Fisheries benefits of Marine Managed Areas in Hawaii

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Colophon

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1. Introduction

Declining fisheries resources worldwide and in Hawaii

Fish and other harvested resources provide economic, social, cultural, and spiritual benefits to people throughout the world. Global fisheries have undergone enormous changes in the past several decades with three-quarters of the world's major fisheries now considered to be harvested at or beyond their maximum capacity (FAO 2000) despite increased regulation in most fisheries sectors. The U.S. has some of the most highly regulated fisheries in the world with substantial investments in science, management plans, monitoring, and enforcement (Eagle et al. 2003), yet 40% of U.S. fisheries are considered overfished (NMFS 2002). Examples include the collapse of cod stocks off New England and Canada, which has led to large-scale ecosystem-wide changes, and economic collapse of many coastal communities in these areas (Kurlansky 1998). Because selective fishing can affect a number of population characteristics (e.g. size and age composition, sex ratio, genetic make-up, and large-scale behavioral phenomena like spawning aggregations) those fish that remain may pass on less-preferred characteristics that may confound future fishing efforts (Sladek Nowlis and Friedlander 2004a). In addition to overexploitation, a variety of factors such as habitat loss, climate change, and natural variability have contributed to the collapse of many fisheries. Regardless of the causes, declining fish stocks have had negative economic, social, and ecological consequences at an unprecedented scale.

Large marine vertebrates such as whales, sharks, turtles, groupers, and manatees were once important components of marine ecosystems worldwide but have been systematically removed from the ocean by humans over the pat 500 yr (NRC 1995, Jackson et al. 2001, Pitcher 2001). Large predatory fish have been reduced to one-tenth of their historic abundance (Myers and Worm 2003) and these top predators have specialized niches that when depleted can lead to a phase transition of ecosystems dominated by lower trophic guilds (Pauly et al. 1998, Pinnegar et al. 2000). The 'shifting baseline syndrome' (Pauly 1995, Sheppard 1995) makes it difficult to determine what constitutes a natural ecosystem and how to mange these ecosystems accordingly.

As is the case elsewhere throughout the world, coastal fisheries in Hawai'i are facing unprecedented overexploitation and severe depletion (Shomura 1987, Smith 1993, Gulko et al. 2000, Friedlander 2003, Lowe 2003). This decline in fish abundance and size, particularly around the more populated areas of the state, is likely the cumulative result of years of chronic overfishing (Shomura 1987; Gulko et al. 2000; Friedlander and DeMartini 2002). Fishing pressure on nearshore resources in heavily populated areas of the main Hawaiian Islands (MHI) appears to exceed the capacity of these resources to renew themselves (Smith 1993). Fish assemblages in the northwestern Hawaiian Islands—a remote area that experiences only limited fishing activity—are dominated by large apex predators, such as sharks and jacks that likely have a profound impact on the structure of the entire coral reef ecosystem (Friedlander and DeMartini 2002). The near-extripration of apex predators and heavy exploitation of lowed trophic levels in the MHI from intensive fishing pressure has resulted in a stressed ecosystem that does not contain the full complement of species and interrelationships that would normally prevail (Friedlander and DeMartini 2002) (Figure 1)

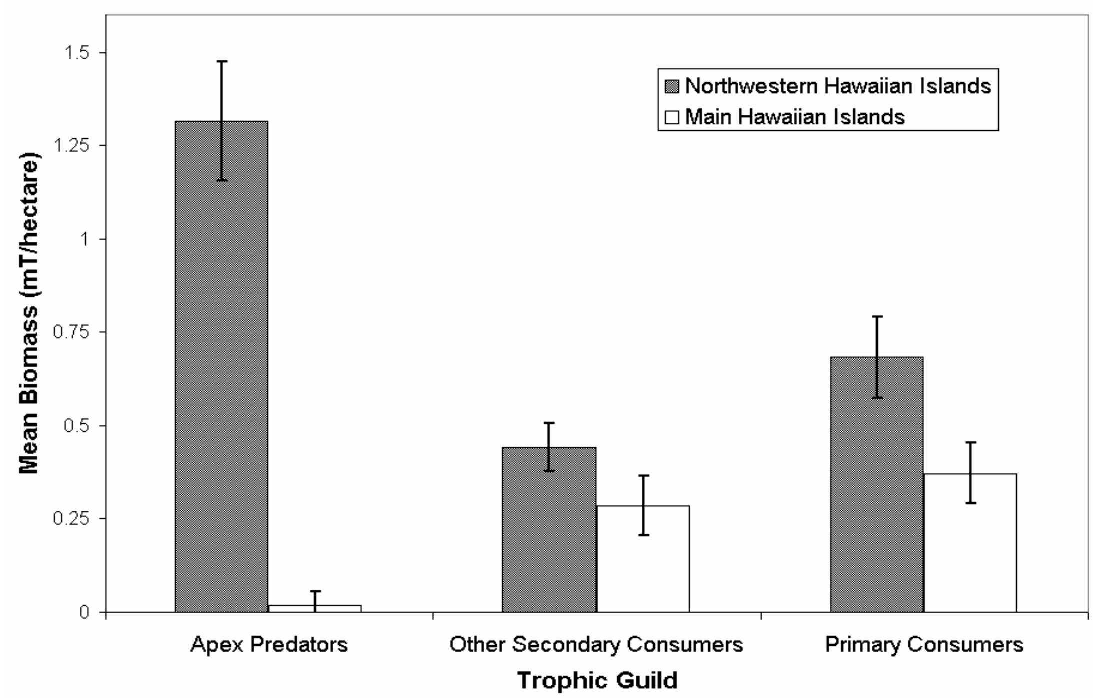


Figure 1: Lightly fished areas in the Northwestern Hawaiian Islands contain greater biomass of all trophic guilds than sites in the main Hawaiian Islands (data from Friedlander and DeMartini 2002). The difference is especially large for apex predators, which account for the majority of all biomass in the Northwestern Hawaiian Islands.

Factors contributing to the decline of inshore fisheries in the MHI include a growing human population, destruction or disturbance to habitat, introduction of new fishing techniques (inexpensive monofilament gill nets, SCUBA, spear guns, power boats, sonar fish finders), and loss of traditional conservation practices (Brock et al. 1985, Lowe 1996, Birkeland and Friedlander 2002, Friedlander et al. 2003). The proliferation of long and inexpensive gill nets has allowed new fishers to enter the fishery and set nets deeper and in locations not previously harvested (Clark and Gulko 1999). Intensive fishing pressure on highly prized and vulnerable species has led to substantial declines in catch as well as size and has raised concerns about the long-term sustainability of these stocks (Friedlander and Parrish 1997, Friedlander and DeMartini 2002, Friedlander and Ziemann 2003, Tissot and Hallacher 2003, Tissot et al. 2004). Despite the opinion of many fishermen that overharvesting is one of the major reasons for the long-term decline in inshore marine resources, there is poor compliance with state fishing laws and regulations (Harman and Katekaru 1988). The lack of marine-focused enforcement and minimal fines for those few cases that have been prosecuted contribute to a lack of incentive by the population to abide by fisheries management regulations.

Under-reporting by commercial fishers and the existence of a large number of recreational and subsistence fishers without licensing or reporting requirements have resulted in uncertainty in actual fisheries catch statistics for the state (Lowe 1996). The nearshore recreational and subsistence catch is likely equal to or greater than the nearshore commercial fisheries catch, with more species taken using a wider range of fishing gear (Friedlander and Parrish 1997, Gulko et al. 2000, Everson and Friedlander 2003).

Why has conventional management failed?

Sustainability and biodiversity conservation are cited as objectives of ecosystem management (National Research Council 1999) yet current management regimes have failed to meet these objectives. Failures in management can be linked to uncertainties due to incomplete knowledge of populations, communities, and ecosystems (Fogarty et al. 2000). Traditional western concepts of fisheries management (maximum sustainable yield, growth overfishing, recruitment overfishing, etc.) have their genesis in single-species population dynamics and stock assessment (Murawski 2000). This approach is primarily concerned with the conservation of the parts as opposed to the interrelationships among them. Many management tools—including size limits, gear limits, quota systems on effort or total catch, and even temporary closures—are used frequently but do not create a refuge for populations, habitats, and ecosystems, nor do they reallocate fishing effort across space (Sladek Nowlis and Friedlander 2004a). The failure of these more conventional management tools is apparent in the status of fished populations around the world. Several challenges contribute to these management failures, including excessive fishing capacity (FAO 2000), environments degraded by fishing and other activities (Watling and Norse 1998), and management systems that require far more information than is available (NRC 1998; PDT 1990; Sladek Nowlis and Bollermann 2002). Another concern is the possibility of critical depensation (Allee effect) where the per capita birth rate declines at low populations because, for example, of the increased difficulty of finding a mate (Allee 1931).

2. Marine Protected Area Theory and Empirical Evidence

Because of the generally poor state of fisheries worldwide, marine resource managers are inspired to consider fresh tools to stem the decline in global fish stocks (FAO 1999). Marine ecosystems are complex with highly variable natural replenishment and therefore require more spatially-based management tools. The Food and Agriculture Organization (FAO) has established a code of conduct that supports the precautionary principle, which states should apply to conservation, management, and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment (FAO1995). It states that the 'absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures.'

Theoretical evidence has been available for decades on policies that scale back fishing rates when abundance drops. One means for achieving a constant escapement-like policy is the use of marine reserves to protect part of the stock (Figure 2). What reserves offer that other management tools cannot is the ability to control fishing rates in a manner that is relatively easy to enforce (PDT 1990; Sladek Nowlis and Friedlander, 2004a) and requires relatively little scientific information (Sladek Nowlis and Bollermann 2002). In addition, reserves prevent habitat disturbance due to fishing, protect non-target organisms, and preserve biodiversity (Bohnsack 1996, Murray et al. 1999, Fogarty et al. 2000). In this paper, we will refer to these reserves as Marine Protected Areas (MPAs) as is common in the fisheries literature. In the accompanying papers of this study, we will refer more broadly to Marine Managed Areas (MMAs) to highlight that these areas tend to have other management aspects than conservation and fisheries, such as tourism.

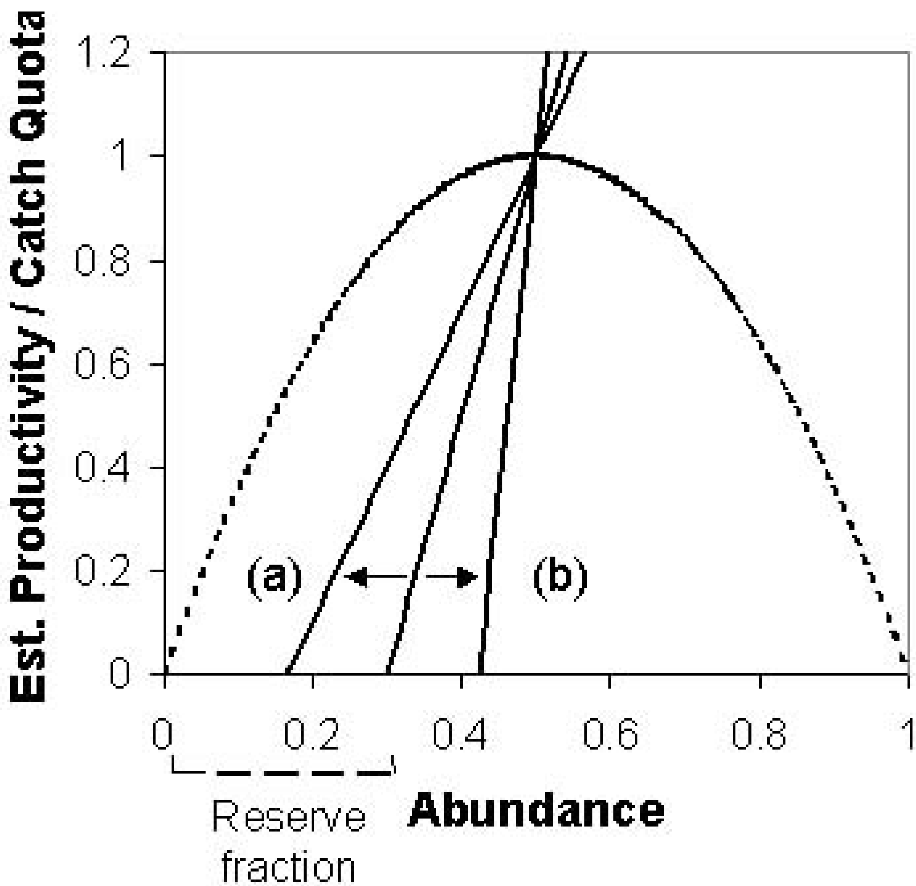


Figure 2 Marine reserves as a tool to achieve constant escapement. The dotted line represents estimated productivity, and the solid lines represent policies that link marine reserves with catch quotas. The centerline represents the use of a reserve encompassing 30% of the unfished stock biomass and fairly aggressive fishing on the remaining stock. Line (a) represents a relatively smaller reserve, with a more-controlled fishing effort but less insurance, while line (b) represents a larger reserve and even more aggressive fishing pressure and greater insurance. The optimal policy will depend primarily on the degree to which the biology, ecology, current abundance, and fishing mortality rate of the stock or stocks are unknown, and thus amount of insurance that is desirable or necessary (from Sladek Nowlis and Bollermann, 2002).

Benefits of MPAs

Benefits of MPAs are:

- Increase stock abundance - Theory supports the ability of marine reserves to rebuild overfished fisheries and enhances catches (Beverton and Holt 1957; DeMartini 1993; Polacheck 1990; Sladek Nowlis and Roberts 1999) and several empirical studies have shown increased catch despite 25% to 40% reserve closures (McClanahan and Kaunda-Arara 1996, Russ and Alcala 1999, Roberts et al. 2001). Catch around Apo Island in the Philippines has increased since the early 1980's despite the closure of more than 10% of the fishing area (Russ and Alcala 1999, *Figure 3*). In contrast, Sumilon Island (25% no-take reserve), also in the Philippines, showed a decline in catch following the opening of the reserve to fishing. Despite the increased fishing area, both total catch and catch per unit effort declined to half of their previous values Subsequent closures showed slight increases in catch but these catches were much smaller than those observed when a complete closure of 25% was in place;

- Preserve desirable traits - Selective fishing can affect a number of population characteristics—size and age composition, sex ratio, genetic make-up, and large-scale behavioral phenomena like spawning aggregations (PDT 1990), while reserves have been shown to preserve these traits;

- Provide spillover of adults and juveniles into fished areas – Movement can serve as a mechanism for exporting productivity from marine reserves to fishing areas. Johnson and colleagues (1999) demonstrated that, in addition to a build-up of biomass within a reserve off Cape Canaveral, Florida, some fish moved in and out of the reserve. Consequently, a number of world record trophy fish were caught in the vicinity of the reserve (Roberts et al. 2001);

- Increase reproductive output and recruitment inside and outside the reserve; - The protection of adult biomass greatly increases reproductive potential (Polacheck 1990; DeMartini 1993; Guenette and Pitcher 1999) and therefore spawning output. Because adult retention and population growth rates provide the engine to power all population-level benefits, leakiness of adults (spillover effect) can have negative consequences to the population (Sladek Nowlis and Roberts 1999). Emerging evidence about fish movement suggests that even fish with the potential to swim long distances might stay in the same area for long periods of time (e.g., Attwood and Bennett 1994; Holland et al. 1996). In support of this notion is the fact that most populations studied in marine reserves responded positively to protection, even though many of the reserves were small (Halpern 2003);

- Insurance against uncertainty - Most fisheries, even those that are actively managed and well studied, are prone to crashing because management reference points have a high likelihood of being off by 50 percent or more (NRC 1998). By protecting a set amount of fish, marine reserves have shown strong potential to protect stocks from collapse in varying and uncertain environments (Lauck et al. 1998; Mangel 1998; Sladek Nowlis and Bollermann 2002);

- Reduce overfishing by controlling fishing mortality (Sladek Nowlis and Bollermann 2002);
- Ecosystem management - By reallocate fishing effort in space and protect populations, habitats, and ecosystems within their borders, marine reserves provide a spatial refuge for the ecological systems they contain (Sladek Nowlis and Friedlander 2004a);
- Maintain system productivity - Destructive fishing practices can disturb habitats essential to fisheries production (Watling and Norse 1998, Morgan and Chuenpagdee 2003). System productivity can also reduce by fishing activity through the disruption of species interactions (Jackson et al. 2001);
- Provide unfished reference areas - distinguish between natural and fishery-related changes in marine systems, dramatically limiting a manager's ability to explain past events and predict future ones.

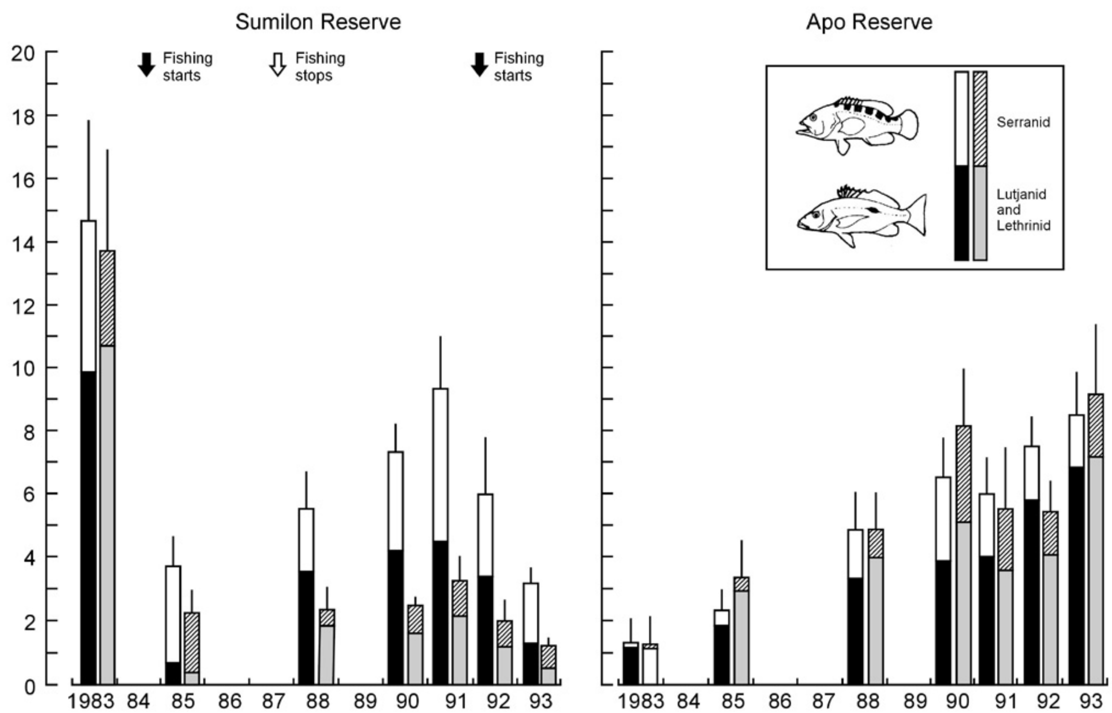


Figure 3: Mean number (left columns at each time) and mean biomass (right columns) of large predatory reef fish (Sub-F. Epinephelinae, F. Lutjanidae and F. Lethrinidae) per 1000 m^2 in the Sumilon and Apo reserves in the Phillipines from 1983-1993. The Sumilon reserve had been protected from fishing for almost 10 years in 1983. Solid arrows indicate when fishing in the reserve began (1984, 1992) and the open arrow indicates when fishing ceased (1987). (Russ and Alcala 1999).

Biodiversity and conservation benefits

Biodiversity can be defined as the variability among living organisms from all sources including terrestrial, marine and other aquatic inter alia ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (de Fontaubert et al 1996). All except one of the presently described phyla (33) occur in the ocean while only about half that occur on land (Norse, 1993). Furthermore, 15 phyla are exclusively marine. Consequently, marine organisms display a much larger phyletic diversity than those on land (Ray, 1988). In addition to its intrinsic value, maintaining marine biodiversity is important to the success of humankind. Norse (1993) detailed the importance of marine biodiversity to humans as follows:

- Food
- Medicine and tools for biomedical research
- Coastal processes and protection
- Global climate control
- Recreational resources
- Knowledge

It has been shown that marine reserves can halt the loss of biodiversity and changes in species interaction too commonly seen under current management strategies by conserving habitats and biological communities (Dayton et al. 1995; Boehlert 1996; Hixon and Carr 1997). Instead of focusing on a system with representative species, we should focus on representative habitats or ecosystems. Ecosystem-level management may be best achieved by acknowledging the ecological phenomena we know in management decisions while also allowing natural systems to function naturally in designated marine reserves.

Endemism is a key attribute of biotic communities. One reason of general biogeographic interest is that speciation and the origin and maintenance of biodiversity are undoubtedly related to degrees of isolation and endemism. The faunas of isolated oceanic archipelagos like the Hawaiian Islands represent species conservation hotspots that have become increasingly important due to the continual losses of fish and other organismal biodiversity on coral reefs (Roberts et al 2002). That over one-half (by numbers and biomass, not merely species-presence) of the fishes on shallow NWHI reefs are endemic to the Hawaiian Islands is a noteworthy finding, given our contemporary appreciation of the nature and magnitude of species loss in the sea (DeMartini and Friedlander in press).

MPA design

A comprehensive zoning process may be preferable to solely designating marine reserves because additional zone types can reduce a number of additional user conflicts while also providing buffers to protect marine reserves from inevitable edge effects. Marine reserve networks have the greatest chance of including all species, life stages, and ecological linkages if they encompass representative portions of all ecologically relevant habitat types (Ballantine 1997; Friedlander and Parrish 1998; Murray et al. 1999). Two of the most basic tenets of marine reserve network design are that all habitats be represented and that the resulting network be self-sustaining (Ballantine 1997).

Stakeholder Driven Process

The input of people from coastal communities will be vital to good design and function of marine reserves and to maintain public support for them. Without this support, enforcement may be greatly compromised and future political changes can lead to the dismantling of reserves (Alcala and Russ 1990). Participatory planning represents a bottom up approach to resource management that incorporates local knowledge into the management process. Incorporating stakeholder group concerns and interests into the management process will increase the perceived legitimacy of decisions and make compliance with rules and regulations easier (Bunce et al. 2000). Stakeholder input provided invaluable information on resource distribution and their uses (Johannes 1997, Friedlander et al. 2003b). By airing concerns and priorities, stakeholders also develop a sense of ownership and a better understanding of the management process. Where reserves have been established without broad public support, they are vulnerable to dismantling when politics shift (e.g., Russ and Alcala 1999) or in danger of never being created in the first place.

Total coverage

Fished populations that fall to less than 30% of their unexploited population size are legally considered to be overfished in the U.S. (NMFS Magnuson Stevens). At this spawning potential ratio (the ratio of total egg production under fishing to total egg production without fishing), egg survival must be 3.3.times its natural survival to maintain the population (Bohnsack et al. 2003). Studies of fish movement and habitat utilization suggest that protecting 20-30% of the habitat would likely protection 20-30% of the population (Bohnsack et al. 2003, Sladek Nowlis and Friedlander 2004a). Based on empirical evidence from temperate and boreal fish populations, a minimum of 20-35% of the spawning biomass should be preserved to conserve viable population size (Mace and Sissenwine 1993). The greater the impacts outside the reserve, the larger the reserve size required.

One means for achieving a constant escapement-like policy is the use of marine reserves to protect part of the stock. In order to ensure productive catches into the future, models have predicted that reserves might have to encompass over half the management area (Lauck et al. 1998; Mangel 1998). Reserve networks need to protect a population consisting of 30 to 50% of its unfished size to insure against collapses in the face of large uncertainties (Lauck et al. 1997; Mangel 2000; Sladek Nowlis and Bollermann 2002).

Size and shape

If individual reserves are too few and large, export of production from reserves to fishing grounds may be limited. If, on the other hand, reserves are universally small, they may provide only limited protection for most species. Suggestions of at least 10 km2 per individual reserve have been proposed to contain viable populations of a wide range of species (Friedlander et al. 2003b). Reserves should be designed to minimize the perimeter to area ration in order to reduce the edge effects outside the reserve (Fogarty et al. 2000). Higher perimeter to area ratios may be desirable to accrue adult spillover and larval replenishment (Fogarty et al. 2000). Straight boundaries that run north-south or east-west are ideal, while complex shapes—like following a depth contour—are difficult to recognize or enforce. Replication of reserve units and selection of appropriate replicated control (i.e., open to fishing) areas will aid greatly in the evaluation of reserve success.

Area selection and habitat types

Representative proportions of all habitats types should be included in any reserve (Ballantine 1997). To be effective, it is generally accepted that MPA networks should be distributed along environmental gradients and should protect representative species and habitat types (Ballantine 1997; Murray et al. 1999), although rare and vulnerable habitat types should be represented more fully (Sladek Nowlis and Friedlander 2003a). It may also be beneficial to focus marine reserve efforts on known ecological connections among habitat types (Appeldoorn et al. 2003). Reserves should provide habitat connectivity for ontogenetic migration, typically from shallow to deeper sites (Parrish 1987, Appeldoorn et al. 2003). Reserve design should also consider diel movement patterns such as the movement of many species from daytime resting habitat on the reef to nocturnal foraging in soft bottom habitats (Holland et. al 1996, Meyer 2003, Friedlander et al. 2002). Choosing areas that are characterized by diverse habitats may foster these ecological connections and increase the capacity of even very small reserves to sustain productive populations within their borders (Appeldoorn et al. 1997).

Networking

An effective reserve design, i.e., reserves that sustain protected populations and enhance non-protected populations, will benefit from our understanding of patterns of larval dispersal and how species attributes (e.g., larval behavior, developmental traits) and environmental features (e.g., hydrographic patterns, geomorphological features) influence such patterns (Cowen et al. 2000, Jones et al. 1999, Roberts 1997, Swearer et al. 1999). Self-replenishment can be achieved by reserves of sufficient size to contain a substantial amount of larval dispersal, or by networking reserves at suitable distances such that propagules produced by populations in one reserve replenish populations in other reserves. Individual reserves are likely to be most effective at supplying productivity to fished areas if there are several small, networked sites (Sladek Nowlis and Roberts 1999). Marginal decreases in the perimeter to area ratio with increasing reserve area declines at larger sizes suggesting diminishing returns at larger reserve sizes (Fogarty et al. 2000). This suggests that several smaller reserves may be more beneficial than one large one particularly when one is concerned with limiting the exposure at the boundaries.

Sources are areas that produce a net gain of fish, some of which move at some point in their life cycle out to other areas. By contrast, sinks are areas that experience a net loss of fish and are only sustained because they are supplemented from sources. Crowder and colleagues (2000) showed that managers could theoretically do more harm than good if they created a marine reserve network that encompassed more sinks than sources. A major flaw with their reasoning, though, was the assumption that sources and sinks are static—that they do not change with the establishment of marine reserves (Sladek Nowlis and Friedlander 2004b). In fact, strong evidence supports the fact that reserves become sources most of the time they are established by creating an area with many fish producing lots of offspring (Appeldoorn et al., 2003).

Dispersal distances for marine larvae ranges from meters to thousands of kilometers with time in the plankton ranging from minutes to months. Examination of a wide range of taxa found dispersal to follow a bimodal distribution with one group of propagules dispersing < 1 km propagules and another group that dispersed > 20 km. (Shanks et al. 2003). These authors suggested that reserves be designed large enough to contain the short distance dispersing propagules and spaced far enough apart that long distance dispersing propagules released from one reserve can settle in adjacent reserves. A reserve 2 km in diameter, would contain all the larval types that disperse <1 km/yr while reserves 4 to 6 km in diameter would be sufficient for maintenance of larger adult populations. A reserve 4 to 6 km in diameter should be large enough to contain the larvae of short distance dispersers and reserves spaced 10 to 20 km apart should be close enough to capture propagules released from adjacent reserves.

One can manage using a quasi-MSY approach by establishing a network of marine reserves likely to encompass the proportion of the biomass of populations of concern necessary to sustain maximum yields (Sladek Nowlis and Bollerman 2003). With this approach, one uses marine reserve to provide insurance for future catches, even if the biology of the system is poorly understood. This approach may be particularly helpful when traditional management will not work due to gaps in knowledge or inability to enforce more subtle management measures, situations when insurance will be of greatest value.

3. Description of Study Sites

Hanauma Bay, Oahu

General description: Hanauma Bay is located on the southeast tip of Oahu and comprises an area of ca. 101 acres. It is an enclosed embayment formed through the partial collapse of two volcanic craters and subsequent erosional processes. High cliffs surround the sandy beach that is partially composed of olivine. The back-reef is composed largely of sand and coral rubble. The reef flat is composed of carbonate with low coral cover and receives heavily impacted by human use. The deeper reefs with more extensive coral cover extend out to the mouth of the bay to 30-meter depths. The bay has a southern exposure but is sheltered from most major oceanic swells. Hanauma Bay was popular with Hawaiian royalty and a favorite fishing spot for King Kamahameha V. It is one of the most heavily used marine preserves in the world, drawing over one million visitors per year.

Approximately 25% of the marine habitat of Hanauma Bay consists of colonized pavement (>10% live coral cover) with an additional 24% consisting of sand (Table 1). Linear reef (12%) and uncolonized pavement with less than 10% live coral cover (11%) also comprise important components of the benthic habitat.

Table 1: Habitat types contained within Hanauma Bay MLCD based on NOAA benthic habitat maps. (Coyne et al. 2001)

Habitat Type	Square Meter	Acres	Proportion of total
Reef/Colonized Pavement	100937.02	24.94	0.25
Sand	98402.37	24.32	0.24
Reef/Linear Reef	47234.20	11.67	0.12
Hardbottom/Uncolonized Pavement	43881.07	10.84	0.11
Unknown	36382.74	8.99	0.09
Reef/Colonized Volcanic Rock/Boulders	29280.45	7.24	0.07
Hardbottom/Uncolonized Volcanic Rock/Boulders	29280.45	7.24	0.07
Reef/Aggregate Coral	27300.26	6.75	0.07
Reef/Patch Reef (Individual)	17135.27	4.23	0.04
Total	7128.69	1.76	0.02

Fisheries Regulations and Use: Hawaii Administrative Rules Title 13, DLNR, Subtitle 4 Fisheries, Part 1, MLCDs, Chapter 28 Hanauma Bay MLCD, Oahu. §13-28-2 Prohibited activities. (1) Fish for, catch, take, injure, kill, possess, or remove any finfish, crustacean, mollusk including sea shell and opihi, live coral, algae or limu, or other marine life, or eggs thereof; (2) Take, alter, deface, destroy, possess, or remove any sand, coral, rock, or other geological feature, or specimen;(3) Have or possess any fishing gear or device, including but not limited to any hook-and-line, rod, reel, spear, trap, net, crowbar, or other device, or noxious chemical that may be used for the taking, injuring, or killing of marine life, or the altering of geological feature or specimen, the possession of which shall be considered prima facie evidence in violation of this rule; or (4) Introduce any food, substance, or chemical into the water, to feed or attract marine life.

Waikiki MLCD, Oahu

General Description: The Waikiki MLCD, established in 1988, is located on the south shore of Oahu and comprises ca. 76 acres. The MLCD includes the waters offshore of Kapiolani Beach Park beginning at the high water mark on the shoreline to a seaward distance of five-hundred yards (457.2 meters) or to the seaward edge of the fringing reef if one occurs beyond five-hundred yards (457.2 meters), between the western boundary delineated by a straight line drawn seaward extending the ewa (western-most) edge of the groin located seaward of the Kalakaua-Kapahulu avenues junction and the eastern boundary delineated by a straight line seaward extending the ewa (western-most) edge of the wall of the Waikiki War Memorial Natatorium.

A reef flat, consisting mostly of rubble and coralline algae with some patches of live coral, extends out from the Waikiki Aquarium seawall for 35 yards to a dredged channel that is about 8 feet deep. The reef flat (3-4 feet water depth) has little topographic relief and is covered with an alien alga, Gracilaria salicornia. At the outer edge of the reef flat, a sharp edge with numerous arches and crevices descends down to about 15-20 feet of water depth. Uncolonized pavement accounts for 43% of the habitat within the MLCD, followed by 50-90% macroalgae at 38%, with an additional 14% consisting of sand (Table 2).

Table 2: Habitat types contained within Waikiki MLCD based on NOAA benthic habitat maps. (Coyne et al. 2001)

Habitat Type	Square Meter	Acres	Proportion of total
Hardbottom/Uncolonized Pavement	134751.73	33.30	0.43
Macroalgae/50-90%	119123.30	29.44	0.38
Sand	42717.69	10.56	0.14
Unknown	15628.42	3.86	0.05
Artificial/Other Man Made Structures	694.60	0.17	>0.01
Total	312915.73	77.32	1.00

Fisheries Regulations and Use: Hawaii Administrative Rules Title 13, DLNR, Subtitle 4 Fisheries, Part 1, MLCDs, Chapter 36 Waikiki MLCD, Oahu.§13-36-2 Prohibited activities. No person shall engage in the following activities in the Waikiki Marine Life Conservation District: (1) Fish for, catch, take, injure, kill, possess, or remove any finfish, crustacean, mollusk including sea shell and opihi, live coral, algae or limu, or other marine life, or eggs thereof; (2) Take, alter, deface, destroy, possess, or remove any sand, coral, rock, or other geological feature, or specimen; or (3) Have or possess in the water, any spear, trap, net, crowbar, or any other device that may be used for the taking or altering of marine life, geological feature, or specimen.

Waikiki-Diamond Head Shoreline Fisheries Management Area

General Description: The Waikiki-Diamond Head Shoreline Fisheries Management Area extends from the ewa wall of the Waikiki War Memorial Natatorium to the Diamond Head Lighthouse, from the highwater mark out to a minimum seaward distance of 500 yards, or to the seaward edge of the fringing reef if one occurs beyond 500 yards.

Uncolonized hardbottom pavement accounts for 55% of the habitat within the FMA (Table 3). Another 18% consisted of macroalgae-dominated substrate, with greater than 10% live coral reef accounting for an additional 15%.

Fisheries Regulations and Use: The Waikiki-Diamond Head Shoreline Fisheries Management Area (FMA) was established in 1978 as a rotating closed area. From 1978 to 1988, management was on a four year cycle with the entire area closed to fishing for two years, then open to hook and line fishing only for one year, followed by one year open to all fishing methods (Brock and Kamm 1993). From July 1998 onward, the management regime was changed to one year closure and one year open to all fishing except gillnets and night spearfishing.

Table 3: Habitat types contained within Waikiki Diamond Head MFA based on NOAA benthic habitat maps. (Coyne et al. 2001)

Habitat Type	Square Meter	Acres	Proportion of total
Hardbottom/Uncolonized Pavement	523378.48	129.33	0.55
Reef/Patch Reef (Individual)	143434.18	35.44	0.15
Macroalgae/10-50%	112871.93	27.89	0.12
Macroalgae/50-90%	54873.13	13.56	0.06
Sand	39939.30	9.87	0.04
Unknown	30214.95	7.47	0.03
Hardbottom/Uncolonized Pavem. with Channels	22921.69	5.66	0.02
Hardbottom/Reef Rubble	18406.81	4.55	0.02
Reef/Spur and Groove Reef	12155.44	3.00	0.01
Artificial/Other Man Made Structures	1389.19	0.34	0.00
Total	959585.09	237.11	1.00

It is open to fishing from January 1 to December 31 of even-numbered years (2000, 2002, etc.). And closed to fishing from January 1 to December 31 of odd-numbered years (2001, 2003, etc.). It is permitted to fish for, take or possess any legal size marine life in season during the “open to fishing” period, provided that only hook-and-line, thrownet, handnet to land hooked fish, and spear fishing and hand harvesting methods are employed.

It is prohibited to fish for, take or injure any marine life (including eggs), or to possess in the water any fishing gear during the “closed to fishing” period. To use any spear between the hours of 6:00 pm to 6:00 am, or have or possess in the water any trap or net except thrownet or handnet to land hooked fish during the “open to fishing” period.

Molokini Shoal MLCD

General Description: The Molokini shoal marine life conservation district is the southern rim of an extinct volcanic crater, 3 miles off Maui. It encompasses 200 acres and was established 1977. The shallow inner cove is the crater's submerged floor. The cove area slopes off from the shoreline to a depth of about 100 feet before dropping off. The bottom consists of sand patches, coral and basaltic boulders. A shallow reef in less than thirty feet of water extends from the shoreline northward at the islet's northwestern point. The back (southern) side of the islet has a steep face that drops off to depths of over 200 feet. Small patches of coral are scattered across the wall. Crevices and outcroppings harbor large populations of fishes.

Fisheries Regulations and Uses: §13-31-3 Prohibited activities. No person shall engage in the following activities in the Molokini shoal marine life conservation district: (1) Fish for, catch, take, injure, kill, possess, or remove any finfish, crustacean, mollusk including sea shell and opihi, live coral, algae or limu, or other marine life, or eggs thereof except as provided for in section 13-31-4(1); (2) Have or possess in the water, any spear, trap net, crowbar, or any other device that may be used for the taking or altering of marine life, geological feature, or specimen; (3) Take, alter, deface, destroy, possess, or remove any sand coral, rock, or other geological feature, or specimen; 31-2 §13-31-5(4) Feed or deliberately introduce any food material, substance, or attractant, directly to or in the vicinity of any aquatic organism, by any means for any purpose except as provided in section 13-31-4(1); (5) Moor boats for commercial activities except as provided for in section 13-31-5; or (6) Anchor a boat when a day use mooring system and management plan is established by this department.

Honolua-Mokule'ia Bay MLCD

General Description: Honolua-Mokule'ia are semi-enclosed bays bordered by north and south basalt cliffs. The surrounding area are for conservation and agriculture use with intermittent stream input.. North and south bay reef flats crest and slope to central 8 to 13 m deep coarse sand channel with beds of Halimeda incrassata. The south reef is composed of coral colonized basalt. The north reef is more developed with higher coral coverage compared to the south. Coverage on both reefs increases with depth. Sand comprises 45% of the total habitat, followed by uncolonized hardbottom (35%), and colonized reef habitat (19%, Table 4). The north reef is sheltered except from winter north Pacific swells. This area has high human use: water recreation, boat traffic, tourism. Fish feeding, anchoring, trampling, sedimentation.

Table 4: Habitat types contained within Honolua-Mokuleia MLCD based on NOAA benthic habitat maps. (Coyne et al. 2001)

Habitat Type	Square Meter	Acres	Proportion of total
Sand	82448.28	20.37	0.45
Hardbottom/Uncolonized Volcanic Rock/Boulders	62975.71	15.56	0.35
Reef/Colonized Volcanic Rock/Boulders	13350.31	3.30	0.07
Reef/Aggregate Coral	11947.85	2.95	0.07
Reef/Colonized Pavement with Channels	9412.64	2.33	0.05
Hardbottom/Uncolonized Pavement	1132.75	0.28	0.01
Total	181267.54	44.79	1.00

Fisheries Regulations and Uses: Prohibited activities. No person shall engage in the following activities in the Honolua- Mokuleia Bay Marine Life Conservation District: (1) Fish for, catch, take, injure, kill, possess, or remove any finfish, crustacean, mollusk including sea shell and opihi, live coral, algae or limu, or other marine life, or eggs thereof; (2) Take, alter, deface, destroy, possess, or remove any sand, coral, rock, or other geological feature, or specimen; or (3) Have or possess in the water, any spear, trap, net, crowbar, or other device that may be used for the taking or altering of marine life, geological feature or specimen.

Kahaluu Beach Park, Hawai'i

General Description: Kahalu'u is the largest sand beach between Kailua and Keauhou on the kona coast of the big island. In the days of the Hawaiian kings, with many of the islands' beaches having dangerous surf and riptides, King Kamehameha wanted a safe place for his family to enjoy the ocean. He had his workers construct a seawall in the surf to protect a small cove on the sunny side of the Big Island. This cove today is known as Kahaluu Beach Park and is one of the most popular swimming and best snorkeling sites in the Kona district.This site is shallow, mostly less than 1 m, with only a few patches of live coral.

Fisheries Regulations and Uses: Kahalu'u Beach Park lies within the Kailua-Keauhou Fish Replenishment Area (FRA) which prohibits the taking of aquatic life for either commerical or non-commercial aquarium purposes or to engage in or attempt to engage in fish feeding..

Wai Opae MLCD

General Description: A shallow basalt/coralline algae platform on the seaward margin of the tide pools causes waves to break, thereby dissipating most of their energy before they enter the pools. The tide pools are one of the few areas on the entire windward coast of the Big Island that are easily accessible almost all of the time. People can drive to within a few yards of the nearest pools and except for during major storms, it is possible to swim in the tide pools under most weather conditions. This makes the pools particularly vulnerable to potential negative impacts from human perturbation.

The MLCD area has a total coral cover of approximately 47% that is dominated by Porites lobata (Hallacher, Tissot, and Walsh, unpublished data).

Fisheries Regulations and Uses: Prohibited activities – No person shall engage in the following activities in the district: (1) take, injure, kill, possess, or remove any marine life; (2) take, alter, deface, destroy, possess, or remove any sand, coral, rock, or other geological feature or specimen; (3) anchor or moor any vessel; (4) conduct commercial activities, such as, but not limited to, commercial tours, dive groups, sightseeing tours, hikes, or guided services.

4. Empirical Information On Fish Assemblage Characteristics

Fish Assemblage Characteristics

Fish assemblage characteristic data were derived from CRAMP data (Friedlander et al. 2003), NOAA fish habitat utilization and MPA efficacy study (Friedlander and Brown 2003), and Wai Opae tidepool investigation (Hallacher, Tissot, and Walsh, unpub.). High species richness, number of individuals, biomass, and diversity in observed at Hanauma Bay, Honolua-Mokule'ia, and Molokini Shoal (Table 5).

Table 5: Fish assemblage characteristics among various MPAs in Hawaii

Location	Species	Num/ha x (1000)	Biomass (t/ha)	Diversity	Evenness
	15.00	3.28	0.39	2.31	0.87
Kahalu‘u Beach Park1	(7.07)	(2.38)	(0.12)	(0.35)	(0.03)
Honolua-Mokule‘ia	22.78	12.04	0.91	2.32	0.76
Bay MLCD[1]	(6.18)	(6.51)	(0.77)	(0.35)	(0.09)
	11.00	3.98	0.41	1.78	0.79
Waikiki MLCD[1]	(6.16)	(3.38)	(0.56)	(0.63)	(0.20)
	10.35	3.67	0.22	1.75	0.81
Waikiki FMA[1]	(5.91)	(2.94)	(0.30)	(0.42)	(0.10)
	27.57	16.71	1.38	2.44	0.74
Hanauma Bay MLCD[2]	(5.35)	(4.86)	(0.30)	(0.31)	(0.06)
Molokini Shoal	20.50	6.86	0.98	2.52	0.84
MLCD[2]	(5.07)	(2.44)	(0.80)	(0.35)	(0.09)
Wai Opae[3]		5.6			
Totals excluding	17.00	10.35	0.54	1.98	0.73
MLCDs	(7.16)	(8.03)	(0.48)	(0.51)	(0.16)

Sources: 1 – NOAA/NOS fish habitat utilization study (Friedlander and Brown 2003). 2 – CRAMP (Friedlander et al. 2003a), and 3 – UH Hilo/DAR long-term data (Hallacher, Tissot, and Walsh). Totals are statewide and based on 208 transects, not including MLCDs.

The lowest values for species richness and biomass were observed at the two Waikiki locations with low biomass also observed at the shallow protected Kahalu‘u Beach Park. Habitat and level of protection seem to be the reasons for these observed differences. These areas with greater protection for fishing and greater habitat quality has fish assemblage values higher than the average values observed on hardbottom habitats around the state while the areas with limited protection from fishing and or poor habitat quality had values below those average values.

Species Composition among Sites

Surgeonfishes dominate the Honolua-Mokule‘ia Bay MLCD based on weight and index of relative dominance (IRD) and (Table A-1 in the Appendix). Seven of the top ten species were surgeonfishes accounting for 58% of total fish biomass at this location. Fishers target many of the species and the abundance and size of these species in the MLCD are evidence that these species are being protected from excessive exploitation.

In contrast to the fish assemblage structure in the Honolua-Mokule‘ia Bay MLCD, fish assemblage structure in the Waikiki MLCD had a greater prevalence of species that are of little extractive value such as the Sargent Major (Abudefduf abdominalis, mamo), the endemic saddle wrasse (Thalassoma duperrey, hi¯na¯lea lauwili), the reef triggerfish (Rhinecanthus rectangulus, humuhumunukunukuapua'a), and belted wrasse (Stethojulis balteata, o¯maka) (Table A-2 in the Appendix). This shift in fish assemblage structure is even more pronounced at the Waikiki FMA where the saddle wrasse is the dominant species based on index of relative dominance (IRD - biomass x frequency of occurrence) (Table A-3 in the Appendix). The brown surgeonfish (Acanthurus nigrofuscus, ma¯i'i'i) was the second most important species in the Waikiki FMA based on IRD. Although this species is consumed locally, it has very low consumptive value.

Dominant species within the Hanauma Bay MLCD included the goldring surgeonfish (Ctenochaetus strigosus, kole), the introduced bluestripe snapper (Lutjanus kasmira, ta'ape), the Achilles tang (Acanthurus Achilles, pa¯ku‘iku‘i), and the endemic spectacled parrotfish (Chlorurus perspicillatus, uhu uliuli) (Table A-4 in the Appendix). The presence of large parrotfishes, particularly large terminal phase males, in Hanauma Bay is an indication of what more natural assemblages of fishes would look like without overexploitation.

Molokini Shoal MLCD contains a diverse assemblage of fishes that is represented by five different families within the top ten dominant species (Table A-5 in the Appendix). Black (Melichthys niger, humuhumu'el'ele) and pink durgon (Melichthys vidua, humuhumuhi'ukole) are the number one and four species based on IRD. These species feed mainly on plankton and are more common on offshore islets. Resource species of interest included one 80 cm giant trevally (Caranx ignobilis, 'ulua aukea) and several large bullethead parrotfish (Chlorurus sordidus, uhu) were observed at Molokini.

The Kahalu‘u Beach Park was dominated by juvenile parrotfishes (Table A-6 in the Appendix). Palenose (Scarus psittacus, uhu) and bullethead (Chlorurus sordidus, uhu) accounted for more than 32% of total fish biomass. This shallow rubble location provided optimal habitat for these species.

The endemic saddle wrasse (Thalassoma duperrey, hi¯na¯lea lauwili) was the dominant species observed in the Wai Opae tidepool MLCD, followed by two species of parrotfishes (Scarus psittacus and S. sordidus), the majority of which were juveniles (Hallacher, Tissot, and Walsh, unpublished data) (Figure 4). Families of fishes representing the top ten species included: parrotfishes (Scaridae), damselfishes (Pomacentridae), wrasses (Labridae), surgeonfishes (Acanthuridae), puffers (Tetraodontidae), and butterflyfishes (Chaetodontidae).

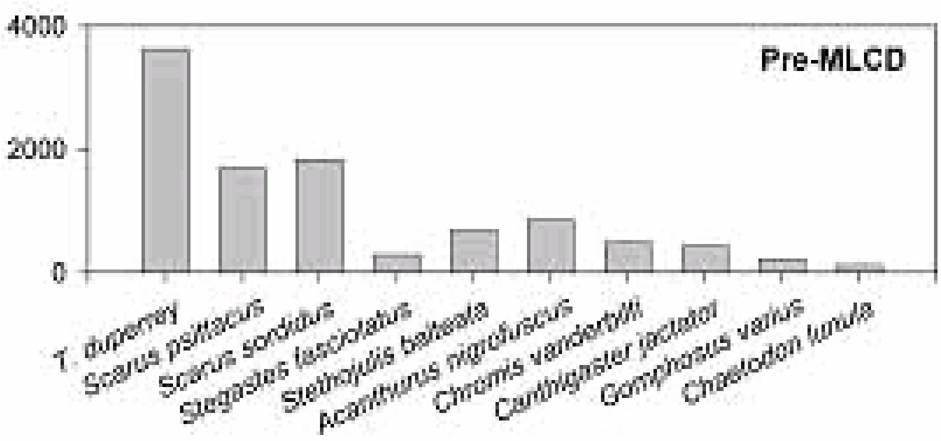


Figure 4: Numerical abundance of top tens species in Wai Opae MLCD prior to MLCD creation (Hallacher, Tissot, and Walsh, unpublished data).

Comparisons of Waikiki MLCD, FMA, and areas open to fishing

Fish assemblage characteristics among fisheries management regimes in Waikiki

Fish assemblage characteristics (species, number, and biomass) differed significantly among fisheries management regimes (MLCD, FMA, and open access) in the uncolonized hardbottom habitat type (<10% live coral cover) in the Waikiki-Diamondhead area (Friedlander and Brown 2003). Although number of species and number of individuals was higher in the MLCD, it was not significantly different from the FMA and open access areas in the uncolonized habitat (Table 6).

Table 6: Comparison of fish assemblage characteristics among various management regimes in uncolonized hardbottom habitats (<10% live coral cover) in the Waikiki-Diamondhead area. MLCD – Marine Life Conservation District, Open – open to all fishing, FMA – Fisheries Management Area (Friedlander and Brown 2003).

Species	Management	Mean (SD)	Statistics	P	Comp
	MLCD	13.00 (6.94)	0.008	0.92	A
	FMA	12.27 (6.92)			A
	Open	11.94 (6.01)			A
Number/ha x (1000)	Management	Mean (SD)	Statistic	P	Comp
	MLCD	5.05 (3.96)	0.11	0.9	A
	Open	4.76 (3.98)			A
	FMA	4.47 (3.45)			A
Biomass (t/ha)	Management	Mean (SD)	Statistics	P	Comp
	MLCD	0.61 (0.73)	9.32	0.009	A
	FMA	0.31 (0.37)			AB
	Open	0.16 (0.14)			C

Table 7: Comparison of fish assemblage characteristics among various management regimes in macroalage habitats in the Waikiki-Diamondhead area.

Species	Management	Mean (SD)	Statistics	P	Comp
	MLCD	9.18 (5.00)	10.06	<0.001	A
	FMA	8.00 (3.46)			A
	Open	3.18 (2.81)			B
Number/ha x (1000)	Management	Mean (SD)	Statistics	P	Comp
	MLCD	3.01 (2.56)	7.42	0.002	A
	FMA	2.69 (1.94)			A
	Open	0.85 (1.12)			B
Biomass (t/ha)	Management	Mean (SD)	Statistics	P	Comp
	MLCD	0.22 (0.25)	12.05	0.003	A
	FMA	0.11 (0.11)			A
	Open	0.03 (0.02)			B

Fish biomass in uncolonized hardbottom habitats was four times higher in the MLCD compared to the open access areas and more than twice as high as in the FMA. In the macroalgae habitats, the number of species, number of individuals, and biomass were all highest in the MLCD, followed by the FMA and lowest in the open access areas (Table 7). Fish biomass was twice as high in the MLCD compared to the areas open to fishing.

Fish assemblage characteristics among fisheries management regimes in West Maui

Fish assemblage characteristics differed among fisheries management regimes (MLCD and open access) in the colonized hardbottom (>10% live coral cover), uncolonized hardbottom (<10% love coral cover), and unconsolidated sediments habitat types along the west Maui coast (Table 8). Although number of species was higher in the MLCD, it was not significantly different from the open access areas except for the uncolonized hardbottom habitats (Table 8). Number of individuals was also higher in the MLCD compared with the open assess areas but only significantly different in the colonized hardbottom habitat (Table 8). Fish biomass was significantly higher in the Honolua-Mokule‘ia MLCD compared to open assess areas for all three habitat types (Friedlander and Brown 2003).

Table 8: Fish assemblage characteristics between the Honolua-Mokule‘ia MLCD and areas open to fishing among different habitat types (Friedlander and Brown 2003).

Species	Colonized Hardbottom	Uncolonized Hardbottom	Unconsolidated sediments
MLCD	24.87 (1.2)	20.17 (2.0)	12.00 (2.24)
Open	20.61(2.0)	14.87 (1.55)	9.47(1.44)
T	1.90	2.03	0.99
P	0.07	0.05	0.32
Number	Colonized Hardbottom	Uncolonized Hardbottom	Unconsolidated sediments
MLCD	15.14 (1.53)	8.18 (1.47)	4.63 (1.16)
Open	10.41 (1.53)	6.05 (1.09)	3.70 (0.81)
T	2.08	1.29	1.69
P	0.047	0.20	0.10
Biomass	Colonized Hardbottom	Uncolonized Hardbottom	Unconsolidated sediments
MLCD	1.37 (0.40)	0.88 (0.25)	0.49 (0.16)
Open	0.41 (0.08)	0.20 (0.04)	0.12 (0.03)
T	3.05	3.71	2.80
P	0.005	<0.001	0.007

Fish trophic structure between management regimes and among habitats

Herbivores were the dominant trophic guild by weight over all habitat types, accounting for over 67% of the total fish biomass observed on transects. These were followed by mobile invertebrate feeders (21%), planktivores (6%), and piscivores (3.4%). Biomass for all trophic guilds was higher in the MLCD compared to areas open to fishing (Figure 5). Piscivores showed the largest difference (1226%) in biomass between areas open to fishing and those closed to fishing. Herbivores showed a 740% difference followed by planktivores (108%), and mobile invertebrate feeders (46%).

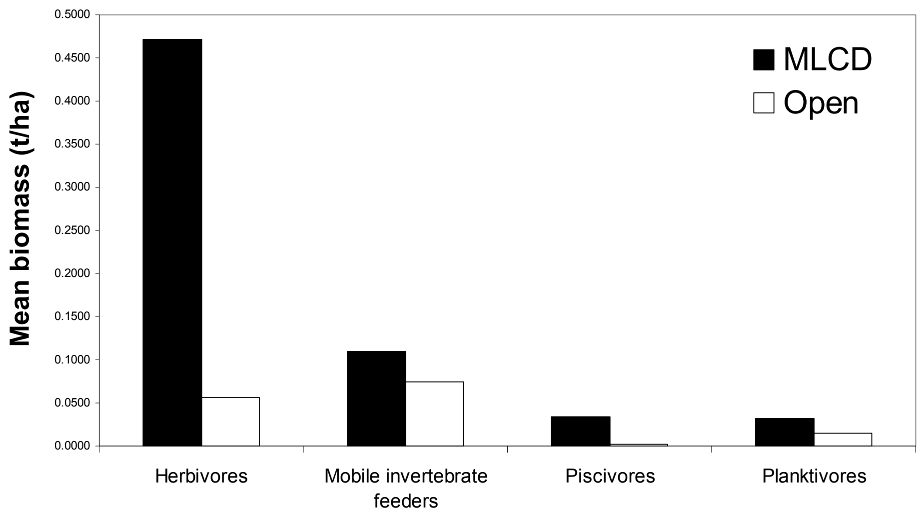


Figure 5 Mean fish biomass (t/ha) among trophic guilds for the Honolua-Mokuleʻia MLCD compared to open access areas (Friedlander and Brown 2003).

Comparison of fish assemblage characteristics between Kahaluʻu Beach Park and similar habitat types within Kailua-Keauhou FRA.

Number of species, number of individuals, biomass, and diversity were all lower at the Kahaluu Beach Park compared with similar uncolonlized (<10% live coral cover) habitat within the Kailua-Keauhou FRA (Table 9). The low habitat heterogeneity in the backreef habitat of the beach park resulted an assemblage dominated by juvenile parrotfishes.

Table 9: Comparison of fish assemblage characteristics between Kahaluu Beach Park and similar habitat types within Kailua-Keauhou FRA.

Assemblage Characteristic	FMA	Kahaluu Beach Park
Species richness	18.00 (5.06)	15.00 (7.07)
Number of individuals	6.65 (4.14)	3.28 (2.38)
Biomass	0.52 (0.32)	0.39 (0.12)
Diversity	2.25 (0.25)	2.31 (0.35)

5. Empirical Information on MPAs in Hawaii – Overall Comparison of Protected Areas

Hawaii Coral Reef Assessment and Monitoring Program (CRAMP)

As part of the Hawaii Coral Reef Assessment and Monitoring Program (CRAMP), fish assemblage structure and habitat utilization patterns were examined at 60 sites around the main Hawaiian Islands (Friedlander et al. 2003a). Areas completely protected from fishing had distinct fish assemblages with higher standing stock and diversity than areas where fishing was permitted or areas that were partially protected from fishing (Table

10, Friedlander et al. 2003a). Hanauma Bay on Oahu and Honolua Bay on Maui, two no-take areas with the highest levels of protection from fishing in the main Hawaiian Islands, had the highest values for most fish assemblage characteristics.

The State of Hawaii has been encouraging community-based management of subsistence fishing areas since 1994, and a number of community-managed areas are now being established. Locations influenced by customary stewardship harbored fish biomass that was equal to or greater than that of no-take protected areas. The remoteness of these locations combined with the light fishing pressure (on-island consumption only) and community oversight has resulted in high standing stock of reef fishes compared to other locations in Hawaii.

Marine protected areas in the main Hawaiian Islands with high habitat complexity, moderate wave disturbance, a high percentage of branching and/or lobate coral coupled with legal protection from fishing pressure had higher values for most fish assemblage characteristics. Habitats with these optimal characteristics should possess fish assemblages with high species richness, abundance, biomass, and diversity (Friedlander et al. 2003a).

Table 10: Fish assemblage characteristics among various management regimes at 60 sites in the main Hawaiian Islands (Friedlander et al. 2003a).

Management	Species Richness	Comp
No-take	24.99	A
Customary stewardship	21.29	AB
Partial protection	19.13	AB
Open access	17.54	B
	Number of individuals	
No-take	146.26	A
Customary stewardship	142.50	A
Partial protection	113.81	A
Open access	105.39	A
	Biomass	
No-take	15.89	A
Customary stewardship	16.27	A
Partial protection	6.07	AB
Open access	6.16	B
	Diversity	
No-take	2.52	A
Customary stewardship	2.33	AB
Partial protection	2.22	AB
Open access	2.14	B

NOAA/NOS Fish Habitat Utilization Study

Coupling the distribution of habitats and species habitat affinities using NOS digital benthic habitat maps has proven to be powerful tool to examine the efficacy of MPAs in Hawaii. Habitat quality and size were important determinates of the effectiveness of the MPAs examined with respect to their fish assemblages (Friedlander and Brown 2003). In most cases, when compared within habitats, fish assemblage characteristics were higher in protected areas compared with areas open to fishing, illustrating the effectiveness of these areas in conserving coral reef fish assemblages (Table 11).

Table 11: Mean fish biomass (t/ha) in areas under various management regimes. MLCD – Marine Life Conservation District, Open – open to all fishing, FMA – Fisheries Management Area. Hard bottom habitats only (Friedlander and Brown 2003).

LOCATION	MLCD	Open	FMA	Comparisons
West Maui	0.68	0.16		MLCD>Open
Kaneohe Bay, Oahu	0.65	0.32		MLCD>Open
South coast, Lanai	0.63	0.44		MLCD>Open
Kailua Kona, Hawaii	1.52	0.94	0.46	MLCD>Open>FMA
Waikiki, Oahu	0.41	0.13	0.22	MLCD>FMA>Open

Size of fishes among management regimes

Mean size of fishes among management regimes at 449 sampling locations around the main Hawaiian Islands showed significantly different (Table 12) with fish in the MLCDs being significantly larger than in open access and slightly larger (but not significantly) than those fishes in the FMAs.

Table 12: Mean size of all fishes among various management regimes. Results of One-way ANOVA: $F_{2,5823}$ = 85.2, P < 0.001. Tukey HSD multiple comparisons test. Management regimes with the same latter are not significantly different at α = 0.05 (Friedlander and Brown 2003).

Management regime	Mean size (cm)	Standard Error	Multiple comparison
MLCD	12.3	0.16	A
Fisheries Management Area	11.9	0.24	A
Open access	9.97	0.11	B

Comparison of parrotfish size frequency distributions between fished and unfished areas

Adult parrotfish are highly prized by fishers and large adult parrotfish (uhu) are rare in locations that are heavily fished. Size frequency distributions of parrotfishes in the Moku o Loe (Coconut Island) Hawai‘i Marine Laboratory Refuge are significantly larger than parrotfishes observed in areas open to fishing (P < 0.001). Examination of the size spectra of parrotfishes greater than 20 cm in length show a significantly (P < 0.05) smaller number of the larger size classes represented in the areas open to fishing compared with Moku o Loe (Coconut Island) Hawai‘i Marine Laboratory Refuge when harvest is prohibited (Figure 6). These larger size classes targeted by fishers also contain a disproportionately greater number of terminal phase males that are important for reproductive success and therefore, population replenishment.

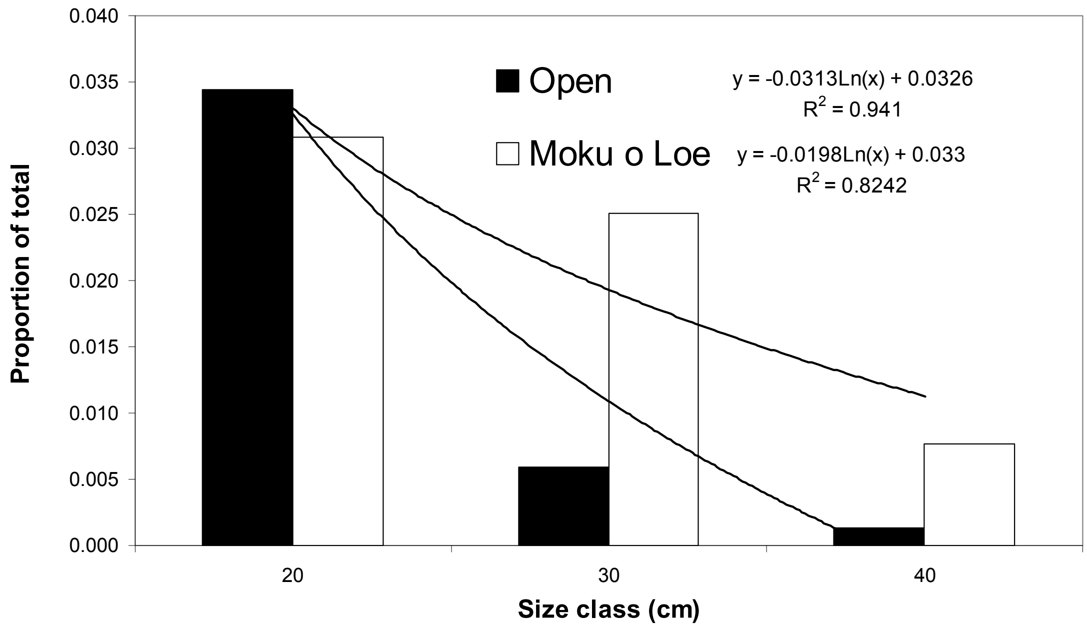


Figure 6: Size spectrum of parrotfishes greater than 20cm around Moku o Loe (Coconut Islands Marine Laboratory Reserve) and patch reefs open to fishing around Kaneohe Bay, Oahu (Friedlander and Brown, 2003).

6. Recommendations for Modifications to Existing MPAS and for the Design and Siting of Future Protected Areas

There are a variety of marine areas in Hawai'i that have some type of protected status. These include Marine Life Conservation Districts (MLCDs), Fisheries Management Areas (FMAs), Fisheries Replenishment Areas (FRAs), a Marine Laboratory Refuge, Natural Area Reserve (NARs), Kahoolawe Island Reserve (KIR), National Wildlife Refuges, the Hawaiian Islands Humpback Whale Sanctuary (Clark and Gulko, 1999) and the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve. In almost all cases examines, protected areas had healthier more diverse fish assemblages with higher standing stock compared with similar adjacent areas. However, many of these reserves are either too small, lack suitable habitats, or are not fully protected from fishing and therefore do not function effectively as refuges (Friedlander 2001, Friedlander et al. 2003a, Meyer 2003). This is the most critical issue to address if reserves are to be an effective fisheries and conservation management tool in Hawai'i.

The value of Hawai'i's commercial coastal fisheries was approximately 2.5 million dollars in 2001 (DeMello 2003). However, 80% of catch consists of two species of coastal pelagics (akule ands opelu). The recreational catch and artisanal catch combined likely exceeds the commercial catches, excluding akule and opelu, and these fishers take a wider variety of species (Friedlander and Parrish 1997, Everson and Friedlander 2003). Income derived from recreational use of the fishery through the sale of fishing tackle, bait, license fees, fuel, etc. is also an important component of the local economy in many areas around the state. For the reasons stated above, MPAs in Hawai‘i should focus more on improving recreational and subsistence catch versus enhancing commercial yield. Although recreational fishers can tolerate a much lower yield than commercials fishers, subsistence fishers need to maintain yields for sustenance and for cultural survival. Although this need does not always translate to a dollar value, its importance to the people of Hawai‘i cannot be neglected. MPAs will also provide insurance against other management inaction as well as providing insurance against environmental disasters. Fishing tourism is important to many coastal states and if Hawaii chooses to pursue this sector, MPAs will be needed to reduce the risk of collapse and rebuild stocks.

Waikiki MLCD

Although the Waikiki MLCD has been a no-take area since 1988, low habitat heterogeneity, degraded reef environment, and small size have resulted in this area having a very low standing stock of fish. However, the size and number of fishes is greater within the MLCD compared to adjacent habitats (Friedlander and Brown 2003, Meyer 2003). Meyer (2003) noted that abundance and size of both target and non-target species was greater in the Waikiki MLCD compared to adjacent fished areas, suggesting that fishing is not the only factor determining patterns in abundance and size. The author noted that despite having generally poor habitat quality, the habitat within the MLCD had greater complexity compared to the adjacent areas. Based on tracking data and the distribution of critical habitat, Meyer (2003) also determined that the area of the Waikiki MLCD (0.32 km^2) would need to be at least tripled in size (1 km^2) to begin to effectively protect more mobile species such as jacks and goatfishes. This modest increase in size along with the inclusion of essential softbottom habitats would greatly improve the effectiveness of the MLCD in conserving reef assemblage structure, however, a much larger area or areas would be necessary to achieve any type of fisheries benefits.

Waikiki-Diamond Head FMA

Visual census data of fishes conducted by DAR since 1978 has shown that fish biomass was higher within the Waikiki-Diamondhead FMA when the area was closed to fishing or open to hook and line only (Brock and Kamm 1993). Despite these closures, standing crop of fishes never exceeded 50 g/m2 and Brock and Kam (1993) attributed this to the lack of adequate shelter habitat. The benefits derived from the closure were quickly lost when the area was open to all types of fishing, but hook-and-line fishing appeared to have little impact on fish standing stock. (Brock and Kamm 1993). Current regulations prohibit fishing on odd-numbered years and prohibit trap and net fishing, except throw nets, and nighttime spearfishing during even-numbered open years. Holland and Meyer (2003) found that alternating closures is less important than the fact that no nighttime spearfishing or gillnetting was allowed in the FMA during open years. Recent analysis of DAR survey data (1985-2000) from the Waikiki-Diamond Head FMA revealed a recovery for most trophic and taxonomic groupings in closed years with declines occurring in open years (DAR unpub. data). The most disturbing trend from this analysis was the overall decline in most trophic guilds over time despite annual closures.

Habitat

In Hawaii, habitats with low spatial relief and limited shelter were found to be associated with low biomass and diversity of reef fishes while highly complex habitats harbored high fish biomass and diversity (Friedlander and Parrish 1998a). Ideally, essential fish habitat in the main Hawaiian Islands should consist of an area with high rugosity or relief with moderate wave exposure that has a high percentage of branching and/or lobate coral coupled with legal protection from fish pressure. Habitats with these optimal characteristics should possess fish assemblages with high species richness, abundance, biomass, and diversity (Friedlander at al. 2003a). If protective areas are to be effective, they must include the diversity of habitats necessary to accommodate the wide range of fish species.

Coupling the distribution of habitats and species habitat affinities using GIS technology enables the elucidation of species habitat utilization patterns for a single species and/or assemblages of animals. This integrated approach is useful in quantitatively defining essential fish habitat and defining biologically relevant boundaries of marine protected areas. By integrating spatial data into the biological sampling design, significant progress can be made towards identifying and quantifying spatial dependencies in habitat utilization by reef fishes. This design also lends itself to elucidating factors that might suggest cause for differential patterns in ontogenetic habitat selection, ergo distribution, within the available landscape. Such patterns in population and community structure are necessary and fundamental components of any intent to understand and maximize the benefits derived from a Marine Protected Area.

Movement

Short and long-term movement patterns of omilu (blue trevally, *Caranx melampygus*) were monitored around Coconut Island (Moku o Lo‘e) (Holland et al. 1996). The limited range of dispersal of recaptured (75.5% within 0.5 km of the release site) and strong site fidelity observed from sonically tagged fish suggest that dispersal is much less than might be predicted for a highly mobile, piscivorous species. The authors suggest that small refugia (e.g. 5 km of reef face) could provide significant protection for this species despite its potential for long-range movements. *Kumu* (whitesaddle goatfish, *Parupeneus porphyreus*), an endemic goatfish and important fisheries species, were acoustically tracked around the Coconut Island refuge for periods up to 93 h (Meyer et al. 2000). The home ranges of all fish were within the boundaries of the Coconut Island reserve. This small reserve (< 1 km^2) was capable of protecting both large juveniles and some spawning size individuals (Meyer et al. 2000). *Kala* (blue spined unicornfish, *Naso unicornis*) were acoustically tracked for periods of up to 22 days in the shallow high-energy fringing reef habitat in the Waikiki Marine Life Conservation District (Meyer and Holland 2001). The home ranges of all of the *kala* tracked were completely encompassed by the boundaries of the 0.32 km^2 Waikiki Marine Life Conservation District.

Monitoring

Assessments of fished vs. protected areas must consider habitat and environmental variables when designing assessment programs in order to properly examine MPA success. Once reserves are established, long-term monitoring programs can be implemented to help determine the effectiveness of the zoning plan and to guide future modifications to either the fishing regulations or the reserve boundaries.

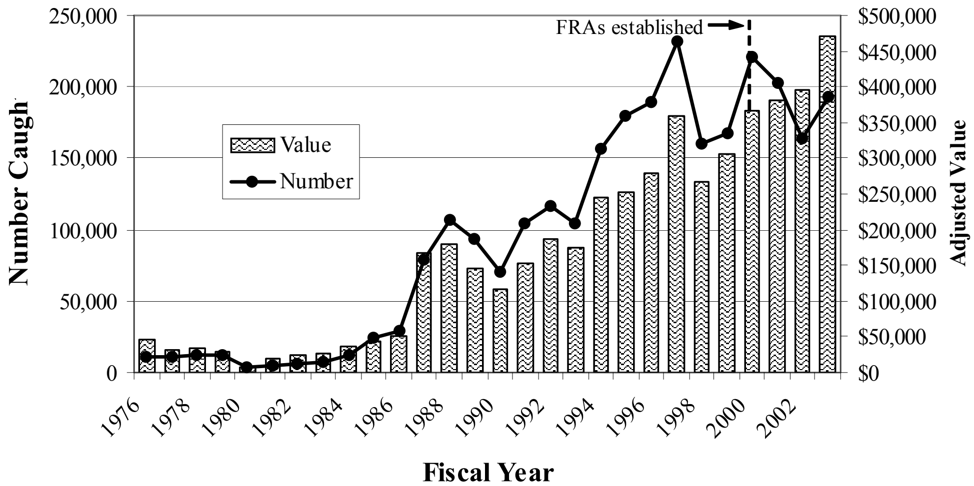
The openness and dynamic nature of ocean environments make it extremely difficult to prove fisheries enhancements statistically because of the difficulty separating reserve effects from other changes that might have occurred (PDT 1990; Sladek Nowlis and Friedlander, 2004b). Marine reserves are as well supported by this sort of evidence as any other fishery management technique in use today and should not be held to a higher standard than these other management measures (Sladek Nowlis and Friedlander, 2004a).

Most commonly, marine reserve monitoring programs compare inside to outside of the reserve). These sorts of comparisons can provide useful information about how fishing is affecting the outside areas with the reserves serving as a control. In this manner, a marine reserve monitoring program can follow a standard ecological before-after-control-impact-pairs design (Sladek Nowlis and Friedlander 2004c). These samples are paired in the sense that the control (reserve) and impact (fishing) sites are examined more or less concurrently. Replication comes from collecting such paired samples at a number of times both before and after the reserve designation. The approach is to test whether the differences between the control and impact sites changed after the reserve was established.

Fisheries yields

In 1998, the state legislature passed Act 306, which established a West Hawai‘i Regional Fisheries Management Area to provide for effective management of marine resources. The West Hawai‘i Fisheries Council, composed of stakeholders and government representatives, developed a network of nine Fish Replenishment Areas (FRAs) encompassing 35.2% (including existing protected areas) of the coastline (Walsh 1999).

Preliminary analysis (Tissot et al., 2004) indicates that three years after closure of the FRAs there have been significant increases in the overall abundance of fishes targeted by collectors. Two species, the yellow tang and Potter’s angelfish (*Centropyge potteri*), showed significant (74-80%) increases in FRAs relative to previously protected reference areas (Walsh et al. 2003). Furthermore, no aquarium fishes declined in abundance in open areas as might be expected if the intensity of harvesting increased outside of the FRAs. In fact, two species displayed significant increases in abundance in the open areas.



Despite a closure of more than 35% of the west Hawaii coast to aquarium fish collecting, the value of fish caught has increased since the closure went into effect in 2000 (Walsh et al. 2003). Of special note is the fact that the dollar value of each yellow tang has increased in the past two years (**Error! Not a valid bookmark self-reference.**). Indeed, the overall value of the West Hawaiʻi aquarium fishery in FY 2003 is the highest it has ever been (Figure 8).

Figure 7: Number and value (adjusted for inflation) of yellow tangs caught in West Hawaiʻi per fiscal year (Walsh et al. 2003).

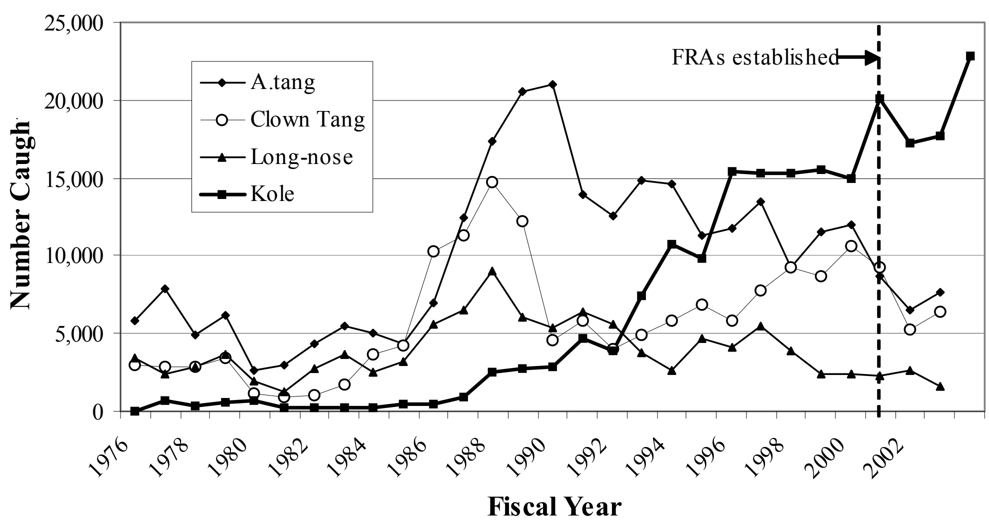


Figure 8: Number caught of top 2nd-5th West Hawaiʻi species per fiscal year (Walsh et al. 2003).

Basic recommendations for reserves in Hawaii

- Larger in size – individual reserves should cover 5-10 km^2
- Incorporate essential fish habitat – areas of high habitat complexity, spawning locations, and essential feeding areas need to be represented fully in reserve design
- More connection between shallow and deep habitats – identify juvenile and adult habitats and provide connections for ontogenetic movement
- More connections between resting and feeding habitats. Identify feeding corridors to connect habitats.
- Reserves should be networked. Several smaller reserves may be more beneficial than one large one particularly when one is concerned with limiting the exposure at the boundaries. A reserve 4 to 6 km in diameter should be large enough to contain the larvae of short distance dispersers and reserves spaced 10 to 20 km apart should be close enough to capture propagules released from adjacent reserves.
- Develop a more ecosystem-based ahupua'a concept that includes shoreline and upland ecosystems and uses
- Recognize that the baseline has shifted and manage to rebuild not to sustain current levels of abundance.
- Develop monitoring programs that incorporate habitat types and examine human use patterns.
- Involvement of local communities is invaluable to the creation and implementation of reserves or reserve networks because they play an important role in the enforceability and social acceptability of reserves.

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Appendix I. Top ten species observed on transects for the Six Study Sites

Table A-1: Top ten species observed on transects at Honolua-Mokule‘ia Bay MLCD (N = 27)

TaxonName	Hawaiian Name	Common Name	Number (No./ha x 1000)	Biomass (t/ha)	Freq	IRD*	% number	% biomass
Naso unicornis	kala	Bluespine Unicornfish	0.20	0.16	0.52	0.082	1.62	17.24
Acanthurus nigrofuscus	ma¯i'i'i	Brown Surgeonfish	1.43	0.06	0.93	0.059	11.83	7.02
Acanthurus triostegus	manini	Convict Tang	0.75	0.10	0.41	0.040	6.20	10.60
Naso lituratus	umaumalei	Orangespine Unicornfish	0.16	0.06	0.56	0.034	1.33	6.62
Acanthurus leucopareius	ma¯ikoiko	Whitebar Surgeonfish	0.24	0.06	0.48	0.028	1.97	6.30
Acanthurus blochii	pualu	Ringtail Surgeonfish	0.17	0.07	0.33	0.024	1.43	7.88
Thalassoma duperrey	hi¯na¯lea lauwili	Saddle Wrasse	1.05	0.02	0.96	0.022	8.71	2.51
Scarus rubroviolaceus	pa¯lukaluka	Redlip Parrotfish	0.23	0.03	0.56	0.015	1.87	2.90
Parupeneus multifasciatus	moano	Manybar Goatfish	0.22	0.02	0.78	0.014	1.80	1.97
Acanthurus olivaceus	na'ena'e	Orangeband Surgeonfish	0.08	0.02	0.41	0.009	0.64	2.51

Table A-2: Top ten species observed on transects at Waikiki MLCD (N = 21)

Taxon Name	Hawaiian Name	Common Name	Number (No./ha x 1000)	Biomass (t/ha)	Freq	IRD*	% number	% biomass
Acanthurus nigrofuscus	ma¯i'i'i	Brown Surgeonfish	0.50	0.06	0.67	0.042	12.44	15.50
Naso unicornis	kala	Bluespine Unicornfish	0.16	0.06	0.57	0.035	4.11	15.02
Acanthurus leucopareius	ma¯ikoiko	Whitebar Surgeonfish	0.18	0.05	0.29	0.014	4.40	11.75
Thalassoma duperrey	hi¯na¯lea lauwili	Saddle Wrasse	0.73	0.01	0.95	0.013	18.28	3.23
Acanthurus triostegus	manini	Convict Tang	0.32	0.02	0.43	0.010	8.13	5.55
Rhinecanthus rectangulus	humuhumunukunukuapua'a	Reef Triggerfish	0.08	0.01	0.67	0.008	2.11	2.93
Abudefduf abdominalis	mamo	Sargent Major	0.27	0.02	0.33	0.006	6.70	4.10
Stethojulis balteata	'o¯maka	Belted Wrasse	0.30	0.01	0.81	0.004	7.46	1.25
Acanthurus blochii	pualu	Ringtail Surgeonfish	0.12	0.02	0.19	0.004	2.97	5.28
Naso lituratus	umaumalei	Orangespine Unicornfish	0.06	0.01	0.24	0.003	1.53	3.37

* IRD = index of relative dominance (biomass x frequency of occurrence).

Table A-3: Top ten species observed on transects at Waikiki FMA (N = 20)

TaxonName	Hawaiian Name	Common Name	Number (No./ha x 1000)	Biomass (t/ha)	Freq	IRD*	% number	% biomass
Thalassoma duperrey	hi¯na¯lea lauwili	Saddle Wrasse	0.91	0.02	0.95	0.018	24.75	8.54
Acanthurus nigrofuscus	ma¯i'i'i	Brown Surgeonfish	0.36	0.03	0.60	0.016	9.81	12.22
Stethojulis balteata	'o¯maka	Belted Wrasse	0.60	0.01	1.00	0.008	16.25	3.82
Rhinecanthus rectangulus	humuhumunukunukuapua'a	Reef Triggerfish	0.08	0.01	0.60	0.007	2.29	5.27
Acanthurus triostegus	manini	Convict Tang	0.21	0.01	0.40	0.005	5.67	5.95
Abudefduf abdominalis	mamo	Sargent Major	0.24	0.02	0.25	0.004	6.65	7.36
Naso lituratus	umaumalei	Orangespine Unicornfish	0.04	0.01	0.30	0.004	1.20	5.46
Naso unicornis	kala	Bluespine Unicornfish	0.05	0.02	0.15	0.002	1.31	7.31
Chlorurus sordidus	uhu	Bullethead Parrotfish	0.06	0.01	0.30	0.002	1.74	2.95
Parupeneus multifasciatus	moano	Manybar Goatfish	0.05	0.00	0.35	0.001	1.31	1.87

Table A-4: Top ten species observed on transects at Hanauma Bay MLCD (N = 7)

TaxonName	Hawaiian Name	Common Name	Number (No./ha 1000)	xBiomass (t/ha)	Freq	IRD*	% number	% biomass
Ctenochaetus strigosus	kole	Goldring Surgeonfish	0.64	0.32	1.00	0.318	28.66	22.34
Lutjanus kasmira	ta'ape	Bluestripe Snapper	0.08	0.09	0.86	0.078	3.56	6.43
Acanthurus achilles	pa¯ku‘iku‘i	Achilles Tang	0.07	0.06	1.00	0.057	3.01	3.98
Chlorurus perspicillatus	uhu uliuli	Spectacled Parrotfish	0.01	0.11	0.43	0.047	0.41	7.67
Melichthys vidua	humuhumuhi'ukole	Pinktail Durgon	0.02	0.05	0.86	0.041	0.96	3.35
Zebrasoma flavescens	lau'i¯pala	Yellow Tang	0.07	0.05	0.86	0.040	3.08	3.25
Abudefduf abdominalis	mamo	Sargent Major	1.36	0.09	0.43	0.039	8.14	6.41
Scarus psittacus	uhu	Palenose Parrotfish	0.09	0.04	0.71	0.029	3.69	2.82
Chromis ovalis		Oval Chromis	0.26	0.07	0.43	0.028	10.94	4.60
Chaetodon miliaris	lauwiliwili	Milletseed Butterflyfish	0.11	0.05	0.57	0.026	4.65	3.25

* IRD = index of relative dominance (biomass x frequency of occurrence).

Table A-5: Top ten species observed on transects at Molokini Shoal MLCD (N = 8)

Taxon Name	Hawaiian Name	Common Name	Number (No./ha 1000)	xBiomass (t/ha)	Freq	IRD*	% number	% biomass
Melichthys niger	humuhumu'el'ele	Black Durgon	0.69	0.31	0.88	0.270	10.06	29.15
Naso lituratus	umaumalei	Orangespine Unicornfish	1.05	0.18	0.88	0.160	15.31	17.30
Lutjanus kasmira	ta'ape	Bluestripe Snapper	0.18	0.04	0.75	0.033	2.62	4.14
Melichthys vidua	humuhumuhi'ukole	Pinktail Durgon	0.07	0.02	0.63	0.013	1.02	2.04
Caranx ignobilis	'ulua aukea	Giant White Trevally	0.01	0.09	0.13	0.012	<0.01	8.76
Ctenochaetus strigosus	kole	Goldring Surgeonfish	0.56	0.01	0.88	0.011	8.16	1.22
Cantherhines dumerilii	'o¯'ili	Barred Filefish	0.09	0.02	0.50	0.011	1.31	2.12
Chlorurus sordidus	uhu	Bullethead Parrotfish	0.07	0.02	0.63	0.009	1.02	1.42
Acanthurus nigrofuscus	ma¯i'i'i	Brown Surgeonfish	0.51	0.01	1.00	0.009	7.43	0.84
Acanthurus olivaceus	na'ena'e	Orangeband Surgeonfish	0.08	0.02	0.38	0.008	1.17	1.94

Table A-6: Top ten species observed on transects at Kahalu'u Beach Park (N = 2)

TaxonName	Hawaiian Name	Common Name	Number (No./ha x 1000)	Biomass (t/ha)	Freq	IRD*	% number	% biomass
Scarus psittacus	uhu	Palenose Parrotfish	0.32	0.07	1.00	0.066	9.76	17.24
Chlorurus sordidus	uhu	Bullethead Parrotfish	0.08	0.05	1.00	0.054	2.44	14.10
Zebrasoma flavescens	lau'i¯pala	Yellow Tang	0.28	0.03	1.00	0.034	8.54	8.93
Acanthurus olivaceus	na'ena'e	Orangeband Surgeonfish	0.16	0.03	1.00	0.031	4.88	8.12
Naso lituratus	umaumalei	Orangespine Unicornfish	0.12	0.03	1.00	0.026	3.66	6.85
Acanthurus triostegus	manini	Convict Tang	0.44	0.04	0.50	0.018	13.41	9.35
Melichthys niger	humuhumu'el'ele	Black Durgon	0.08	0.03	0.50	0.013	2.44	6.74
Rhinecanthus rectangulus	humuhumunukunukuapua'a	Reef Triggerfish	0.08	0.01	1.00	0.012	2.44	3.01
Novaculichthys taeniourus		Rockmover	0.24	0.01	0.50	0.007	7.32	3.87
Calotomus carolinus		Stareye Parrotfish	0.04	0.01	0.50	0.007	1.22	3.82

* IRD = index of relative dominance (biomass x frequency of occurrence).