THE EFFECTIVENESS OF A MARINE RESERVE ON THE DENSITY AND DIVERSITY OF REEF FISHES IN GUAM

By

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Title: The Effectiveness of a Marine Reserve on the Density and Diversity of Reef Fishes in Guam

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The effectiveness of a marine reserve was investigated within 2.25 yr before, and within 1.5 yr after its implementation in 2001. Data from fish surveys within the Piti Reserve in Guam, Mariana Islands were analyzed to determine if fish density and diversity were influenced by reserve protection. Visual surveys within 50 m x 5 m transects and 30-min interval timed-swim counts were conducted within different habitats on the forereefs (two at the 6.1 m, two at the 9.1 m, two at the 12.2 m., and two at the 15.2 m depths) and reef flats (seagrass, coral/rubble, and channel). A paired t-test, Wilcoxin signed rank test, and Scheirer-Ray-Hare two-way ANOVA for ranked data, where appropriate, were used to determine density responses to protection. Shannon diversity indices were calculated to compare species richness and abundance, and evenness values were calculated to determine how equally abundant species are within the reserve.

The results suggest that density and diversity of reef fishes increased within the brief period of reserve protection. Three species, *Acanthurus nigricauda* and *Naso* *lituratus* (both Acanthuridae), and *Parupeneus multifasciatus* (Mullidae) responded significantly to protection in the forereef habitat. Diversity was significantly higher on the forereef habitat, with species distributed more evenly over time. Lastly, the data indicate that protection may have short-term effects upon certain species; long-term monitoring in permanent reserves is needed to evaluate the overall effects of protection.

TO THE OFFICE OF GRADUATE SCHOOL AND RESEARCH

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INTRODUCTION

The effectiveness of marine reserves as a fisheries management and conservation strategy has received considerably more attention within the last few years. This interest arises not just from the realization that conventional fisheries management, which is designed for single species, may be unsuited for tropical regions (Roberts and Polunin 1991, Rudd et al. 2002, Halpern 2003), but also from the understanding that there are potential problems and obstacles in implementing, designing, and selecting marine reserves because of social or political processes (Halpern 2003, Roberts et al. 2003). When reserves are considered or have been used as a management option, questions regarding the goals of a reserve usually arise. These goals are usually to protect stocks and habitats, maintain biodiversity, restore ecosystem balance, and support fisheries by contributing towards the replenishment of larvae and adults to adjacent fished areas (Florida Forum Report 1997, Nowlis and Roberts 1999, Roberts et al. 2001, Bergen and Carr 2003, Lubchenco et al. 2003, Hooker and Gerber 2004, Williamson et al. 2004).

The number of empirical studies involving marine reserves has increased within the last ten years (Willis et al. 2003, Gell and Roberts 2003). The majority of these studies focuses upon the abundance of stocks within reserves and to a lesser extent upon the effects of spillover and larval export from reserves (Polunin and Roberts 1993, Rakitin and Kramer 1996, Russ and Alcala 1996, Wantiez et al. 1997, Edgar and Barrett 1999, Roberts et al. 2001, National Research Council (NRC) 2001, Rudd et al. 2002, Halpern 2003, Willis et al. 2003, Gell and Roberts 2003, Palumbi 2003). Despite the increase in studies, criticism has been raised about the efficacy of marine reserves as a management strategy (Halpern 2003, Gell and Roberts 2003). Scientists have questioned whether the management goals for a marine reserve are clearly defined, or if a reserve has been successful in fulfilling its management goals (Tupper 2002, Jameson et al. 2002, Willis et al. 2003, Botsford et al. 2003, Bergen and Carr 2003). Many reserves have been created through political or social processes, but few have been created or designed with an understanding of how reserves are affected by biological factors, how they affect other biological factors within and outside of reserves, and how biological goals can be met more effectively (Roberts et al. 2003, Halpern 2003, Gell and Roberts 2003).

Many previous studies have demonstrated the effectiveness of marine reserves on the abundance of fishes (Alcala 1988, Russ and Alcala 1989, 1994, 1998, Polunin and Roberts 1993, Rakitin and Kramer 1996, Wantiez et al. 1997, Edgar and Barrett 1999, Chiappone et al. 2000, Roberts et al. 2001, Walmsley and White 2003, Williamson et al. 2004, Nardi et al. 2004). These studies have shown significant increases for certain families and species of fishes within reserves as compared to non-reserve areas. The quality of empirical evidence supporting the use of reserves is often questioned, however (Gell and Roberts 2003, Bergen and Carr 2003, Halpern 2003, Edgar et al. 2004). Many studies have problems with replication, lack of control sites, and a lack of time series data collection (Willis et al. 2003, Halpern 2003, Edgar et al. 2004). In regard to fisheries benefits, studies on the effects of spillover are emerging from a wide range of habitats and fisheries, but studies of larval export remain limited (Palumbi 2003, Gell and Roberts 2003). Critics argue that empirical evidence for benefits to fisheries is merely speculative, and conventional approaches can achieve the same ends (Bergen and Carr 2003). Tupper (2002) pointed out that the use of conventional approaches, such as bag and slot limits, has resulted in size increases of red and black drum across the entire fisheries on the east coast of Florida. Furthermore, he stated that the establishment of the marine reserves in the Merritt Island National Wildlife Refuge in east Florida has resulted in trophy size fish only within a limited area outside their boundaries.

Other factors that are obstacles for the success of marine reserves are pollutants and sediments from atmospheric, terrestrial, and oceanic sources. If reserves are located in areas where they are subject to numerous and uncontrollable stressors, the environment can be degraded and protection compromised (Jameson et al. 2002). Insufficient community and state capacity for the support and management of reserves are also important determinants that affect reserve success (Jameson et al. 2002, Rudd et al. 2002). When communities collectively support the reserves and government agencies provide the necessary financing, monitoring, enforcement, and technical expertise, reserves will have the greatest potential in achieving their goals (Jameson et al. 2002, Rudd et al. 2002).

Because marine reserve research is still in its infancy, there has been little scientific basis to assess the effectiveness of various reserve designs and few quantitative approaches to monitor reserves (Botsford et al. 2003, Hooker and Gerber 2004). For this reason, many models and criteria for the design of marine reserves have appeared recently (Willis et al. 2003). These models and criteria can help resource managers better design reserves so goals may be attained (Nowlis and Roberts 1999, Gerber et al. 2002, Botsford et al. 2003, Gaines et al. 2003, Airamé et al. 2003, Carr et al. 2003, Gerber et al. 2003, Roberts et al. 2003, Leslie et al. 2003, Neigel 2003, Shanks et al. 2003, Stewart et al. 2003, Hooker and Gerber 2004, Micheli et al. 2004a). Resource managers need to determine whether marine reserves are the best management strategy or if existing reserves can be better managed in order to reach their goals (Tupper 2002). If reserves are not a viable management option, they are either not worth implementing or need to be restructured (Jameson et al. 2002).

In 1988, a study was conducted by the Guam Department of Agriculture's Division of Aquatic and Wildlife Resources (DAWR), the local government agency responsible for controlling and regulating the fisheries, to assess the feasibility of delineating 20% of Guam's coast as marine reserves. The study assessed sixty sites, and the following general criteria were used to select the marine reserves sites (Guam DAWR 2000e): (1) the reserves should be established in areas that have broad habitat diversity; (2) the areas must be large enough to serve as a resource refuge and to accommodate the needs of the prospective users without focusing overuse of the areas and creating negative environmental impact; (3) the areas should be equally accessible to residents as well as visitors; (4) the boundaries must be well defined and easily recognized inside and outside the reserves; (5) the area should provide protection for spawning fishes; (6) the areas should benefit recreational users and fishers; (7) conflicts of interest between user groups should be kept to a minimum, while surveillance and enforcement are maximized; and (8) safety must be a major factor in selecting areas for reserves.

From these criteria, DAWR proposed initially five permanent and four rotating reserves in 1993. After public comments and written testimonies from hearings, DAWR removed the four rotating reserves. In 1995, DAWR held another set of public hearings. During this process, one community asked to reinstate a rotating reserve and to change its status to that of a permanent reserve. This brought the number of permanent reserves to six. One of the reserves was removed by the Twenty–Fourth Guam Legislature, and five reserves, which represent approximately 11.5% of the Guam's coast, were eventually established through Public Law 24-21 on May 17, 1997. Because of legal issues (Corbett 1998), enforcement of the reserves was delayed until January 2001.

Prior to the implementation of the marine reserves, the management of fishes on Guam involved a conventional approach that included restrictions on gear, such as mesh sizes and lengths of nets, and the use of destructive methods, such as poisons or chemicals. There were no restrictions on fish sizes, catch limits, spearfishing, or gill netting. The use of these limited conventional approaches has not been successful on Guam. Evidence for this is provided by the Guam DAWR inshore fisheries creel survey. From 1985 to 1997, annual inshore fishery harvests declined by approximately 49%, from 88.6 metric tons to 45.6 metric tons, and catch per unit effort declined approximately 74%, from 0.72 kg/gear-hour (gh) to 0.19 kg/gh (Guam DAWR 2000a–m).

The conventional management approach was re-evaluated by DAWR, and the use of marine reserves was selected as an alternative option. One factor leading to this decision was the idea that enforcement would be easier in an area completely closed or partially closed to fishing, as compared to implementing size or catch limits on fishes where enforcement officers would have to inspect each fisher's catch for compliance. Also, reserves were viewed as an efficient way to manage fisheries while preserving stocks, biodiversity, and coral reef ecosystems.

With the establishment of marine reserves on Guam, the opportunity exists to evaluate the role of marine reserves as an alternative management approach to reef fisheries. Thus far, two studies (M.H. Tupper pers. comm. 2001, Tsuda and Donaldson 2004) have been conducted on the abundance and diversity of fishes within reserves, but these studies have little or no baseline data that may be used for comparison. To improve data quality, studies should take measurements before and after the creation of a reserve (Halpern 2003).

The present study compares data from a reserve and non-reserve site that was collected within 2.25 yr before implementation with that collected within 1.5 yr after implementation. I addressed the following question: Is there a difference in the density and diversity of fishes within a marine reserve compared to a non-reserve area?

MATERIALS AND METHODS

Study Area

Guam, the southernmost and largest of the Marianas Islands, is a U.S territory located in the western Pacific Ocean at 13°28' N 144°45' E. The island is approximately 48 km long and 6 to 14 km wide, with an estimated land area of 560 km² (Amesbury and Callaghan 1981). The climate is tropical, and easterly trade winds occur throughout half of the year. Northern Guam, which contains a freshwater lens, is relatively flat with uplifted limestone that rises to 259 m (Amesbury and Callaghan 1981). Southern Guam is dominated by steep sloping mountains and hills that reach a maximum elevation of 405 m (Amesbury and Callaghan 1981). Fringing reefs surround most of the island and vary in width from 10 to more than 100 m. Barrier reefs enclose a shallow and deep lagoon at the southern and central western part of the island, respectively.

Study Sites

The Piti Reserve, the experimental site, (Figure 1) is a no-take reserve with an area of approximately 3.64 km² (D.R. Burdick pers. comm. 2004) that is located on the western (leeward) side of the island. The reef flat is developed irregularly and ranges in width from 72 m on the western end to 978 m on the eastern end (Randall and Eldredge 1976). A narrow outer reef flat, resembling a barrier reef with a shallow lagoon, encloses the eastern end of the reserve; a number of deep pools and a natural sink (karst formation) approximately 9.1 to 9.7 m in depth (Tsuda and Donaldson 2004) encircle the eastern end. The western end consists of a channel, with much of the reef flat around it exposed

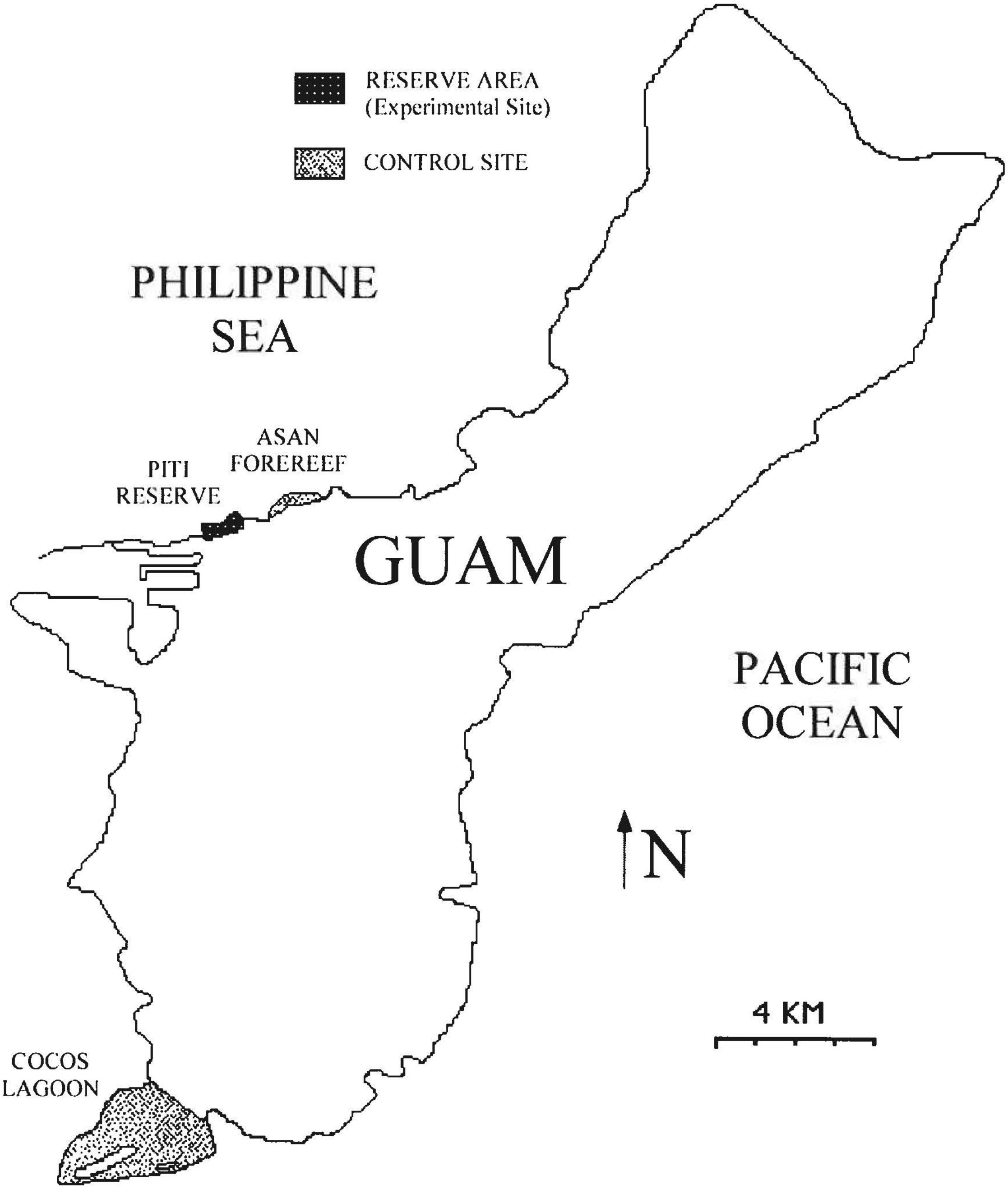

Figure 1. Map of experimental and control sites.

during low tide. Sand mixed with silt, clay, and rubble dominates the inner reef flat, while reef rock with scattered boulders dominates the outer reef flat. Corals are absent to moderately abundant, and seagrasses are distributed along the inner reef flat (NOAA National Centers for Coastal Ocean Science (NCCOS) 2005). The forereef slope consists mainly of rocks and boulders scattered throughout the area, and little live coral cover. The angle of the forereef slope is steep with very little distance between depths (Randall and Eldredge 1976).

Cocos Lagoon, located at the southern end of the island, is the control site for the reef flat component of this study. The lagoon is triangular in shape and includes a shallow area enclosing a smaller, deeper area. A barrier reef surrounds the lagoon, while an irregularly developed fringing reef extends from shore. The area of the lagoon and barrier reef is 10 km^2 (Randall and Eldredge 1976). Sand mixed with rubble and patches of reef rock dominate the shallow lagoon area. Sand and rubble dominate the fringing reef, while reef rock and rubble dominate the barrier reef. Corals are absent to moderately abundant on both the fringing and barrier reef, and scattered to moderately abundant in the shallow lagoon area. Seagrasses occur mostly on the inner fringing reef, and are scattered to moderately abundant on the barrier reef and shallow lagoon, especially where the lagoon borders the fringing reef (Randall and Eldredge 1976, NOAA National Centers for Coastal Ocean Science (NCCOS) 2005).

The Asan forereef slope, the control site for the forereef slope component of this study, is on the western side of the island adjacent to the Piti Reserve. The site is similar to the forereef slope of the preserve except for fewer boulders scattered throughout the area (Randall and Eldredge 1976).

Transects

Belt transects, 50 m x 5 m, were laid out within Piti Reserve, Asan forereef slope, and Cocos Lagoon. Eight belt transects (two at the 6.1 m, two at the 9.1 m, two at the 12.2 m., and two at the 15.2 m depths) were laid out on each of the forereef slopes of the Piti Reserve and Asan. Eight transects (three within the seagrass zone, three within the coral and rubble zone, and two within the reef channel) were laid out on each of the reef flats of the Piti Reserve and Cocos Lagoon. The transects were sampled from 1998 (November 6, 10, 13, and December 14, 17) to 1999 (June 21, 29, and September 8, 16), and from 2001 (June 19, 28, and July 3, 17, 26) to 2002 (March 7, April 2, 25, and May 22, 24, 30.

Two to four snorkelers or scuba divers, who deployed a measuring tape secured at both ends to delineate the length of the transect, surveyed it. Fishes were counted along the transect line by two observers, one to the left and the other to the right of the transect line. Concurrently, a new transect line was laid by a third and fourth observer while the other observers counted fishes along the first transect line. Then, the first two observers moved on to the second transect and repeated the counting process while the tape from the first transect was retrieved and, if necessary, deployed again. This process continued until all transects were laid and all fish counts completed.

Observers swam slowly at a constant pace and recorded the number of individuals of each species observed from each of ten families of fishes (Table 1). These species were chosen because they are targeted commonly by fishers, while a few, such as *Bolbometopon muricatum* (Scaridae) and *Cheilinus undulates* (Labridae), were based upon rare occurrences in reported catches (Guam DAWR 2000a-n). Juvenile and adult scarids that could not be identified were included in the unidentified scarid category (Table 1). Fish species identifications followed Myers (1999).

The transects were separated end to end by at least 5 m. In addition to the placement of the markers (PVC pipes), Global Positioning System (GPS) coordinates were recorded, photographs were taken of landmarks, and maps were made for subsequent use in relocating transect sites.

Interval Timed-Swim Counts

Interval counts, which involved recording the number of food fish species, butterflyfishes, and individuals per 30-min observation period, were conducted on the reef flats and the forereef slopes of each site. For the purposes of the present study, food fish species are defined as those species caught for human consumption, excluding *Selar crumenophthalmus* (Carangidae) and species within the family Siganidae (Guam DAWR 2000a-n). Four interval counts (two between the 6.1–9.1 m and two between the 12.2-15.2 m depths) were conducted between two transect sites along the forereef slopes at the Piti Preserve and Asan sites. Three interval counts (one within the seagrass zone, one within the coral and rubble zone, and one within the reef channel) were conducted on each of the reef flats of the Piti Preserve and Cocos Lagoon. These counts occurred from 1998 (November 24, 27, and December 3, 17) to 1999 (January 28, June 21, 29, and September 8), and from 2001 (August 28, November 6, and December 6) to 2002 (March 7, April 2, May 9, and June 5, 6, 20).

Table 1. List of families and species censused in the study.

Family	Species	Family	Species
Acanthuridae	*Acanthurus blochii*	Lutjanidae	*Lutjanus fulvus*
	Acanthurus lineatus		*Lutjanus gibbus*
	Acanthurus nigricans		*Lutjanus monostigmus*
	Acanthurus nigricauda		
	Acanthurus olivaceous		
	Acanthurus triostegus	Mugilidae	*Moolgarda seheli*
	Acanthurus xanthopterus		*Ellochelon vaigiensis*
	Naso lituratus		
	Naso unicornis		
		Mullidae	*Mulloidichthys flavolineatus*
			Parupeneus barberinus
Carangidae	*Caranx ignobilis*		*Parupeneus bifasciatus*
	Caranx melampygus		*Parupeneus multifasciatus*
	Caranx papuensis		
	Caranx sexfasciatus		
		Scaridae	*Bolbometopon muricatum*
			Cetoscarus bicolor
Kyphosidae	*Kyphosus cinerascens*		*Chlorurus frontalis*
	Kyphosus vaigiensis		*Chlorurus microrhinos*
			Chlorurus sordidus
			Hipposcarus longiceps
Labridae	*Cheilinus fasciatus*		*Scarus altipinnis*
	Cheilio inermis		*Scarus globiceps*
	Cheilinus trilobatus		*Scarus psittacus*
	Cheilinus undulatus		*Scarus rubroviolaceous*
	Hemigymnus melapterus		*Scarus schegeli*
	Oxycheilinus unifasciatus		Unidentified scarids (Group)
Lethrinidae	*Lethrinus harak*	Serranidae	*Cephalopholis argus*
	Lethrinus obsoletus		*Cephalopholis urodeta*
	Lethrinus xanthochilus		*Epinephelus fasciatus*
	Monotaxis grandoculus		*Epinephelus merra*
			Epinephelus polyphekadion

Data Analyses

A two-tailed paired t-test was used to compare fish densities within sites, families, and species over time (Sokal and Rohlf 1995). A two-way analysis of variance (ANOVA) (Sokal and Rohlf 1995) was the preferred method to compare fish densities between sites, families, species, and time, but the assumptions of the ANOVA could not be met. When the assumptions of the ANOVA were not met, even after square root and log transformations, the non-parametric Wilcoxon signed rank test and Scheirer-Ray-Hare (SRH) two-way ANOVA for ranked data were used to analyze densities (Sokal and Rohlf 1995). Statview 5.0 Statistical System for PC (Abacus Concepts 1998) was used to calculate the two-tailed paired t-test and the Wilcoxon signed rank test, while BIOMstat 3.3 Statistical Software for Windows (Rohlf and Slice 1999) was used to calculate the Scheirer-Ray-Hare (SRH) two-way ANOVA for ranked data.

Species richness (the number of species, S) and abundance (total abundance of all species, N) were recorded within each site before and after reserve implementation. For determinations of species diversity, a Shannon diversity index (H') was calculated to compare species richness and abundance over time in each study site (Magurran 1988). Then, diversity evenness (E) values were calculated to determine how equally abundant species are within each of the study sites (Magurran 1988). Finally, a t-test was used to compare differences in diversities over time (Magurran 1988).

RESULTS

Density

Overall densities within Asan forereef slope, Cocos Lagoon, Piti forereef slope, and Piti reef flat before and after reserve implementation varied at each site (Figure 2). After reserve implementation, higher abundances were observed within the reserve sites than the non-reserve sites (Figure 2). Asan forereef slope was the only site that had a significant decrease after reserve implementation (paired t-test, $t = 2.59$, $df = 7$, $p = .036$) (Figure 2). There was a significant interaction between location and time (SRH two-way ANOVA, $H = 9.12$, $df = 3$, $p = 0.028$). However, no significant difference was detected for time (Table 2).

Densities of families within Asan forereef slope varied before and after reserve implementation (Figure 3). Lower densities were recorded for all families except the Labridae after implementation, with the Scaridae having the highest density and the Labridae having the lowest density (Figure 3). The Mullidae was the only family that showed a significant difference in density after reserve implementation (paired t-test, $t = 3.00$, $df = 7$, $p = 0.0199$) (Figure 3). *Chlorurus sordidus* was the most abundant species at the Asan forereef slope before and after reserve implementation (Figure 4). All but three species were observed to have lower densities after implementation (Figure 4). Analysis of *Cephalopholis urodeta* (paired t-test, $t = 2.39$, $df = 7$, $P = 0.048$) and *Parupeneus multifasciatus* data (paired t-test, $t = 3.00$, $df = 7$, $p = 0.020$) indicated that they were the only species with significant differences in density before and after implementation (Figure 4). There were significant differences detected between family

(SRH two-way ANOVA, H = 1.08, df = 4, p = 0.0003) and time (SRH two-way ANOVA, H = 7.79, df = 1, p = 0.0053) within the Asan forereef slope (Table 3). The species factor (SRH two-way ANOVA, H = 51.46, df = 13, p = 0.000001) and the interaction of species and time (SRH two-way ANOVA, H = 22.88, df = 13, p = 0.0431) were significantly different after implementation (Table 4).

Within Cocos Lagoon, the Scaridae appears to predominate during both time periods (Figure 5). Unidentified scarids, followed by *Chlorurus sordidus*, were the most abundant species recorded within the lagoon (Figure 6). No significant differences existed within families (Figure 5) and species (Figure 6) after reserve implementation. Significant differences did exist between family (SRH two-way ANOVA, H = 18.18, df = 6, p = 0.0058), time (SRH two-way ANOVA, H = 3.98, df = 1, p = 0.0459) and the interaction of family and time (SRH two-way ANOVA, H = 12.64, df = 6, p = 0.0491) (Table 5). Likewise, species (SRH two-way ANOVA, H = 57.41, df = 15, p = 0.0000007) and time (SRH two-way ANOVA, H = 4.71, df = 1, p = 0.0301) differed significantly after implementation (Table 6).

There was a preponderance of individuals from the families Acanthuridae and Scaridae within Piti forereef slope after reserve implementation (Figure 7). Of the two families, significantly higher densities were detected within the Acanthuridae (paired t-test, t = -5.12, df = 7, p = 0.0014) (Figure 7). The three most abundant species after implementation were *Acanthurus nigricauda,* followed by *Naso lituratus* and *Naso nigricans* (Figure 8). Of these three species, densities were significantly higher within *Acanthurus nigricauda* (Wilcoxin signed rank, tied Z = -2.52, n = 8, tied p = .012) and *Naso lituratus* (paired t-test, t = -3.01, df = 7, p = 0.020) (Figure 8). Similarly, the density of *Parupeneus multifasciatus* was significantly higher (paired t-test, t = 2.38, df = 7, p = 0.049) (Figure 8). No significant differences were detected with the other species (Figure 8). There were significant differences between family (SRH two-way ANOVA, H = 23.93, df = 4, p = 0.00008) and the interaction of family and time (SRH two-way ANOVA, H = 14.73, df = 4, p = 0.0053) (Table 7). Species (SRH two-way ANOVA, H = 44.84, df = 8, p = 0.0000003) and time (SRH two-way ANOVA, H = 8.12, df = 1, p = 0.0044) factors exhibited significant effects after reserve implementation (Table 8).

The Scaridae predominated within Piti reef flat before and after reserve implementation (Figure 9). There were no significant differences detected within the Scaridae or other families (Figure 9). Unidentified scarids were the most abundant group after reserve implementation, although no significant differences were found within any of the species (Figure 10). Significant differences did exist between the factors family (SRH two-way ANOVA, H = 14.15, df = 3, p = 0.0027) (Table 9) and species (SRH two-way ANOVA, H = 32.56, df = 10, p = 0.0003) (Table 10) after reserve implementation.

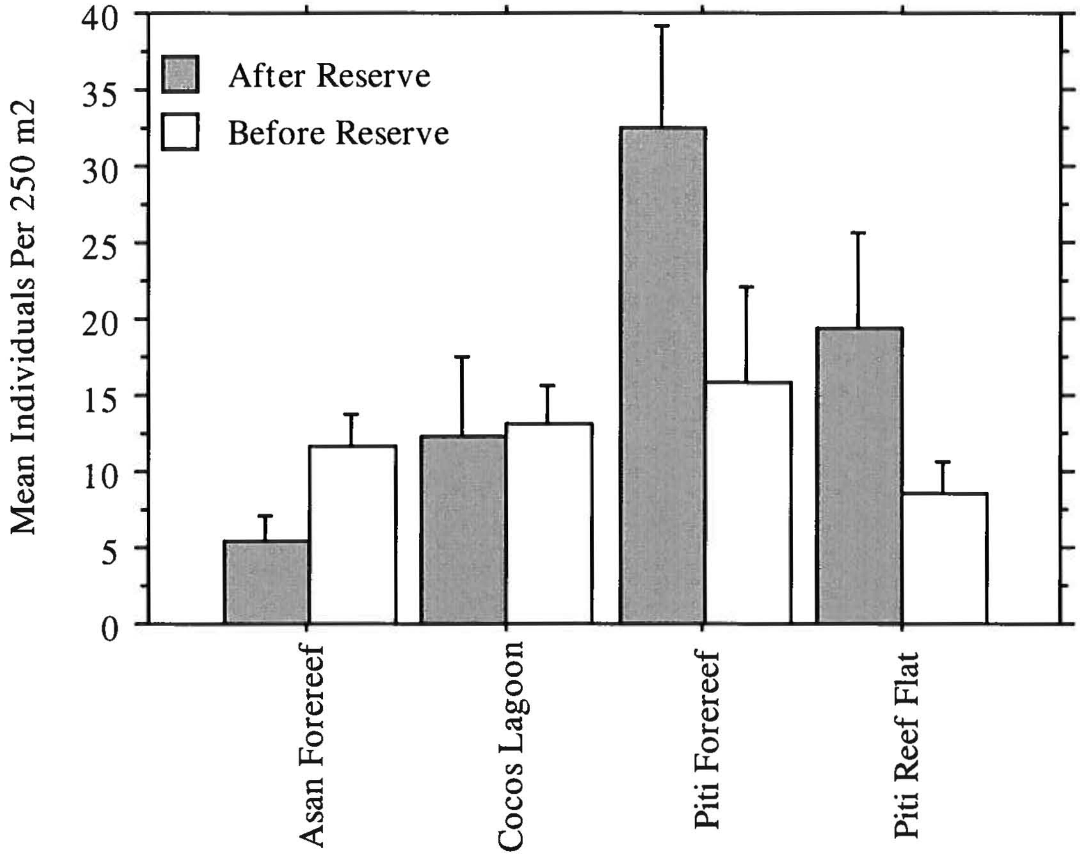

Figure 2. Mean densities (individuals per 250 m^2) +/- 1 standard error of reef fishes before and after reserve implementation within Asan forereef slope, Cocos Lagoon, Piti forereef slope, and Piti reef flat.

Table 2. Scheirer-Ray-Hare two-way analysis of variance (ANOVA) for ranked data; factors are location (Asan forereef slope, Cocos Lagoon, Piti forereef slope, and Piti reef flat) and time (before and after reserve implementation) with n = 8 transects. * Denotes significant difference.

Source	**SS**	**df**	**MS**	**H**	**p**
Location	2547.88	3	849.30	7.35	0.0616
Time	9.00	1	9.00	0.03	0.8720
Location x Time	3163.13	3	1054.38	9.12	0.0277*
Within	16120.00	56	287.86		
Total	21840.00	63	346.67		

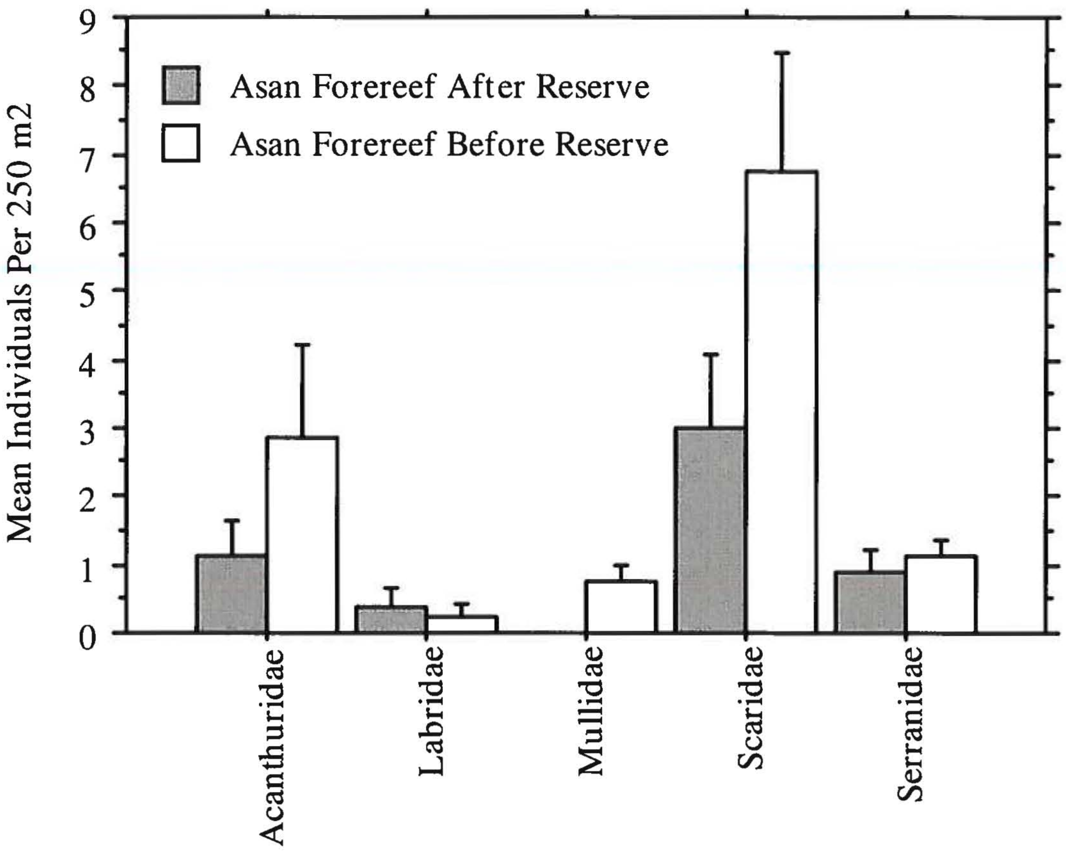

Figure 3. Mean densities (individuals per 250 m²) +/- 1 standard error of five families of reef fishes within Asan forereef slope before and after reserve implementation.

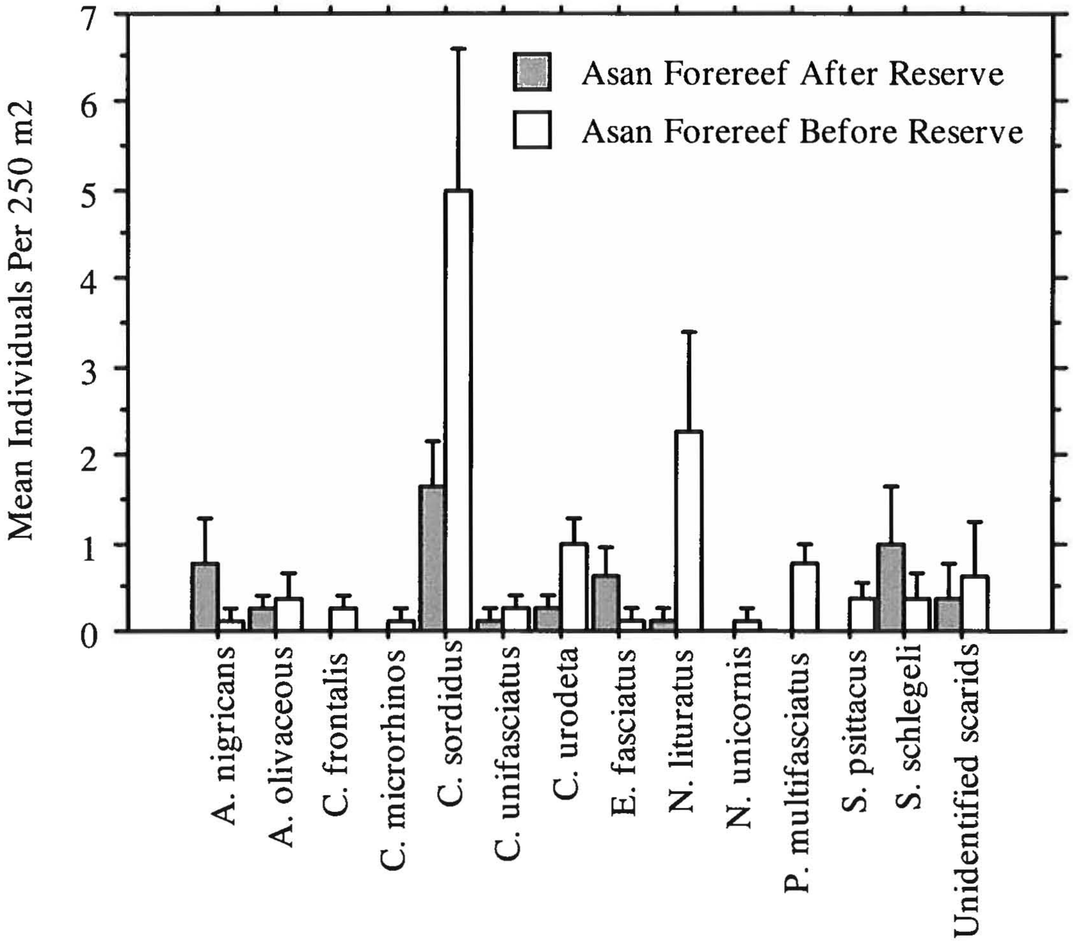

Figure 4. Mean densities (individuals per 250 m²) +/- 1 standard error of fourteen species of reef fishes within Asan forereef slope before and after reserve implementation.

Table 3. Scheirer-Ray-Hare two-way ANOVA for ranked data; factors are family and time (before and after reserve implementation) within Asan forereef slope with n = 8 transects. * Denotes significant difference.

Source	**SS**	**df**	**MS**	**H**	**p**
Family	11382.13	4	2845.53	1.0780	0.0003*
Time	4205.00	1	4205.00	7.7870	0.0053*
Family x Time	1778.88	4	444.72	3.2942	0.5098
Within	25294.00	70	361.34		
Total	42660.00	79	540.00		

Table 4. Scheirer-Ray-Hare two-way ANOVA for ranked data; factors are species and time (before and after reserve implementation) within Asan forereef slope with n = 8 transects. * Denotes significant difference.

Source	**SS**	**df**	**MS**	**H**	**p**
Species	216139.75	13	16626.13	51.46	0.000001*
Time	15711.50	1	15711.50	3.74	0.0531
Species x Time	96108.25	13	7392.94	22.88	0.0431*
Within	608640.50	196	3105.31		
Total	936600.00	223	4200.00		

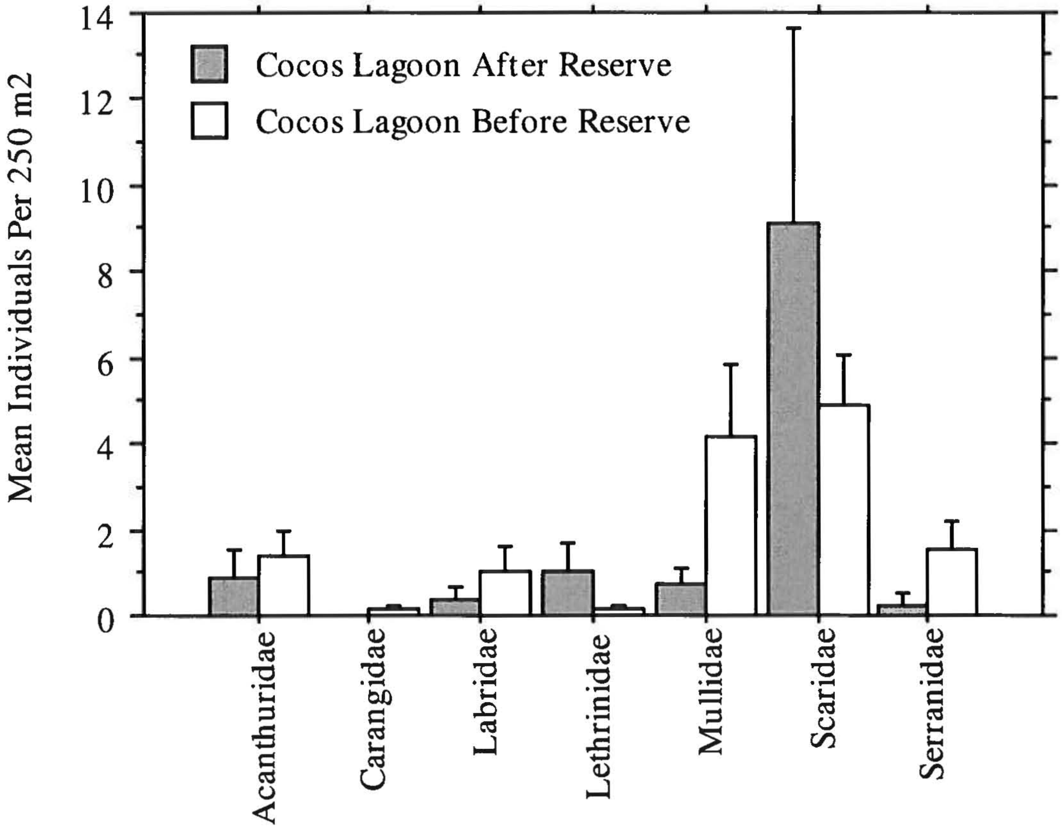

Figure 5. Mean densities (individuals per 250 m²) +/- 1 standard error of seven families of reef fishes within Cocos Lagoon before and after reserve implementation.

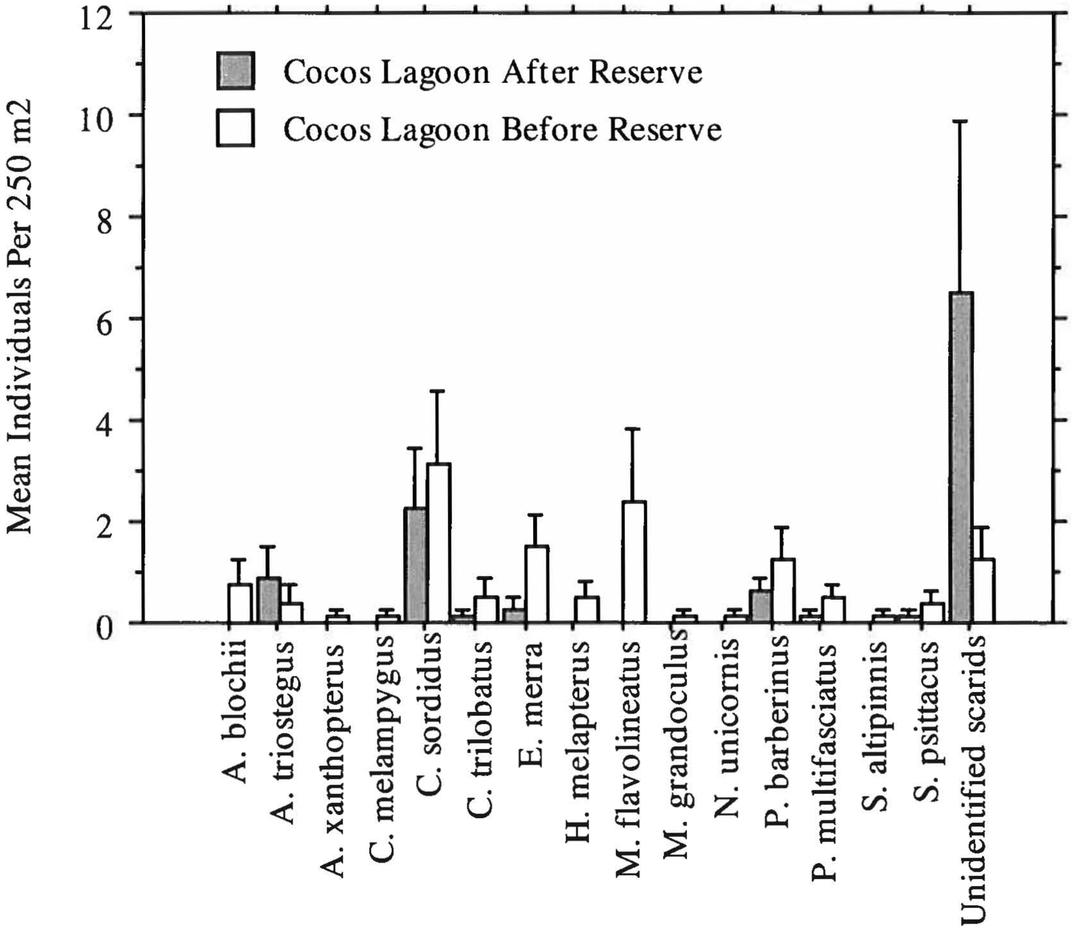

Figure 6. Mean densities (individuals per 250 m²) +/- 1 standard error of sixteen species of reef fishes within Cocos Lagoon before and after reserve implementation.

Table 5. Scheirer-Ray-Hare two-way ANOVA for ranked data; factors are family and time (before and after reserve implementation) within Cocos Lagoon with n = 8 transects. * Denotes significant difference.

Source	**SS**	**df**	**MS**	**H**	**p**
Family	19176.00	6	3196.00	18.18	0.0058*
Time	4201.75	1	4201.75	3.98	0.0459*
Family x Time	13332.25	6	2222.04	12.64	0.0491*
Within	80358.00	98	819.98		
Total	117068.00	111	1054.67		

Table 6. Scheirer-Ray-Hare two-way ANOVA for ranked data; factors are species and time (before and after reserve implementation) within Cocos Lagoon with n = 8 transects. * Denotes significant difference.

Source	**SS**	**df**	**MS**	**H**	**p**
Species	314742.63	15	20982.84	57.41	0.0000007*
Time	25800.39	1	25800.39	4.71	0.0301*
Species x Time	109782.23	15	7318.82	20.02	0.1710
Within	947754.75	224	4231.05		
Total	1398080.00	255	5482.67		

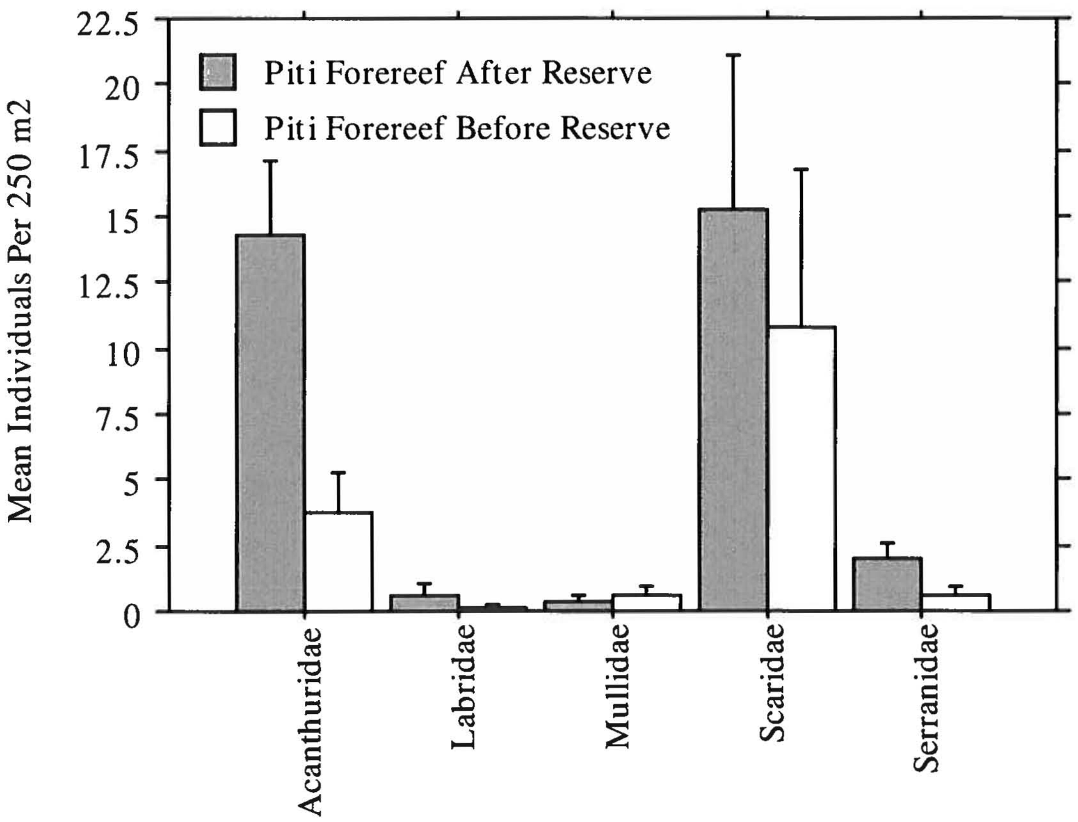

Figure 7. Mean densities (individuals per 250 m^2) +/- 1 standard error of five families of reef fishes within Piti forereef slope before and after reserve implementation.

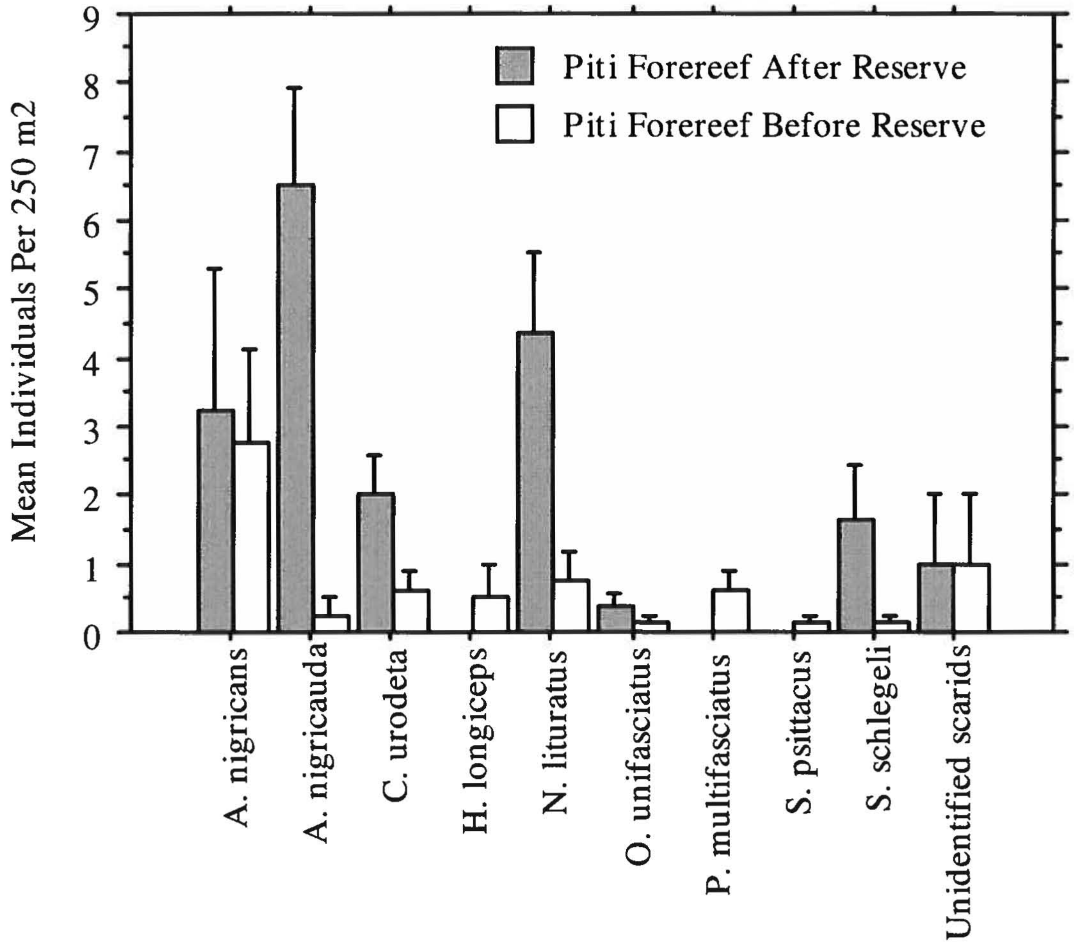

Figure 8. Mean densities (individuals per 250 m^2) +/- 1 standard error of nine species of reef fishes within Piti forereef slope before and after reserve implementation.

Table 7. Scheirer-Ray-Hare two-way ANOVA for ranked data; factors are family and time (before and after reserve implementation) within Piti forereef slope with n = 8 transects. * Denotes significant difference.

Source	**SS**	**df**	**MS**	**H**	**p**
Family	12924.63	4	3231.16	23.93	0.00008*
Time	1862.45	1	1862.45	3.45	0.0633
Family x Time	7956.18	4	1989.04	14.73	0.0053*
Within	19916.75	70	284.53		
Total	42660.00	79	540.00		

Table 8. Scheirer-Ray-Hare two-way ANOVA for ranked data; factors are species and time (before and after reserve implementation) within Piti forereef slope with n = 8 transects. * Denotes significant difference.

Source	**SS**	**df**	**MS**	**H**	**p**
Species	78025.38	8	9753.17	44.84	0.0000003*
Time	14121.36	1	14121.36	8.12	0.0044*
Species x Time	24248.76	8	3031.09	13.94	0.0834
Within	132424.50	126	1050.99		
Total	248820.00	143	1740.00		

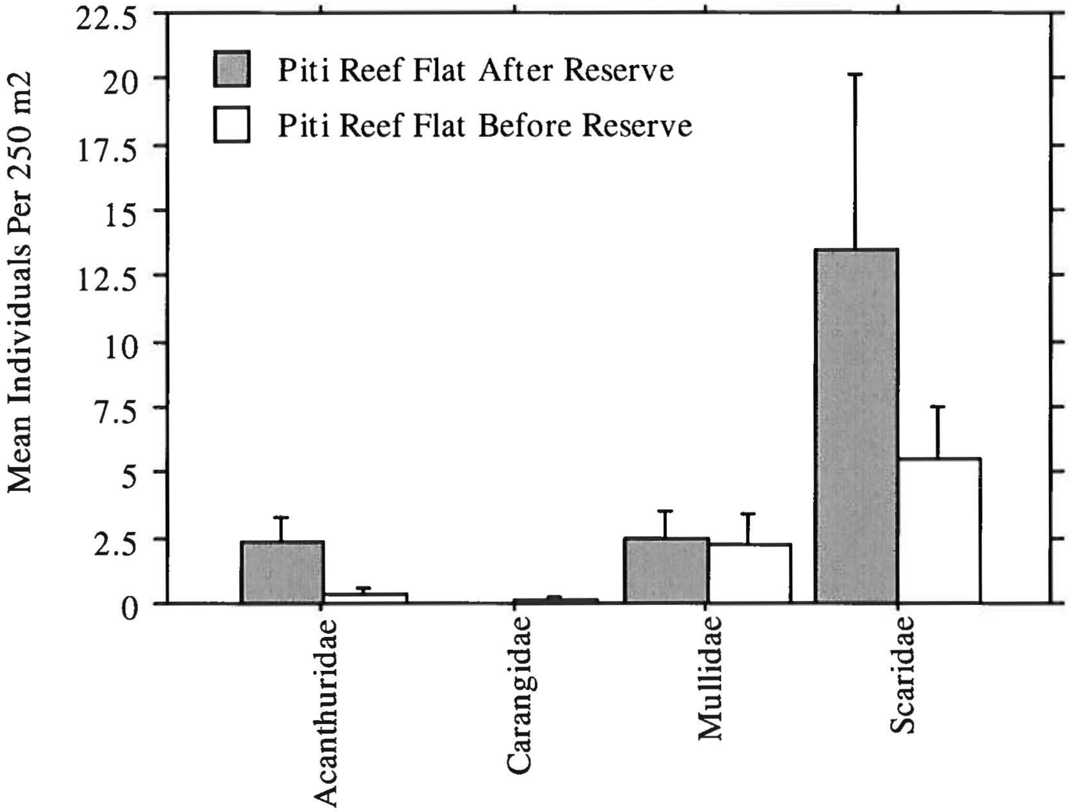

Figure 9. Mean densities (individuals per 250 m²) +/- 1 standard error of four families of reef fishes within Piti reef flat before and after reserve implementation.

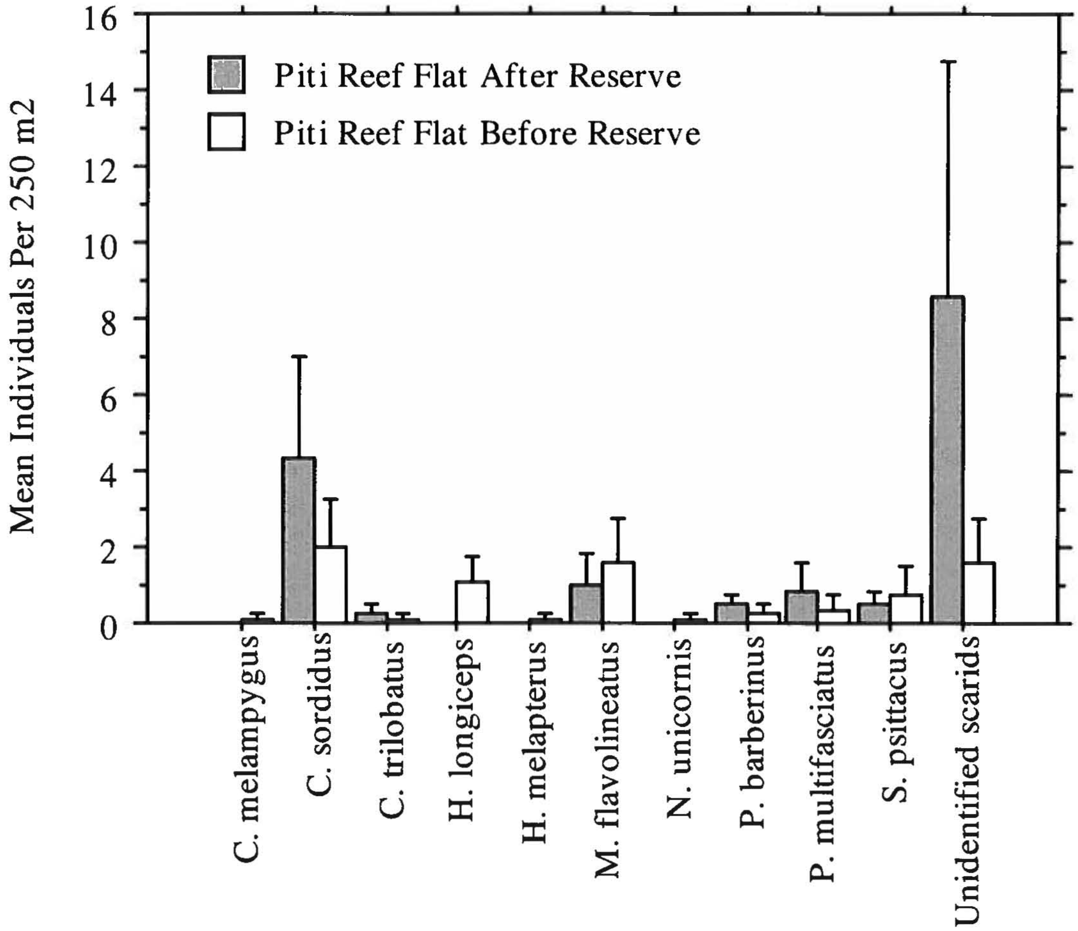

Figure 10. Mean densities (individuals per 250 m²) +/- 1 standard error of eleven species of reef fishes within Piti reef flat reef before and after reserve implementation.

Table 9. Scheirer-Ray-Hare two-way ANOVA for ranked data; factors are family and time (before and after reserve implementation) within Piti reef flat with n = 8 transects. * Denotes significant difference.

Source	**SS**	**df**	**MS**	**H**	**p**
Family	4903.88	3	1634.63	14.15	0.0027*
Time	175.56	1	175.56	0.51	0.4767
Family x Time	166.31	3	55.44	0.48	0.9233
Within	16594.25	56	296.33		
Total	21840.00	63	346.67		

Table 10. Scheirer-Ray-Hare two-way ANOVA for ranked data; factors are species and time (before and after reserve implementation) within Piti reef flat with n = 8 transects. * Denotes significant difference.

Source	SS	df	MS	H	p
Species	84522.63	10	8452.26	32.56	0.0003*
Time	23.27	1	23.27	0.009	0.9246
Species x Time	26640.85	10	2664.09	10.26	0.4178
Within	343113.25	154	2228.01		
Total	454300.00	175	2596.00		

Species Diversity

Species richness (the number of species, S) within Asan forereef slope, Cocos Lagoon, Piti forereef slope, and Piti reef flat varied before and after reserve implementation (Table 11). Species richness was greater within Asan forereef slope than within either reserve site prior to implementation (Table 11). After reserve implementation, Piti forereef slope had the greatest number of species (Table 11). Shannon diversity indices (H') were greater within Asan forereef slope and Cocos Lagoon than the reserve sites prior to implementation (Table 11). After implementation, diversity indices were higher within the reserves sites with the exception of Asan forereef slope (Table 11). A similar pattern for evenness (E) was seen between the four sites before and after reserve implementation (Table 11). Overall, species were distributed more evenly within the reserve sites than within the non-reserve sites (Table 11). Asan forereef slope (paired t-test, $t = 4.99$, $df = 1143$, $p < 0 .001$) and Piti forereef slope (paired t-test, $t = 4.99$, $df = 1549$, $p < 0 .001$) were significantly more diverse after implementation, while Cocos Lagoon was significantly less diverse (paired t-test, $t = 4.99$, $df = 653$, $p < 0 .001$), (Table 11).

Table 11. Species richness (S), total abundance of all species combined (N), species diversity (Shannon index, H'), and evenness (E) for Asan forereef slope, Cocos Lagoon, Piti forereef slope, and Piti reef flat before and after reserve implementation. The results of the paired t-test for analyzing the Shannon diversity index before and after reserve implementation are given. * Denotes significant difference.

Location	S	N	H'	E	t-test and p-value
Asan Forereef Before Reserve	53	604	2.89	.728	t = 4.99, df = 653, p < .001*
Asan Forereef After Reserve	55	656	3.24	.809	
Cocos Lagoon Before Reserve	42	276	3.16	.847	t = 8.75, df = 1143, p < .001*
Cocos Lagoon After Reserve	35	378	2.32	.652	
Piti Forereef Before Reserve	45	692	2.68	.705	t = 5.53, df = 653, p < .001*
Piti Forereef After Reserve	72	1193	3.06	.716	
Piti Reef Flat Before Reserve	41	314	2.80	.753	t = 1.56, df = 653, p > .05
Piti Reef Flat After Reserve	42	461	2.92	.780	

DISCUSSION

Protection influenced the density and diversity of reef fishes within the Piti Reserve. The question of whether there is a difference in the density and the diversity of reef fishes was addressed by analyzing data from the reserve and non-reserve areas within 2.25 yr before and within 1.5 yr after reserve implementation in 2001. Overall individuals, families, and species were analyzed for changes in density, while measures of species diversity and evenness were analyzed for changes in diversity (Magurran 1988). Previous studies on diversity addressed species richness only (Russ and Alcala 1998, Wantiez et al. 1997, Edgar and Barrett 1999, Garcia-Rubies and Zabala 1990 cited in Palumbi 2001). Because the effects of fishing on the abundance of individual species may differ from that upon families (Russ and Alcala 1998), the three levels (overall individuals, species, and families) of fish densities were analyzed to obtain a more complete and detailed picture of the marine reserve effects.

Four-to-seven families and nine-to-sixteen species from the four study sites were analyzed for changes in density over time. Differences were either undetectable or impossible to measure for other families and species, possibly because of their low frequency of occurrence in counts or patchy distributions, with fishes aggregating in particular areas. These possibilities contributed to statistical variability and a reduction in the power of tests (Edgar et al. 2004).

Two null hypotheses were tested in the present study. The first null hypothesis was that there is no difference in the density of fishes between a marine reserve and non-reserve area. The alternative hypothesis was that there is a difference in the density of fishes between a marine reserve and non-reserve area. The second null hypothesis was that there is no difference in the diversity of fishes between a marine reserve and non-reserve area. The alternative hypothesis was that there is a difference in the diversity of fishes between a marine reserve and non-reserve area. If marine reserves are an effective management strategy, there should have been an increase in fish density and diversity within the reserve. The density and diversity of fishes within the non-reserve area should have decreased or remained the same. In the Houtman Abrolhos Islands off the coast of Western Australia, three-fold and seven-fold increases in the abundance of *Plectropomus leopardus* in two marine reserves relative to non-reserve areas were recorded eight years after protection (Nardi et al. 2004). If my null hypotheses were not rejected, then fish density and diversity would not increase within the reserve. If my null hypotheses were rejected in favor of the alternative hypotheses, then fish density and diversity would have increased within the reserve.

The results indicate contrasting effects of the reserve upon the density and diversity of reef fishes. Reserve protection appears to have no effect upon individual fishes overall, but there was variation in family and species responses to protection. More than 50% of the families and species analyzed were not affected by protection. This outcome departed from the prediction of increased density. Observed abundances, however, were generally higher in the reserve areas after implementation than in non-reserve areas. Protection also appears to increase diversity within the forereef slope but not the reef flat of the reserve. Contrasting results for diversity were detected within the forereef slope and reef flat of the non-reserve areas. Temporal differences in diversity and the species factor within the forereef slope of the reserve are probably caused by responses of individual species to protection. Certain species may have exhibited stronger responses to protection over time rather than many species responding to protection (Micheli et al. 2004b). The increase in diversity on the forereef slope of the non-reserve area may indicate a spillover or recruitment effect (Halpern et al. 2004, Russ et al. 2004) evident only in terms of diversity, not abundance. The extent of the present study excludes analysis of these effects. Alternatively, larval recruits that originated elsewhere may have settled in the non-reserve area.

Life-history characteristics alone seemed insufficient to predict responses to protection (Russ and Alcala 1998). Short-lived, fast-growing species with strong recruitment usually respond to protection more rapidly than long-lived, slow-growing species with low recruitment (Palumbi 2001, 2002). *Scarus psittacus*, a fast growing species (Choat and Robertson 2002, Froese and Pauly 2005), did not show a response to protection. This may indicate that complex linkages in ecological communities, such as direct and indirect effects of species interactions, may influence responses to protection (Micheli et al. 2004a). Predator–prey interactions did not appear to affect the community structure of reef fishes within the reserve at the time of the study because of the high abundance of prey species as opposed to predator species. Jennings and Polunin (1997) indicated that predation upon herbivorous and invertebrate-feeding fishes by piscivorous fishes did not play an important role in structuring reef fish communities in Fiji. In the present study, the strong negative effects of protection on many species in the lower trophic groups, such as herbivores, may be explained by species interactions (i.e., competition) and vulnerability to over-fishing (Russ and Alcala 1998, Micheli et al. 2004a, b).

The degree of exploitation has some effect upon family and species responses to protection (Halpern and Warner 2002, Russ and Alcala 2003, Micheli et al. 2004b). Heavily targeted species appear to respond to reserve protection (Rowley 1994 cited in Halpern and Warner 2002, Russ and Alcala 2003), and biological responses may be rapid (Halpern and Warner 2002). Acanthurids on the forereef slope at the Piti Reserve responded quickly to protection. The Acanthuridae, in particular *Naso lituratus*, are highly targeted in the local fisheries (Guam DAWR 2000l–o, 2001). This may suggest that marine reserves are an effective strategy for rebuilding herbivorous species such as acanthurids over a short time period. Other studies of acanthurids provided similar results (Polunin and Roberts 1993, Rakitin and Kramer 1996, Wantiez et al. 1997). These studies documented increases in the abundance of acanthurids, but at four, eleven, and five years after reserve implementation. The previous two studies, however, lacked a before-after control-impact design (BACI) (Halpern et al. 2004). *Parupeneus multifasciatus* also responded to protection quickly on the forereef slope at the Piti Reserve, although it is not as highly targeted as *Naso lituratus* (Guam DAWR 2000l–o, 2001). Previous studies demonstrated that mullids make good candidates for reserve protection (Holland et al. 1993, Wantiez et al. 1997, Meyer et al. 2000). In contrast, mullids consistently declined in density over time at the Apo Reserve in the Philippines in the absence of fishing (Russ and Alcala 1998).

The Acanthuridae, *Naso unicornis* alone, and *Mulloidichthys flavolineatus* did not respond to protection on the reef flat of the reserve, despite the fact that *Naso unicornis* and the *Mulloidichthys flavolineatus* are more vulnerable than *Naso lituratus* in the local fisheries (Guam DAWR 2000l–o, 2001). One explanation for this outcome is that an underwater observatory located in a karst formation on the reef flat of the Piti Reserve is attracting a large number of fish (Tsuda and Donaldson 2004). The area of the observatory is used by a large number of diving operations and is a major attraction for tour companies. A common practice by the operations is fish feeding, which attracts a considerable number of fish to the area in addition to fish that are already attracted to the observatory's structure (Tsuda and Donaldson 2004). This situation needs further examination in order to resolve this question completely.

Predatory species are highly vulnerable in the local fisheries (Guam DAWR 2000l–o, 2001). If degree of exploitation alone is a factor in determining a species response to protection, predators should have increased in abundance. This study, however, indicates a noticeable lack of predatory species within the reserve sites. Halpern and Warner (2002) concluded that predators as a trophic group showed no distinct differences in response to reserve protection, although individual species may respond according to their life history traits or degree of exploitation. In contrast, Micheli et al. (2004b) stated that protection influences top trophic groups, with abundances of top predators increasing gradually through time. Predatory species may have not responded to protection in the present study, because they are generally long-lived, slow-growing species (Halpern and Warner 2002) requiring long durations for recovery (Russ and Alcala 2003, 2004). An alternative explanation is that many of the predatory species are highly mobile and encompass home ranges extending outside of the reserve (Holland et al. 1996, Kramer and Chapman 1999, Palumbi 2002, Nardi et al. 2004, Wetherbee et al. 2004,). The protective function of the reserve may be limited for these species, because the reserve is small and only a portion of the predatory species may utilize the reserve (Kramer and Chapman 1999, Palumbi 2002, Wetherbee et al. 2004). The lack of predatory species may be an indication of the general state of over-fishing in Guam.

Empirical short-term studies of marine reserve effects have reported similar results but with different species. White 1988 and Clark et al. 1989 (both cited in Roberts and Polunin 1991) conducted studies within two years of reserve protection. White (1988) reported that total fish abundance increased by 173%, 89%, and 45%, respectively, within three reserves in the Philippines, while Clark et al. (1989) reported that the abundance of lutjanids increased by 93% and haemulids by 439% in a Florida marine reserve. They attributed the increases to the prohibition on fishing within the reserves. On average, the density of fishes roughly doubles and diversity is 20% to 30% higher within marine reserves (Halpern 2003). Significant increases in population densities and diversity result within one to three years after the establishment of marine reserves (Halpern and Warner 2002). These findings are consistent with the results of this study.

Based upon the results of this study, both null hypotheses are rejected in favor of the alternative hypotheses that there are differences in the density and diversity of fishes between a marine reserve and non-reserve area. The prediction of increased density and diversity of fishes within the reserve is supported by the data from the forereef slope of the reserve. The density effect is most apparent for the Acanthuridae, especially *Acanthurus nigricauda* and *Naso lituratus*. At Apo Island, Philippines, the biomass of Carangidae and Acanthuridae tripled over an eighteen year period, but did not differ in a non-reserve area (Russ et al. 2004). In Tasmania, the number of fishes increased at the Maria Island Marine Reserve over a six year period (Edgar and Barrett 1999).

Acanthurid populations declined by approximately 75% from 1985 to 1996 on Guam based on inshore fisheries creel surveys (Guam DAWR 2000a-l). If the acanthurids are recovering because of protection in reserves, then the overgrowth of algae on Guam's reefs (Global Coral Reef Monitoring Network (GCRMN) 2004) can possibly be controlled to allow for a healthier reef ecosystem (National Research Council (NRC) 2001).

The increased diversity effect is prominent in the forereef slope of the reserve. This indicates that various species are recruiting or immigrating into the reserve, and that the spatial distribution of species is spread more evenly rather than patchily within the reserve. Walmsley and White (2003) reported average increases of 8.3% in species richness within four reserves in the Philippines over nineteen years of reserve protection.

In conclusion, significant responses in fish density and diversity within the reserve imply that certain exploited species are protected, and suggest the importance of permanent reserves for restoring multispecies objectives, top trophic groups, and overall community structure. The spatial and temporal scales required for reserve success may vary among trophic groups and species depending upon different factors, such as fishing intensity, recruitment, or species interactions (Jennings and Polunin 1997). Because no time series data for the reserve and non-reserve areas are available, there is equivocal evidence that the reserve is a successful management strategy. Long-term spatial and temporal monitoring with a before-after impact-control design to account for the dynamic nature of the reserve is needed to elucidate further effects of the marine reserve.

Comprehensive studies involving daily movement patterns, habitat use, dispersal rates, spillover, species interactions, and recruitment are needed within the reserve. These studies may eventually answer questions about the effects of the reserve upon trophic groups, families of fishes, or certain species that exhibit specific behavior patterns, such as high mobility, and could help to improve the design of this and other reserves.

REFERENCES

Abacus Concepts. 1998. Statview Statistical System for PC. Abacus Concepts, Berkeley, California.

Airamé, S., J.E. Dugan, K.E. Lafferty, H. Leslie, D.A. Mcardle, and R.R. Warner. 2003 Applying ecological criteria to marine reserve design: A case study from the California Channel Island. Ecological Applications. 13:S178-S184

Alcala, A.C. 1988. Effects of marine reserves on coral fish abundances and yields of Philippine coral reefs. Ambio. 17:194-199.

Amesbury, S.S. and P. Callaghan. 1981. Territory of Guam fisheries development and management plan. Coastal Zone Management Section, Bureau of Planning, Government of Guam, Agana, Guam. 99 pp.

Bergen, L.K. and M.H. Carr. 2003. Establishing marine reserves: How can science best inform policy. Environment. 45:8-19

Bohnsack, J.A. 1994. Marine reserves: They enhance fisheries, reduce conflicts, and protect resources. NAGA, The ICLARM Quarterly. July. 4-7 pp.

Bohnsack, J.A. 1994. How marine fishery reserves can improve reef fisheries. Proceedings of the Gulf and Caribbean Fisheries Institute. 43:217-241.

Botsford L.W., F. Micheli, and A. Hastings. 2003. Principles for the design of marine reserves. Ecological Applications. 13:S25-S31

Cappo, M. and I.W. Brown. 1996. Evaluation of sampling methods for reef fish populations of commercial and recreational interest. CRC Reef Research Technical Report No. 6, Townsville, Queensland, Australia. 72 pp.

Carr M.H., J.E. Neigel, J.A.Estes, S. Andelman, R.R. Warner, and J.L Largier. 2003. Comparing marine and terrestrial ecosystems: Implications for the design of coastal marine reserves. Ecological Applications. 13:S90-S107.

Chiappone, M., R. Sluka, and K.S. Sealay 2000. Groupers (Pisces: Serranidae) in fished and protected areas of the Florida Keys, Bahamas and northern Caribbean. Marine Ecology Progress Series. 198:261-272.

Choat J.H. and D.R. Robertson. 2002. Age-based studies on coral reef fishes. Pages 57-80 in Sale P.F., ed. Coral Reef Fishes: dynamics and diversity in a complex ecosystem. Academic Press, San Diego, California.

Corbett, D.H. 1998. Public Law 24-21 (Fishing Regulations) issues. Office of the Attorney General Guam Memorandum AGR 97-0842, Agana, Guam. 4 pp.

Crosby. M.P. and E.S. Reese. 1996. A manual for monitoring coral reefs with indicator species: butterflyfishes as indicators of change on Indo-Pacific reefs. Office of Ocean and Resource Management, National Oceanic and Atmospheric Administration, Silver Springs, MD. 45 pp.

Edgar, G.J. and N.S. Barrett. 1999. Effects of the declaration of marine reserves on Tasmania reef fishes, invertebrates, and plants. Journal of Experimental Marine Biology and Ecology. 242:107-144.

Edgar, G.J., R.H. Bustamante, J.-M. Fariña, M. Calvopiña, C. Martinez, and M.V. Toral-Granda. 2004. Bias in evaluating the effects of marine protected areas: the importance of baseline data for the Galapagos Marine Reserve. Environmental Conservation. 31:212-218.

English, S., C. Wilkinson, and V. Baker. 1997. Survey manual for tropical marine resources 2nd edition. Australian Institute of Marine Science, Townsville, Queensland, Australia. 390 pp.

Florida Forum Report #1. 1997. Marine reserves and special management areas. Florida Institute of Oceanography, St. Petersburg, Florida. 29 pp.

Froese, R. and D. Pauly. Editors. 2005. FishBase. World Wide Web electronic publication. www.fishbase.org, version (01/2005).

Gaines, S.D., B. Gaylord, and J.L. Largier. 2003. Avoiding current oversight in marine reserve design. Ecological Applications. 13:S32-S46.

Gell, F.R. and C.M. Roberts. 2003. Benefits beyond boundaries: The fishery effects of marine reserves. Trends in Ecology and Evolution. 18:448-455.

Gerber, L.R., P.M. Kareiva, and J. Bascompte. 2002. The influence of life history attributes and fishing pressure on the efficacy of marine reserves. Biological Conservation. 106:11-18.

Gerber, L.R., L.H. Botsford, A. Hastings, H.P. Possingham, S.D. Gaines, S.R. Palumbi, and S. Andelman. 2003. Population models for marine reserve design: A retrospective and prospective synthesis. Ecological Applications. 13:S47-S64.

Global Coral Reef Monitoring Network (GCRMN). 2004. Status of the Coral Reefs of the World. Australian Institute of Marine Science, Townsville, Queensland, Australia. 557 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000a. Annual report 1985. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 143 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000b. Annual report 1986. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 143 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000c. Annual report 1987. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 146 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000d. Annual report 1988. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 142 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000e. Annual report 1989. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 216 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000f. Annual report 1990. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 176 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000g. Annual report 1991. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 164 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000h. Annual report 1992. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 116 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000i. Annual report 1993. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 124 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000j. Annual report 1994. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 125 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000k. Annual report 1995. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 124 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000l. Annual report 1996. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 136 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000m. Annual report 1997. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 147 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000n. Annual report 1998. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 178 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2000o. Annual report 1999. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 169 pp.

Guam Division of Aquatic and Wildlife Resources (DAWR). 2001. Annual report 2000. Federal Aid Sport Fish and Wildlife Restoration, Department of Agriculture, Government of Guam, Mangilao, Guam. 169 pp.

Halpern, B.S. and R.R. Warner. 2002. Marine reserves have rapid and lasting effects. Ecology Letters. 5:361-366.

Halpern, B.S. 2003. The impact of marine reserves: do reserves work and does reserve size matter? Ecological Applications. 13:S117-S137.

Halpern, B.S., S.D. Gaines, and R.R. Warner. 2004. Confounding effects of the export of production and the displacement of fishing effort from marine reserves. Ecological Applications. 14:1248-1256.

Holland, K.N., J.D. Peterson, C.G. Lowe, and B.M. Wetherbee. 1993. Movements, distribution, and growth rates of the white goatfish *Mulloides flavolineatus* in a fisheries conservation zone. Bulletin of Marine Science. 52:982-992.

Holland, K.N., C.G. Lowe, and B.M. Wetherbee. 1996. Movements and dispersal patterns of blue trevally (*Caranx melampygus*) in a fisheries conservation zone. Fisheries Research. 25:279-292.

Hooker, S.K. and L.R. Gerber. 2004. Marine reserves as a tool for ecosystem based management: the potential importance of megafauna. Bioscience. 54:27-39

Jameson, S.C., M.H. Tupper, and J.M. Ridley. 2002. The three screen doors: can marine protected areas be effective? Marine Pollution Bulletin. 44:1177-1183.

Jennings, S. and N.V.C. Polunin. 1997. Impacts of predator depletion by fishing on the biomass and diversity of non-target reef fish communities. Coral Reefs. 16:71-82.

Kramer, D.L. and M.R. Chapman. 1999. Implications of fish home range size and relocation for marine reserve function. Environmental Biology of Fishes. 55:65-79.

Leslie, H., M. Ruckelshaus, I.R. Ball, S. Andelman, and H.P. Possingham. 2003. Ecological Applications. 13:S185-S198.

Lubchenco, J., S.R. Palumbi, S.D. Gaines, and S. Andelman. 2003. Plugging a hole in the ocean: the emerging science of marine reserves. Ecological Applications. 13:S3-S7.

Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, New Jersey. 179 pp.

McCormick, M.I. and J.H. Choat. 1987. Estimating total abundance of a large temperate reef fish using visual belt transects. Marine Biology. 96:469-478.

Meyer, C.G., K.N. Holland, B.M. Wetherbee, and C.G Lowe. 2000. Movement patterns, habitat utilization, home range size, and site fidelity of whitesaddle goatfish, *Parupeneus porphyreus*, in a marine reserve. Environmental Biology of Fishes. 59:235-242.

Micheli, F., P. Amarasekare, J. Bascompte, and L.R. Gerber. 2004a. Including species interaction in the design and evaluation of marine reserves: some insights from a predator-prey model. Bulletin of Marine Science. 74:653-669.

Micheli, F., B.S. Halpern, L.W. Botsford, and R.R. Warner. 2004b. Trajectories and correlates of community change in no-take marine reserves. Ecological Applications. 14:1709-1723.

Myers, R.F. 1999. Micronesian reef fishes, 3rd ed. Coral Graphics, Barrigada, Guam. 330 pp.

National Research Council (NRC). 2001. Marine protected areas, tools for sustaining ocean ecosystems. National Academy of Sciences, Washnigton, DC. 272 pp.

Nardi, K., G.P. Jones, M.J. Moran, and Y.W. Cheng. 2004. Contrasting effects of marine protected areas on the abundance of two exploited reef fishes at the sub-tropical Houtman Abrolhos Islands, Western Australia. Environmental Conservation. 31:160-168.

Neigel, J.E. 2003. Species-area relationships and marine conservation. Ecological Applications. 13:S138-S145.

NOAA National Centers for Coastal Ocean Science (NCCOS). 2005. Shallow-Water Benthic Habitats of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands (CD-ROM). NOAA Technical Memorandum NOS NCCOS 8, Biogeography Team, Silver Spring, MD.

Nowlis, J.S. and C.M. Roberts. 1999. Fisheries benefits and optimal design of marine reserves. Fishery Bulletin. 97:604-616.

Palumbi, S.R. 2001. The ecology of marine protected areas. Pages 509-530 in M.D. Bertness, S.M. Gaines, and M.E. Hixon, eds. Marine Community Ecology. Sinauer Associates, Sunderland, Massachusetts.

Palumbi, S.R. 2002. Marine reserves: a tool for ecosystem management and conservation. Pew Oceans Commission Report on Issues Facing the Ocean. Arlington, Virginia. 45 pp.

Palumbi, S.R. 2003. Population genetics, demographic connectivity, and the design of marine reserves. Ecological Applications. 13:S146-158.

Polunin, N.V.C. and C.M. Roberts. 1993. Greater biomass and value of target coral reef fishes in two small Caribbean marine reserves. Marine Ecology Progress Series. 100:167-176.

Rakitin, A. and D.L. Kramer. 1996. Effect of a marine reserve on the distribution of coral reef fishes in Barbados. Marine Ecology Progress Series. 131: 97-113.

Randall, R.H. and L.G. Eldredge. 1976. Atlas of the reefs and beaches of Guam. Coastal Zone Management Section, Bureau of Planning, Government of Guam, Agana, Guam. 191 pp.

Roberts, C.M. and N.V.C. Polunin. 1991. Are marine reserves effective in management of reef fisheries? Reviews in Fish Biology and Fisheries. 1:65-91.

Roberts, C.M., J.A. Bohnsack, F. Gell, J.P Hawkins, R. Goodridge. 2001. Effects of marine reserves on adjacent fisheries. Science. 294:1920-1923

Roberts, C.M., G. Branch, R.H. Bustamante, J.C. Castilla, J. Dugan, B.S. Halpern, K.D. Lafferty, H. Leslie, J. Lubchenco, D. McArdle, M. Ruckelshaus, and R.R. Warner. 2003. Application of ecological criteria in selecting marine reserves and developing reserve networks. Ecological Applications. 13:S146-158.

Rohlf, F.J. and D.E. Slice. 1999. BIOMstat for Windows®. Statview software for biologists, version 3.3. Applied Biostatistics, Inc, Port Jefferson, New York.

Rudd, M.A., M. H. Tupper, H. Folmer, and G.C. van Kooten. 2002. Policy analysis for tropical marine reserves: challenges and directions. Fish and Fisheries. 3:1-21.

Russ, G.R. 1984. Effects of protective management on coral reef fishes in the Philippines. ICLARM Newsletter. October. 12-13 pp.

Russ, G.R. and A.C. Alcala. 1989. Effects of intense fishing pressure on an assemblage of coral reef fishes. Marine Ecology Progress Series. 56:13-27.

Russ, G.R. and A.C. Alcala. 1994. Sumilon Island Reserve: 20 years of hope and frustration. Naga, The ICLARM Quarterly. July. 8-12 pp.

Russ, G.R. and A.C. Alcala. 1996. Do marine reserves export adult fish biomass? Evidence from Apo Island, central Philippines. Marine Ecology Progress Series. 132:1-9.

Russ, G.R. and A.C. Alcala. 1998. Natural fishing experiments in marine reserves 1983-1993: roles of life history and fishing intensity in family responses. Coral Reefs. 17: 399-416.

Russ, G.R. and A.C. Alcala. 2003. Marine reserves: rates and patterns of recovery and decline of predatory fish, 1983-2000. Ecological Applications. 13:1553-1565.

Russ, G.R. and A.C. Alcala. 2004. Marine reserves: long-term protection is required for full recovery of predatory fish populations. Oecologia. 138:622-627.

Russ, G. R., A.C. Alcala, A. P. Maypa, H. P. Calumpong, and A.T. White. 2004. Marine reserve benefits local fisheries. Ecological Applications. 14:597-606.

Shanks, A.L., B.A. Grantham, and M.H. Carr. 2003. Propagule dispersal distance and the size and spacing of marine reserves. Ecological Applications. 13:S159-169.

Sokal, R.R. and F.J. Rohlf. 1995. Biometry: the principles and practice of statistics in biological research. 3rd ed. W. H. Freeman and Company, New York. 887 pp.

Stewart, R.R., T. Noyce, and H.P. Possingham. 2003. Opportunity cost of *ad hoc* marine reserve design decisions: an example from South Australia. Marine Ecology Progress Series. 253:25-38.

Tsuda, R.T. and T.J. Donaldson. 2004. Cumulative and secondary impacts: Seawalker, Scuba Bob, and the Fish Eye Underwater Observatory, Piti and Cocos Lagoon, Guam. University of Guam Marine Laboratory Technical Report No. 108. Mangilao, Guam. 85 pp.

Tupper, M.H. 2002. Marine reserves and fisheries management. Science. 295:1233.

Walmsley, S.F. and A.T. White 2003. Influence of social, management, and enforcement factors on the long-term ecological effects of marine sanctuaries. Environmental Conservation. 30:388-407.

Wantiez, L., P. Thollot, and M. Kulbicki. 1997. Effects of marine reserves on coral reef fish communities from five islands in New Caledonia. Coral Reefs. 16:215-224.

Wetherbee, B.M., K.N. Holland, C.G. Meyer, and C.G. Lowe. 2004. Use of a marine reserve in Kaneohe Bay, Hawaii by the giant trevally, *Caranx ignobilis*. Fisheries Research. 67:253-263.

Wilkinson, C, A. Green, J. Almany, and S. Dionne. 2003. Monitoring coral reef marine protected areas version 1: a practical guide on how monitoring can support effective management of MPAs. Australian Institute of Marine Science, Townsville, Queensland, Australia. 68 pp.

Williamson, D.H., G.R. Russ, and A.M. Ayling. 2004. No-take marine reserves increase abundance and biomass of reef fish on inshore fringing reefs of the Great Barrier Reef. Environmental Conservation. 31:149-159.

Willis, T.J., R.B. Millar, R.C. Babcock, and N. Tolimieri. 2003. Burdens of evidence and the benefits of marine reserves: putting Descartes before des horse? Environmental Conservation. 30:97-103.