i's coral reefs were rich and fish stocks must have been abundant to be able to support the Hawaiian people. Fisheries were maintained by cultural and natural refuges, which supported large reproductive stocks. In the last 200 years reef fisheries have substantially decreased because traditional harvest management methods are no longer generally practiced, and because technological advances have made fishes easier to catch and freeze. With the disappearance of the refuges that protected large breeding fish, we now need to establish new refuges or fish replenishment areas to bring fisheries yield back up to previous levels.

Where Have All the Fishes Gone?

In pre-European times, there were more Hawaiians living on food from the reefs than there are now. Oahu is more densely populated at present, but the other Hawaiian islands may have had more people in times past, and more of their protein came from the sea (Fig. 1). Much of the fish we eat today is imported. The reefs back then must have been very productive to have supported large populations. The chiefs and the konohiki must have managed things well.

Figure 1- Hawaiians have traditionally been intimate with the sea and have used it as their refrigerator. (Photo by Alan Friedlander)



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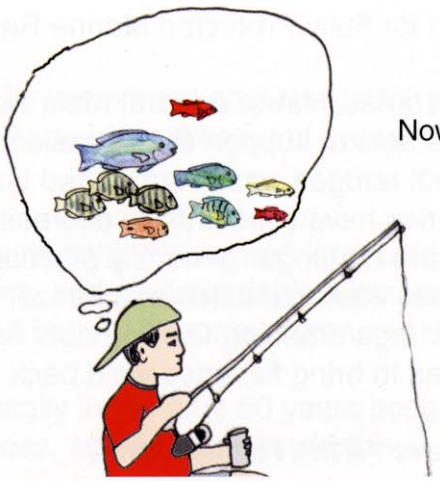
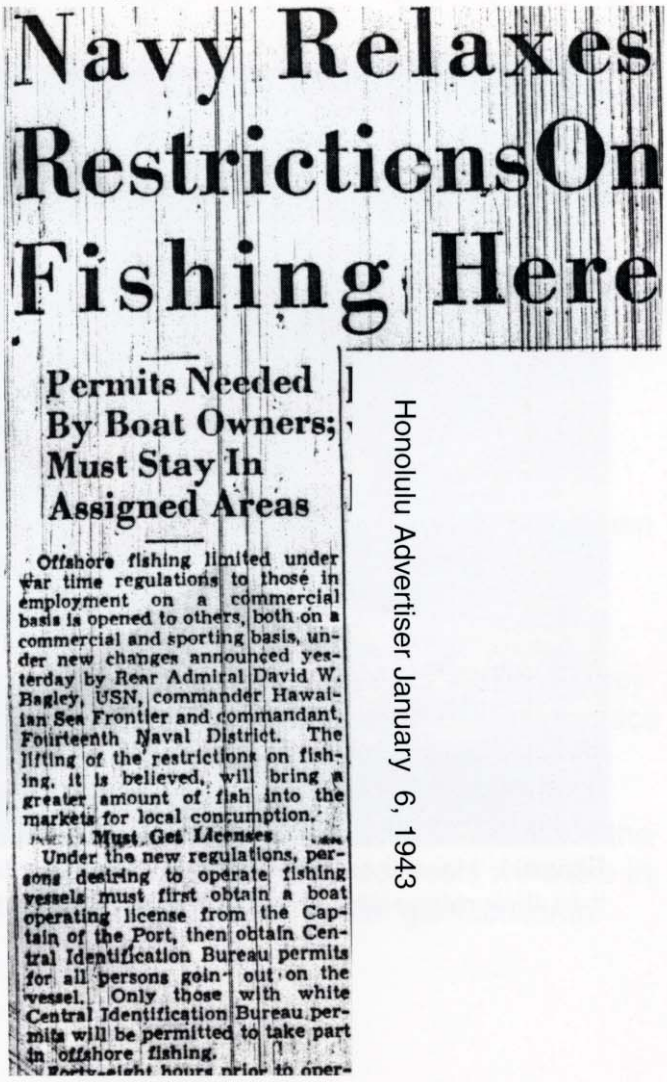


Now

Today reef fish stocks are depleted in the Main Hawaiian Islands (MHI) compared to a century ago. Shomura (1987) reported that fishermen and scientists observed a steady decrease in the abundance of living resources in the MHI over the past century. Today most fishermen assume that small fish assemblages dominated by herbivores (fish that eat limu) with almost no large predators are the norm. This perception of less and less as the natural condition from generation to generation is called the "sliding baseline". It is also a weakness of science that the concept of what is natural, as well as the goals for sustainable fisheries, diminish from generation to generation.

However, some of the fishermen that were active over a half century ago and are still around remember when the fish assemblages around the MHI were more rich and abundant. Louis K. (Buzzy) Agard remembers the "great fisheries experiment" of World War II. Before World War II, the Hawaiians were actively catching reef fishes, but in 1941, the U.S. military prohibited fishing from boats offshore because the military was using hydrophones to constantly listen for enemy vessels. Small offshore fishing vessels made noises that interfered with or confused the interpretation of signals from the hydrophones. Fishing virtually stopped for four years. At the end of the war in 1945, the fishery was reopened and there were so many large fish "it was unbelievable". For a brief period during World War II, there were dense schools of large ulua (jacks) in the MHI which is still the case in the Northwestern Hawaiian Islands (NWHI).



Navy Relaxes Restrictions On Fishing Here

Permits Needed By Boat Owners; Must Stay In Assigned Areas

Offshore fishing limited under war time regulations to those in employment on a commercial basis is opened to others, both on a commercial and sporting basis, under new changes announced yesterday by Rear Admiral David W. Bagley, USN, commander Hawaiian Sea Frontier and commandant, Fourteenth Naval District. The lifting of the restrictions on fishing, it is believed, will bring a greater amount of fish into the markets for local consumption.

Must Get Licenses

Under the new regulations, persons desiring to operate fishing vessels must first obtain a boat operating license from the Captain of the Port, then obtain Central Identification Bureau permits for all persons going out on the vessel. Only those with white Central Identification Bureau permits will be permitted to take part in offshore fishing.

Forty-eight hours prior to oper-

Honolulu Advertiser January 6, 1943

The major cause of the long-term decline of the stocks in the MHI is overfishing (Shomura 1987; Harman and Katekaru 1988). Fishing pressure has reduced many nearshore fish resources in the MHI to levels below the capacity of the resources to replenish themselves (Smith 1993; Friedlander and DeMartini 2002) (Fig.2). Aquarium collectors also have been shown to have a substantial negative effect on populations of targeted ornamental species. In contrast, populations of fishes can replenish themselves in areas where fishing is prohibited (Grigg 1994). This indicates that if breeding stocks are completely protected in some areas, we may be able to bring fisheries production back to traditional levels.

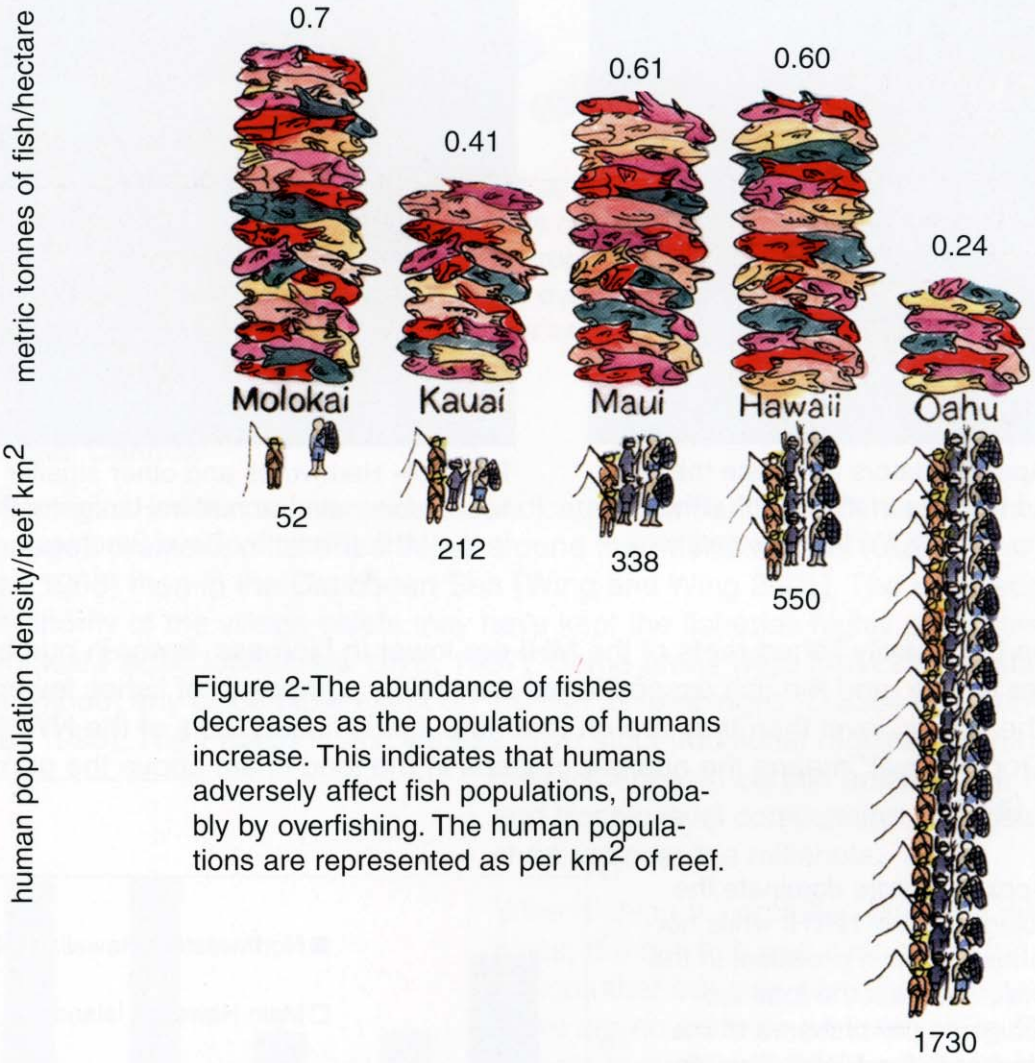


Figure 2-The abundance of fishes decreases as the populations of humans increase. This indicates that humans adversely affect fish populations, probably by overfishing. The human populations are represented as per km^2 of reef.

According to Buzzy Agard, the fishing was good in the NWHI for the five to six years it took for fishermen to "gear up", obtain boats, and get operational. In the early 1950s, Buzzy Agard started fishing on French Frigate Shoals in the NWHI. When he first arrived, he spotted a school of large moi and harvested them. He tells that there were "no more moi the next day, the next week, or ten years later". He said he learned that "the reefs of the NWHI are fragile and need to be managed with care."

In the NWHI, large jacks, sharks and other top predators are dominant in the fish assemblages as is expected in unfished areas (Fig. 3), whereas fish assemblages in the MHI are dominated by herbivores (Fig. 4), although the herbivores have also been fished down and their numbers are lower than in the NWHI (Friedlander and DeMartini 2002).

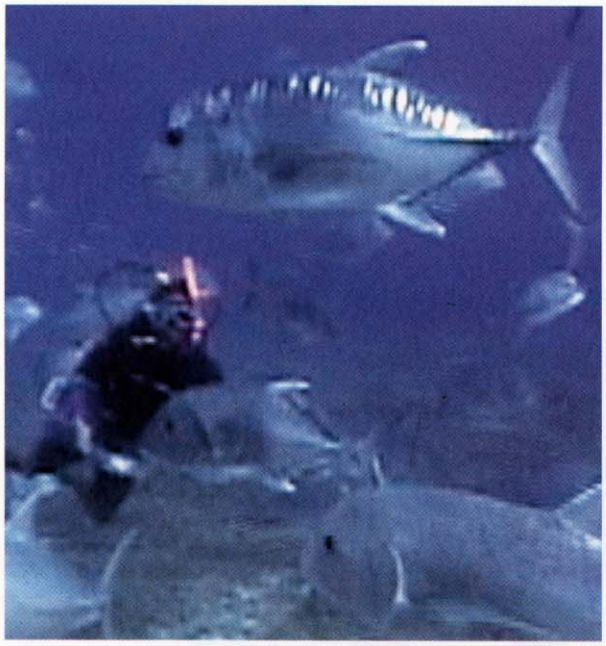


Figure 3- Apex predators dominate the reef at Pearl and Hermes in the NWHI. (Photo of Ryan Okano from NOWRAMP expedition)

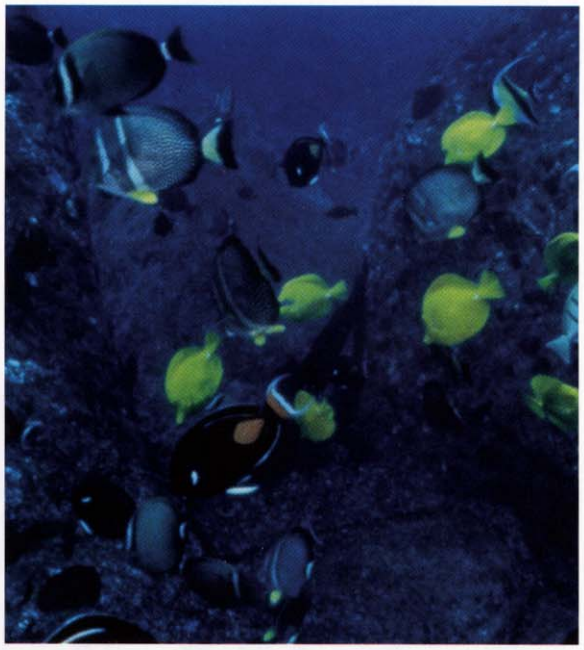
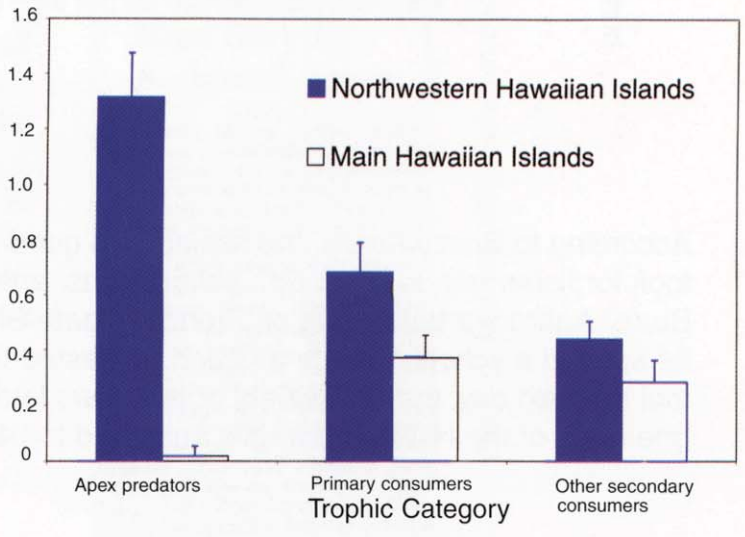


Figure 4- Herbivores and other smaller reef fishes dominate the reef in Hanauma Bay in the MHI. (Photo by Dave Strichtes)

The fish on the heavily fished reefs of the MHI are lower in biomass, fewer in numbers, and smaller in size, and the fish assemblages are mainly composed of fishes lower down on the trophic level than they are on the more lightly fished reefs of the NWHI (Fig. 5). "Trophic level" means the number of steps in the food chain above the primary producers (algae).

Figure 5- Apex predators dominate the fish assemblages of the NWHI while herbivorous fishes are most prevalent in the MHI. However, note that the total biomass of herbivores per unit area of the reef is still higher in the NWHI. The biomass of fish in the NWHI is 3.6 times that of the MHI.



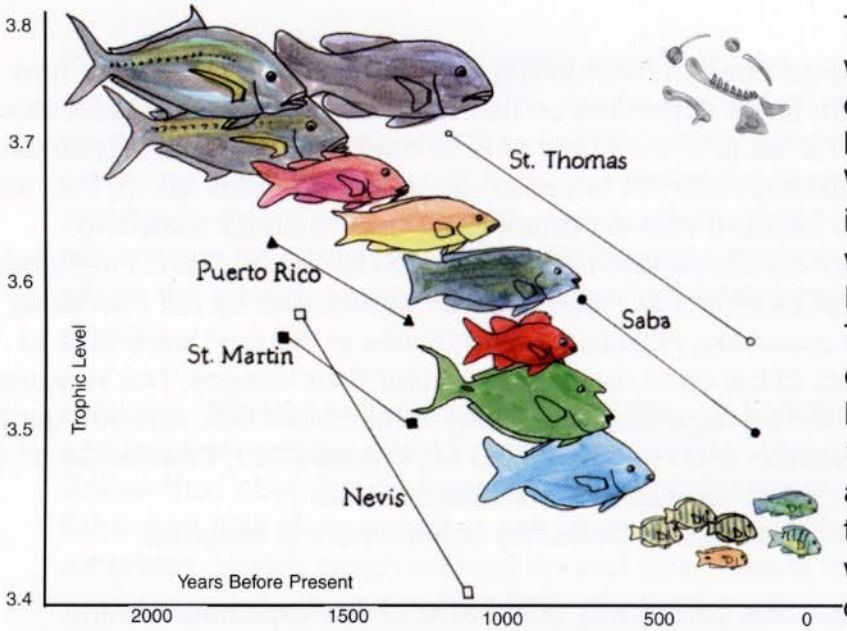


Figure 6- Middens indicate that fish in the diets of native islanders in the Caribbean represented lower trophic levels as the centuries passed. These signs indicate overfishing occurred long before Europeans arrived. (Data are from Wing and Wing 2001.)

Throughout history and all over the world, patterns of decrease in abundance, size, and average trophic level have indicated overfishing. Wing and Wing (2001) investigated fish bones in middens (archaeological kitchen wastes) on the Caribbean islands of Puerto Rico, Nevis, St. Martin, St. Thomas, and Saba and found they decreased in size and mean trophic level (Fig. 6) in these areas between 1900 and 600 years ago. Daniel Pauly and others (1998) demonstrated that the index of trophic levels around the world substantially decreased where overfishing occurred. The coral reef fish assemblages in the MHI show both of these the signs of extreme overfishing that started decades ago.

Traditional Controls

Archaeological evidence from middens indicates that traditional fishing communities generally managed prehistoric fisheries better around the Pacific islands (Dalzell and Adams 1997; Dalzell 1998) than in the Caribbean Sea (Wing and Wing 2001). The knowledge, customs and authority of the village chiefs may have kept the fisheries highly productive in much of the tropical Pacific (Johannes 1978, 1997). Some areas were harvested sustainably for 3500 years without any discernible effect on the fish assemblages (Dalzell and Adams 1997; Dalzell 1998). The Palauans and Yapese have strict traditional regulations that still maintain their fisheries. In certain areas of the Pacific the size and trophic level composition of fishes has not changed over the millennia.

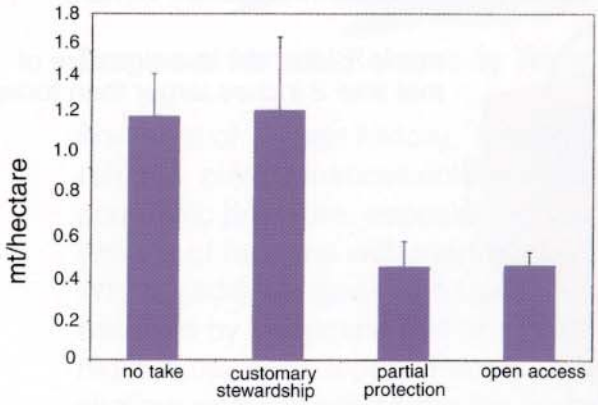


Figure 7-The standing stock of reef fishes in a fully protected refuge is about the same as on a reef harvested by subsistence fishing under traditional stewardship. The standing stocks on reefs with partial or rotational protection are not substantially different than on reefs completely open to any fishing. (CRAMP Unpublished data)

When fishing is controlled by some local MHI communities, the catch is well over twice that of other regions that are only partially protected or for which there are no controls on fishing (Fig. 7). The harvest system in such communities is based on social and cultural controls that are strictly enforced. It is interesting to note that traditional fishing practices can maintain the same breeding stock as fully protected reserves. Partially protected reserves or rotational reserves do no better than open areas.

Restrictions on harvesting for the purpose of maintaining sustainable fisheries is not a new concept. The Hawaiians in ancient times depended on fish and other reef resources for food and this dependency drove them to an understanding of how coral reef resources replenish themselves. The restrictions on fishing were not based on quotas or amounts taken, but rather on times and places so as not to interfere with important processes such as spawning (Titcomb 1972; Pacific American Foundation and Hui Malama O Mo'omomi 2001; Friedlander et al. 2002). By allowing the fish populations to replenish themselves, and by not interfering with important activities such as spawning, Hawaiian communities in the past were able to maintain the productivity and yield of the coral reef fisheries near their villages. The Hawaiians in the past had a strict code of conduct regarding the taking of resources that was stringently enforced (Pacific American Foundation and Hui Malama O Mo'omomi 2001; Friedlander et al. 2002). Social enforcement of a code of conduct is more effective than government control and regulations, but local community commitment is essential.

In traditional Hawai'i, important species particularly vulnerable to overexploitation were reserved for the ruling chiefs. Prior to the 1800s at least half of the Hawaiian population was not allowed to eat ulua, kumu, and sea turtles (Abbott 1984). Moi were reserved for the ali`i or chiefs. Moi are now seriously overfished (Friedlander and Zieman [in press]) and individuals are substantially smaller, with less of the stock reproductively active than 30 years ago (Fig. 8). This is a particular problem for moi because large individuals are generally female. When there aren't very many of them, the population is mostly male and the reproductive potential of the stock is seriously reduced.

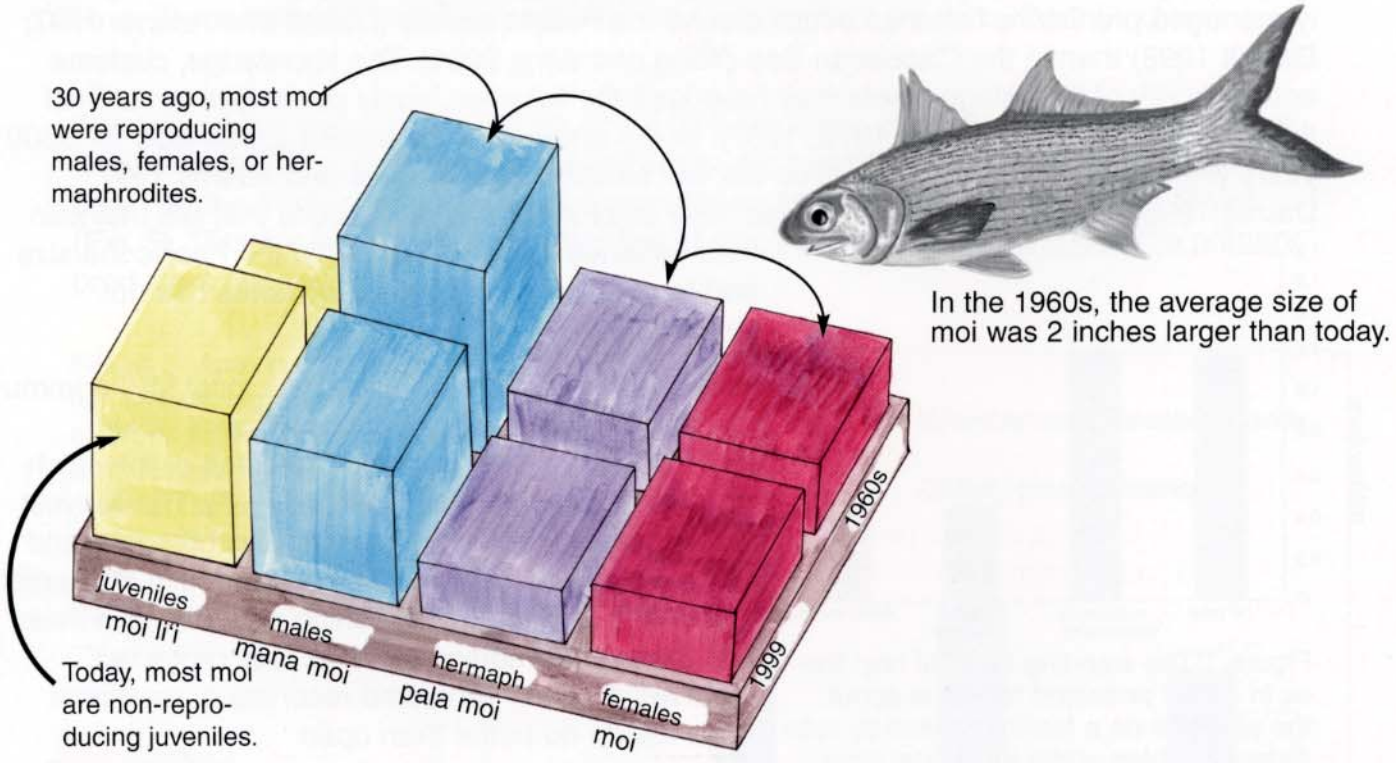


Figure 8- Overfishing of some species of fishes on coral reefs is particularly risky when the sexes are different sizes. There are now very few female moi and most of the harvested individuals are non-reproducing juveniles.

In ancient Hawaiian culture, a young fisherman was required to watch the older fishermen at work and to hold the catch, but he was not allowed to actually fish until he had years of training. He had to know the life history, behavior and ecology of the fishes before he was allowed to catch them (Friedlander et al. 2002). The authority of village and family elders was respected. Island cultures emphasized heritage, tenure, and responsible stewardship of resources because these cultures developed on islands where the consequences of over-harvesting limited resources, such as starvation, were obvious.

However, Western culture, with its emphasis on freedom of the individual, is attractive and has had a major effect in undermining the structure of Pacific island societies. Rather than obey the customs and strict regulations of the kupuna or elders, young fishermen now claim a right to fish as much as they please and anywhere they like. American culture, which evolved on vast quantities of land and resources, has led young people to think it is their birthright to take whatever natural resources are around without regard for the needs of their communities or future generations.

The Palauans and Yapese still practice a sustainable coral reef fishing culture with its stabilizing effect on family and social structure (Birkeland 1997). In Palau, fishing is often a cooperative activity in which each of the family members has an important role. Fishing is working together. As fishing becomes easier with improved technology and more commercial and less of a family matter, family and social structure lose another part of their foundation. According to some interviews, the number of suicides and criminal acts increase on Pacific islands as fisheries move away from the control of family and villages. The economic consequences of the loss of traditional controls over reef fisheries are not easily recognized by policy makers. Western commercial fishing practices favor short-term gain and tend to benefit a few at the expense of many. However, the State of Hawai'i has been encouraging community-based enforcement of subsistence fishing areas since 1994. Traditional management areas are being established throughout the MHI.

Demise of Natural Refuges by Technology

For most of human history, fish and other marine species have had naturally protected refuges, places inaccessible to fishing. But rapid improvements in gear and escalating economic pressure, especially in the last 50 years, have completely changed the interactions of humans with marine resources, virtually eliminating those refuges (Fig. 9). When traditional gear was used to catch fish, there were always some fish that escaped by swimming fast or into deeper water. Most fish were able to sleep safely at night in the dark depths. People such as Palauan fishermen could spear some fish in shallow water at night from the surface by torchlight (Johannes 1981), but without scuba and underwater lights, fishermen were not likely to take them all.

American Samoan subsistence fishermen spoke eloquently about recent changes in their fisheries at public hearings in Pago Pago in April 2001. They described how they were able to go out and spear enough preferred fish for their families in just half an hour by free diving until 1994. That was the year commercial divers started using scuba, underwater lights, and high-powered boats. Once scuba arrived, the commercial catch from coral reefs increased by up to 15 times the previous catch with up to one-fifth of the population of parrotfishes taken in a given year (Page 1998). By the year 2000 subsistence fishermen could no longer catch the large or preferred fish; they had become too scarce and too deep. The commercial fishermen argued that commercial fishing with scuba was necessary because only fishermen using scuba can get the large fish wanted for weddings or other festive occasions. The overwhelming majority of Samoans at the public hearing argued that if fishing using scuba was banned, large fish would then become available for many more Samoans. They concluded that if scuba fishing was prohibited, commercial fishermen could make a living fishing by free diving. The use of scuba in fishing was prohibited by order of the Government of American Samoa in March 2001. The commercial fishers took their scuba operation to Samoa (previously Western Samoa) and within a few months the people in two districts comprising 20 villages established a traditional ban on the use of scuba in fishing. There is presently a movement among Samoan people to have the government establish a national ban.

bumphead parrotfish

Most coral reefs had natural refuges before modern technology made them easily accessible. Herds of large bumphead parrotfishes with individuals up to 153 cm [5 ft] and 75 kg [165 lb] were a spectacular part of the fish assemblages on Guam until the late 1970s. Large Napoleon wrasse with individuals up to 180 cm [5.9 ft] and 190.5 kg [420 lb]) were also a common sight. Although the huge parrotfish slept in herds out on the open sand, they slept in the dark and some of them in water too deep for free diving. Napoleon wrasse slept in crevices. When scuba, underwater lights, bangsticks and high-powered boats came to Guam, a few fishermen were able to virtually eliminate the large parrotfish and the large Napoleon wrasse from the reefs. The last large schools of bumpheads were seen on Guam in the 1970s.

Modern technology and economics have also allowed the efficient manufacture of inexpensive monofilament gill nets. They are now produced so efficiently that they are essentially disposable. Fishermen can lay long gill nets in new areas and in deeper water than they could previously (Clark and Gulko 1999). Lay gill nets are very effective at catching reef fish because several sections can be connected together to form very long walls that ensnare everything that runs into them. They also catch sea turtles and may even entangle monk seals. These nets frequently get hung up on coral and destroy fish habitat. They are often abandoned because they are not so expensive to replace. Abandoned gill nets and traps can "ghost-fish" for years. In 1998, officials of the State of Hawai'i gathered nearly five miles of net from coral reefs in Hawai'i in a six-month period (Clark and Gulko 1999). Lay gill nets have caused the depletion of coral reef fishes in many areas of the MHI.

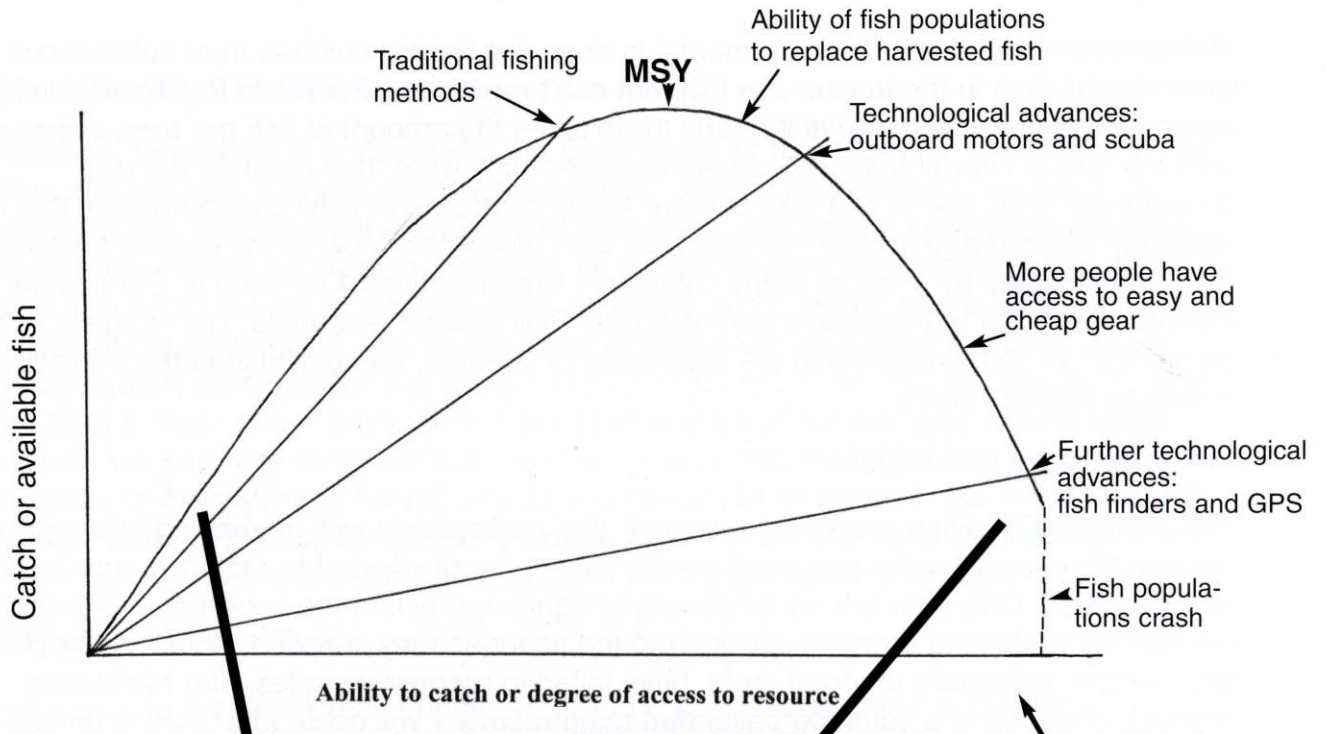


Figure 9a-The diagram shows the decrease in available fish as the ability to catch fish improves. MSY means Maximum Sustainable Yield.

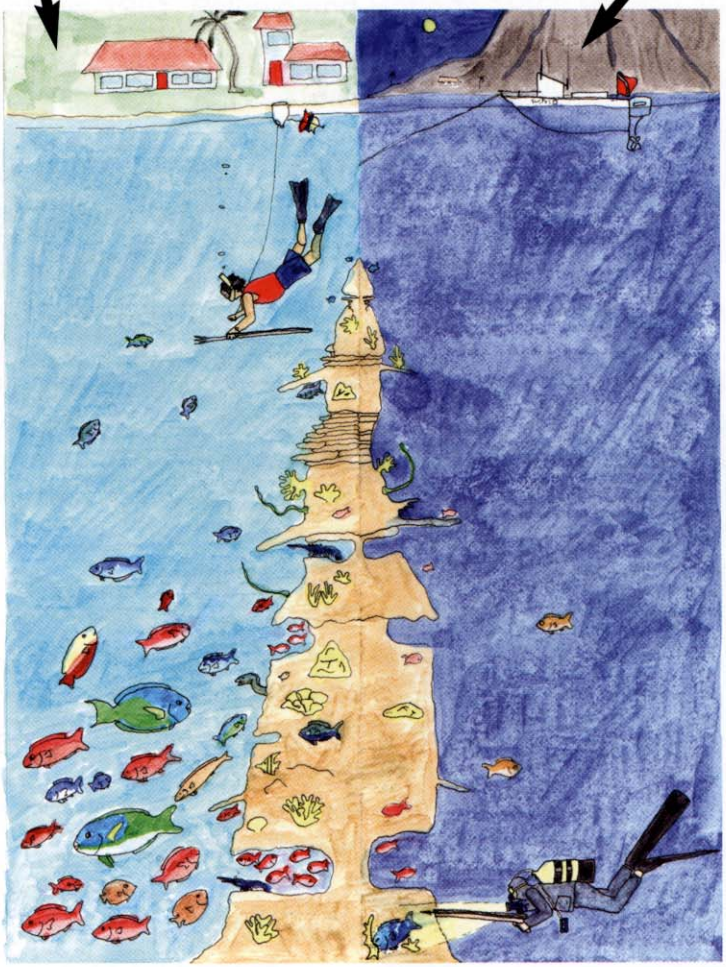


Figure 9b-The number, size, and variety of fishes are much lower in areas where advanced technologies such as scuba, underwater lights, and powerboats are used.

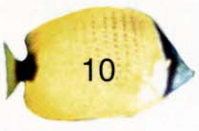
Refrigeration has also been instrumental in changing fishing cultures from subsistence to commercial. Fish in the freezer are fish that can't reproduce. People in traditional fishing communities are able to harvest nearly three times the amount of fish per area compared with the rest of Hawaii (Fig. 7) because they take only what they need for the day (Friedlander et al. 2001). But take is more easily controlled in fishing communities that are relatively isolated and able to manage their own resources. Most of the coastal areas of the MHI are occupied by a mix of many cultures in urban settings. On much of Oahu, local communities have lost management authority over their marine resources. The "tragedy of the commons", in combination with the availability of freezers, has diminished the traditional Hawaiian fishing culture.

The Importance of Refuges

The demise of tradition combined with gear that catches fish with increasing efficiency make refuges necessary for the preservation of breeding stock needed to replenish and increase fisheries yield. Only now are we beginning to again appreciate the importance of natural refuges for sustaining breeding stocks and the fisheries they supplied. Some overexploited populations, especially on coral reefs, have failed to recover decades after harvesting ceased, challenging a common belief that rapid recovery will occur after fishing pressure is removed. Severe depletion undermines population resilience by altering reproduction, recruitment, behavior, habitat integrity and interactions with other species. Technology, economic pressure and new enterprises (e.g. collecting live coral reef fish for aquariums and restaurants, bioprospecting, and deepwater harvesting) are developing rapidly. With increasing fishing pressure and serial depletion of fish stocks along with the loss of natural refuges and habitat destruction, it is important to examine the potential of establishing refuges that have proven to be effective in allowing moderately depleted populations to rapidly recover.

Severe Depletion May Be Permanent

Unfortunately, re-created refuges may not be able to bring back locally extinct populations. Over a hundred tons of black-lipped pearl oysters were taken from Pearl and Hermes Reef in the NWHI in 1927. Paul Galtsoff found several hundred survivors three years later, but only a few were found during a National Marine Fisheries Service (NMFS) survey in 1993 and only six were found during an intensive survey late in the year 2000 involving over a dozen trained observers, 63 years after the last recorded harvest. In the late 1930s hundreds of tons of sea cucumbers were harvested from Truk (now Chuuk) Lagoon, but only two individuals of a commercially valuable species were observed in a survey of eight sites in 1988, half a century later. The fish populations on a newly discovered pinnacle off northwestern Guam, Haputo Reef, have been monitored since fishing began in 1967 in order to obtain data needed to estimate maximum sustainable yield (Ikehara et al. 1970). The populations were fished down in one year. Guam's Division of Aquatic and Wildlife Resources reports that there has been no indication that they have recovered after 34 years. Likewise, a grouper spawning aggregation was taken by a Taiwanese fishing boat in the Denges Channel of Palau in 1986 and as of 2001 the grouper population had not returned.



Other Causes of Fisheries Decline

Although overfishing is undoubtedly the main cause of the decline in fish stocks in the MHI, it is possible that pollution, sedimentation, coastal development, estuary loss, inappropriate management of freshwater resources, and natural ecosystem changes also contributed to the decline. However, all trophic classes of fishes are more abundant and larger in size around the atolls and reefs in the NWHI where there are no significant freshwater inputs and no estuaries (Friedlander and DeMartini 2002). Even though urban development has undoubtedly contributed to fish habitat loss in the MHI, the "island mass effect" says there should be far greater fish biomass around larger islands. We can only conclude that the main reason that the NWHI has more fish is the absence of overfishing. If fishing pressure continues at its present rate in the MHI without adequate protection for breeding stocks, reducing pollution and sedimentation and restoring estuaries and natural stream flows will not necessarily result in more fish.

Refuges Definitely Work

Refuges can greatly increase biomass size and abundance of fish populations (Roberts and Polunin 1991; Polunin and Roberts 1993; Rowley 1994; Roberts 1995; Bohnsack 1996; Palumbi 2001; Halpern 2001). Marine reserves are used as a stock replenishment tool by Australia, Belize, Chile, Ecuador, New Zealand, Philippines, South Africa and the United States. Once a refuge is established in an area with apporpriate habitat and no poaching, an increase in biomass within the refuge can become obvious in about a year or two. The targeted species and more heavily depleted stocks will show an increase first. Once breeding populations are protected, the average size of the fishes tends to increase more rapidly than the numbers of fishes because an increase in numbers requires the production and recruitment of juveniles. All 32 marine reserves reviewed by Palumbi (2001) demonstrated positive effects on size or abundance of targeted fish or invertebrates. While the evidence is overwhelming that fully protected refuges rapidly enhance resident fish populations, other fisheries management techniques such as quotas, size limits, gear restrictions, and/or partial or temporary closures have consistently failed over the years.

Marine Life Conservation Districts (MLCD) in Hawaii that have functioned as refuges have been successful in rebuilding reef-fish stocks. The biomass of reef fishes in Hanauma Bay is substantially higher than in any other area of Oahu. The reef fish standing stocks in the Honolua-Mokuleia Bay (Maui) and Kealakekua Bay (Hawaii) MLCDs have also increased dramatically since they were established as no-take areas (Friedlander 2001).

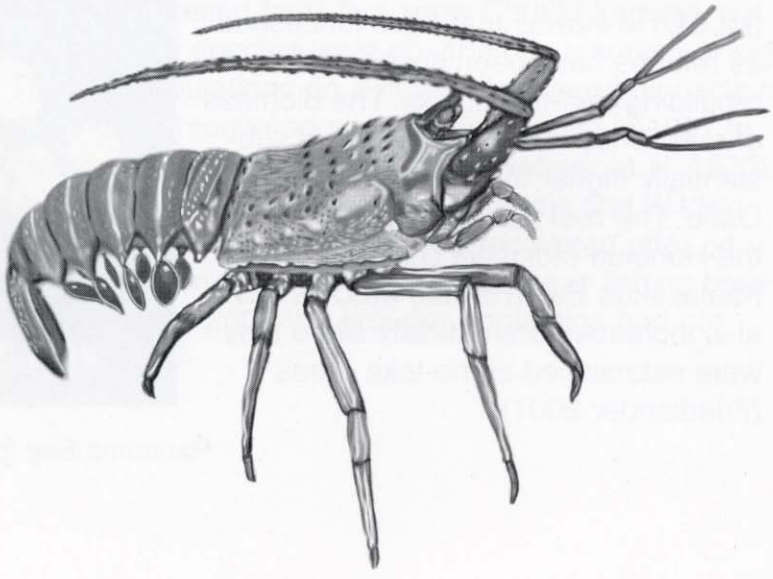
Hanauma Bay (photo by Dave Strichtes)

Refuge Size

It has been demonstrated that refuges as small as 0.1 km^2 will produce a rapid increase in biomass, abundance (density), size distribution and diversity of the fish fauna (Roberts and Hawkins 1997), especially if they are part of a network of refuges. Halpern (2001) documented 81 sites at different locations around the world, each with local control sites for comparison, and observed that the abundance of fishes in refuges is at least twice that of the same area outside the refuges, while the biomass of fishes inside the refuges is three times the biomass of fishes outside. The average size of fishes within a refuge is 30% greater than the average size of fishes outside. The species diversity of fishes within a refuge is 20% greater than the diversity of fishes outside. He concluded that the effectiveness of a refuge depends on total area rather than size (Halpern 2001). Ten small refuges of one km^2 each should have the same effect in increased biomass as one large 10-km^2 refuge. In terms of fisheries yield, biomass and the mean size of the fish are most important for the production of offspring, so even small refuges, if there are enough of them, may enhance fisheries. A minimum of 20% of total fish habitat is recommended.

But biomass, abundance (density), fish size and species diversity are only part of what is damaged by overfishing. Unlike the NWHI, which have an abundance of top predators, few fish in the higher trophic levels are found on MHI reefs. While small refuges will increase the total biomass of a fish assemblage, large refuges may be necessary to bring back higher trophic level fish such as large ulua. Viable, self-maintaining habitats may also have threshold sizes. Certain habitats in small refuges may be devastated entirely by vessel groundings and other cataclysmic events such as hurricanes.

Although smaller refuges may be more susceptible to disasters, several refuges can spread the risk among several locations. Several refuges may also work better for fishery enhancement because the spill-over of large fishes might be spread across a larger area and so a network of refuges may result in less travel and cost for fishermen. Public consensus may be easier to obtain and enforcement may be easier for smaller refuges. A network of smaller refuges may also have a better chance of representing all habitat types than one or two large refuges of equivalent total size. However, larger refuges are also needed precisely because of the spill-over effect and the movement of large fecund fishes out of the refuges.



Permanently closed refuges also benefit the reproductive potential of other marine life, such as lobsters. A four-inch lobster (carapace length) will make three times as many eggs as a two inch lobster.

The Spill-over Effect

Large fish moving out of the refuges can also improve fishing just outside of the protected areas. World record game fishes of several species were caught close to the edge of the marine reserves at Merritt Island National Wildlife Refuge (Johnson et al. 1999) at Cape Kennedy. Recreational fishermen were frequently observed "fishing the edge", concentrating along the edge of the marine reserves, presumably expecting enhanced catches of fishes wandering out of the reserves (Johnson et al. 1999).

Alcala and Russ (1990) documented in the Philippines that nearly twice as many fish could be caught on 75% of the reef as compared to the entire reef if 25% was set aside as fully protected reserves (Fig. 10), probably because of movements of fish out of the more densely populated reserve. Nontargeted species also increase in abundance when part of the reef is set aside in fully protected reserves, possibly because of the use of nonselective fishing methods in non-protected areas. The spill-over effect of the reef area protected by a Philippine village helped sustain a consistent production of 15 metric tons of fish per km^2 per year.

Refuges usually show an increase in abundance and benefits of spill-over to the local fishery within three to five years (Roberts and Hawkins 2000) as long as there are areas within the effective region in which there exists reproductive stock. However it may take ten years for the spill-over effect to be noticed among the larger predators such as ulua.

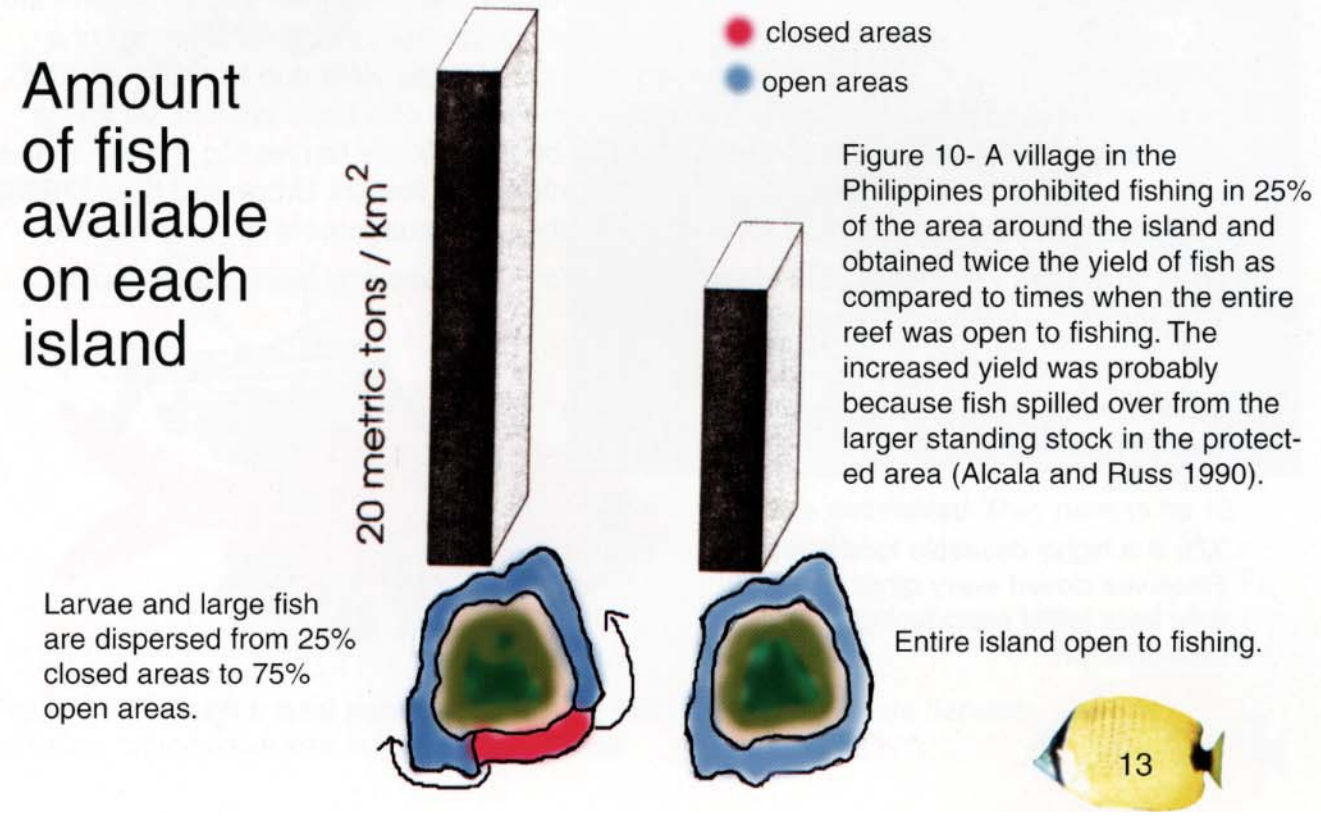
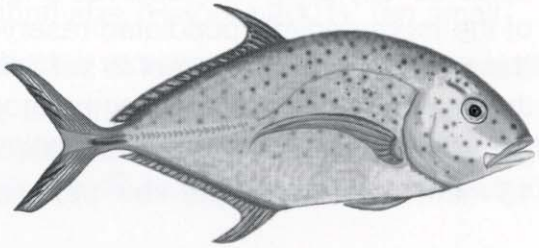


Figure 10- A village in the Philippines prohibited fishing in 25% of the area around the island and obtained twice the yield of fish as compared to times when the entire reef was open to fishing. The increased yield was probably because fish spilled over from the larger standing stock in the protected area (Alcala and Russ 1990).

Partially Protected Refuges Do Not Work

Fully protected reserves have been proven very beneficial to fisheries, but a partially protected refuge, such as one closed for only part of the year or damaged by other human impacts or susceptible to poaching, is not substantially different from an area open to fishing (Fig. 7). Even a small amount of poaching can undermine the success of a refuge. Fishermen tend to disregard regulations when there is a lack of enforcement and prosecution and the penalties are not severe enough to deter violators. Enforcement by traditional fishing communities has been far more effective than government regulations. Poaching is a perpetual problem throughout the MHI and is a major factor in determining whether refuges will be able to successfully increase the fisheries yield for Hawai`i's citizens.

A special problem of poaching is the taking of small young fish, lobsters, octopus and opihi (limpets) before they can reproduce. In Hanalei Bay, Kauai, 97% of the omilu taken had not yet reached sexual maturity (Fig. 11) and therefore had not yet had the chance to produce offspring (Friedlander and Parrish 1997).

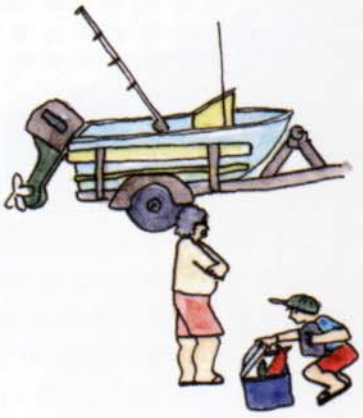


Omilu need to be 12 inches to reach maturity.

A rotational reserve system does not work because the time required for a stock to recover adequate reproductive capacity is longer than the time it takes to destroy it once the reserve is opened to fishing. This is true because fishing pressure is often more intensive once the area is opened. A stock may be quickly depleted and the length of time it may take to recover extended, especially if spawning aggregations are harvested. The benefits of reserves to the fishery come from the establishment of a large breeding stock. The increased production of fisheries yield due to spill-over and increased fecundity is analogous to living on the interest of a bank account (Roberts and Hawkins 2000). If you deplete your capital by periodically harvesting the fish in the reserve, sooner or later there will be no more interest to live on. Brock and Kam (1993) demonstrated that the standing stock of the Fisheries Management Area at Waikiki-Diamond Head was never able to exceed 50 g/m^2 because any buildup was rapidly lost each time the area was opened to fishing.

'U'u (menpachi) have to be 6.5 inches to reproduce.They do not reach that size until they are 6 years old.

'U'u is a highly desirable food fish. Reserves closed every other year may favor faster reproducing, less desirable fish.



All these omilu are undersized. They have to be 12 inches to reproduce.

Figure 11- Through a creel survey, it was found that nearly all omilu are harvested below reproductive size in Hanalei Bay, Kauai.

Poor quality habitat will also diminish the effectiveness of a refuge. A MLCD has been in effect in Waikiki since 1988, but this area contains very degraded reef habitat comprised of a shallow, low-relief reef flat affected by the activities of thousands of tourists and no longer replenished by an estuary that has been drained and turned into a golf course, so it probably will never again support a rich assemblage of fishes. The State of Hawaii has established ten MLCDs, nine Fisheries Management Areas, a Marine Laboratory Refuge, and a Natural Area Reserve (Clark and Gulko 1999), but these are only effective in allowing the buildup of reproductive stocks of fishes if they contain good coral reef habitat, have some topographic relief, and are permanently protected from harvesting and other human impacts.

Powerful Management Tools

Refuges provide a wide range of benefits. They enhance fisheries by protecting breeding stock composed of larger, more fecund individuals. Fecundity (egg production) increases exponentially with body size in fishes. One 27-inch female omilu produces as many eggs as 84 12-inch omilu (Fig. 12). Large fishes usually reproduce more frequently and produce higher quality eggs than small fishes of the same species. It is assumed that a major benefit of refuges is to protect large individuals that greatly enhance the reproductive output of the stock for the area. By allowing large fish to contribute to the gene pool, refuges also protect genetic diversity with-

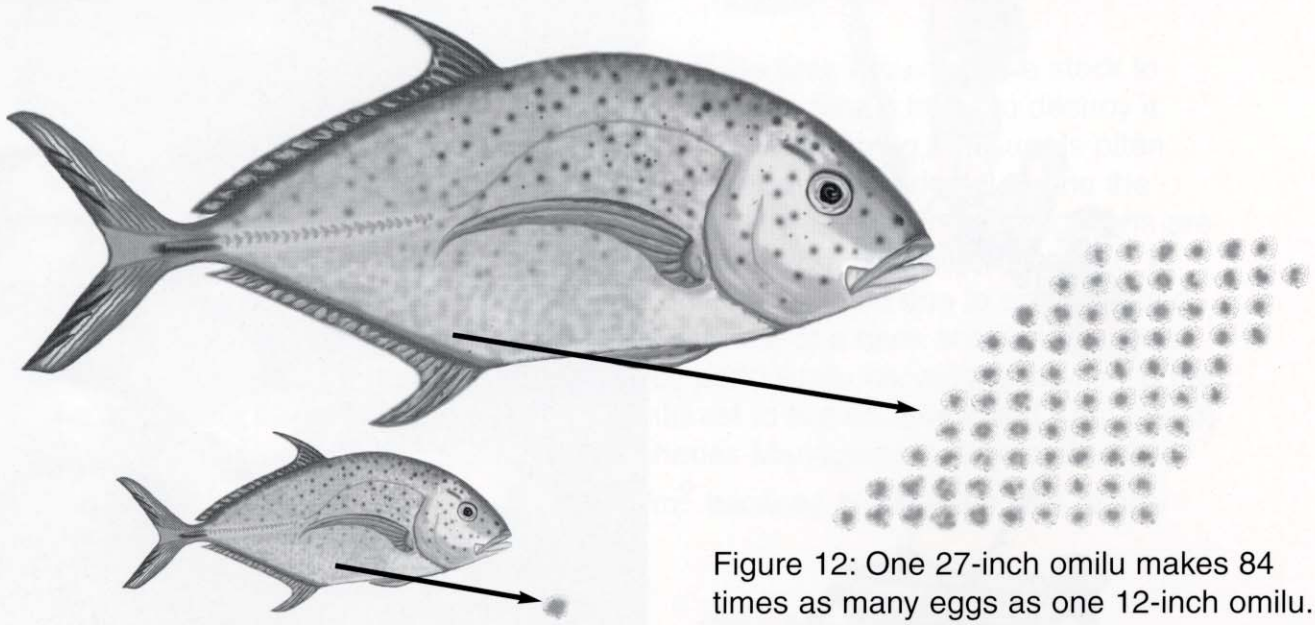


Figure 12: One 27-inch omilu makes 84 times as many eggs as one 12-inch omilu.

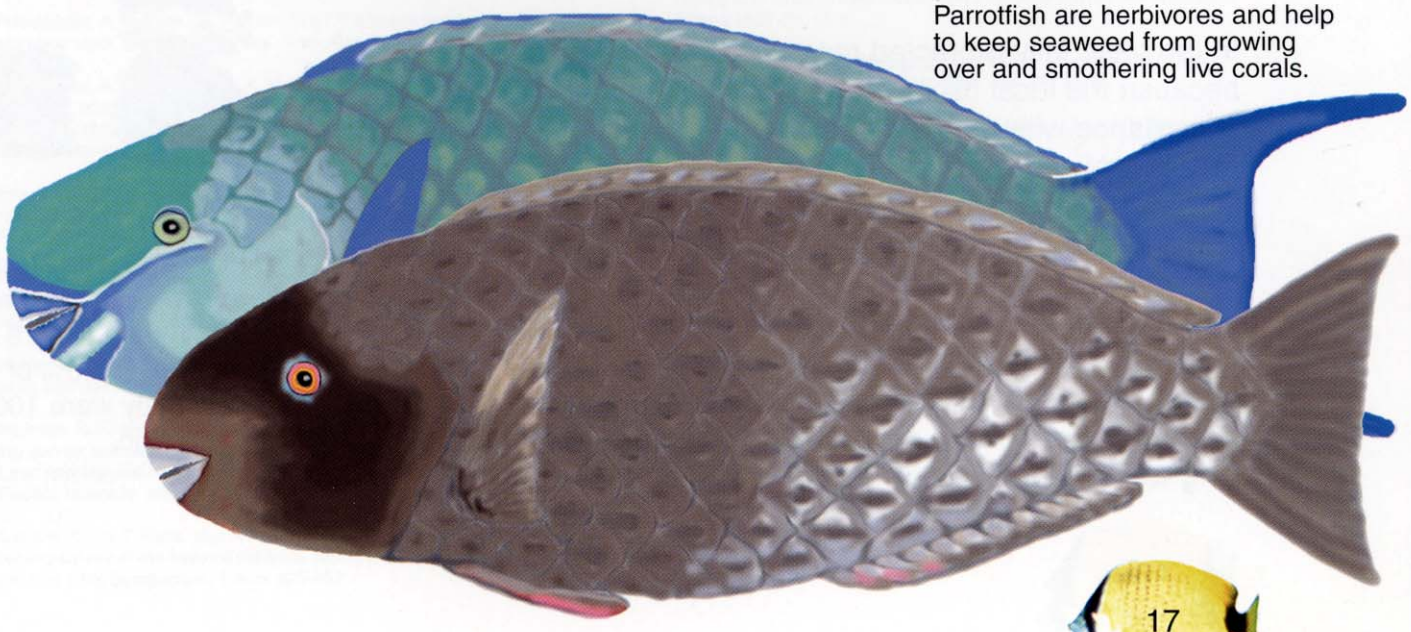
in fish populations. In unexploited populations of top predators, the substantially greater fecundity of larger individuals means that a relatively few larger individuals can provide a substantial portion of the genetic input to the next generation. However, fishermen tend to target larger fish and after a while only small individuals remain. In heavily fished populations, nearly all the genetic input is from smaller fish, who in turn produce small fish that reproduce early. Once reproduction starts, fish put their energy into producing eggs and sperm and their growth rate slows down. Eventually large individuals disappear from the population and the biomass of the entire fishery is reduced.

In Guam, weke (goatfishes) appear common to the fishermen, but just a bit smaller than in the past. However, this slight reduction in size has reduced the reproductive potential of this species to only 5% of its unfished potential (Davis 1992). Many coral reef species have a "right-angle life history", which means they rapidly grow to adult size before reproducing (Choat and Robertson 2001). Therefore size cannot be used reliably to distinguish adults from juveniles and there is a definite chance that fishermen will fish down the adult population, leaving almost none to reproduce. Refuges are important to maintain the reproductive capability of fishes.

Value of Reef Resources

In 1998 ocean-related tourism brought $797 million into Hawai'i, while commercial nearshore fisheries brought in a gross income of only $5 million (Clark and Gulko 1999). The relative size of the economic contribution of tourism compared with that of commercial fisheries is similar all over the world. In 1992 tourism was a $3 trillion industry, while the total commercial marine fisheries catch was worth about $70 billion (Weber 1993). The cost of operating commercial marine fisheries was $124 billion, including about $50 billion in subsidies. For the most part commercial fisheries are subsidized by taxpayers. For each dollar invested in catching a marine fish commercially, 60 cents is regained by the sale of fish and 40 cents is donated by taxpayers (Weber 1993).

In Bermuda, fishermen were so over-harvesting the herbivorous fishes that there were no longer enough to keep the algae under control and the algae began smothering corals. This in turn damaged the tourism industry, which brought several times more money into Bermuda than did the commercial fishing industry (Butler et al. 1993). The tourism industry and those industries indirectly associated with the coral reefs employed several times the number employed by the commercial fishing industry. The Chamber of Commerce evaluated the situation and concluded that the commercial fishing industry was a burden on the economy and on employment possibilities in Bermuda. The Chamber of Commerce then took the information and statistics to the Governor and asked the government to buy out the commercial fishermen. The government of Bermuda did just that.



Parrotfish are herbivores and help to keep seaweed from growing over and smothering live corals.

The Palauans have always lived close to their reef resources and have been exceptionally knowledgeable about the life histories and ecology of reef species. In 1992, diving activities by tourists to see the fish and reefs brought in over $12 million per year directly, not counting additional revenue from hotels, restaurants, and transportation. To protect the economy, the government of Palau passed the Marine Protection Act of 1994, which prohibits commercial exploitation of reef fishes between March and July each year, the period when most of the reef fishes spawn.

Hawaii Needs a Network of Refuges Throughout the Archipelago

Hawai'i is a larger archipelago than Bermuda or Palau, with many different life styles. Commercial fishing is part of our society. We need a network of refuges to protect biodiversity and bring up productivity and fisheries yield to the levels we had before the demise of traditional management measures and before technological advances made fish so easy to capture. A creel census in Hanalei, Kauai, showed that the amount of fish caught by fishermen was two to 100 times more than what was listed on commercial catch reports. Nevertheless, tourism brings several times as much income and employment to society as extractive fisheries. However, tourism also can be potentially harmful to coral reefs if not managed properly.

The stocks of Hawaiian coral reef fish in the MHI are at most 20 to 25% of what they were a hundred years ago (Shomura 1987; Clark and Gulko 1999; Friedlander and DeMartini 2002) (Fig. 13). As has been said since Epicurus in the 3rd century B.C., there is no free lunch. If we want to build up the potential yield of our coral reef fisheries, it is imperative that we rebuild a reproductive stock. In order to do this, we must establish a network of marine refuges throughout the Hawaiian archipelago. Although there are several MLCDs and FMAs, less than one percent (< 1 %) of the reef area in Hawai'i is fully protected. Partial protection is not effective (Fig. 7).

1900 2001

Figure 13-The stocks of Hawaiian coral reef fish in the MHI are at most 20 to 25% of what they were 100 years ago.

In the past, fully protected reserves were not necessary because the local fishing communities managed their reefs in accordance with the natural cycles of the resources. Because of this, Hawaiians were able to harvest reef fishes and, at the same time, maintain their reproductive stocks. Local control and a sense of place promoted traditional harvest management policies and a code of stewardship. We need to recognize and adopt that heritage more broadly. In addition, marine reserves must be created to replace the natural refuges that have been lost because of improved fishing technology. We need these refuges to rebuild reef fish stocks and bring the long-term yields back up to their previous levels.

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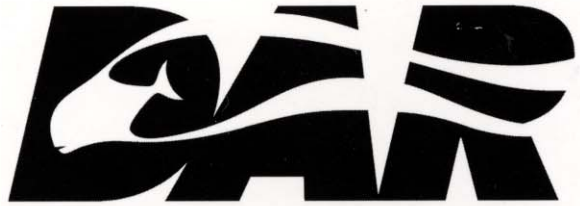

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