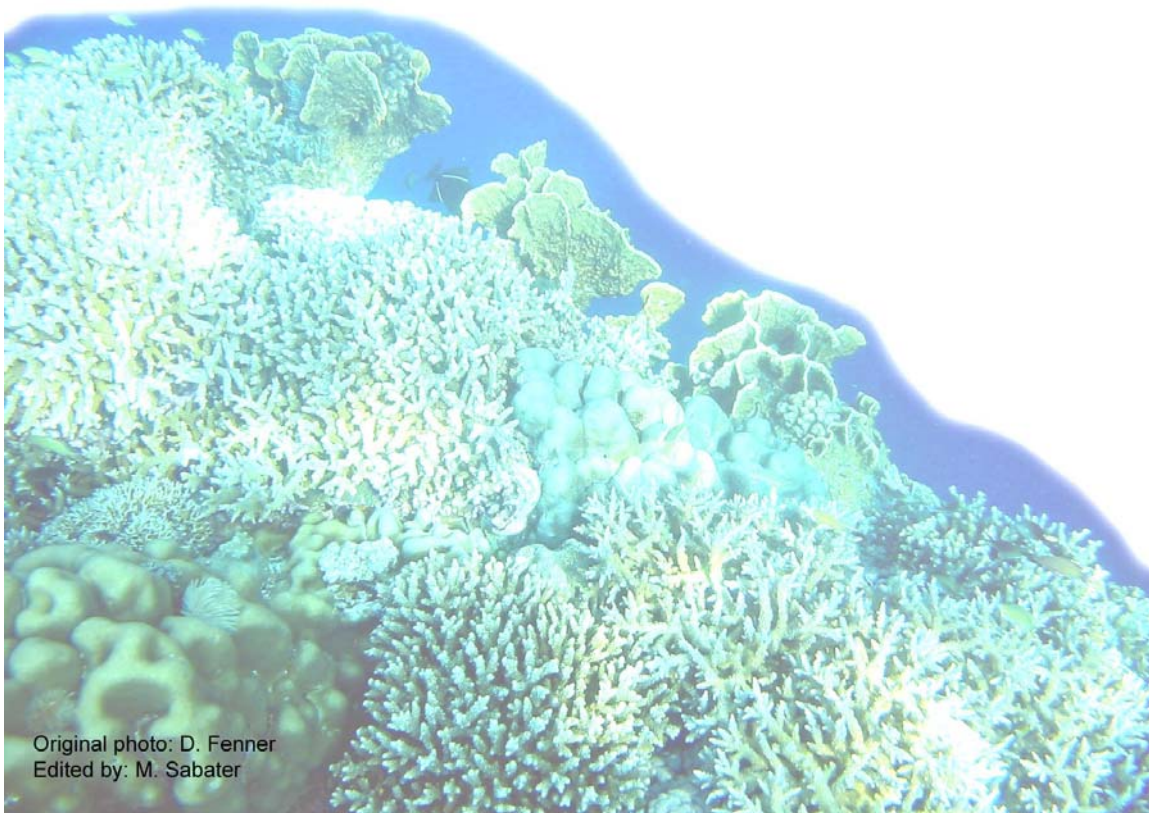
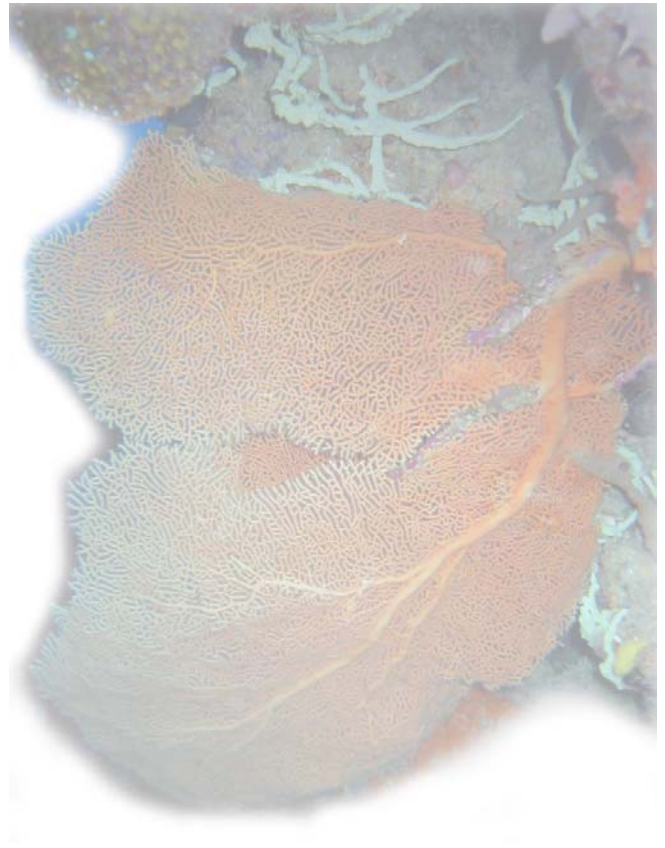


Spatial variation in biomass, abundance and species composition of “key reef species” in American Samoa

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EXECUTIVE SUMMARY

American Samoa is a small remote oceanic archipelago, increasing its importance of protection of its coral reefs and conservation of its marine resources. The fishery is important to the Samoan way of life and provides subsistence to its people. Problems associated with population growth, climate change, and chronic natural and anthropogenic disturbances are rapidly emerging, threatening coral reefs and its associated fisheries. Prior to management intervention, the status and underlying dynamics affecting the populations of reef fishes important to fisheries should be determined. Biologically and ecologically sound data assure fisheries manager that the intervention or strategy applied will be effective, efficient and provide maximum benefit for all resource users.

A key reef species is defined as a fish species that is targeted for recreation and subsistence, including those secondarily targeted when primary species occur in small numbers. Determining abundance and biomass is useful to assess how much fish is available. Several surveys have been conducted in American Samoa by various off-island researchers but this is the only study that focused solely on fish known to be used as food. By focusing only on certain groups of species, the data generated will be more accurate. Reconnaissance surveys were conducted at 54 sites around Tutuila, Aunu'u, and associated reefs of Nafanua and Taema Banks. Replicated belt transect surveys were conducted in 24 out of 30 permanent monitoring sites around Tutuila, Aunu'u and Taema Banks. We used a hierarchical nested design to determine the effects of spatial scaling on species distributions, biomass, and abundance patterns.

Our data shows that populations of key reef species in American Samoa are currently in a stable status. Seventeen percent of the sites surveyed are in very high biomass category ($>40.1 \text{ mt/km}^2$); 50% at high ($20.1\text{-}40 \text{ mt/km}^2$); 21% at moderate ($10.1\text{-}20 \text{ mt/km}^2$); and only 13% at low biomass category ($5.1\text{-}10 \text{ mt/km}^2$). The mean biomass value for Tutuila alone ranges from 5.99 mt/km^2 in Aua to 106.59 mt/km^2 in Pagaitua Point. Scaling analysis showed significant variations in abundance and biomass lies at higher spatial scales (from habitat level to exposure level), where significantly higher biomass occurs at point reef habitats and south shore sites. The high fish biomass in point reef areas is attributable both to species composition and effects of habitat quality on growth and survival. The high fish biomass on southern shores of Tutuila is due to the extent of true coral reef habitats which result in greater protection of key reef species and availability of food source. The species composition differ between exposure and between habitat such that species that have strong ties with true coral reefs are found mostly on the south shore and those that have wide habitat preference are found also in the north shore where a significant amount of the bottom substrate is colonized volcanic pavement.

The results from this study could be utilized by the Marine Protected Area Program in the design and planning for the establishment of MPAs. Insights on scaling, species composition, spatial patterns in coral cover, and trends in fish biomass and abundance at various spatial scales are important considerations in the design of protected areas.

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GENERAL INTRODUCTION

Coral reefs are complex ecosystems, and are affected by numerous factors such as natural environmental forces, disturbance, and anthropogenic stressors. The reefs of American Samoa are small, isolated and located between the center of coral reef diversity in the western Pacific and the depauperate eastern Pacific, making them a vulnerable environment. Such reefs may be dependent primarily on its own stock for replenishment over time since the potential of surrounding small islands as source of recruits is yet to be established. Large scale disturbances such as crown of thorn (COT) outbreaks, hurricane and mass bleaching are documented threats to this reef. The COT outbreak that occurred in the 1970's caused a dramatic reduction in coral cover in bays and to a lesser extent at exposed reef areas to the reef in Tutuila and Aunu'u (Birkeland and Randall 1979, Birkeland et al 1987, Zann 1992). Hurricanes are considered an acute disturbance that occur at large spatial scales (Karlson and Hurd 1993, Connell 1997, Connell et al. 1997). This is known to devastate reefs both by removal of whole colonies and by smothering of remaining corals through substrate re-suspension. American Samoa was hit by 2 severe storms in early 1990 that caused a decrease in live coral cover and physical alteration of bottom composition (Birkeland et al 1996, Green et al 1999). Mass coral bleaching is coupled with the abnormal increase in sea surface temperature (SST) either brought about by El Niño Southern Oscillation (ENSO) or localized weather conditions. Other factors that have synergistic effects with increased SST resulting in bleaching are low tides, low mixing of boundary layers, absence of wind forcing thereby less surface flow, and clear water. Chronic hot weather-low tide anomalies pose more threat to reefs than oceanic anomalies like ENSO and Pacific Decadal Oscillations (PDOs) (Heron and Skirving 2004). American Samoa experienced a localized bleaching event in 1994 and 1998 due to still water and hot weather. Abnormally hot days coincided with a low tide event resulting in heated water especially on shallow reef areas giving rise to bleaching. Another bleaching event occurred in 2002 that's coupled with an ENSO event for the whole Pacific.

Anthropogenic disturbance is often more destructive than natural disturbance. This is because of its varying intensity (depending on the type) and its chronic nature. Coral assemblages have been shown to recover from acute disturbance but failed to do so from chronic disturbance (Connell et al. 1997). Humans have contributed significantly to the alteration of the natural disturbance regime (Vitousek et al. 1997) and further affect the recovery of perturbed sites (Paine et al. 1998, Buddemeier and Smith 1999, Wilkinson 1999, Hoegh-Guldberg 1999, Nyström et al. 2000). Although anthropogenic disturbance is only very recent compared to natural disturbance, its impact is of greater concern because it adds to the total disturbances reefs have not evolved to adapt to it and the disturbance is often chronic instead of acute (Richmond 1993).

The small islands and limited resources of American Samoa are particularly vulnerable to impacts brought about by human-induced stresses. The main island of Tutuila is inhabited by 97% of the population and is, thus, the most vulnerable. American Samoans are Polynesians by ancestral descent, and so are a culture raised on fishing. Fishing has

been the way of life for thousands of years. Like any culture external influences have caused them to adapt and undergo social and economic changes, thereby affecting their resource utilization. Western influence has shifted their country from subsistence to a mixed economy (Hill 1977, Craig et al 1993). New technologies have enabled remaining fishermen to use more efficient methods to increase their catch. This includes use of SCUBA to increase their bottom time, spearguns enabling them to target bigger fish, and powerful boat engines enabling them to cover more area in one day (Wass 1980).

When SCUBA assisted spearfishing was introduced in 1994, there was a drastic increase in fish catch targeting mostly large fish. Parrotfish have since been heavily exploited, giving rise to a 15 fold increase in catch (Page 1998). Such efficient techniques enabled fishermen to harvest 18.7% of the standing stock. This was the basis for banning SCUBA spearfishing within the territory through Executive Order 002-2001 by Governor Tauese Sunia.

Large scale disturbances, environmental forcing, and anthropogenic induced perturbations creates changes in spatial patterns in species distribution (Dai 1993, Edmunds and Bruno 1996, Adjeroud 1997a, Adjeroud 1997b, Gleason 1998, Murdoch and Aronson 1999, Hughes et.al. 1999, Goffredo and Chadwick-Furman 2000, Adjeroud et al. 2000, Diaz et al. 2000, Harriott and Banks 2002, Pandolfi 2002, Vermeij and Bak 2002). The patterns of damage from 3 sequential storm events in Mexico varied across space due to variability in the storms severity and spatial distribution (Lirman et al. 2001). Only half of the reefs surveyed showed a significant decrease in coral cover after the storms suggesting that the immediate effect of the disturbance was significantly less than predicted. The long term effect of the storm depended on post disturbance processes such as fragment re-attachment, re-growth and regeneration of damaged colonies. The most common effect of coral bleaching was the mortality of different species of corals that created an open space for algal recruitment (McClanahan 2000, Ostrander et al. 2000, Carriquiry et al. 2001, Diaz-Pulido and McCook 2002). Susceptibility to this disturbance varies among taxa, therefore, reefs respond differently due to variations in species composition (Baird and Marshall 1998, Marshall and Baird 2000, Baird and Marshall 2002).

Environmental and disturbance gradients have shown to structure marine communities. Gradients in wave exposure have been shown to affect distribution of reef fishes (Hilomen and Gomez 1988, Hilomen et al. 2000, Gust et al 2001, Mateo and Tobias 2001, Friedlander et al 2003, Garpe and Ohman 2003). Gradients in fishing pressure has been found to produce variations in the motile epifaunal community structure brought about by either exploiter-mediated coexistence or the habitat quality of the surrounding benthos (Dulvy et al. 2002). The hard coral cover has been reported to decline while algal cover increased with increasing fishing intensity which caused variations in fish community structure. The effects of dredging (resulting in sedimentation) in Ko Phuket, Thailand in 1986-1987 and a low sea-level anomaly in 1997-1998 were more evident in the inner than in the outer flats where massive corals species were only partially affected indicating that these species were adapted to intertidal living which contributed to the resilience of the reef flat community from these types of perturbation (Brown et al. 2002).

The spatial pattern of benthic characters could affect distribution of reef fishes. One mechanism could be change in habitat distribution, habitat quality, food source abundance, or change in distribution of invertebrates that are food source for reef fish tightly coupled with a certain benthic attribute. The coral reef fish assemblage in the main Hawaiian Islands responded to changes in habitat complexity and quality (Friedlander et al 2003). This study showed higher biomass at sheltered areas than areas exposed to strong wave action. In contrast, Gust et al (2001) showed higher biomass (at least for parrotfish) in exposed areas in the GBR. In the Caribbean, patterns of reef fish distribution follows distribution of different benthic characters such as live, dead, branching corals and algae as well as physical parameters such as exposure, depth, and rugosity (Garpe and Ohman 2003). Juvenile fishes respond to the distribution of patch reefs, seagrass, rubble, algal plains, and sand flats which they utilize as grow-out and feeding areas (Mateo and Tobias 2001).

Given the variability and spatial dynamics in reef fish distribution, incorporating this in the design of marine protected areas (MPAs) would increase its probability of success. MPAs are becoming a popular tool for conservation and fisheries management. It enables protection of fish stocks and ensures the integrity and viability of habitats (Bohnsack 1996, Bohnsack and Ault 1996). By protecting habitat integrity (along with its underlying ecological and biological processes) and its associated fauna, one mitigates the cascading effects of species removal from the ecosystem.

Designing an effective MPA, however, is still a challenge. Usually it is a balance (but often a trade-off) between its biological, economic, social, logistical, and political components. Often times these latter factors supercede the biological requirements needed for the proper functioning and effectiveness of the MPA. Information on location, habitat integrity, species distributions and other biological parameters are necessary to design an MPA that will be effective (Dugan and Davis 1993, Friedlander and Parrish 1998, Murray et al 1999).

American Samoa is still in its infancy in terms of setting up formal or institutionalized marine reserves (aside from the Rose Atoll National Wildlife Refuge established in 1973; and Fagatele Bay National Marine Sanctuary which was established in 1986). The earliest MPA was established in 2001 by the Community-Based Fisheries Management Program of DMWR in the village of Poloa. Nine additional village-MPAs have been established to date. However, none of these village-MPAs or even the Fagatele Bay National Marine Sanctuary can be considered as permanent or completely no-take. In 2000 late Governor Tauese Sunia requested the Department of Commerce to develop a plan to protect 20% of American Samoa's coral reef. A workshop was held in 2002 for government agencies involved with coral reefs in order to come up with a territorial plan for the establishment of "no-take" MPAs. The result of this is a workshop proceeding that describes steps needed to achieve the 20% goal. An MPA coordinator was hired in 2004 in order to revise and update the plan for the territory and coordinate all inter-agency activities that contribute to the accomplishment of the goal. In 2005, a five-year plan was drafted in order to fund the activities for the establishment of the MPAs under the

Sportfish Restoration Grant of FedAid. This, however, won't be initiated until the end 2006. The revised "MPA plan" became an MPA strategy and was completed in 2006 (Oram 2006). This describes the steps needed by the territory in order to achieve the protection of 20% of its coral reefs. With the MPA strategy completed, the team will then proceed in selecting sites that will comprise the 20% no take areas.

Since the reefs of American Samoa are threatened by both natural and anthropogenic disturbances, determining the status of one of its fishery resources (key reef species) is the first step for management. However, determining the status of key reef species alone is not enough to see the whole picture. The dynamics and distribution patterns (species and spatial) will have to be considered as well. These could provide insights on how resilient our reefs are to disturbance. These may also provide information on proper management strategy to secure the availability of the resource for future generations. The Key Reef Species Program provides ecological and biological information for fisheries management by the Department of Marine and Wildlife Resources. The aims of this study were:

1. to assess the status of the key reef fish community in American Samoa;
2. to determine patterns in distribution of key reef fish across various spatial scales using biomass and abundance incorporating exposure and habitat as driving factors;
3. describe the trophic structure of the key reef fish community;
4. determine what parameters affecting the distribution of each trophic group;
5. determine species distribution across different spatial scales; and
6. describe the structure of the key reef fish community.

The information generated by the program could also be used by the MPA Program in order to properly design their MPAs. This will give some insights for the MPA Program on:

1. where to conduct reconnaissance surveys;
2. determining the spatial extent of the MPA;
3. probable location of the MPA; and
4. parameters or criteria to evaluate possible MPA sites.

METHODOLOGY

Study site

This study was conducted in American Samoa located in the Central Pacific between 13 to 14 degrees South latitude (Figure 1). It is comprised of five volcanic islands (Tutuila, Aunu'u, Ofu, Olosega, and Ta'u) and two atolls (Rose and Swains Atoll). Due to logistic and time constraints, this study was only conducted in the main island of Tutuila and its immediate vicinity (Aunu'u Island and Taema Banks). Tutuila Island is the center of the territory where it inhabits 97% of the population. Most of the villages are found along the coastal area but mostly concentrated at inner bay areas. Prevailing winds comes from the south for most times of the year. South easterly winds tend to be continuous but low intensity. Northwesterly winds occurs at a shorter period but is characterized by strong intensity and usually coupled with hurricanes. There are no distinct seasons but the first quarter of the year generates more rain than the remaining months.

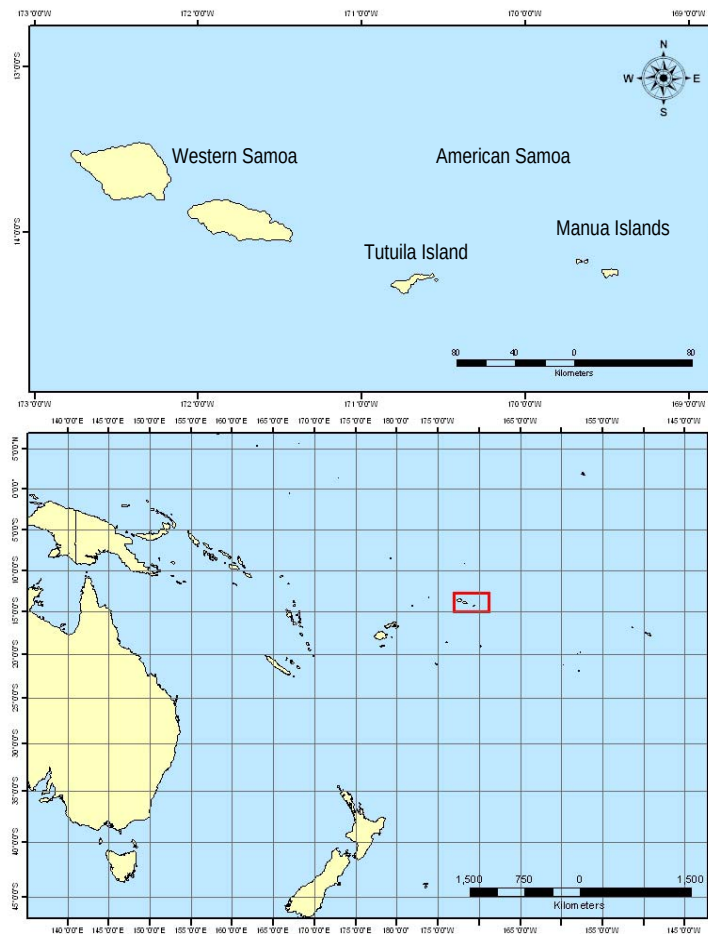


Figure 1. Location map of American Samoan Archipelago

Sampling design

Reconnaissance surveys were conducted at 54 sites around the islands of Tutuila and Aunu'u and the nearby banks of Taema and Nafanua (Figure 2) to obtain qualitative descriptions of the reefs and categorize each site into different habitats and reef type. Fish community structure in each site was also noted. Coordinates for each site were determined using the CMap Electronic Charting System. The recon survey involved spot dives lasting for 20 minutes recording pre-determined qualitative descriptions of the reef, physical parameters, benthic assemblage, fish species composition and community structure, and presence/absence of disturbance. Monitoring

sites were selected randomly following the design described below.

The sampling design followed a modified nested hierarchical design similar to that of Green 1996, 2002 where the island of Tutuila was subdivided into 2 exposures (northern and southern exposures which are also the cartographic sides of the island) accounting for the varying levels of wave exposure due to inherent intensity of the tradewinds (Figure 2). The north shore of Tutuila is exposed to more intense wave action generated by the stronger wind coming from the northwesterly trade occurring between January to March. This is also the hurricane season where waves generated by the storms reaching up to 4-5 meters (12 to 15 feet). The north shore could therefore be considered as more exposed to high intensity waves. A period of calm weather on both side of the island occurs between April to June. The SE trade occurs from July to December characterized by a continuous low intensity wind generating moderate wave action. The south shores exposed to this condition are more sheltered by Nafanua and Taema Banks.

Within each exposure, the island is further subdivided into two strata: the eastern and western sectors. This accounts for the longitudinal variations in exposure due to the island's topographic and geomorphic characteristics. The southwestern side of Tutuila is acutely angled resulting in further sheltering from the southeasterly trade.

Each sector is subdivided into two habitat types: embayment and point habitats. Point habitats are reef areas located at the topographic tips of the island. These are considered to be more exposed than embayment reef habitats that are found well within the base of the bays. Each habitat type has 2-4 replicate sites and each site has 3-5 replicate transects. The location of all permanent monitoring sites and nesting divisions are described in Figure 2. The nesting scheme is illustrated in Figure 3. A total of 24 sites were surveyed but the data was truncated to 16 to achieve a balanced design.

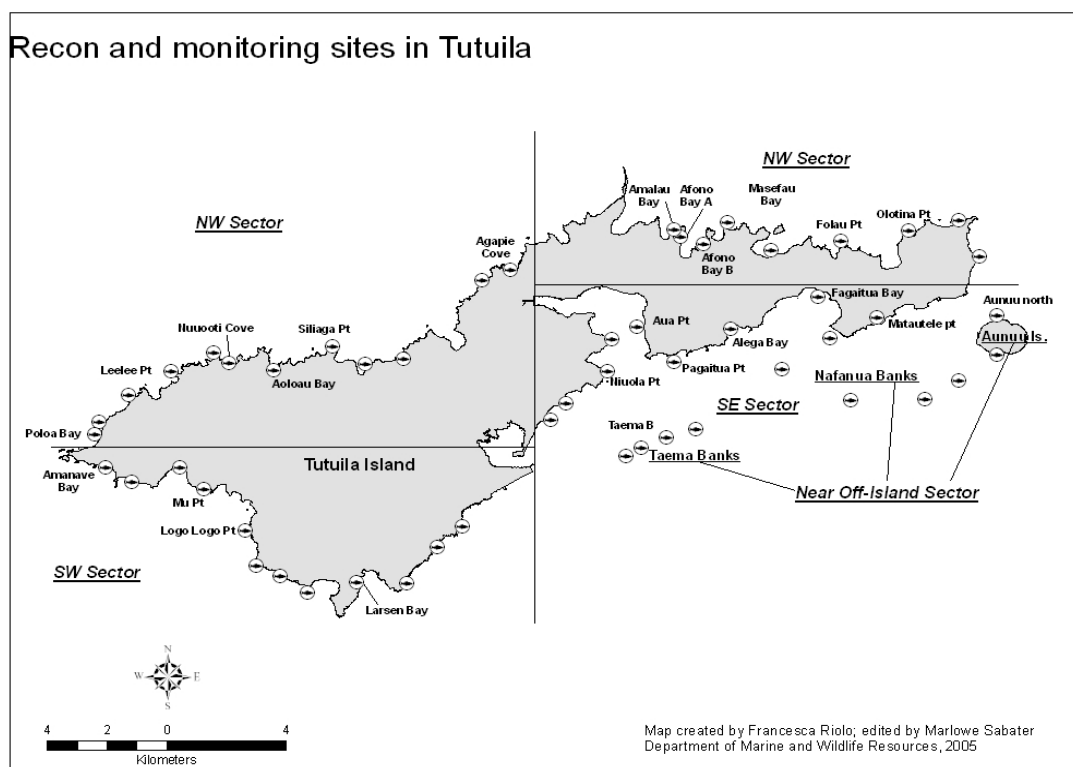


Figure 2. Map of Tutuila, Aunu'u, Taema and Nafanua Banks. Points are reconnaissance survey sites. Permanent monitoring sites are points with labels.

Level 5: Exposure	North				South			
Level 4: Sector	NW		NE		SW		SE	
Level 3: Habitat	Bay	Point	Bay	Point	Bay	Point	Bay	Point
Level 2: Site	Agapie Cove Nuuooti Cove	LeeLee Pt Siliaga Pt	Afono Bay Masefau Bay	Folau Pt Olotina Pt	Amanave Bay Larsen Bay	Mu Pt LogoLogo Pt	Aua_Harbor Leanaosaulii	Matautele Pt Pagaitua Pt
Level 1: Replicate transect	T1: n=7 T2: n=7 T3: n=7	T1: n=7 T2: n=7 T3: n=7	T1: n=7 T2: n=7 T3: n=7	T1: n=7 T2: n=7 T3: n=7	T1: n=7 T2: n=7 T3: n=7	T1: n=7 T2: n=7 T3: n=7	T1: n=7 T2: n=7 T3: n=7	T1: n=7 T2: n=7 T3: n=7

Figure 3: Heirarchical nested sampling scheme of the fish visual census survey. Twenty four sites were assessed but only 16 were included in the analysis to ensure a balanced design. Sites and replicate transect were selected at random from 54 reconnaissance-surveyed sites. n = number of observation points within each transect

Field survey methods

Fish Visual Census (FVC)

Fish visual census were conducted in 24 out of the 30 permanent monitoring sites around Tutuila Island and the nearby reefs of Aunu'u Island and banks of Taema and Nafanua. Approximately four replicate 30-meter transects were laid on the reef substrate at the reef slope at 10 meter depth. This zone was selected because it is present in all of the sites and is where the majority of the representative families of key reef species are found. A 5x5 meter sampling area was used at every transition point (every 5 meters) in each transect. The total length and number of all key reef species were estimated visually within the sampling area and were identified to species level.

The biomass of each fish recorded was computed by converting the length data to weights using the allometric length-weight conversion formulae:

Equation 1: $W = a * L^b$

Where: W = individual weight (grams)
 L = Fork length of fish (cm)
 a & b = constants for each species generated from series regressions of its length and weight; derived from FishBase and ReefSum

The biomass for each individual for each species was divided by the area of the transect (150 m²) to come up with a species-biomass per unit area estimate (g/m²). The unit was converted to mt/km². Density was summarized as individual per 150 m². The biomass and density data was averaged across sites per habitat to determine spatial trends.

Video Transect

Benthic community surveys were also carried out at the same transects used for FVC. A diver swam slowly and recorded the substrate and associated benthic community using an underwater video camera. Footage was digitized using Pinnacle Studio™ v.8.3.17 (Pinnacle Systems 2002) and “still-frames” (photos) were grabbed using VirtualDub 1.6.0 (Lee 2002). The program was set to grab at least 50 frames per transect to maximize data and minimize frame overlaps. The benthos data was extracted from the photos using CPCe v.3.0 (NCRI 2001). Benthic assemblages that are easy to identify were characterized to lifeform level while the difficult ones only to general categories (hard coral, soft coral, other fauna, abiotic, etc.). The percentage cover per lifeform, category, and transect plus the variance are automatically generated by the program in Excel format. The cover data live coral, macroalgae, and coralline algae were averaged within sites.

Data analysis

Data analysis differs between sections of the report. This covers parametric analysis that tests hypotheses and exploratory analysis that deals with patterns of species distribution across various spatial scales.

CHAPTER 1: EFFECT OF SPATIAL SCALE ON VARIATION IN BIOMASS AND ABUNDANCE OF KEY REEF SPECIES IN AMERICAN SAMOA

INTRODUCTION

The spatial distribution of organisms is rarely random: often underlying processes create patterns at different scales. For example, the reef fish distribution in the Great Barrier Reef follows an exposure gradient evident at scales of tens of kilometers (Gust et al 2001), while those in the Indian Ocean respond to spatial variations in various habitat parameters (Garpe and Ohman 2003).

Our aim was to test effects of scale on patterns of distribution of food fish in American Samoa. Furthermore, we aimed to determine possible proxy indicators or predictive factors that may drive the distribution pattern using benthic assemblages as habitat and food-source parameters. The results could be used to guide the current effort in establishing marine protected areas within the territory.

The complex nature of coral reef ecosystems made determining patterns and structure challenging. We incorporated scaling in our sampling design since our objective was to elucidate patterns of distribution of benthic assemblages across spatial scale of the entire island (Hughes 1994, Klein and Orlando 1994). Sampling at a single scale can lead to erroneous results when interpretations are extrapolated to larger scales.

Utilizing the advantages of spatial scaling in the analysis of biomass and abundance puts the conclusions into a more useful management context. Distribution of species differs at various spatial scale brought about by stochastic environmental and demographic factors. Variations in species-abundance distribution for corals and fish are affected by environmental stochasticity occurring at a particular spatial scale (Connolly et al 2005). Management intervention should, therefore, be robust to encompass a spectrum of environmental variability to which managed organisms are exposed and to ensure niche similarity (Pandolfi 2002). Large spatial scales (hundreds of kilometers) reflect variation in history, dispersion and regional processes while at small scales disturbance plays a major role. Scaling was also used in the management (specifically the zoning strategy) of the Florida Reef Track (Murdoch and Aronson 1999). The presence of large scale variations, however, puts emphasis on the importance of careful selection of sampling scale, design, and interpretation of monitoring data (Edmunds and Bruno 1966).

METHODS OF ANALYSIS

Status of key reef species

The status of the key reef species was assessed using biomass categories proposed by Hilomen et al (2000). These categories were based on thousands of underwater visual census from areas with heavy fishing to the most pristine sites in the Philippines. The

ranges for each category were based on histograms from frequency distribution of biomass values. The categories are as follows:

Very low: 1-5 mt/km²; Low: 5.1-10 mt/km²; Moderate: 10.1-20 mt/km²; High: 20.1-40 mt/km²; and Very high: >40.1 mt/km²

Effect of fish abundance and size on biomass

Factors that lead to changes in biomass across spatial scale were determined by regression using abundance and size as predictors. Size estimates and abundance are intrinsic factors in the computation of individual weight. A multiple regression analysis was performed to test the relative contributions of abundance and size estimates to biomass values across all scales. Abundance and size are treated as predictors for biomass since both are integral part of the weight calculation. A stepwise regression was performed where the most significant predictors are entered first followed by the next and if the fit was not improved then the predictor will be removed from the model (Kleinbaum et al. 1988). The interaction term was included as the product of abundance and size.

Scales of variations in biomass

The biomass and abundance data were square-root transformed to reduce differences between extreme values. A mixed model ANOVA with hierarchical nesting design was used to determine differences in biomass at various nesting level. The nesting levels incorporate the spatial scaling from exposure down to transect level where the smallest scale is nested within a larger spatial scale. The primary advantage in using this analysis is that it provides a finer detail on variations occurring at various spatial scales as compared to just the overall variations in biomass and abundance. Another advantage is that the effects of random selection of transect and sites to biomass and abundance could also be assessed. Un-nested results were also presented in order to confirm the primary advantage.

Relationships between benthic percentage cover and fish biomass and abundance

The ANCOVA was used to determine the effect of benthic cover on fish biomass and abundance. Reef fishes have strong association with the benthos thus we used live coral cover, macroalgae and coralline algae (makes up approximately 90% of the cover for each site) as controlling factors for biomass and abundance. Several data sets from FVC were used for this analysis. First was the overall abundance and biomass which included all fish surveyed. Second was using biomass and abundance data of each trophic group as dependent variable (specifically carnivore, herbivore and omnivore). This was done in order to determine which trophic groups are affected by the variations in benthic assemblages.

Effects of habitat variations on trophic structure of key reef species

Factor analysis was used to determine underlying patterns in species distribution in terms of abundance. Correlation coefficients were used to evaluate relationship of species under each factor group (data was log transformed, rotated using normalized varimax). Factor scores were assigned to each case based on the factor loadings and multiple regression

was used to determine responses for each factor to covariates specifically live coral, macroalgae, and coralline algae cover.

Statistica™ 6.0 (Stat-Soft 2001) statistical package was used for all analyses.

RESULTS

Status of key reef species in American Samoa

Seventeen percent of the sites surveyed are in very high biomass category; 50% at high; 21% at moderate; and only 13% at low biomass category.

Driving factor for biomass

The interaction between abundance and size (product of abundance and size) had the most significant association with biomass ($R^2 = 0.890$) while adding abundance to the equation only increased the R^2 by 0.045 but was still significant. The abundance data will be used as proxy indicator for biomass in the subsequent sections to minimize the confounding effects of size in the resulting patterns (particularly in the factor analysis)

Table 1. Multiple regression analysis on effect of abundance and size estimates as predictors of biomass. The interaction between abundance and size significantly contributed to R-square change followed by abundance. Size had no significant effect on change in abundance.

Model	R	R-Square	SE Est	p
Log Abundance*Size	0.944	0.890	0.161	0.000
Log Abundance	0.967	0.936	0.124	0.000

Biomass of key reef species across spatial scales

The biomass of key reef species varies greatly among sites, with mean values ranging from 5.99 in Aua inside the harbor to 106.59 mt/km² in Pagaitua Point (Figure 4). The high value at Pagaitua Point was due to large schools of surgeon fish (*Ctenochaetus striatus* and *Acanthurus blochii*), parrotfish (*Chlorurus sordidus* and *C. japanensis*) and fusiliers (*Pterocaesio tile*). Large red-lip parrotfish (*Scarus rubroviolaceus*) contributed to 46.79% of the average biomass in this site. Aua had the lowest biomass due to low abundance of fish composed mostly of small *C. striatus*.

There were no apparent trends when comparing at site levels due to high fluctuations in biomass values (Figure 4). Higher spatial scale comparisons indicate significantly higher biomass at point areas than embayment areas within sectors (3 out of 4 cases) (Figure 5; Table 2). Results also indicate that treating sites and transects as random factors had a significant effect on biomass trends where any slight change in site or transect location can result in a change in trend. There was no significant west to east variations in biomass. South shore of Tutuila had significantly higher biomass than north. Significant variations in biomass occurred at habitat to exposure levels. Mean biomass between un-

nested habitat, sites, and replicates are significant. Live coral and macroalgae were shown to be significant covariates to fish biomass.

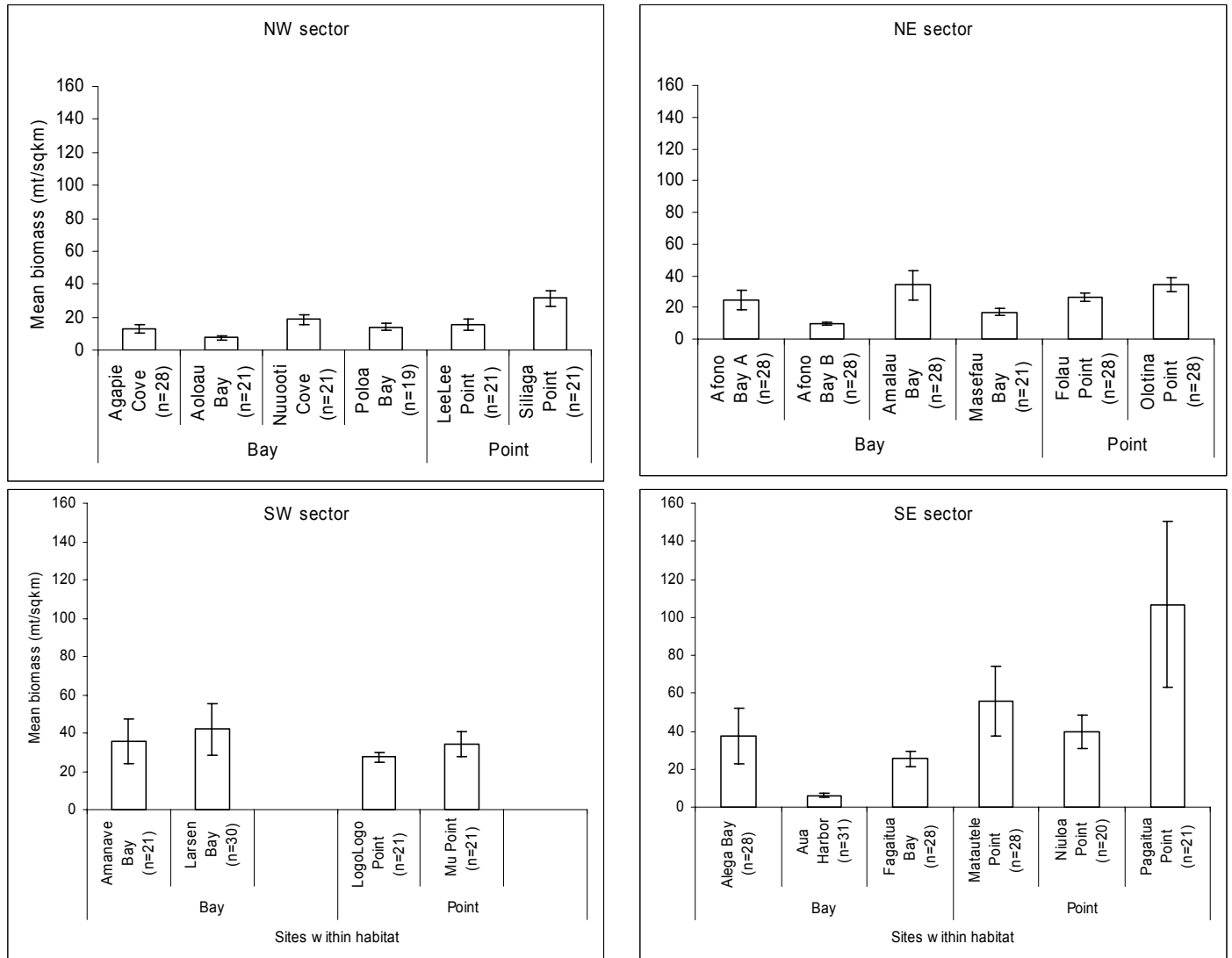


Figure 4. Mean biomass of key reef species among sites nested within habitats. Habitat is nested within sector (individual box). Each sector is nested within exposure (northern exposures are the top 2 boxes while southern exposures are the bottom 2). Only 16 out of 24 was used for the statistical analysis to satisfy the balanced requirement of mixed model ANOVA with nested design.

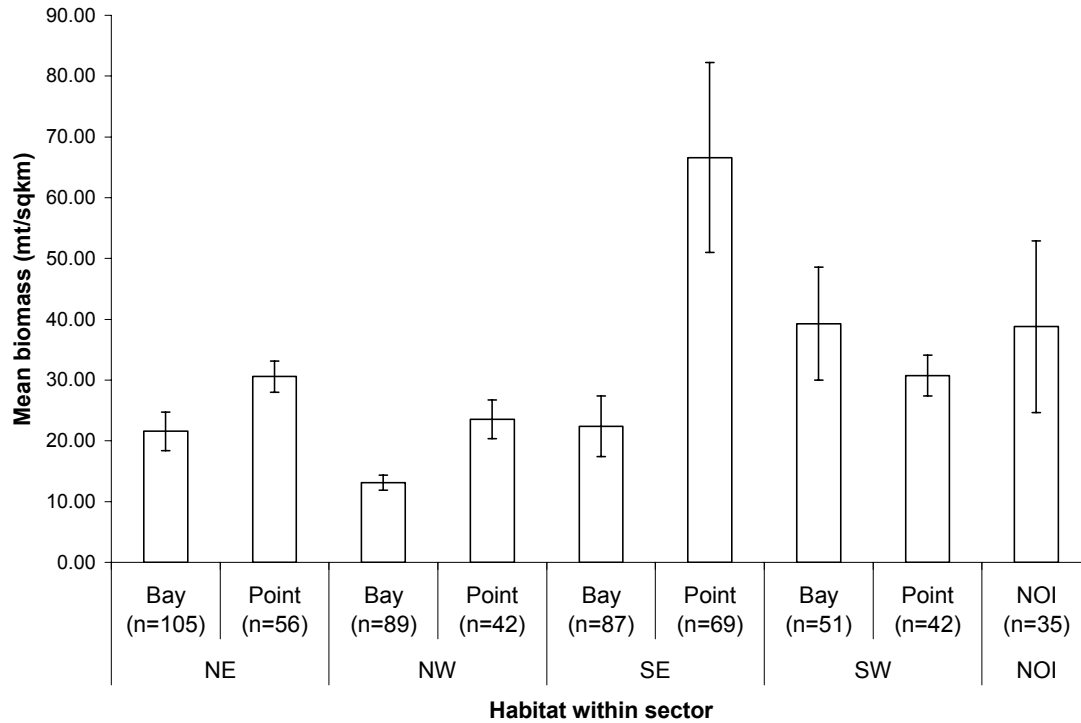


Figure 5. Mean biomass of key reef species in embayments and point areas within sectors. Error bars are standard error of the mean. N is number of observation points (approximately 7 in each transect). The acronyms below the n values are cartographic sector of the island while NOI stands for the “near off-island” sector.

Table 2. Analysis of Co-Variance with heirarchical nested design testing for variations in mean biomass across spatial scales. Covariates used are live coral cover (habitat character), macroalgae, and coralline algae (as food associated character).

General Effects	Effects (F/R)	df	SS	MS	F	p	sig
Intercept	Fixed	1	2.733	2.733	0.481	0.489	
Exposure	Fixed	1	65.741	65.741	11.562	0.001	**
Section(Exposure)	Fixed	1	11.797	11.797	2.075	0.151	
Habitat(Section)	Fixed	1	59.455	59.455	10.456	0.001	**
Site(Habitat)	Random	1	1.286	1.286	0.226	0.635	
Replicate(Site)	Random	2	3.064	1.532	0.269	0.764	
Section	Fixed	1	2.731	2.731	0.480	0.489	
Habitat	Fixed	1	64.670	64.670	11.373	0.001	**
Site	Random	1	27.709	27.709	4.873	0.028	*
Replicate	Random	2	46.493	23.247	4.088	0.018	*
Live coral cover	Fixed	1	22.157	22.157	3.897	0.049	*
Macroalgae cover	Fixed	1	37.373	37.373	6.573	0.011	*
Coralline algae cover	Fixed	1	20.718	20.718	3.644	0.057	
Error		321	1825.229	5.68607			

* significant (p<0.05)

** highly significant (p<0.01)

Abundance of key species across spatial scales

Abundance followed the same trend as biomass where there were high site variations except for sites at the northwest sector (Figure 6). Abundance is significantly higher on point areas, east side, and southern exposure (Table 3). Lower nesting levels were not significant.

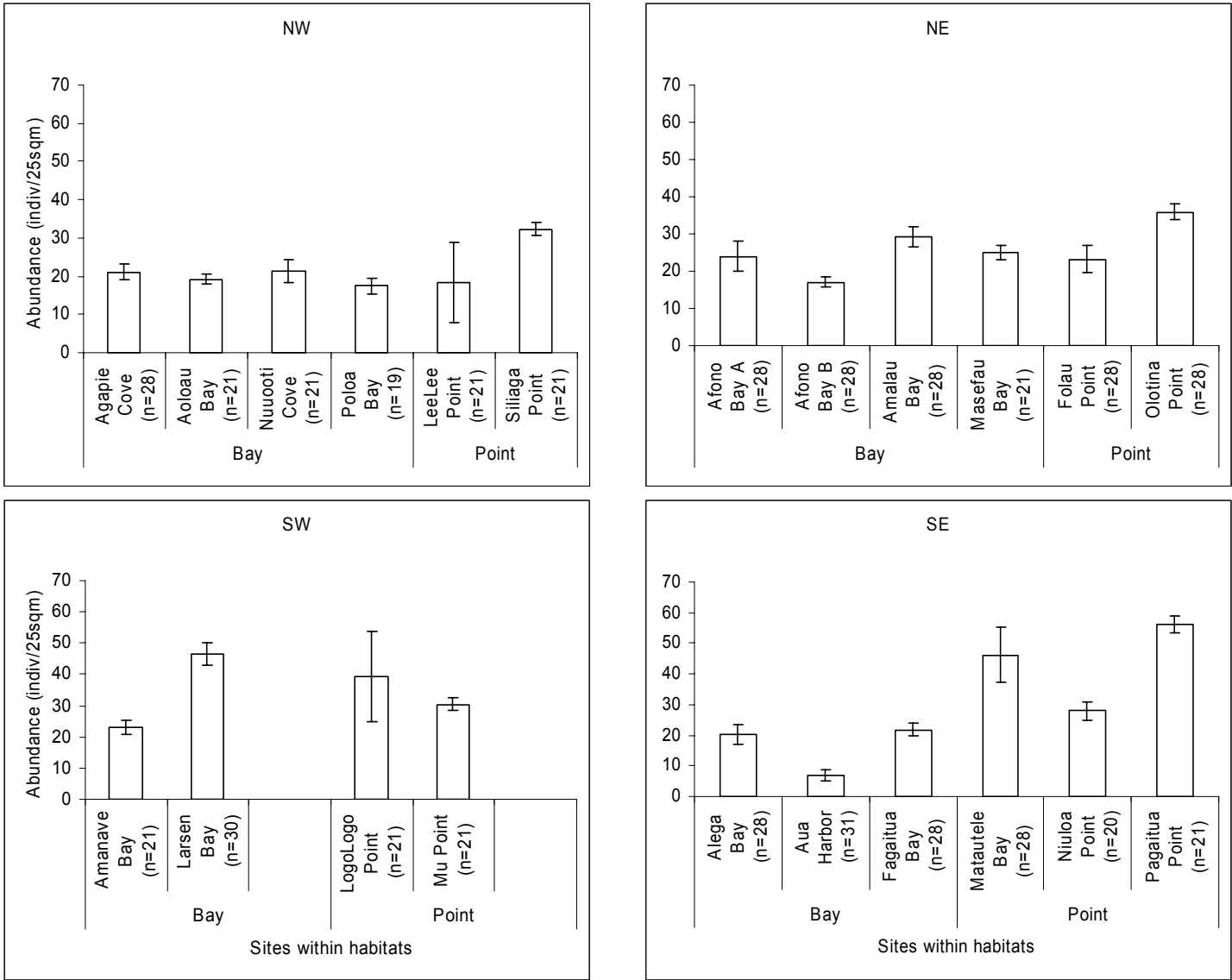


Figure 6. Mean abundance of key reef species across sites nested within habitats. Habitat is nested within sector (individual box). Each sector is nested within exposure (northern exposures are the top 2 boxes while southern exposures are the bottom 2)

This also indicates that the differences seen at higher nesting levels are fixed. In contrast with the lower levels, random selection of replicates within sites and sites within habitats does not affect the biomass outcome.

Table 3. Analysis of Co-Variance with heirarchical nested design testing for variations in mean abundance across spatial scales. Covariates used are live coral cover (habitat character), macroalgae, and coralline algae (as food associated character).

General Effects	Effects (F/R)	df	SS	MS	F	p	sig
Intercept	Fixed	1	13.081	13.081	4.458	0.036	
Exposure	Fixed	1	20.106	20.106	6.852	0.009	**
Section(Exposure)	Fixed	1	28.935	28.935	9.861	0.002	**
Habitat(Section)	Fixed	1	26.926	26.926	9.177	0.003	**
Site(Habitat)	Random	1	11.257	11.257	3.836	0.051	
Replicate(Site)	Random	2	5.645	2.822	0.962	0.383	
Section	Fixed	1	5.470	5.470	1.864	0.173	
Habitat	Fixed	1	30.733	30.733	10.474	0.001	**
Site	Random	1	23.771	23.771	8.101	0.005	*
Replicate	Random	2	36.781	18.390	6.268	0.002	*
Live coral cover	Fixed	1	8.943	8.943	3.048	0.082	
Macroalgae cover	Fixed	1	16.378	16.378	5.582	0.019	*
Coralline algae cover	Fixed	1	11.493	11.493	3.917	0.049	*
Error			941.883	2.93422			

* significant ($p < 0.05$)

** highly significant ($p < 0.01$)

Trophic level analysis

The trophic structure of the key reef species community follows the normal trophic pyramid where there are fewer carnivores than herbivores (Figure 7). The highest carnivore population was found in Agapie Cove with a total of 182 individuals/600sqm dominated by the flagtail grouper (*Cephalopholis urodeta*) and yellowspot emperor (*Gnathodentex aureolineatus*). Herbivores are the dominant trophic group at all survey sites. The highest herbivore population was found in Matautele Point with 965 individuals/600sqm dominated by striped bristletooth (*Ctenochaetus striatus*) and whitecheek surgeonfish (*Acanthurus nigricans*). Zooplanktivores are also abundant in Larsens Bay, Pagaitua and Matautele Point (394, 320, and 238 individuals/600sqm, respectively) primarily due to bluestreak fusilier (*Pterocaesio tile*).

Factor and regression analyses were used to determine underlying patterns in species associations brought about by certain driving factors (in this case benthic attributes). Carnivores and herbivores were the only trophic groups included in the analysis since they have direct association with the benthos used as food source or habitat utilization. The explained variance covers 69.87% of the total variance for the selected variables (abundance of carnivore species). Among the carnivore species only squaretail grouper (*Plectropomus areolatus*), redspot emperor (*Lethrinus lentjan*) and lyretail grouper (*Variola louti*) were affected by live coral cover (Table 4). All three are roving predators that inhabit areas with rich coral growth. The bigeye emperor (*Monotaxis grandoculis*), snappers (*Lutjanus monostigma* and *Aphareus rutilans*), and slingjaw wrasse (*Epibulus insidiator*) were affected by macro and coralline algae cover. All are zoobenthic feeders

in which their food items are commonly found in areas associated with macroalgae and coralline algae components.

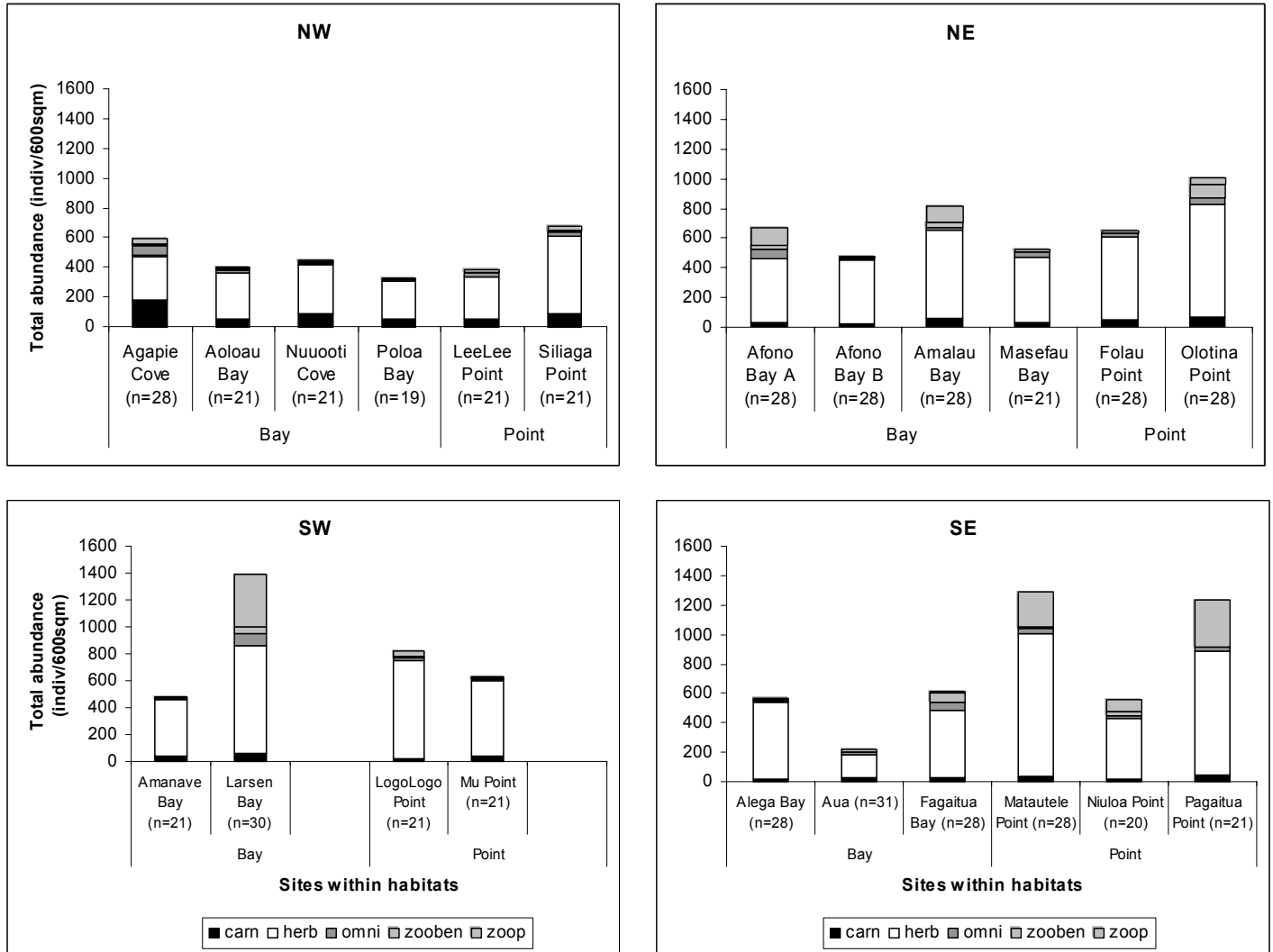


Figure 7. Total abundance of key reef species assigned to its respective trophic category across sites nested within habitats and habitats within sector. (Carn: carnivores; Herb: herbivores; Omni: omnivores; Zooben: zoobenthic feeders; Zoop: zooplanktivores)

Herbivores showed no association with live coral cover but responded significantly to macro and coralline algae cover. Factors representing five species of parrotfish (*Scarus forsteni*, *S. rivulatus*, *S. niger*, *S. oviceps* and *Chlorurus japanensis*) and three species of surgeonfish (*Acanthurus olivaceus*, *A. nigrofuscus*, and *Ctenochaetus striatus*) showed significant correlation with macroalgae (Table 5). These species are found in lagoons and seaward side of coral reef areas and feeds primarily on benthic algae and filamentous blue-green algae. *Hipposcarus longiceps* and *S. ghobban* had significant correlations with live coral and coralline algae cover which was unexpected given their ecological or trophic characteristics.

Table 4. Multiple-regression of factor scores of carnivore species and benthic cover (live coral-LCC, macroalgae-MA and coralline algae-CA). Factor score was treated as the dependent variable and cover as dependent variable. Only significant species associations are shown.

A. Live coral cover

Species	Control factor	R	R-square	F(1,81)	p
<i>Plectropomus areolatus</i>	LCC	0.266	0.071	6.186	0.015
<i>Lethrinus lentjan</i>					
<i>Variola louti</i>					

B. Macro and coralline algae cover

Species	Control factor	R	R-square	F(1,81)	p
<i>Monotaxis grandoculis</i>	MA	0.288	0.083	7.325	0.008
<i>Lutjanus monostigma</i>	CA	0.227	0.052	4.399	0.039
<i>Aphareus rutilans</i>					
<i>Epibulus insidiator</i>					

Table 5. Multiple-regression of factor scores of herbivore species and benthic cover (live coral-LCC, macroalgae-MA and coralline algae-CA). Factor score was treated as the dependent variable and cover as dependent variable. Only significant species associations are shown.

A. Macroalgae cover

Species	Control factor	R	R-square	F(1,81)	p
<i>Scarus forsteni</i>	MA	0.234	0.055	4.703	0.033
<i>Acanthurus olivaceus</i>					
<i>Scarus rivulatus</i>		0.254	0.065	5.599	0.020
<i>Scarus niger</i>					
<i>Ctenochaetus striatus</i>					
<i>Chlorurus japanensis</i>					
<i>Acanthurus nigrofuscus</i>		0.320	0.102	9.219	0.003
<i>Scarus oviceps</i>					

B. Coralline algae cover

Species	Control factor	R	R-square	F(1,81)	p
<i>Hipposcarus longiceps</i>	CA	0.367	0.135	12.624	0.001
<i>Scarus ghobban</i>					

DISCUSSION

Status of key reef fish population

Our data indicates that the fish populations in a majority of the sites around Tutuila and nearby island and banks are in good condition (based on biomass categories) (Hilomen et al. 2000). The data presented confirms the levels obtained by other researchers. The most recent fish survey done by the American Samoa Coral Reef Monitoring Program (ASCRMP) listed 72% of the sites as in the very high biomass category, and 28% at high

category (Whaylen and Fenner 2005a). None of their sites had low biomass. This could be due to lack of random selection of sites. The sampling protocol targeted true reef areas. Area of sampling is not likely to be a factor since both monitoring is of the same order of magnitude in terms of area coverage. This report covers a total of 13,500 m² from 83 transects while ASCRMP monitoring 11,662 m² from 66 transects. The data also falls within the range of mean biomass reported by Green (2002). Green had 76% of her sites in the very high category while 24% was at high levels. Highest biomass was located in Nuuuuli at 282 mt/km² and lowest 36 mt/km² in Leone. Green's survey again targeted well developed reef areas resulting to high biomass values. It also reports all fish species within the belt transect while our study targets only food fish.

Areas with high to very high biomass estimates imply minimal fishing pressure or protection for at least 5 years (Tun et al. 2004). There were no locally initiated MPA structures established on island until 2001 (with the exception of Fagatele Bay) but still showed high biomass values. Abundance and biomass of fish increased through time even in the absence of MPAs. Data from protected areas in Hawaii showed fish biomass during the closed season in protected areas is higher than areas continually open to fishing (Friedlander and Brown 2004). Their biomass values for closed season within protected areas are comparable to most of the areas surveyed in Tutuila. Friedlander and DeMartini (2002) reported biomass values from the northwestern Hawaiian islands (minimal fishing) and main Hawaiian islands (overfished) to be at 2.44 t/ha and 0.68 t/ha, respectively. Tutuila has an average of 1.36 t/ha based on Green's 2002 survey which is at 55% level of the NWHI. This is the only report comparable with the Friedlander study since both studies records all fish species within belt transects. Sixty percent of Green's 2002 data are key reef species at 0.81 t/ha which is still above the 30% spawning potential ratio of an un-fished reef like the NWHI. Our study records only key reef species yielding only 0.30 t/ha which is at 12% of the NWHI levels but 50% of the MHI.

The high biomass levels are attributed to the minimal fishing pressure occurring around the island. One factor that has contributed to these trends is the significant decrease in fishing effort in the past 25 years (Coutures 2003, Saucermann 1995, 1996, Ponwith 1991). This allowed stocks to recover and re-populate the reefs. This was shown in Green's 2002 data (1996-2002) and Birkeland et al. (2004) where Fagatele Bay and other sites around Tutuila showed an increase in abundance through time.

Spatial patterns: predator and prey relationship

We found significant variation in biomass and abundance across spatial scales. These differences were due to spatial differences in habitat availability and association of food item to percent cover of live coral, macro, and coralline algae. The high biomass at the south shore was due to abundance of available reef habitat. Reefs at the north shore are mostly concentrated in embayment areas and point areas are mostly volcanic pavement. *P. areolatus*, *V. louti* and *L. lentjan* were the species that responded to live coral cover. They are known to be highly associated with areas with high coral growth (Hiatt and Strasburg 1960). These are roving predator that feeds mostly on fish and are highly associated with coral reef habitats (Masuda and Allen 1993). The effect of live coral cover could be direct where it provides fish habitat or indirect where it influences the

distribution of the food source of these species. The same pattern was observed with other carnivorous species namely, *M. grandoculis*, *L. monostigma*, *A. rutilans*, and *E. insidiator* whose primary food items (gastropods, benthic crustaceans, ophiuroids, echinoids) are found in areas dominated by macroalgae and coralline algae.

Macrozoobenthic assemblages have been shown to be abundant in areas with higher macroalgae cover (Kotta and Orav 2001) because dense macroalgae cover provides higher habitat complexity (Hardwick-Witman and Mathieson 1983).

Live coral cover, on the other hand, is not a controlling factor for herbivores. Herbivores responded to macro algae and coralline algae cover. These benthic characters have a direct effect on herbivores since the former are primary producers while the latter is the primary consumer. Distribution of herbivores is dictated by abundance of their food item (Mateo and Tobias 2001). Herbivores in turn control the distribution and abundance of benthic species (Boaventura et al 2002; Lewis 1986). Spatial patterns in herbivores are also controlled by interspecific interactions with other roving herbivores (Choat and Bellwood 1985). Feeding territories are known to be present in some species where aggression or tolerance of other herbivores takes place.

Spatial patterns: biomass and habitat relationship

There was a higher biomass and abundance of key reef species at the exposed point reef areas than the sheltered embayment reef areas. Thus, it appears that important processes influencing abundance and biomass of key reef species varies between exposure regimes and abundance of coral reef habitats. A similar pattern was found in the Great Barrier Reef where exposed areas had higher biomass and abundance of parrotfish (Gust et al 2001). GIS mapping of coral reefs from satellite photos (NOAA NCCOS. 2005) revealed more coral reef habitat along the southern shores of Tutuila. A similar trend can be seen in Green's 2002 data set where higher mean fish biomass was recorded on reefs located along the south shore of Tutuila. Habitat utilization is one major factor contributing to the distribution patterns of organisms (Garpe and Ohman 2003).

Most villages are found within the sheltered embayment areas where fishing is therefore most concentrated (Inshore Creel Data; S. Mariner pers. comm.). The ocean condition on reefs located at geographic points is characterized by frequent large swells breaking at the crest area thus hindering fishing activities. This variation could have led to higher numerical abundance and biomass at point areas than in bays. The presence of a fishing gradient alone, however, could not fully explain this spatial pattern since fishing has continually been decreasing in the past 25 years (Coutures 2003). Other contributing factors such as environmental induced stress resulting in habitat degradation may explain these variations, wherein this is as yet untested in American Samoa.

Spatial patterns: live coral cover across scales

The spatial pattern in live coral cover is interesting because it showed a different pattern on the south versus north shores. For the north shore, point areas have significantly less live coral cover than embayment but the reverse trend occurs at the south shore (Appendix 1 and 2). The reefs at the north shore are concentrated mostly at sheltered bays while point areas are mostly volcanic pavements colonized by encrusting corals and

coralline algae. Reefs may be underdeveloped at point areas due to strong wave action. Wave exposure has been determined as a major inhibiting factor for reef development in Hawaii where most of the reefs are found in sheltered bay areas (Grigg 1983, 1998). The reefs at the south shore, however, are well developed extending to point areas. It is possible that the wave intensity at the south shore is lessened due to dissipation of wave energy originating from offshore by Taema and Nafanua Banks. The SW side of Tutuila also has a well-developed coral reef area since it's protected from the SE trade.

Little variation was observed between transects within each site. This indicates that individual transects within a site are adequate to represent the site as a whole. Sites within a habitat, however, varied significantly indicating that random site selection within a certain habitat is not enough to represent the habitat as a whole. This stochasticity in spatial distribution of live coral cover should be considered in various management strategies (Murdoch and Aronson 1999)

Implications for fisheries management

The marine protected areas are becoming a popular tool for fisheries management. Permanent no take zones to ensure habitat integrity that leads to an increase in fish population has been studied extensively (Alcala 2000; McClanahan and Shafir 1996; Wantiez et al 1997; Roberts and Polunin 1991; Russ and Alcala 1996a, 1996b). Designing an effective MPA, however, has proven to be a challenge (Sobel and Dahlgren 2004). The size and management scheme to operate and maintain MPA varies among location and objectives of the MPA. Design tools based on ecologically and biologically sound data are being used to ensure long term effectiveness of MPAs.

Our results could provide useful information on the size of protected area to be established in American Samoa. The main objective of this MPA is to preserve biodiversity and reproductive potential of fish and corals assuming that the underlying processes leads to ecosystem resilience are maintained (Oram 2006). Optimizing the size of the MPA will aid efforts to reach these goals. The MPA must be designed large enough to support the persistence of the species (NRC 2001). It is important to consider both the number of species it contains and the dispersal range of mobile species. Results of this study indicate that significant differences in biomass occur at larger spatial scales (habitat levels and above). Differences in biomass at the site level were negligible. Higher biomass occurs at reefs located at point areas and for fishery management these stocks should be protected therefore MPAs should be designed to protect points rather than bays. What is interesting, the south shore showed higher live coral cover at point areas as well (Appendix 1). Based on these biological parameters, point habitats on the south shore are the best locations for establishment of MPAs since these areas contain high coral cover and key reef species biomass.

The MPA Strategy describes establishment of 20% of the coral reefs in American Samoa as "strict no-take". How to come up with this 20% is open for discussion. This study suggests choosing a number of large areas with certain habitat characteristics to comprise the territorial MPA instead of several small "interconnected" MPA sites. Considering the un-nested results of the ANOVA, site selection being a random effect, had a significant

impact on biomass results (Table 2). This high degree in variation will have serious implications on the design of the MPA. This effect, however, is minimized when random site selection is confined within a certain habitat. This would translate to designing MPAs at a larger scale. Our data recommends establishing MPAs within habitats, if possible point reef areas, but since point areas in Tutuila are not contiguous, a series of uninhabited bays and points would enable protection of higher fish stocks and benthic assemblage.

CHAPTER 2: VARIATIONS IN COMMUNITY STRUCTURE OF KEY REEF SPECIES ACROSS SPATIAL SCALES IN AMERICAN SAMOA

INTRODUCTION

The island of Tutuila is about 1.54 – 1.28 million years old (McDougall 1985) and coral reefs are still forming in some parts of the island. The reefs are not distributed uniformly around the island thus each site is characterized by a different habitat type. Each habitat type will have a different set of assemblage that are adapted to the environment and resources they are exposed to. Knowing the distribution patterns of species composition benefits reef and fisheries manager by focusing on sites where species of interest are found abundant.

Species distributions are known to be structured by factors influencing growth, survival, and environmental plasticity. In reef fish predation, availability of shelter, and early survivorship during recruitment are known to be major factors (Shulman 1985). Settlement is also affected by oceanographic or biological factors (e.g. *Thalassoma bifasciatum*, Victor 1986). While habitat structure is one of the most important factors affecting species distributions. The relationship between fish and habitat depends strongly on the family and trophic group to which species belongs (Ohman and Rajasuriya 1998).

Species distributions are variable at different spatial scales and taxonomic levels or among different taxa. For example, high within transect variation in acanthurids, labrids and scarids related to high variability in distributions but not in butterfly and damsel fish (Williams 1981).

Reefs in American Samoa are patchy at various the spatial scales (discussed in the previous chapter) and the habitat distribution is highly variable (NOAA NCCOS 2005). Reef fish communities may vary along a gradient depending on the availability of suitable habitat for recruitment, food source and shelter. The aim of this study is to determine the distribution pattern of species composition in key reef fish community brought about by difference in habitat type and side of the island. We used underwater survey techniques to determine species composition at each replicate transect. We used scaling to determine what comprises the key reef fish community and patterns of distribution at each spatial scale. We predict that different species comprise different habitats and side of the island brought about by differences in habitat availability and characteristics. The information generated from this study could help design a better management strategy for protection of habitat, diversity and fisheries in general.

METHODS OF ANALYSIS

Fish assemblage composition

The percent contribution of each species to the total biomass was computed by using the formula:

$$\text{Equation 1: } \% \text{ biomass}_{\text{species A}} = \left[\frac{\text{Total biomass}_{\text{species A}}}{\text{Total biomass}_{\text{species AZ}}} \right] \times 100$$

This shows which species that contributes most to the key reef species biomass. The index of relative dominance is given by (Friedlander et al. 2003):

$$\text{Equation 2: } \text{IRD} = \% \text{ frequency detected within transect} \times \% \text{ biomass contribution}$$

Species diversity across spatial scales

The number of species, Pielou's evenness, and Shannon-Wiener index were used as diversity measures for key reef species across spatial scales. Each parameter was plotted across habitat type within sectors.

Spatial trend in species distribution

The average biomass and abundance data was collected per species across sites. A value of zero was assigned to sites where a particular species was undetected. A similarity matrix was generated using Bray-Curtis similarity index, and data was square-root transformed to reduce extreme values.

The similarity values were plotted on a two-dimensional scale where points of the sites that are similar in species composition aggregate closely (multidimensional scaling analysis). Stress value was generated to establish reliability of the aggregation. In the event of high stress value (greater than 0.18) a cluster analysis should supplement the 2-dimensional plot ensure proper grouping (Clarke and Warwick 2001).

An analysis of similarity was performed on the similarity value to determine significant variations in sites due to exposure, sector, habitat, and substrate type. A Global-R and significance value was generated for each factor. R value close to 1 indicates high level of differences and values close to 0 indicates no differences.

Variations in species composition across exposure and habitat

The similarity of species contribution analysis was used to determine which species had a significant contribution to the similarity and dissimilarity of sites. The program was set to determine species that contribute to the 90% of the total population variance.

The PRIMER-E™ v.5.2.9 for Windows (PRIMER-E 2002) was used for all analysis.

RESULTS

Fish assemblage composition

The key reef species assemblage is dominated by Acanthuridae in terms of both biomass and numerical abundance (Table 6). The Acanthurid, the brown bristletooth (*Ctenochaetus striatus*) occurred at 100% of transects and accounted for 21.9% of total biomass. The second most dominant is the white cheek surgeon fish (*Acanthurus nigricans*) contributing to 7.6% of total fish biomass and 11.87% of numerical abundance. Other common species were big eye emperor (*Monotaxis grandoculis*), the black snapper (*Macolor niger*), two small grouper species (*Cephalopholis argus* and *Cephalopholis urodeta*), and the pink tail triggerfish (*Melichthys vidua*). The most abundant parrotfish are *Chlorurus japonensis* and *C. sordidus*. The redlip parrotfish (*Scarus rubroviolaceus*) is the third most dominant and third highest in biomass. The top parrotfish in term of biomass is the tan face parrotfish (*Chlorurus frontalis*) since they are often sighted as terminal phase adults in schools.

Table 6. Top 20 dominant key reef species in the 24 sites (83 transects) surveyed in Tutuila, Aunuu, and Taema Banks. Species are ordered according to decreasing index of relative dominance (IRD)

Family	Species name	Trophic guild	Frequency	Number	Biomass	IRD
Acanthuridae	<i>Ctenochaetus striatus</i>	Herbivore	100.00	42.38	21.85	2185.01
Acanthuridae	<i>Acanthurus nigricans</i>	Herbivore	92.77	11.87	7.58	703.58
Scaridae	<i>Chlorurus japonensis</i>	Herbivore	77.11	2.22	4.72	363.81
Acanthuridae	<i>Naso lituratus</i>	Zooplanktivore	56.63	1.67	2.73	154.76
Scaridae	<i>Chlorurus sordidus</i>	Herbivore	65.06	3.95	2.13	138.74
Lethrinidae	<i>Monotaxis grandoculis</i>	Carnivore	48.19	0.84	2.52	121.51
Scaridae	<i>Scarus rubroviolaceus</i>	Herbivore	36.14	0.55	3.26	117.96
Acanthuridae	<i>Acanthurus lineatus</i>	Herbivore	42.17	1.95	2.74	115.40
Scaridae	<i>Chlorurus frontalis</i>	Herbivore	15.66	0.98	7.35	115.17
Scaridae	<i>Scarus oviceps</i>	Herbivore	34.94	0.96	2.51	87.58
Serranidae	<i>Cephalopholis urodeta</i>	Carnivore	68.67	2.65	1.27	87.19
Scaridae	<i>Scarus forsteni</i>	Herbivore	26.51	0.59	2.98	79.03
Balistidae	<i>Melichthys vidua</i>	Omnivore	51.81	1.39	1.46	75.87
Lutjanidae	<i>Macolor niger</i>	Zooplanktivore	26.51	0.50	1.97	52.26
Serranidae	<i>Cephalopholis argus</i>	Carnivore	50.60	0.89	0.82	41.38
Caesionidae	<i>Pterocaesio tile</i>	Zooplanktivore	10.84	5.40	3.53	38.28
Scaridae	<i>Scarus psittacus</i>	Herbivore	27.71	1.04	0.74	20.52
Acanthuridae	<i>Zebrasoma scopas</i>	Herbivore	33.73	1.38	0.59	19.99
Scaridae	<i>Scarus globiceps</i>	Herbivore	18.07	0.54	1.10	19.93
Scaridae	<i>Scarus frenatus</i>	Herbivore	20.48	0.29	0.95	19.49

Herbivores dominated the feeding guilds accounted for 66.3% of biomass and 74.6% of numerical abundance, while zooplankton feeders made up 13% of biomass and 12.1% of abundance due to abundance of the blue streak fusiliers (*Pterocaesio tile*). Carnivores are the third dominant trophic guild comprising only 9.1% of the total biomass and 7.5% of

the total abundance. Nekton feeders, omnivores and zoobenthos feeders comprised only 11.5% and 7.6% of the total biomass and abundance, respectively, combined.

Overall pattern of diversity, evenness, and dominance

The number of species within a transect varied from site to site but ranged from 21 species in Aoloau Bay to 45 in Olotina Point. The data were summarized according to habitat types nested within sectors. Point areas had a higher number of species than bay areas in 3 out of 4 sectors (Figure 8). Higher evenness is found in point areas at the NW and SE sectors and the reverse is true for the NE and SW sectors. Thus, point areas in the NW and SE are more diverse than bays, and bay areas in the NE and SW sectors are more diverse than points. Number of species at near-off-island sites is the lowest but one of the highest in evenness. The Shannon-Wiener Plot shows a similar pattern to evenness. The near off-island sites showed moderate diversity.

Dominance by only a few species is evident in the NE and SW sectors, as well as and bays within NW and SE sectors, as shown by the lower evenness values. The numbers of individuals in these cases are constrained to only a few species.

Species composition across spatial scales

Exploratory data analysis revealed significant differences between exposure, sector, and habitat in terms of biomass and species composition. There is a well-defined separation of the north from south shore sites (Figure 9). Taema Banks, Pagaitua Point and Aua are considered outliers due to differences habitat characteristics

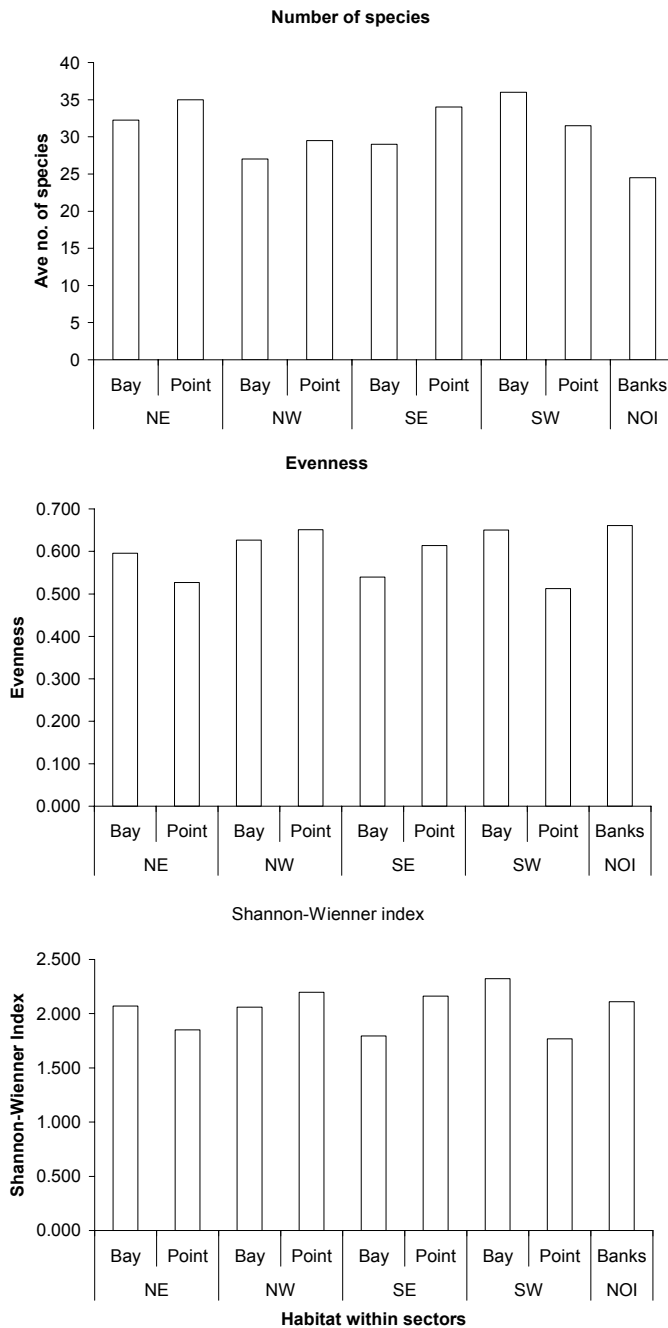


Figure 8. Diversity measures in points and bay habitats within sectors in Tutuila

and influence of land based pollution. The stress value (how well the distances in the ordination plot correspond to the dissimilarity values) is 0.17 is within the range that is considered reliable without having to perform a cluster analysis to verify the groupings (Clarke and Warwick 2001). Using habitat as factor revealed separate groupings for sites located in bays versus those found in points with very little overlap (Figure 10).

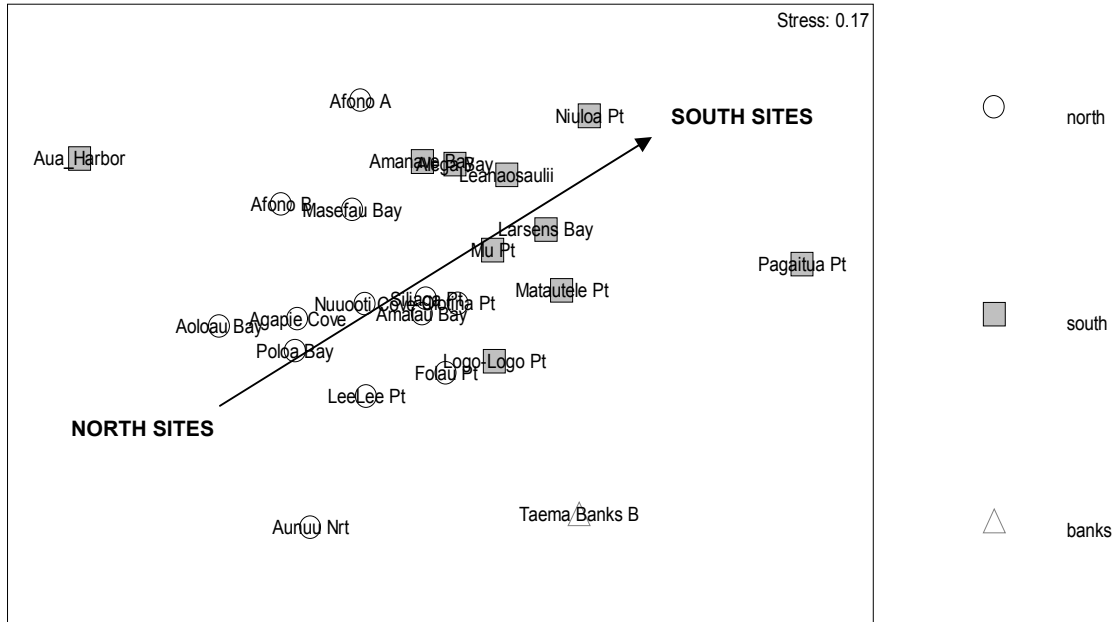


Figure 9. Two-dimensional plot of biomass of key reef species across sites showing differences in biomass between north and south shore site in American Samoa.

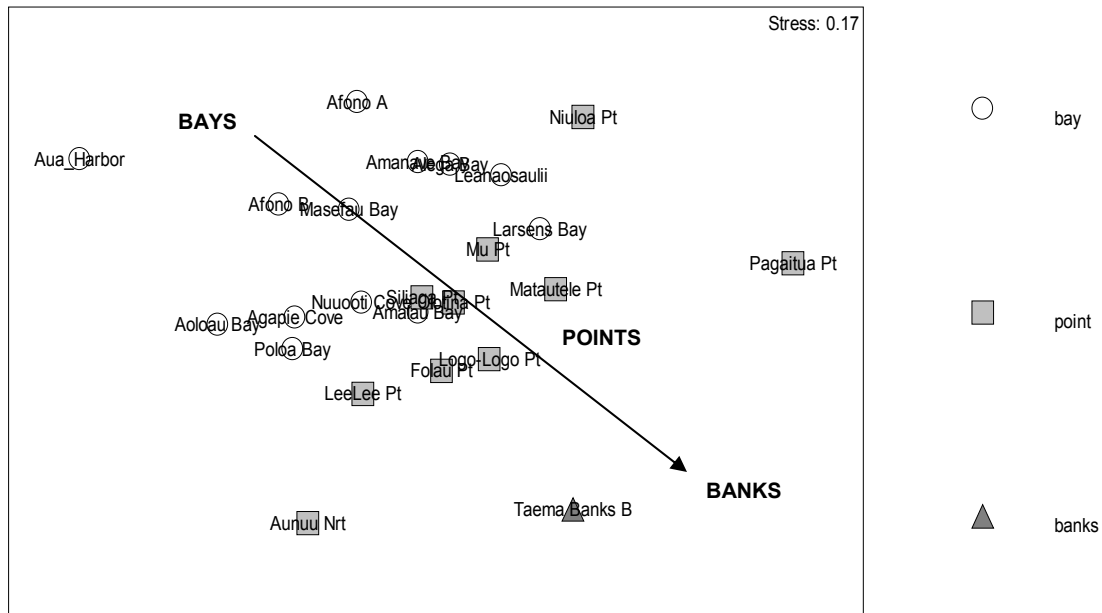


Figure 10. Two-dimensional plot of biomass of key reef species across sites showing differences in biomass between habitats (embayment and point areas) in American Samoa.

The emerging pattern in the differences in biomass across exposure and habitats were shown to be highly significant (Table 7). Biomass in Taema Banks was not included in the analysis because it only comprised of 1 sample.

Table 7. Analysis of Similarity of biomass by grouping factors (exposure and habitat)
The bank site was deleted as grouping factor due to having only 1 data point.

Groups	Possible permutations	Actual permutation	Number >= Observed	R-statistic	p	sig
North * South	1144066	999	0	0.332	0.001	**
Bay * Point	1144066	999	19	0.157	0.02	*

* significant ($p < 0.05$)

** highly significant ($p < 0.01$)

Species composition between exposure and habitat

Approximately 50% of the species that contributed to the similarity of sites based on exposure and habitat type are present at both subgroup (north and south for exposure; bays and points for habitat types) (Table 8 and 9). Only 25% of the species had a significant contribution that distinguishes each sub-grouping. The species that are present on both subgroups are also the species that are listed under the top 20 most dominant species (Table 6) except for *Balistapus undulatus*, *Parupeneus bifasciatus*, *Lutjanus bohar*, *Halichoeres hortulanus*, and *Aphareus rutilans*.

Variations in biomass of *Chlorurus frontalis* had the highest contribution to the difference between the northern and southern shores of Tutuila (Table 10). The white cheek surgeonfish (*Acanthurus nigricans*) is the second most dominant in the south shore. This is the second most dominant species at overall levels in Tutuila. The blue streak fusilier (*Pterocaesio tile*) is the third dominant species contributing to 13% to the zooplanktivore population. The high biomass of *Acanthurus lineatus*, *Naso lituratus*, *Melichtys vidua*, *Gnathodentex aureolineatus*, and *Cephalopholis urodeta* had a small contribution but significant influence on the dissimilarity of the north from the south shore sites. Only 11 species from the north shore sites contributed to the dissimilarity therefore the main species assemblage that significantly affects the distribution are the south shore assemblages. The difference between habitats is driven by high biomass of *A. lineatus* in reefs located in point areas (Table 11). *C. frontalis* are mostly located in embayment areas while *A. nigricans*, *C. striatus* and *P. tile* usually co-occur with *A. lineatus* in point reef areas. Majority of the species that drives the difference between habitats occurs at high biomass levels in point areas.

Table 8. Percentage contributions of key reef species determining the similarity of sites within exposure. Data was limited only to species with the highest contribution (top 90%)

Species	North	South
<i>Ctenochaetus striatus</i>	24.82	22.02
<i>Acanthurus nigricans</i>	11.81	10.66
<i>Chlorurus japanensis</i>	7.7	7.31
<i>Cephalopholis urodeta</i>	6.81	2.33
<i>Naso lituratus</i>	5.26	1.21
<i>Cephalopholis argus</i>	4.03	2.1
<i>Monotaxis grandoculis</i>	3.73	6.39
<i>Scarus rubroviolaceus</i>	2.91	1.7
<i>Chlorurus sordidus</i>	2.86	4.75
<i>Acanthurus lineatus</i>	2.44	2.01
<i>Parupeneus bifasciatus</i>	1.47	0.95
<i>Halichoeres hortulanus</i>	1.45	0.91
<i>Scarus oviceps</i>	1.27	2.71
<i>Balistapus undulatus</i>	0.95	1.49
<i>Aphareus rutilans</i>	0.92	2.49
<i>Zebrasoma scopas</i>	0.8	1.5
<i>Melichthys vidua</i>	4.38	
<i>Acanthurus nigrofuscus</i>	1.98	
<i>Lutjanus bohar</i>	1.61	
<i>Scarus forsteni</i>	1.41	
<i>Gnathodentex aureolineatus</i>	1.1	
<i>Parupeneus cyclostomus</i>	0.91	
<i>Scarus psittacus</i>		3.95
<i>Kyphosus cinerascens</i>		3.22
<i>Scarus frenatus</i>		2.65
<i>Macolor niger</i>		2.57
<i>Acanthurus achilles</i>		1.64
<i>Pterocaesio tile</i>		1.59
<i>Chlorurus frontalis</i>		1.29
<i>Acanthurus guttatus</i>		1.27
<i>Lutjanus monostigma</i>		1.02
<i>Scarus spinus</i>		0.98

Table 9. Percentage contributions of key reef species determining the similarity of sites within habitats. Data was limited only to species with the highest contribution (top 90%)

Species	Bays	Points
<i>Ctenochaetus striatus</i>	25.08	23.87
<i>Chlorurus japanensis</i>	10.34	4.79
<i>Acanthurus nigricans</i>	9.72	14.1
<i>Monotaxis grandoculis</i>	5.39	3.93
<i>Cephalopholis urodeta</i>	5.2	4.01
<i>Chlorurus sordidus</i>	3.46	4.53
<i>Cephalopholis argus</i>	3.25	3.03
<i>Scarus rubroviolaceus</i>	3.05	1.68
<i>Naso lituratus</i>	2.6	4.22
<i>Melichthys vidua</i>	1.66	3.66
<i>Macolor niger</i>	1.4	1.32
<i>Scarus oviceps</i>	1.38	2.41
<i>Balistapus undulatus</i>	1.29	0.96
<i>Parupeneus bifasciatus</i>	1.11	1.4
<i>Lutjanus bohar</i>	0.96	1.48
<i>Scarus frenatus</i>	0.95	1.07
<i>Aphareus rutilans</i>	2.17	
<i>Zebrasoma scopas</i>	2.03	
<i>Scarus forsteni</i>	1.67	
<i>Halichoeres hortulanus</i>	1.65	
<i>Parupeneus cyclostomus</i>	1.62	
<i>Acanthurus nigrofuscus</i>	1.46	
<i>Cetoscarus bicolor</i>	1.04	
<i>Caranx melampygus</i>	0.9	
<i>Acanthurus lineatus</i>		5.75
<i>Acanthurus achilles</i>		2.31
<i>Pterocaesio tile</i>		1.43
<i>Zebrasoma veliferum</i>		1.38
<i>Kyphosus cinerascens</i>		1.35
<i>Scarus psittacus</i>		1.03
<i>Scarus spinus</i>		1.05

Table 10. Percentage contribution of various key reef species to the dissimilarity between the northern and southern exposure of the island of Tutuila, American Samoa.
Only species in the top 90% were included (species with the highest contributions)

Species	Mean biomass		Mean dissimilarity	SD dissimilarity	% contribution
	North	South			
<i>Chlorurus frontalis</i>	2.06	29.83	2.51	0.63	4.17
<i>Acanthurus nigricans</i>	12.27	21.33	1.79	1.17	2.97
<i>Pterocaesio tile</i>	0.7	17.57	1.78	0.81	2.95
<i>Scarus oviceps</i>	2.42	8.65	1.72	1.15	2.85
<i>Acanthurus lineatus</i>	8.05	3.22	1.69	1.11	2.81
<i>Ctenochaetus striatus</i>	42.67	52.57	1.59	1.31	2.64
<i>Macolor niger</i>	1.55	8.78	1.56	0.81	2.59
<i>Naso lituratus</i>	6.55	2.9	1.53	1.36	2.55
<i>Scarus rubroviolaceus</i>	2.22	14.31	1.44	0.87	2.39
<i>Monotaxis grandoculis</i>	3.05	8.87	1.42	1.51	2.36
<i>Chlorurus sordidus</i>	2.11	8.95	1.4	1.26	2.33
<i>Chlorurus japanensis</i>	7.73	12.82	1.37	1.23	2.27
<i>Kyphosus cinerascens</i>	0.63	3.99	1.34	1.36	2.23
<i>Scarus psittacus</i>	0.13	3.3	1.32	1.42	2.19
<i>Melichthys vidua</i>	4.65	1.15	1.31	1.19	2.18
<i>Scarus globiceps</i>	0.48	5.73	1.19	0.71	1.98
<i>Scarus frenatus</i>	1.19	3.37	1.17	1.33	1.95
<i>Caesio teres</i>	2.62	4.85	1.1	0.68	1.83
<i>Lutjanus bohar</i>	1.16	2.84	1.04	1.11	1.73
<i>Melichthys niger</i>	0.1	10.9	1.01	0.55	1.68
<i>Scarus forsteni</i>	0.87	3.75	0.98	1.14	1.62
<i>Mulloidichthys vanicolensis</i>	1.98	3.61	0.94	0.52	1.57
<i>Gnathodentex aureolineatus</i>	2.99	0.4	0.93	0.78	1.55
<i>Cephalopholis urodeta</i>	3.64	2.12	0.91	1.17	1.51
<i>Naso caesius</i>	0	10.69	0.89	0.48	1.47
<i>Scarus spinus</i>	0.43	2.29	0.87	0.92	1.45
<i>Gymnosarda unicolor</i>	0.92	6.56	0.84	0.42	1.39
<i>Acanthurus guttatus</i>	0.09	2.32	0.82	0.97	1.36
<i>Zebrasoma scopas</i>	1.18	1.27	0.82	1.17	1.36
<i>Cephalopholis argus</i>	2.46	1.25	0.78	1.13	1.29
<i>Lutjanus monostigma</i>	0.24	1.74	0.77	0.92	1.28
<i>Cetoscarus bicolor</i>	0.35	2.07	0.75	0.89	1.24
<i>Triacodon obesus</i>	9.13	0	0.74	0.28	1.23
<i>Aphareus rutilans</i>	0.5	1.7	0.71	1.13	1.17
<i>Acanthurus nigrofasciatus</i>	1.07	0.13	0.7	1.13	1.17
<i>Acanthurus achilles</i>	0.46	1.44	0.7	1.31	1.17
<i>Parupeneus bifasciatus</i>	0.71	1.03	0.64	1.21	1.07
<i>Balistapus undulatus</i>	0.5	0.96	0.64	1.07	1.07
<i>Epibulus insidiator</i>	0.12	0.86	0.58	0.81	0.97
<i>Chlorurus microrhinos</i>	0.79	3.33	0.56	0.44	0.93
<i>Acanthurus nigricauda</i>	4.45	0.13	0.56	0.37	0.92
<i>Naso unicornis</i>	1.15	0	0.55	0.75	0.91
<i>Halichoeres hortulanus</i>	0.48	0.89	0.55	1.44	0.91
<i>Aphareus furca</i>	0.57	0.8	0.55	0.9	0.91
<i>Parupeneus cyclostomus</i>	0.49	0.53	0.53	1.07	0.88
<i>Caranx melampygus</i>	0.3	0.68	0.52	1.07	0.86
<i>Cheilinus trilobatus</i>	0.34	0.41	0.46	1.08	0.76
<i>Zebrasoma veliferum</i>	0.35	0.41	0.43	0.93	0.72
<i>Acanthurus blochii</i>	0	5.31	0.43	0.33	0.71
<i>Cantherhines dumerili</i>	0.6	0.05	0.41	0.74	0.68
<i>Scarus altipinnis</i>	0	1.39	0.41	0.49	0.67
<i>Scarus niger</i>	0.8	0.04	0.39	0.6	0.65
<i>Lutjanus gibbus</i>	0.08	3.11	0.38	0.39	0.63
<i>Plectorhinchus orientalis</i>	0.6	0.11	0.36	0.6	0.6
<i>Coris aygula</i>	0.17	0.32	0.36	0.79	0.6
<i>Acanthurus olivaceus</i>	0.3	0.15	0.35	0.7	0.58
<i>Hemigymnus melapterus</i>	0	0.37	0.33	0.92	0.55
<i>Acanthurus xanthopterus</i>	0.04	0.43	0.33	0.76	0.55
<i>Calotomus carolinus</i>	0.13	0.41	0.33	0.62	0.54
<i>Aprion virescens</i>	0.19	0.51	0.31	0.56	0.52
<i>Naso annulatus</i>	0	1.12	0.28	0.47	0.47
<i>Lutjanus fulvus</i>	0.15	0.11	0.27	0.77	0.46
<i>Sufflamen bursa</i>	0.2	0.02	0.27	0.94	0.45

Table 11. Percentage contribution of various key reef species to the dissimilarity between bays and point habitats in the island of Tutuila, American Samoa. Only species in the top 90% were included (species with highest contributions)

Species	Mean biomass		Mean dissimilarity	SD dissimilarity	% contribution
	Bay	Point			
<i>Acanthurus lineatus</i>	1.26	12.05	2.35	1.17	3.96
<i>Chlorurus frontalis</i>	14.46	13.71	2.03	0.59	3.42
<i>Acanthurus nigricans</i>	10.31	23.89	1.85	1.16	3.12
<i>Ctenochaetus striatus</i>	36.28	60.87	1.84	1.45	3.1
<i>Pterocaesio tile</i>	5.28	11.62	1.68	0.85	2.84
<i>Scarus oviceps</i>	4.5	5.95	1.64	1.16	2.78
<i>Chlorurus sordidus</i>	1.75	9.41	1.53	1.42	2.58
<i>Naso lituratus</i>	3.57	6.77	1.52	1.38	2.57
<i>Chlorurus japanensis</i>	9.01	11.15	1.44	1.25	2.42
<i>Scarus rubroviolaceus</i>	2.52	13.92	1.42	0.86	2.4
<i>Melichthys vidua</i>	1.48	5.27	1.4	1.11	2.36
<i>Macolor niger</i>	6.48	2.37	1.32	0.87	2.23
<i>Monotaxis grandoculis</i>	4.56	6.91	1.31	1.4	2.21
<i>Triaenodon obesus</i>	0	11.87	1.14	0.33	1.93
<i>Kyphosus cinerascens</i>	1.38	3.01	1.1	0.97	1.85
<i>Scarus globiceps</i>	1.63	4.23	1.07	0.67	1.81
<i>Melichthys niger</i>	0	11.04	1.07	0.58	1.81
<i>Caesio teres</i>	4.67	2.18	1.04	0.69	1.75
<i>Gnathodentex aureolineatus</i>	1.65	2.15	1.01	0.86	1.7
<i>Gymnosarda unicolor</i>	0	7.75	1	0.47	1.69
<i>Scarus frenatus</i>	2.28	1.96	0.98	1.11	1.66
<i>Lutjanus bohar</i>	2.06	1.68	0.97	1.15	1.64
<i>Scarus forsteri</i>	1.03	3.54	0.97	1.15	1.63
<i>Scarus spinus</i>	0.38	2.35	0.89	0.92	1.51
<i>Naso caesius</i>	0	10.69	0.88	0.47	1.49
<i>Mulloidichthys vanicolensis</i>	2.66	2.73	0.88	0.54	1.48
<i>Scarus psittacus</i>	1.41	1.63	0.86	1.09	1.46
<i>Zebrasoma scopas</i>	1.92	0.31	0.81	1.18	1.37
<i>Acanthurus achilles</i>	0.3	1.64	0.79	1.47	1.33
<i>Cephalopholis urodeta</i>	3.04	2.91	0.78	1.21	1.32
<i>Cephalopholis argus</i>	2.07	1.76	0.75	1.34	1.26
<i>Cetoscarus bicolor</i>	1.46	0.63	0.67	0.95	1.14
<i>Aphareus rutilans</i>	0.8	1.31	0.67	1.11	1.14
<i>Lutjanus monostigma</i>	1	0.76	0.64	0.91	1.09
<i>Acanthurus nigrofuscus</i>	0.8	0.49	0.63	1.13	1.07
<i>Zebrasoma veliferum</i>	0.07	0.78	0.62	1.25	1.05
<i>Acanthurus guttatus</i>	1.26	0.8	0.62	0.85	1.04
<i>Parupeneus bifasciatus</i>	0.88	0.81	0.62	1.26	1.04
<i>Aphareus furca</i>	0.37	1.06	0.6	0.94	1.02
<i>Balistapus undulatus</i>	0.64	0.78	0.58	1.06	0.98
<i>Parupeneus cyclostomus</i>	0.75	0.2	0.57	1.13	0.96
<i>Chlorurus microrhinos</i>	0.79	3.33	0.56	0.44	0.94
<i>Naso unicornis</i>	0.71	0.57	0.55	0.7	0.92
<i>Halichoeres hortulanus</i>	0.55	0.8	0.54	1.42	0.92
<i>Acanthurus nigricauda</i>	4.56	0	0.52	0.35	0.88
<i>Caranx melampygus</i>	0.47	0.45	0.51	1.1	0.85
<i>Epibulus insidiator</i>	0.57	0.27	0.45	0.8	0.77
<i>Cheilinus trilobatus</i>	0.38	0.37	0.44	1.1	0.74
<i>Acanthurus blochii</i>	0	5.31	0.43	0.33	0.72
<i>Aprion virescens</i>	0	0.75	0.41	0.62	0.7
<i>Scarus niger</i>	0.7	0.16	0.39	0.61	0.66
<i>Cantherhines dumerili</i>	0.58	0.09	0.39	0.75	0.66
<i>Plectorhinchus orientalis</i>	0.31	0.48	0.38	0.63	0.65
<i>Lutjanus gibbus</i>	0.08	3.11	0.38	0.39	0.64
<i>Acanthurus olivaceus</i>	0.42	0	0.37	0.76	0.62
<i>Scarus microrhinos</i>	0	1.52	0.34	0.33	0.58
<i>Balistoides conspicillum</i>	0	0.83	0.33	0.46	0.55
<i>Coris aygula</i>	0.37	0.06	0.32	0.78	0.54
<i>Lutjanus fulvus</i>	0.23	0	0.31	0.88	0.52
<i>Calotomus carolinus</i>	0.16	0.38	0.3	0.58	0.51
<i>Scarus altipinnis</i>	1.07	0	0.27	0.42	0.46
<i>Sufflamen bursa</i>	0.15	0.08	0.27	0.9	0.46
<i>Plectropomus areolatus</i>	0.09	0.39	0.27	0.5	0.46

DISCUSSION

Fish assemblage composition

The key reef species in American Samoa is dominated by herbivores in families Acanthuridae and Scaridae. Their abundance controls the benthic algal population resulting in a low percentage cover of algae in general (macro, turf and filamentous algae combined) (Appendix 3). Algae are abundant in Afono A, Amalau Bay, Masefau Bay, Folau Point, Poloa Bay, and Siliaga Point, all of which are north shore sites. These sites or areas within sites contain algal farms brought of *Acanthurus lineatus*, *Stegastes nigricans* and *Pomacentrus philippinus*. But looking at biomass and abundance of herbivores at these sites, levels are high. This is because these species of fish are territorial and drive off other herbivores, keeping the algal turfs high. It appears that algal cover is dependent on the species composition of the site. Overall, the levels of grazing in American Samoa's reefs can be considered as high. Exclusion or removal of herbivores results in increased algal cover (Lewis 1986, Morrison 1988). Because macroalgae compete with corals, macroalgae are not considered good for coral reefs (with possible exception of *Halimeda sp.*).

There is an evident dominance of *Ctenochaetus striatus* and *Acanthurus nigricans* at 10 meter depth (shown in Table 6). The abundance of these species reduced evenness and thus diversity. Their success on these reefs is attributed to their life history characteristics. They have the ability to recruit in high numbers and have the ability to evade predators by swimming away at high speeds for short periods. They also have the capability to protect themselves by using their caudal blades to injure a predator in the event of capture. The ecological implication of their dominance is yet to be known. But one obvious advantage is control of the proliferation of filamentous algae on reefs.

Variations in species composition across exposure and habitat

The differences between exposures and between habitats were due to varying biomass of certain species that constitutes the unique composition at each grouping factor. The main difference between north and south shores is the extent of coral reef areas that provide better habitat for fish (NOAA NCCOS 2005). The south side of Tutuila has a more developed coral reef that has a greater extent. Reef development at the north side is mostly found in the inner bay areas that are sheltered from strong waves that inhibit reef growth. Our analysis showed species associated with the north and south shore sites. Species that are not common to both are found mostly at the south shore are the ones associated with true reefs while those found mostly at the north shore are able to occupy non-true reef substrate as well as coral reefs, and so were found on both shores. For example, *Cephalopholis urodeta* were observed to occupy volcanic pavements utilizing gaps and crevices in the basalt substrate as refuge. This species has a wide habitat preference (Sluka 2000). The abundance of *Chlorurus frontalis* at the south shore supports the tight association of this species to well developed reef areas observed by Bellwood and Choat (1990). Majority of the south shore sites are true coral reef areas. A well developed reef area provides more shelter for fish due to its high benthic complexity. High habitat rugosity in reefs was shown to have high correlation with species richness (Luckhurst and Luckhurst 1978). The south shore of Tutuila, therefore

provides more protection of fish from predators than the less complex counterpart (colonized volcanic pavement) at the north shore. Presence of shelter from predators is known to control species distributions (Shulman 1985)

Acanthurus lineatus occurred mostly on exposed point areas. It utilizes the high water motion to farm benthic filamentous algae which grows best in high flow environments. Filamentous algae and algal turfs are abundant in areas with clear water, strong light intensity, and high water movement to maximize their primary productivity (Adey and Steneck 2003). Planktivores also occur in this habitat due to abundance of zooplankton that migrate vertically and concentrated by horizontal flow of water that converges at the points (Hamner and Hauri 1981).

Implications for fisheries management

Determining diversity, species composition and patterns of species distribution provides an insight on how population structures are formed and their relationship to the physical system. Managing multi-species groups is difficult if the distribution is unknown. Knowing where important species occur can allow managers to select which sites to protect or manage. Determining functional groups (in this case using trophic assignment) is also used to understand the dynamics of the population and how it relates to the ecosystem as a whole. The reefs of American Samoa are known to be resilient to certain disturbances, particularly hurricanes, crown of thorns, and mass bleaching. The resilience is attributed to the abundance of herbivores that graze upon fleshy algae that tends to recruit on dead coral substrate. The abundance of coralline algae also contributes to the resilience by providing suitable substrate for new coral recruits to settle on. With little fleshy algae and abundant coralline algae, corals are favored over macroalgae (Fenner, pers comm.) The abundance of corals on the reef thereby continually provides suitable habitat for fish to utilize as shelter, food source, and recruitment habitat.

Knowing the existence of difference between the exposure (north and south shore) and habitats (bays versus points) in terms of levels of biomass, abundance, and species composition provides useful information on the extent of management needed to conserve the limited resources of American Samoa. Focus should be aimed on conserving habitat integrity of areas with unique species composition, high biomass, and intact and well developed coral reefs. This report expounds on the importance of point habitats at the south shore of Tutuila since it is the major driver that accounts for the difference between exposure and habitat. Some of the species located in these reef areas are found to be in high biomass true in that habitat and side of the island. Management efforts should therefore be concentrated in these areas to maximize the economic and ecological gain.

This study provides an insight on how species are distributed across space (between exposure and habitat type). Any management intervention geared towards protecting some key reef species must take into account the variability of their distribution. This could guide the design of “no-take” MPAs aiming for restoring population of key reef species. This study also provides data on abundance of several species indicating that these populations (especially the herbivores) are in a stable state and available for consumption. Close monitoring of key reef species is necessary in order to determine

sustainability of the population for fisheries. Caution must be taken for extraction not to exceed sustainable levels that could tip the ecosystem balance. Excess removal of herbivores, for example, could lead to a drastic change in the coral reef ecosystem shifting the dominance from corals and coralline algae to fleshy and macroalgae.

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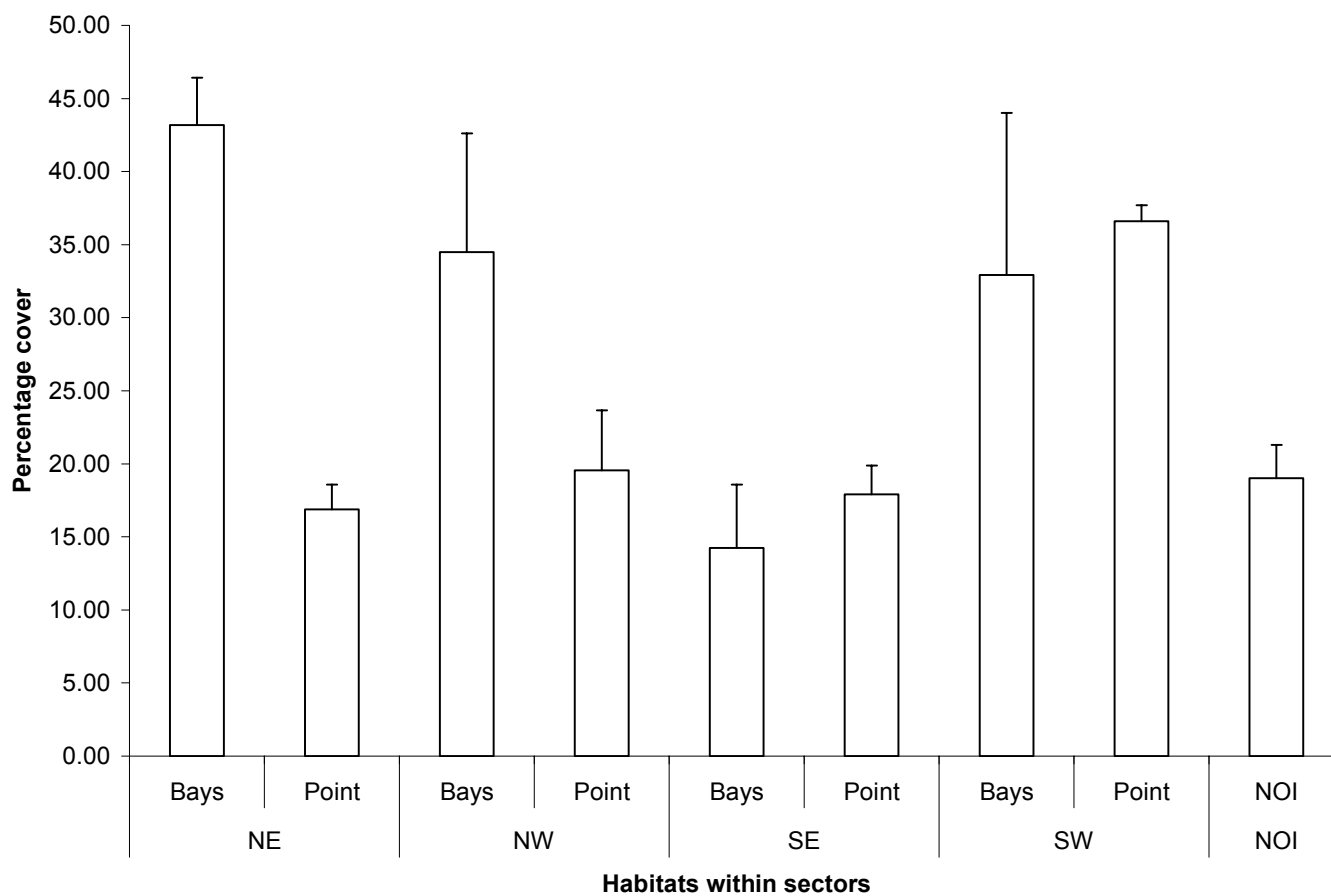
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APPENDICES

Appendix 1



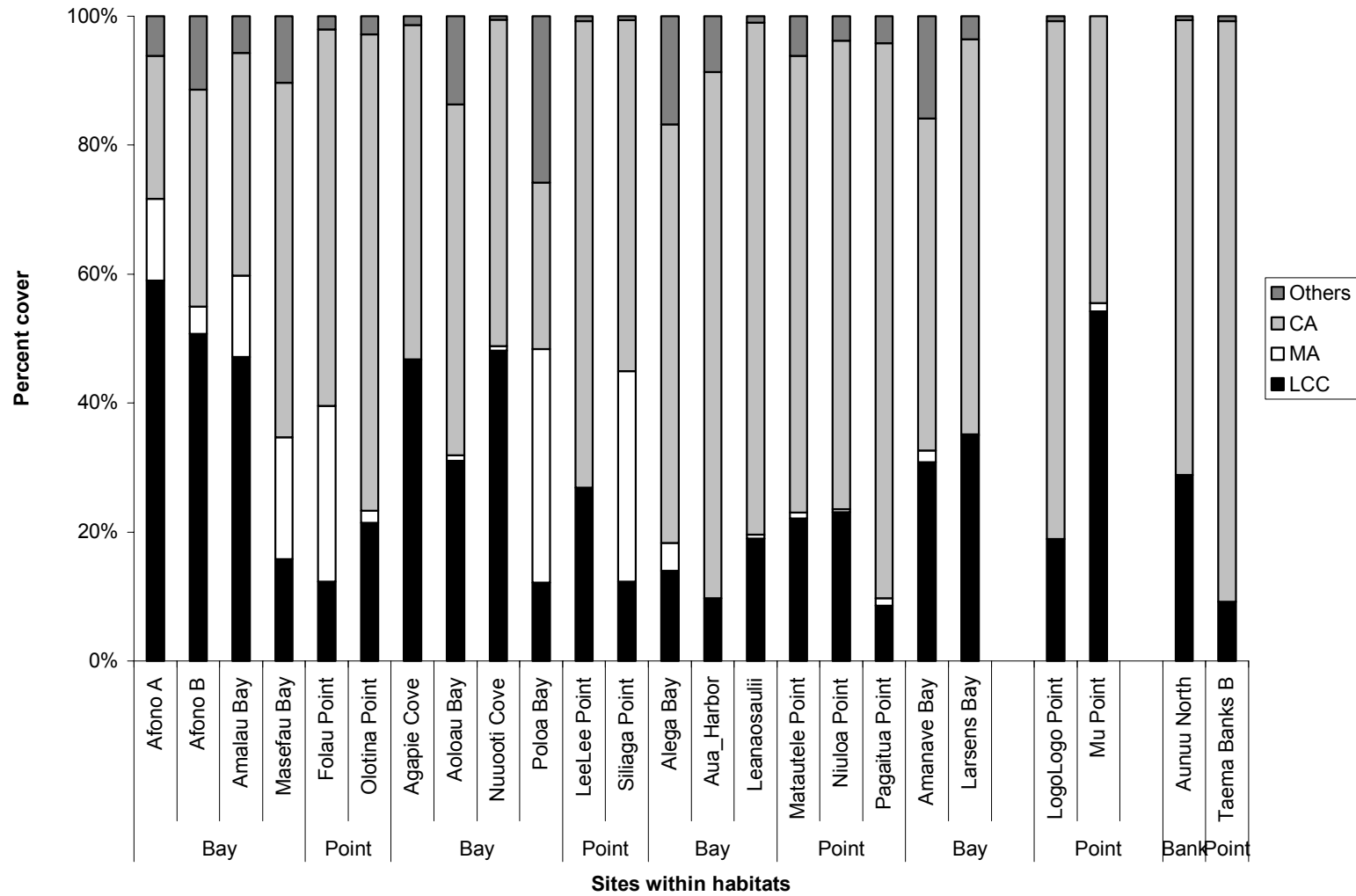
Percentage cover of live corals between habitats within sectors. Error bars are in standard error.

Appendix 2

Nested ANOVA on percentage cover of live corals in Tutuila, American Samoa

	SS	df	MS	F	p
Intercept	8842.555	1	8842.555	3157.437	0.000
Exposure	1.010	1	1.010	0.361	0.549
Sector(Exposure)	191.918	2	95.959	34.264	0.000
Habitat(Sector)	210.704	2	105.352	37.618	0.000
Sites(Habitat)	61.183	2	30.592	10.923	0.000
Replicate(Site)	10.680	4	2.670	0.953	0.433
Error	907.378	324	2.801		

Appendix 3



Percentage cover of live corals, macroalgae, coralline algae, and other benthic components.

Appendix 4

Species list of key reef species observed within the transects distributed to respective trophic categories

Carnivores	Herbivores	Nekton feeders	Omnivores	Zoobenthic feeders	Zooplanktivores
Aphareus furca	Acanthurus achilles	Aulostomus chinensis	Aluterus scriptus	Anampses caeruleopunctatus	Caesio caerulea
Aphareus rutilans	Acanthurus blochii	Caranx melampygus	Amanses scopas	Bodianus axillaris	Caesio teres
Aprion virescens	Acanthurus guttatus	Gymnosarda unicolor	Balistapus undulatus	Bodianus mesothorax	Macolor niger
Cephalopholis argus	Acanthurus lineatus	Rastrelliger kanagurta	Balistoides conspicillum	Cheilinus trilobatus	Naso annulatus
Cephalopholis urodeta	Acanthurus maculiceps	Sphyrna barracuda	Balistoides viridescens	Cheilinus undulatus	Naso caesius
Epibulus insidiator	Acanthurus nigricans	Triaenodon obesus	Cantherhines dumerili	Coris aygula	Naso lituratus
Epinephelus fasciatus	Acanthurus nigricauda		Canthigaster compressa	Diodon hystrix	Naso tuberosus
Epinephelus hexagonatus	Acanthurus nigrofusus		Melichthys niger	Gomphosus varius	Naso unicornis
Epinephelus melanostigma	Acanthurus olivaceus		Melichthys vidua	Halichoeres binotopsis	Odonus niger
Epinephelus polyphemus	Acanthurus pyroferus		Ostracion meleagris	Halichoeres hortulanus	Pempheris oualensis
Gnathodentex aureolineatus	Acanthurus triostegus		Ostracion solorensis	Hemigymnus melapterus	Pterocaesio pisang
Lethrinus lentjan	Acanthurus xanthopterus		Sufflamen bursa	Mulloidichthys vanicolensis	Pterocaesio tile
Lethrinus obsoletus	Calotomus carolinus		Zebrasoma scopas	Neoniphon argenteus	
Lethrinus xanthochilus	Cetoscarus bicolor		Zebrasoma veliferum	Parupeneus barberinoides	
Lutjanus bohar	Chlorurus frontalis			Parupeneus barberinus	
Lutjanus fulvus	Chlorurus japanensis			Parupeneus bifasciatus	
Lutjanus gibbus	Chlorurus microrhinos			Parupeneus cyclostomus	
Lutjanus kasmira	Chlorurus sordidus			Parupeneus indicus	
Lutjanus monostigma	Ctenochaetus striatus			Parupeneus multifasciatus	
Monotaxis grandoculis	Hipposcarus longiceps			Plectorhinchus orientalis	
Oxycheilinus unifasciatus	Kyphosus bigibbus			Plectorhinchus vittatus	
Plectropomus areolatus	Kyphosus cinerascens				
Thalassoma hardwickii	Scarus altipinnis				
Thalassoma quinquevittatum	Scarus festivus				
Variola albimarginata	Scarus forsteni				
Variola louti	Scarus frenatus				
	Scarus ghobban				
	Scarus globiceps				
	Scarus niger				
	Scarus oviceps				
	Scarus psittacus				
	Scarus rivulatus				
	Scarus rubroviolaceus				
	Scarus schlegeli				
	Scarus spinus				

Appendix 5

Comparisons on detecting number of species using bounded survey methods: the case for American Samoa

Five studies with available data were compared in order to determine variations in the number of species detected using various methods and area sampled. Methods ranged from underwater visual census to sample collection with literature reviews. The number of species listed depended heavily on the program that designed the study. The lists in 2 out of 5 studies were predetermined thus comparison is inconclusive.

A total of 116 species of reef fish were recorded in 83 transects covering 24 sites around Tutuila, Aunu'u and Taema Banks. This is only a small proportion of the total species listing of Wass 1984 (991 species), less than half of those listed by Birkeland et al 2004 (264 species), Green 2002 (305 species), Whaylen and Fenner 2005a (291 species). This was expected since we restricted our sampling to those species known to be consumed locally. Eighty eight percent of the species listed in the Wass (1984) were not listed in the present study. Wass (1984) included pelagics and some deep water fish (bottomfish) not usually found at a depth of 10 meters. Note that the methods, number of sites and sampling area used in each study vary making comparisons difficult. Since this study focuses only on food fish, this can be considered as subsets of other studies that records all species of fish. Fifty six to sixty one percent of species recorded in other studies that used underwater surveys are either non-food fish (gobies, blennies, damsels, butterfly, etc.) or are food fish that are not reef fish and so were not detected in this sampling design.

Number of species recorded within 83 transects in 24 sites in Tutuila, Aunu'u, Nafanua, and Taema Banks comparing between studies done in American Samoa.

Study	Methods	Sampling area	Total no of sites	Total area covered	Total no of species	No w/in transect	% data lost due to method	% no of species not w/in transect
Sabater and Tofaeono (2006)	Belt transect	5x30	24	13,500 sqm	116	116	0.00	0.00
Whaylen and Fenner (2005)	Point count & spot dive	$\pi(7.5)^2$	11	11,662 sqm	291	69	76.29	60.14
Green (2002)	Belt transect (Tutuila only)	3x50	18	13,500 sqm	305	165	45.90	61.97
Birkeland et al (2001)	Belt transect	2x100 & 2x30	15	1,200 sqm	264	unknown	N/A	56.06
Wass (1984)	Lit review and sample collection	N/A	N/A		991	N/A	N/A	88.29

Many fewer species are typically found within bounded survey methods (belt transect and SPC) than in methods that cover much larger areas. Loss of diversity data could be due to either methods or stochastic event/distribution of species at particular space and time. Zero loss is reported in this study because this is the baseline data set and only species within the transects were recorded. Stationary point counts had 76.29% species unrecorded while Green's belt transect had 45.90%.

The species area curve appears to be reaching an asymptote from 11 to 24 sites implying that most of the reef fish species were being recorded (Figure A). This indicates a species-area effect where greater area surveyed yields more species. However, if a log plot is used, instead of getting an apparent asymptotic curve, a straight line is produced (Figure B). This indicates that the species accumulation follows a log function. This in turn implies that the curve is not approaching the upper limit to number of species (Fenner, in preparation). Green (2002) recorded 55 species in her initial survey and accumulated to 110 species more after 17 sites. The present study had the second highest level where initial numbers were at 31 rising to 117. Whaylen and Fenner (2005) had the lowest initial number of species recorded at 27 accumulating to only 69 after 11 samples. These differences in diversity pattern across samples are not indicative of variations in diversity across space but differences in the methods of recording species.

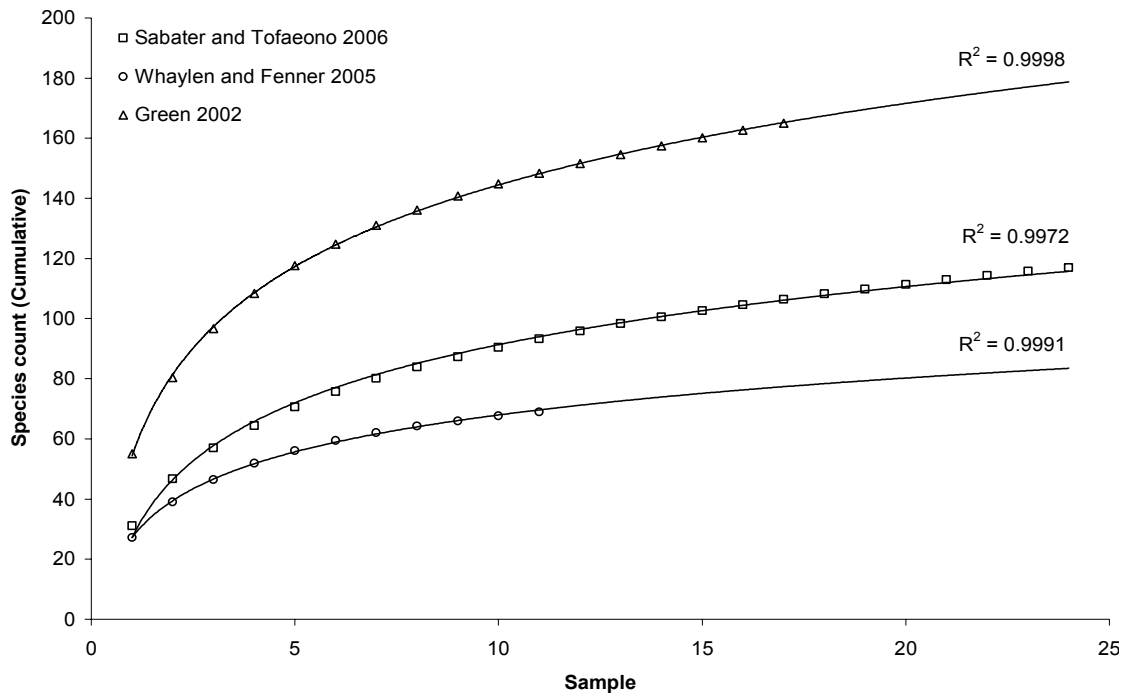


Figure A. Cumulative species area plot of sampling effort of three fish survey studies done in the main island of Tutuila. Data had undergone 999 rounds of permutation producing a smooth curve.

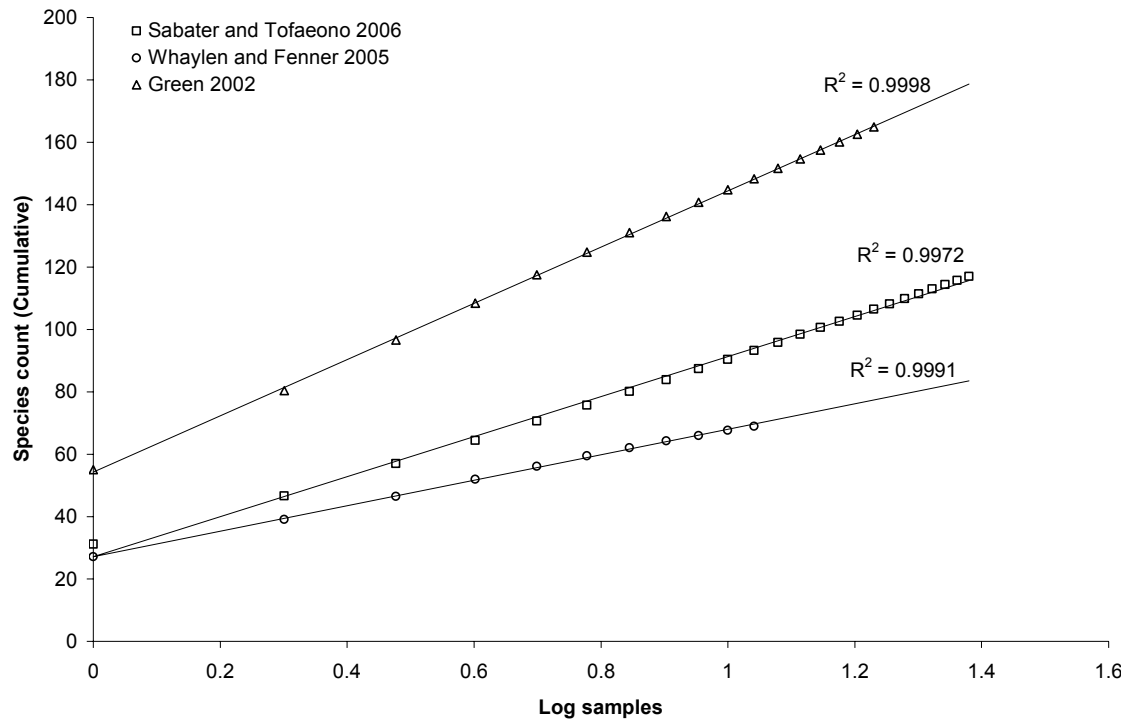


Figure B. Cumulative species area plot converting number of samples to log function of three fish survey studies done in the main island of Tutuila.

Diversity trends between studies

This study had the lowest number of species recorded based on the species list generated. This is because we targeted only key reef species (food fish). Surprisingly, when comparing the total number of species listed in Green (2002) and Whaylen and Fenner (2005b), 45.90% and 76.29% of the species recorded did not appear in the transect. In Whaylen and Fenner (2005b), their species list totals 291, but only 69 were observed in the stationary point counts. Their core monitoring focuses only on commercially and ecologically important groups (Whaylen and Fenner 2005b). Two hundred twenty two species were recorded in the biodiversity dives and off-sampling periods (recreational snorkeling and dives). The species list in Green (2002) totaled 305 species but only 165 appeared in her 2002 Tutuila sites. Some species might have only appeared in the Manua transects or was detected in 1996 but not in 2002. The variations in the log-species-accumulation curve of the three studies were not due to changes in species diversity but are actually sampling effects. Green recorded all species found within the boundary of her belt transect resulting in more species recorded. This study recorded only key reef species while Whaylen and Fenner had pre-identified groups of species to record. There is also the effect of the method where stationary point count assesses fish one species at a time therefore increasing the probability of missing out a targeted species when it's not its turn to be recorded. Overall, this gives an insight on the weakness of fixed boundary survey methods to detect high levels of diversity due to stochastic factors, high variability of spatial scale distribution of reef fish and limited capacity of the observers to record one species at a time.

Appendix 6

Mean biomass, abundance, and size of key reef species in 24 sites in American Samoa. Data is distributed across a hierarchical spatial scale from site to sector. N is the number of observation points in approximately 4 transects.

Sector	Habitat	Site	Biomass (mt/km2)		Abundance (indiv/m2)		Size (cm)	
			Mean	SE	Mean	SE	Mean	SE
NE	Bay	Afono Bay A (n=28)	24.55	6.45	23.93	3.99	16.57	0.91
		Afono Bay B (n=28)	9.55	1.08	17.04	1.37	15.89	0.42
		Amalau Bay (n=28)	33.91	9.41	29.25	2.84	17.68	0.55
	Point	Masefau Bay (n=21)	17.10	2.19	25.10	1.93	16.40	0.97
		Folau Point (n=28)	26.44	2.57	23.14	3.67	19.60	0.89
		Olotina Point (n=28)	34.67	4.41	35.93	2.05	19.33	0.85
NW	Bay	Agapie Cove (n=28)	12.84	2.24	21.11	2.20	14.37	0.77
		Aoloau Bay (n=21)	7.41	1.36	19.14	1.32	14.61	0.51
		Nuuooti Cove (n=21)	18.43	3.29	21.24	3.05	17.54	1.81
	Point	Poloa Bay (n=19)	13.90	2.24	17.42	2.07	16.68	0.68
		LeeLee Point (n=21)	15.59	3.66	18.19	10.51	15.48	0.82
		Siliaga Point (n=21)	31.54	4.70	32.33	1.81	17.97	0.77
SE	Bay	Alega Bay (n=28)	37.53	14.52	20.25	3.36	19.24	0.71
		Aua Harbor (n=31)	5.99	1.21	6.97	1.93	18.31	0.57
		Fagaitua Bay (n=28)	25.39	3.81	21.75	2.06	20.54	0.52
	Point	Matautele Point (n=28)	55.79	18.59	46.21	9.10	20.35	0.47
		Niuloa Point (n=20)	39.76	8.84	27.90	2.95	22.19	0.37
		Pagaitua Point (n=21)	106.59	43.67	56.05	2.76	20.08	1.01
SW	Bay	Amanave Bay (n=21)	35.44	11.69	23.05	2.16	19.85	0.54
		Larsen Bay (n=30)	41.96	13.66	46.50	3.61	17.62	0.39
		LogoLogo Point (n=21)	27.30	2.55	39.24	14.35	18.16	1.01
	Point	Mu Point (n=21)	34.18	6.20	30.33	2.04	19.77	0.75
		Taema Banks B (n=21)	49.59	11.79	25.00	2.50	22.68	0.69
		Aunuu north (n=14)	27.96	16.49	19.14	3.74	20.74	0.54

Appendix 7

Percent cover of live coral, algae, coralline algae, and other benthic components at 24 sites in American Samoa. "Algae" is composed of turf, filamentous and macroalgae.

Sector	Habitat	Sites	Live coral	"Algae"	Coralline algae	Others
NE	Bay	Afono A	59.01	12.64	22.23	6.13
		Afono B	50.72	4.25	33.64	11.38
		Amalau Bay	47.15	12.60	34.57	5.69
		Masefau Bay	15.82	18.90	54.91	10.36
	Point	Folau Point	12.34	27.26	58.38	2.02
		Olotina Point	21.41	1.87	73.88	2.84
	Bay	Agapie Cove	46.67	0.08	51.91	1.34
		Aoloau Bay	31.02	0.84	54.48	13.66
		Nuuooti Cove	48.11	0.69	50.67	0.54
		Poloa Bay	12.13	36.20	25.89	25.78
NW	Point	LeeLee Point	26.84	0.06	72.36	0.74
		Siliaga Point	12.29	32.63	54.49	0.59
	Bay	Alega Bay	13.96	4.35	64.90	16.80
		Aua_Harbor	9.72	0.03	81.61	8.64
		Leanaosaulii	19.01	0.60	79.38	1.00
SE	Point	Matautele Point	22.06	0.98	70.79	6.17
		Niuloa Point	23.08	0.49	72.63	3.80
		Pagaitua Point	8.60	1.12	86.12	4.17
		Amanave Bay	30.80	1.81	51.54	15.85
	Bay	Larsens Bay	35.02	0.16	61.28	3.55
SW	Point	LogoLogo Point	18.94	0.00	80.33	0.73
		Mu Point	54.23	1.25	44.52	0.00
	Bank	Aunuu North	28.85	0.00	70.56	0.60
NOI	Point	Taema Banks B	9.18	0.00	90.04	0.78