# Estimation of reef fish abundance and documentation of habitat characteristics in the proposed Tinian Marine Sanctuary

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The following personnel from the Division of Fish and Wildlife (DFW) participated in this survey;

*Saipan DFW*:

Michael S. Trianni, Floyd Masga, Jacinto Taman, Tony Flores, Katharine Miller and Jesus Omar.

*Tinian DFW*:

Henry King, Henry Cabrera

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Alfred Castro of Tinian volunteered his time to participate in the survey.

## ABSTRACT

At the request of the Tinian Department of Lands and Natural Resources a fisheries survey was organized and conducted in the proposed Tinian Marine Sanctuary in spring 1999 by the Commonwealth of the Northern Mariana Islands (CNMI) Division of Fish and Wildlife (DFW), with assistance from the CNMI Division of Environmental Quality (DEQ).

A stratified random sampling design was implemented to estimate fish abundance by family/group and by sample strata in the proposed sanctuary. Results found that population size generally followed stratum size except for strata located near the harbor entrance, where ANOVA results found mean densities to be significantly lower than in strata further from the harbor entrance. ANOVA results detected significant differences for abundance with respect to depth, where deeper strata contained significantly higher mean densities.

ANOVA results for rugosity found significant differences by strata and by depth. The former result found high rugosity near the harbor entrance, which contrasted with the low percent coral cover measured there. The highest rugosity was found in the shallowest depth ranges, which concurred with the general trend for percent coral cover. The results of ANOVA for percent coral cover detected significant differences for both strata and depth, although further delineation was precluded by a significant interaction.

Regression analysis found no relationship between abundance and percent coral cover or rugosity.

Comparison of fish compositions between this survey and data collected from other areas and by other protocols found considerable differences for some family/groups, most notably amongst the food fish the families Lethrinidae (emperors) and Lutjanidae (snappers). Amongst the non-food fish the Chaetodontidae (butterflyfish). These three groups were found to be under-represented in the sampled strata within the proposed sanctuary.

Estimates of fish abundance, rugosity, and percent coral cover provided a template for future comparison using the same sampling protocol, which could be improved by implementing an optimal allocation design. It was concluded that sanctuary legislation incorporate strict regulations on fishing, along with stringent regulations to reduce the incidence of suspended sediment within sanctuary boundaries.

## INTRODUCTION

Coral reef fisheries are difficult to manage. These fisheries are multi-specific and harvested by a wide variety of gear types. In the CNMI, where population growth is occurring at an alarmingly high rate, mostly from a rather broad spectrum of immigrants, conventional controls on catch are hard to justify socially while gear restrictions and size limits are virtually impossible to administer.

The human pressure on coral reef fisheries combined with developmental perturbations has been detrimental to reef habitat structure and subsequently reef fish resources. In short, management of coral reef fisheries in the CNMI has not provided protection against the overexploitation of reef fish resources and degradation of marine habitat by human induced activities.

There is a critical need for *permanent* spatial, and possibly temporal, reef fish sanctuaries in the hope that they will act as insurance against fishery "collapse". Setting aside marine sanctuaries to serve as spawning stock and to ensure habitat integrity, not only for coral reef fish but for food organisms as well, may be the only viable means of management to maintain levels of spawning stock biomass necessary to refurbish and/or sustain coral reef fisheries.

The Second CNMI Legislature introduced and passed what ultimately became Public Law 2-51 in 1981. This law established the Division of Fish and Wildlife (DFW) and identified its' objectives and responsibilities. The primary purpose of the DFW is to provide for the conservation of fish, game and endangered species of the CNMI and its' exclusive economic zone (EEZ), which extends 200 miles seaward from island shorelines. The EEZ surrounds fourteen major islands that lie in a north-to-south arc of about 460 miles in length (Figure 1). This island arc ranges from approximately 14 degrees North to 20.5 degrees North latitude. Although the vast majority of the EEZ is open ocean, the nearshore waters surrounding the islands contain a myriad of habitats, most notably those associated with coral reefs.

In fall of last year the Saipan DFW was contacted by the Tinian Department of Lands and Natural Resources (DLNR) to provide assistance in the development of a marine sanctuary from Gurguan Point to Carolinas Point (Figure 2). A qualitative survey of the proposed sanctuary was conducted in November 1998. Also in November 1998, representatives from both the Saipan DFW and Tinian DLNR were present at a public hearing on Tinian concerning the proposed sanctuary.

As part of the CNMI DFW's Marine Sanctuaries program, the DFW with assistance from the Department of Environmental Quality (DEQ) conducted underwater visual transects towards the goal of determining selected fish abundance in the proposed Tinian Marine Sanctuary. Surveys were conducted from February 18-25, 1999.

## METHODS

Stratified random sampling was used to estimate fish abundance in the proposed sanctuary. A qualitative assessment of the habitat types constituting the sanctuary was undertaken by way of towing to determine strata boundaries, with seven strata being identified (Figure 3).

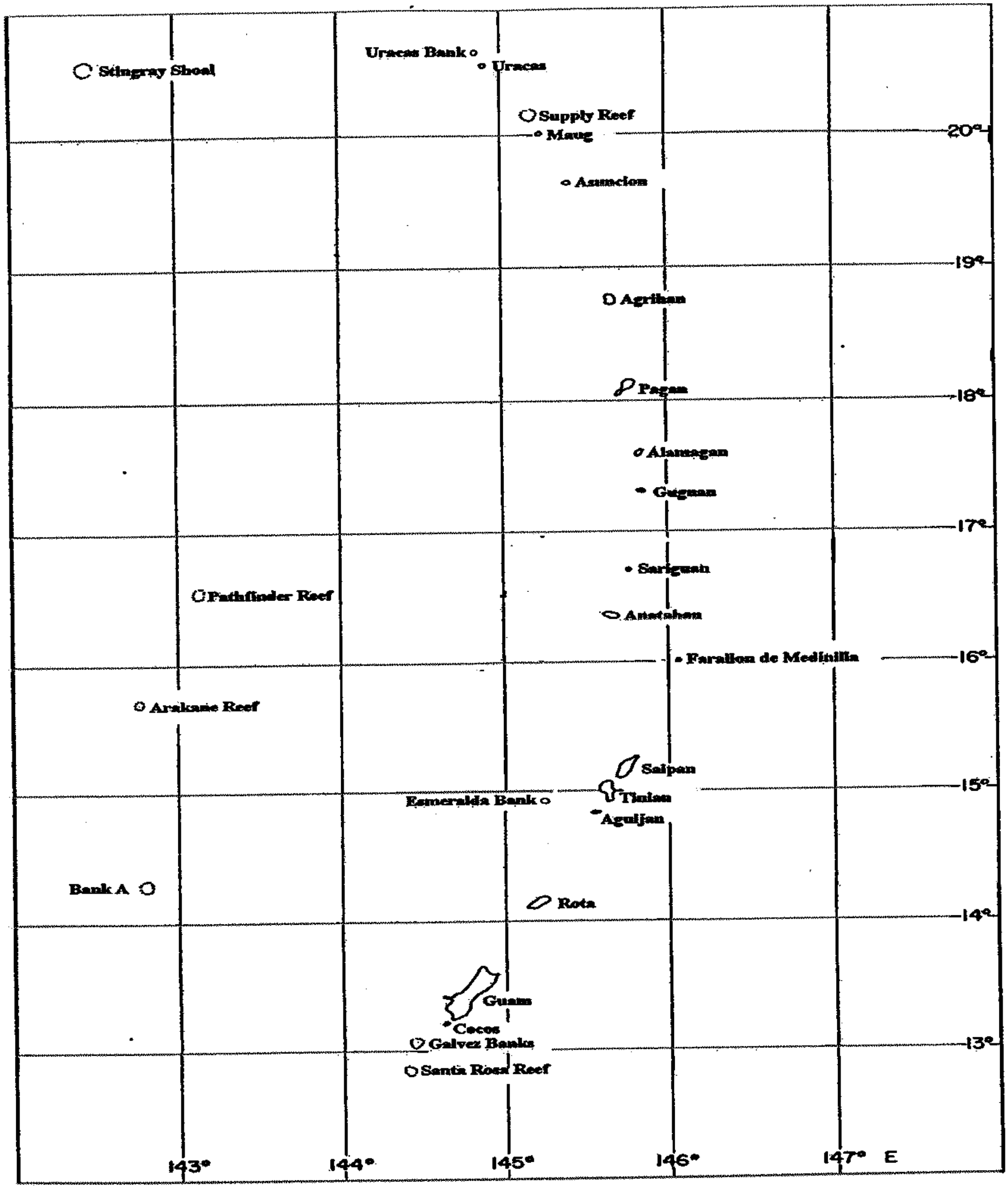


Figure 1. The Mariana Archipelago.

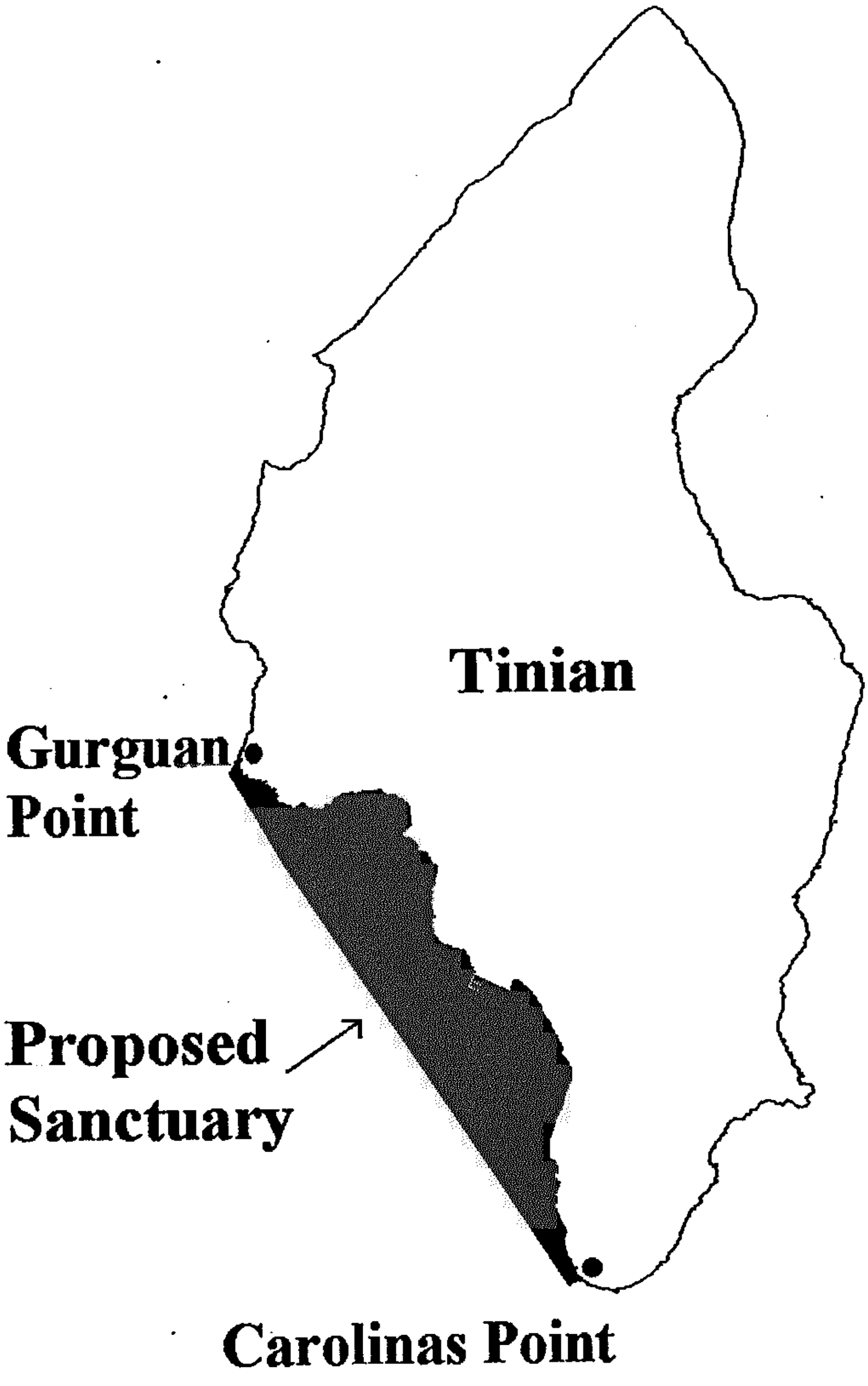


**Figure 2.** The proposed Tinian Marine Sanctuary.

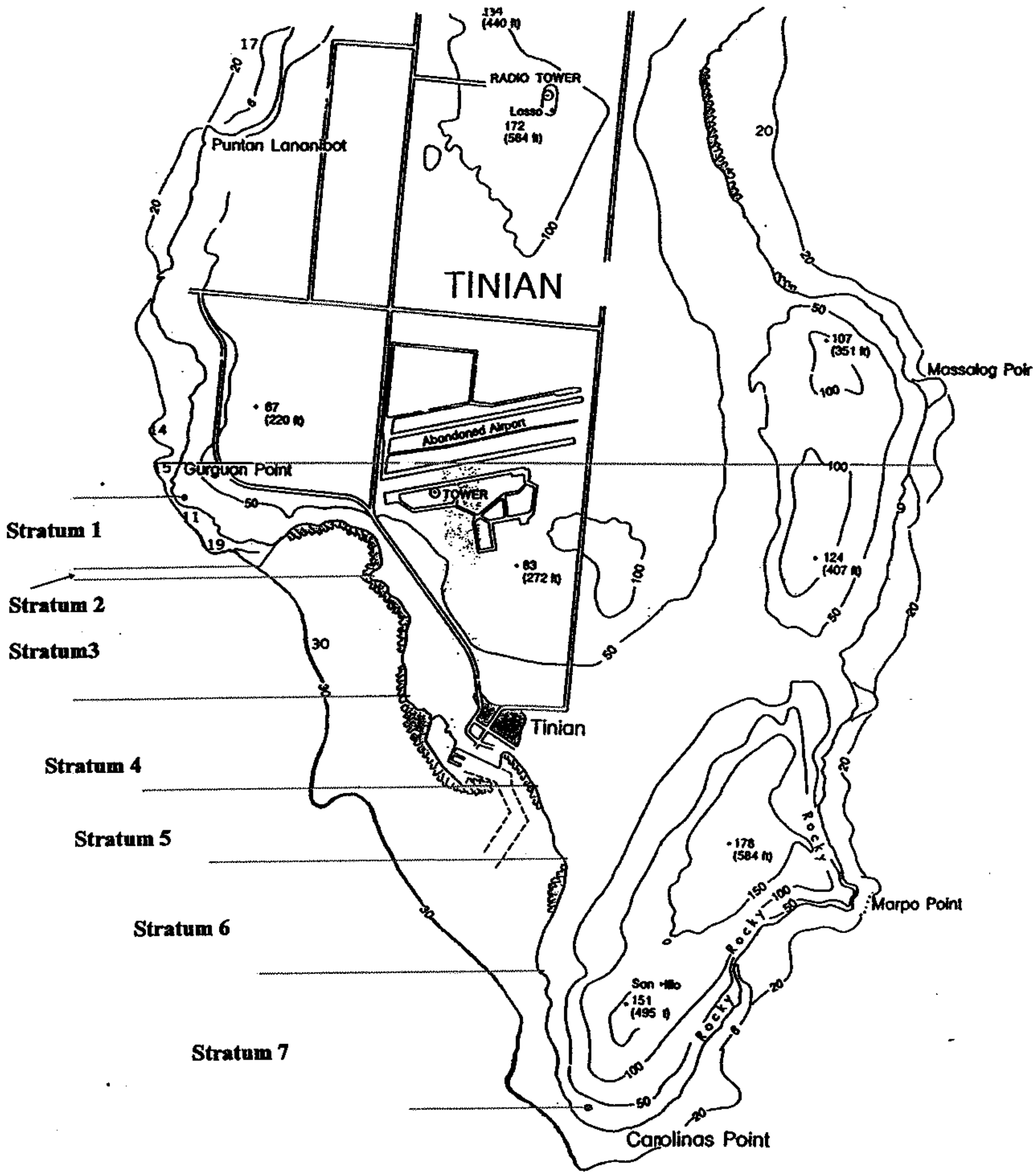


**Figure 3.** Sample strata in the proposed Tinian Marine Sanctuary. Boundary of sanctuary was 30 fathom contour (shown). Sampled boundary was 10 fathom contour (not shown).

Underwater visual fish counts were conducted along randomly placed 25 meter long by 5 meter wide transects (125 $m^2$) in depth strata of 15, 25, 35 and 45 feet(10-19, 20-29, 30-39, 40-49, respectively). All fish observed were identified to the family level, with some families further divided into subfamilies (Acanthuridae), or by developmental stage (Scaridae). Sampling was conducted in strata 2-6, while strata 1 & 7 were found to have very steep profiles with very little habitat in the specified sampled depth range. In addition to fish counts, two other parameters were measured. The first was rugosity, which is a measure of the spatial heterogeneity (three-dimensional structure) of the benthic habitat. This was accomplished by laying a chain along the transect line, and follows a method employed by Friedlander and Parrish (1998). Rugosity was then obtained dividing total chain length by transect length. The second parameter was percent coral cover, estimated by several random placements of a partitioned one-meter square quadrate along the transect line.

The number of samples taken within the sanctuary was determined by using estimates of the mean abundance and variance calculated from preliminary transects conducted in heavily fished and lightly exploited reef slope areas on Saipan. A formula developed by Elliot (1977) was used to determine the number of samples required to achieve a predetermined level of precision;

$$n_r = \frac{s^2}{mD^2}$$

Where $n^r$ = number of samples, $s^2$ = estimate of variance, $m$= mean, and $D^2$= desired level of precision (as a percent estimate of the true mean).

Simple proportional allocation was used to determine the number of transects per stratum (Cochran 1977). This technique weighs sample size by stratum size. The procedure for obtaining population estimates for each family/group follows.

Where $N$ equaled the size of the $h^{th}$ strata. Stratum weights were defined as:

$$W_h = N_h/N$$

The unbiased estimate of the population mean was determined by:

$$\bar{y}_{st} = \sum^{L} (W_h)\bar{y}_h$$

Where $y_h$ represents the estimated stratum means, and $y_{st}$ the unbiased estimator of the population mean, $u$.

The overall unbiased estimate of variance was determined as:

$$\hat{V}(\bar{y}_{st}) = \sum W_h^2 (\frac{s_h^2}{n_h})(\frac{N_h - n_h}{N_h})$$

The unbiased estimate of total population size was then calculated as:

$$\hat{Y} = N(\bar{y}_{st})$$

Bounds on the error of estimation were computed following Cochran (1977):

$$B = \pm 2\sqrt{\hat{V}(\bar{y})}$$

Results of the sampling scheme were then compared to the expected sampling variance and bounds on error of estimation if optimal allocation were employed.

Because the cost per unit sampled was not considered to differ between strata, the total sample size was weighted to determine the number of samples that would have been taken per strata using optimal allocation. The allocation weight per strata was defined as:

$$W_h' = \frac{N_h s_h}{\sum N_h s_h}$$

Regression analysis and ANOVA were used to test for significant correlation amongst parameters and significant differences between strata, respectively. The following transformations were made for ANOVA to approximate data normality; abundance log (x + 1), percent coral cover arcsin $(\%)^{0.5}$, and rugosity arcsin $(1/\text{rugosity}\%)^{0.5}$ (Freidlander and Parrish 1998). The rugosity transformation results in variables that are inversely related to rugosity. Due to an unbalanced design, ANOVA was calculated using Type III sum of squares (Shaw and Mitchell-Olds 1993).

## RESULTS

### *Sample Size*

Data collected during preliminary transect work from two locations on Saipan were used to generate estimates of the mean and variance for abundance, as required for the equation developed by Elliot (1977). The number of transects required to achieve a precision level of 25% was estimated to be 105. This level of precision was deemed acceptable with regard to time and logistical constraints. It was therefore decided that 100 transects would be sampled from five of then seven strata. Strata 1 and 7 were not sampled due to the limited amount of habitat within the sample depth range of 15-45 feet. A total of 99 transects were sampled during the 10-day survey. This resulted in a precision of the mean of about 26%.

### *Rugosity and Coral Cover*

Summary statistics are given for the parameters of rugosity and coral cover in Table 1 below. Mean rugosity was highest in strata 2 and 6, while mean percent coral cover was highest in strata 2 and 4. Figures' 4 and 5 depict means and standard deviations for rugosity and percent coral cover, respectively. These figures show overlap for both parameters between strata,

**Table 1.** Summary statistics for rugosity (n=89) and percent coral cover (n=89).

| *Stratum* | *Rugosity* | | | *% Coral Cover* | | |
|---|---|---|---|---|---|---|
| | **Mean** | **Variance** | **Range** | **Mean** | **Variance** | **Range** |
| 2 | 1.218 | 0.0087 | 1.092-1.373 | 44.7 | 382.3 | 13.5-83.5 |
| 3 | 1.143 | 0.0060 | 1.015-1.248 | 28.9 | 484.7 | 3.1-68.7 |
| 4 | 1.118 | 0.0071 | 1.004-1.301 | 39.8 | 145.5 | 17.7-61.4 |
| 5 | 1.191 | 0.0176 | 1.012-1.604 | 19.7 | 218.7 | 3.1-56.3 |
| 6 | 1.226 | 0.0269 | 1.095-1.675 | 26.4 | 236.7 | 7.6-63.5 |

indicating a potential lack of significance. ANOVA results testing for differences between strata for rugosity and percent coral cover are listed in Tables' 2 and 3, respectively. A significant difference was found for rugosity between strata and depth (Table 2). For all significant ANOVA results the Tukey Honestly Significant Difference test, one of the most conservative multiple range tests (Dowdy and Weardon 1991), was used to test for the location of the significance. The Tukey test for strata indicated that the significant difference occurred between stratum 4 and strata 2, 6, and 5. Stratum 3 was not significantly different from stratum 4 or the other strata. Because the variables tested are inversely related to rugosity it is necessary to view the multiple range test similarly. The difference in depth was significant between the 35-foot depth range and the 15 and 25-foot depth ranges. The 45-foot depth range was not significantly different from either grouping.

ANOVA detected significant differences for percent coral cover between both strata and depth (Table 3). A significant interaction was also detected, which superceded the multiple range-test (Figure 6).

Regression analysis did not detect a correlation between rugosity, percent coral cover and abundance.

*Abundance*

Summary statistics for fish abundance per stratum are given in Table 4. A total of 29 families and 31 groups were observed. Over 71% of the fish observed were classified as non-food fish. The most abundant food fish group was the subfamily Acanthurinae (surgeonfish) within the family Acanthuridae, accounting for over 43% of the total food fish observed (Table 5). The second most abundant group were the Labridae (wrasses-29%), followed by the subfamily Nasinae (unicornfish-7%) and Scaridae (parrotfish initial phase-7%)(Table 5). Over 64% of the food fish family/groups were observed within each stratum.

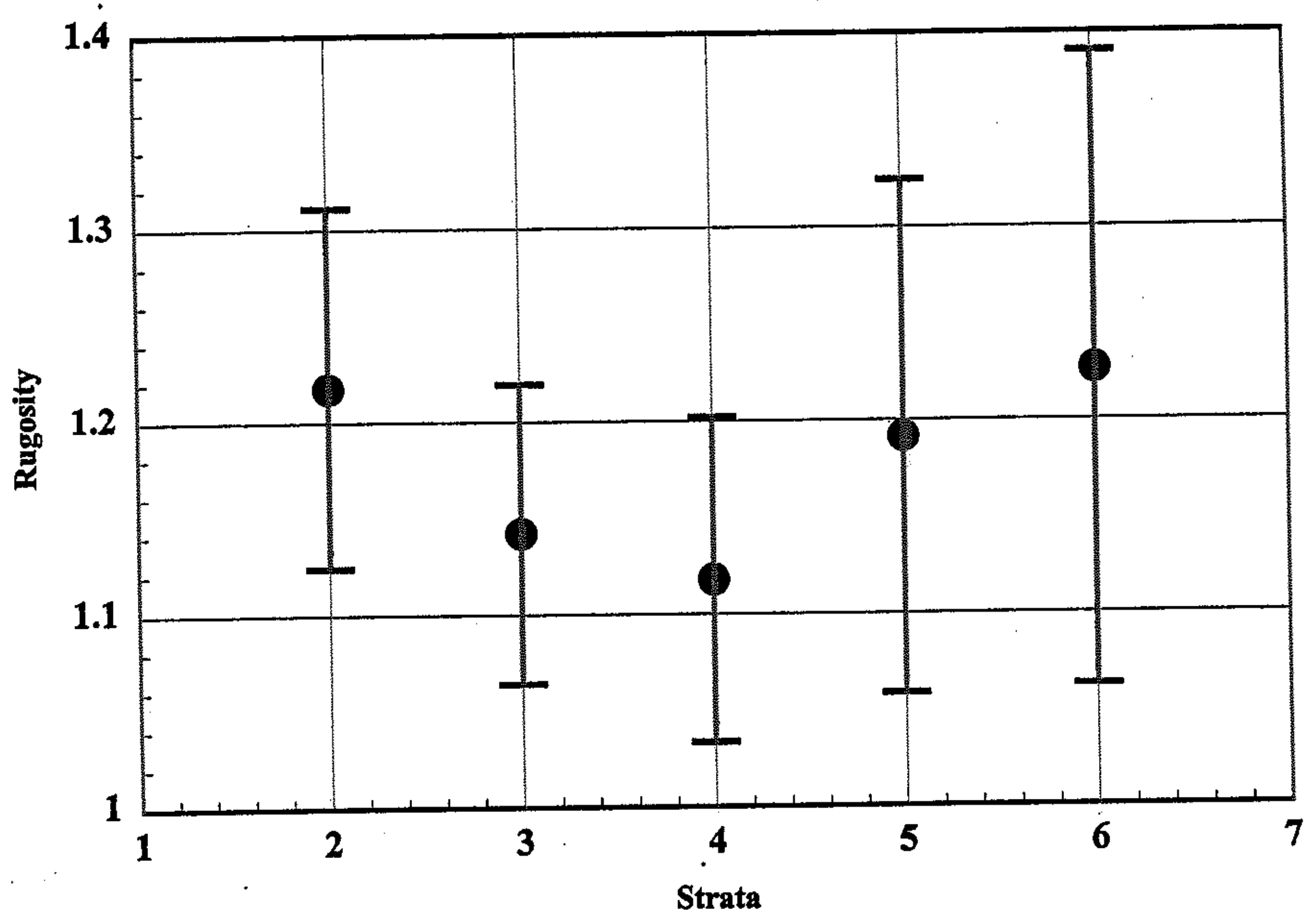


Figure 4. Mean and standard deviation for rugosity by strata.

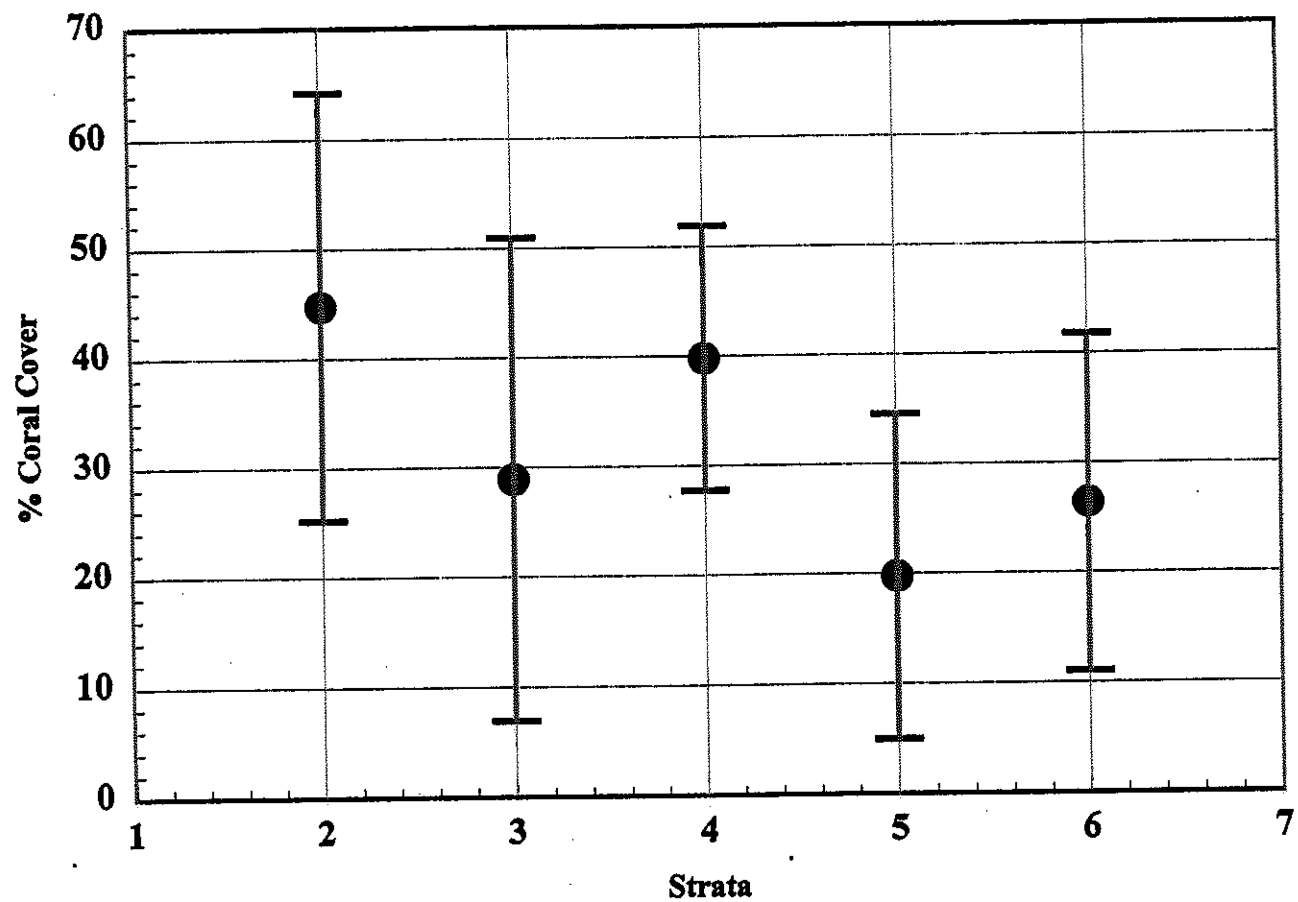


Figure 5. Mean and standard deviation for percent coral cover by strata.

**Table 2.** ANOVA results and multiple range tests for rugosity.

| Source | Df | MS | F-Ratio | P-Value |
|---|---|---|---|---|
| MAIN EFFECTS | | | | |
| A:Strata | 4 | 102.43 | 5.73 | 0.001 |
| B:Depth | 3 | 63.53 | 3.55 | 0.019 |
| INTERACTIONS | | | | |
| AB | 12 | 14.95 | 0.84 | 0.613 |
| RESIDUAL | 62 | 17.88 | | |

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Multiple Range Tests for Rugosity by Strata

Method: 95.0 percent Tukey HSD

| Strata | Count | LS Mean | Homogeneous Groups |
|---|---|---|---|
| 2 | 16 | 28.02 | X |
| 6 | 16 | 28.44 | X |
| 5 | 25 | 29.83 | X |
| 3 | 11 | 30.83 | XX |
| 4 | 14 | 35.03 |  X |

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Multiple Range Tests for Rugosity by Depth

Method: 95.0 percent Tukey HSD

| Depth | Count | LS Mean | Homogeneous Groups |
|---|---|---|---|
| 25 | 17 | 28.78 | X |
| 15 | 25 | 29.00 | X |
| 45 | 18 | 31.44 | XX |
| 35 | 22 | 32.49 |  X |

**Table 3.** ANOVA results for percent coral cover.

| Source | Df | MS | F-Ratio | P-Value |
|---|---|---|---|---|
| MAIN EFFECTS | | | | |
| A:Strata | 4 | 195.59 | 10.59 | 0.000 |
| B:Depth | 3 | 195.06 | 10.06 | 0.000 |
| INTERACTIONS | | | | |
| AB | 12 | 45.22 | 2.53 | 0.009 |
| RESIDUAL | 62 | 17.87 | | |

Table 4. Total, mean, and variance per fish family/group from each section sampled in the proposed Tinian Marine Sanctuary. February 1999.

| Section | 6 | | | 5 | | | 4 | | | 3 | | | 2 | | | All Strata | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Family/Group | Total | Mean | Var. | Total | Mean | Var. | Total | Mean | Var. | Total | Mean | Var. | Total | Mean | Var. | Total | Mean | Var. |
| ***Food Fishes*** | | | | | | | | | | | | | | | | | | |
| Acanthuridae/Surgeon | 153 | 9.6 | 35.996 | 420 | 15.6 | 75.256 | 298 | 12.5 | 32.775 | 157 | 9.8 | 56.163 | 285 | 17.8 | 99.629 | 1313 | 13.3 | 66.196 |
| Acanthuridae/Unicorn | 8 | 0.5 | 0.800 | 29 | 1.1 | 2.687 | 70 | 2.9 | 14.341 | 32 | 2.0 | 3.333 | 88 | 5.5 | 8.133 | 227 | 2.3 | 8.679 |
| Balistidae | 4 | 0.3 | 0.200 | 28 | 1.0 | 5.268 | 17 | 0,7 | 0.998 | 14 | 0.9 | 0.917 | 19 | 1.2 | 2.829 | 82 | 0.8 | 2.327 |
| Carangidae | 0 | | | 0 | | | 0 | | | 0 | | | 1 | 0.1 | 0.063 | 1 | 0.01 | 0.010 |
| Haemulidae | 0 | | | 0 | | | 0 | | | 0 | | | 1 | 0.1 | 0.063 | 1 | 0.00 | 0.010 |
| Holocentridae | 13 | 0.8 | 10.563 | 7 | 0.3 | 0.892 | 0 | | | 7 | 0.4 | 1.063 | 38 | 2.4 | 41.983 | 65 | 0.7 | 9.085 |
| Labridae | 106 | 6.6 | 24.117 | 200 | 7.4 | 20.251 | 247 | 10.3 | 73.259 | 148 | 9.3 | 58.467 | 181 | 11.3 | 73.963 | 882 | 8.9 | 49.430 |
| Lutjanidae | 0 | | | 0 | | | 1 | 0.04 | | 0 | | | 1 | 0.6 | | 2 | 0.02 | 0.020 |
| Mullidae | 8 | 0.5 | 0.667 | 3 | 0.1 | 0.103 | 10 | 0.4 | 1.297 | 5 | 0.3 | 0.363 | 10 | 0.6 | 1.050 | 36 | 0.4 | 0.683 |
| Nemipteridae | 0 | | | 15 | 0.6 | 0.872 | 9 | 0.4 | 0.332 | 6 | 0.4 | 0.517 | 16 | 1.0 | 3.733 | 46 | 0.5 | 1.047 |
| Scaridae/Initial | 13 | 0.8 | 2.163 | 31 | 1.1 | 10.516 | 8 | 0.3 | 0.841 | 13 | 0.8 | 1.629 | 148 | 9.3 | 102.467 | 213 | 2.2 | 29.150 |
| Scaridae/Terminal | 2 | 0.1 | 0.117 | 33 | 1.2 | 7.026 | 56 | 2.3 | 14.232 | 1 | 0.1 | 0.063 | 5 | 0.3 | 0.363 | 97 | 1.0 | 6.081 |
| Serranidae | 16 | 1.0 | 2.533 | 4 | 0.1 | 0.131 | 8 | 0.3 | 0.493 | 10 | 0.6 | 0.650 | 18 | 1.1 | 2.383 | 56 | 0.6 | 1.146 |
| Siganidae | 1 | 0.1 | 0.063 | 13 | 0.5 | 0.644 | 10 | 0.4 | 0.428 | 0 | | | 0 | | | 24 | 0.2 | 0.328 |
| ***Non-Food Fishes*** | | | | | | | | | | | | | | | | | | |
| Apoganidae | 12 | 0.8 | 2.067 | 1 | 0.04 | 0.037 | 2 | 0.1 | 0.080 | 7 | 0.4 | 0.796 | 2 | 0.1 | 0.250 | 24 | 0.2 | 0.573 |
| Chaetodontidae | 14 | 0.9 | 3.050 | 6 | 0.2 | 0.949 | 11 | 0.5 | 1.042 | 12 | 0.8 | 1.800 | 16 | 1.0 | 1.333 | 59 | 0.6 | 1.529 |
| Cirrhitidae | 65 | 4.1 | 12.863 | 33 | 1.2 | 2.795 | 34 | 1.4 | 8.775 | 45 | 2.8 | 5.096 | 20 | 1.3 | 1.533 | 197 | 2.0 | 6.928 |
| Microdesmidae | 29 | 1.8 | 4.829 | 29 | 1.1 | 3.225 | 87 | 3.6 | 19.114 | 7 | 0.4 | 0.529 | 33 | 2.1 | 5.396 | 185 | 1.9 | 8.258 |
| Ostracidae | 0 | | | 12 | 0.4 | 0.949 | 29 | 1.2 | 6.259 | 0 | | | 1 | 0.1 | 0.063 | 42 | 0.4 | 1.961 |
| Pempheridae | 3 | 0.2 | 0.296 | 3 | 0.1 | 0.179 | 0 | | | 0 | | | 0 | | | 6 | 0.1 | 0.098 |
| Pomacanthidae | 13 | 0.8 | 1.629 | 6 | 0.2 | 0.487 | 12 | 0.5 | 0.783 | 10 | 0.6 | 1.717 | 10 | 0.6 | 1.183 | 51 | 0.5 | 1.048 |
| Pomacentridae | 579 | 36.2 | 256.429 | 1238 | 45.9 | 363.131 | 1809 | 75.4 | 1253.636 | 1333 | 83.3 | 905.563 | 1294 | 80.9 | 3149.050 | 6253 | 63.2 | 1405.810 |
| Syngnathidae | 35 | 2.2 | 12.163 | 7 | 0.3 | 1.353 | 27 | 1.1 | 5.332 | 15 | 0.9 | 6.196 | 1 | 0.1 | 0.063 | 85 | 0.9 | 4.939 |
| Tetradontidae | 0 | | | 15 | 0.6 | 2.026 | 7 | 0.3 | 0.563 | 13 | 0.8 | 0.829 | 2 | 0.1 | 0.117 | 37 | 0.4 | 0.890 |
| Blennidae | 40 | 2.5 | 23.867 | 94 | 3.5 | 19.875 | 177 | 7.4 | 47.636 | 68 | 4.3 | 25.933 | 32 | 2.0 | 3.733 | 411 | 4.2 | 28.518 |
| Gobiidae | 18 | 1.1 | 5.183 | 25 | 0.9 | 3.764 | 40 | 1.7 | 5.014 | 41 | 2.6 | 3.729 | 44 | 2.8 | 9.133 | 168 | 1.7 | 5.458 |
| Zanclidae | 2 | 0.1 | 0.117 | 20 | 0.7 | 3.276 | 60 | 2.5 | 12.696 | 0 | | | 3 | 0.2 | 0.163 | 85 | 0.9 | 4.837 |
| Penguipedidae | 2 | 0.1 | 0.250 | 4 | 0.1 | 0.131 | 1 | 0.04 | 0.042 | 3 | 0.2 | 0.296 | 3 | 0.2 | 0.296 | 13 | 0.1 | 0.176 |
| Unid. | 6 | 0.4 | 0.250 | 0 | | | 21 | 0.9 | 16.636 | 16 | 1.0 | 14.000 | 0 | | | 43 | 0.4 | 6.575 |
| Monocanthidae | 0 | | | 2 | 0.1 | 0.071 | 0 | | | 0 | | | 0 | | | 2 | 0.02 | 0.020 |
| Scorpaenidae | 0 | | | 0 | | | 0 | | | 2 | 0.1 | 0.250 | 0 | | | 2 | 0.04 | 0.040 |
| Moranidae | 0 | | | 0 | | | 0 | | | 0 | | | 1 | 0.1 | 0.063 | 1 | 0.01 | 0.010 |
| | 1,142 | | | 2,278 | | | 3,051 | | | 1,965 | | | 2,273 | | | 10,709 | | |

**Table 5.** Population estimates for reef fish groups in the proposed Tinian Marine Sanctuary.

| Family/Group | Population Estimate |
|---|---|
| ***Food Fish*** | |
| Acanthuridae-Surgeon | 569,763 |
| Acanthuridae-Unicorn | 93,963 |
| Balistidae | 35,288 |
| Carangidae | 625 |
| Haemulidae | 625 |
| Holocentridae | 27,538 |
| Labridae | 377,700 |
| Lutjanidae | 4,333 |
| Mullidae | 14,763 |
| Nempheridae | 20,425 |
| Scaridae-Initial Phase | 86,375 |
| Scaridae-Terminal Phase | 41,163 |
| Serranidae | 22,700 |
| Siganidae | 11,025 |
| ***Non-Food Fish*** | |
| Apogonidae | 10,868 |
| Chaetodontidae | 25,875 |
| Cirrihthidae | 86,913 |
| Microdesmidae | 78,938 |
| Ostracidae | 17,525 |
| Pempheridae | 2,788 |
| Pomacanthidae | 21,288 |
| Pomacentridae | 2,657,575 |
| Sygnathidae | 38,013 |
| Tetradontidae | 16,463 |
| Blennidae | 177,313 |
| Gobiidae | 71,263 |
| Zanclidae | 35,538 |
| Penguidpedidae | 4,995 |

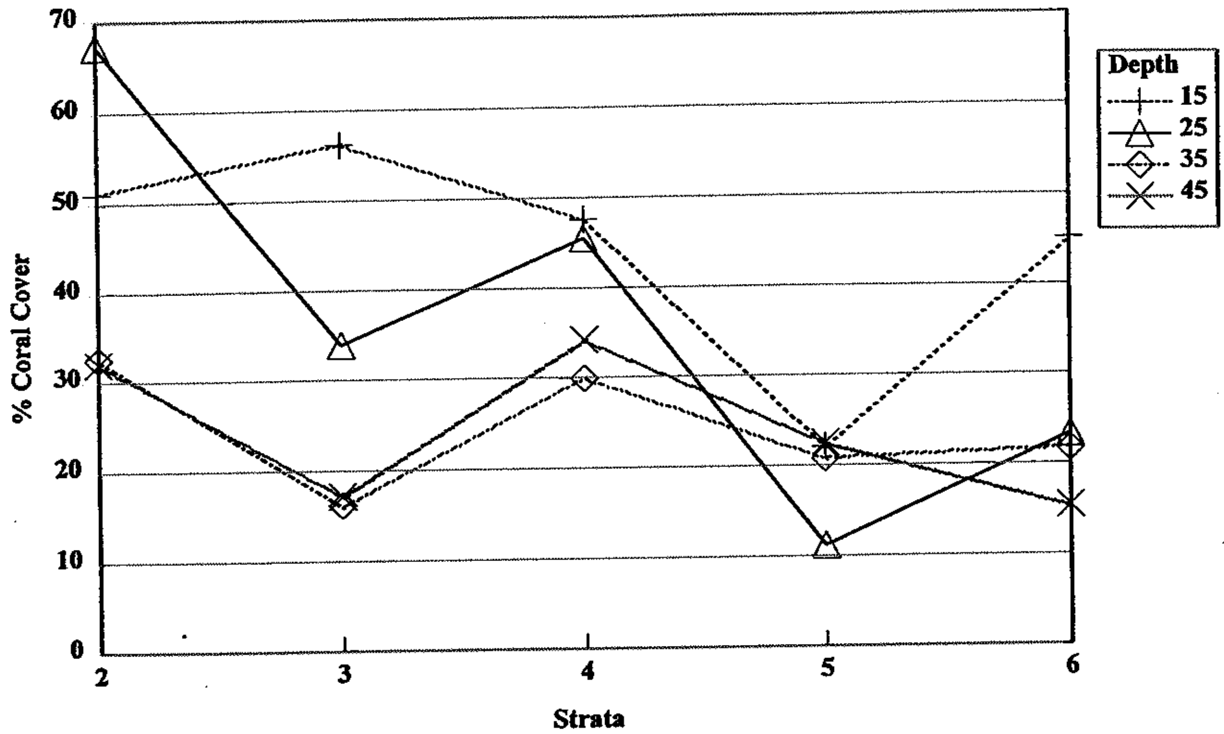


**Figure 6**. Interaction plot for percent coral cover.

The most abundant non-food fish were the Pomacentridae (damselfish), followed by the Blennidae (blennies) (Table 5). The damselfish were found to be significantly dominant, accounting for over 81% of the total non-food fish observed, with blennies accounting for 5%. Over 58% of the non-food fish family/groups were observed within each stratum.

ANOVA results for abundance are shown in Table 6. Significant differences in abundance were found for strata and depth, with a marginally significant interaction detected (Figure 7). The 45-foot depth range was significantly different from the 25-foot depth range. All other strata were grouped. The interaction plot shows a general downward trend in abundance from strata 2 to 6, except for the very low least squares mean in stratum 2 for the 25-foot depth range.

Table 7 shows total population estimates per stratum derived from the stratified random sampling design, bounds on the error of estimation, estimated size of each stratum (equal to area within 10 fathom depth contour), and mean number of individuals per 100 $m^2$. Estimated total population size generally followed overall stratum size, except for stratum 6, which recorded the lowest density of fish. The highest density was recorded in stratum 2, followed by stratum 4.

Comparisons of simple proportional allocation versus optimal allocation per stratum are shown in Table 8. The number of samples taken per stratum using simple proportional allocation generally agreed with the number recommended using optimal allocation. The one

**Table 6.** ANOVA results and multiple range tests for abundance.

| Source | Df | MS | F-Ratio | P-Value |
|---|---|---|---|---|
| MAIN EFFECTS | | | | |
| A:Strata | 4 | 0.981 | 6.64 | 0.000 |
| B:Depth | 3 | 0.652 | 4.41 | 0.007 |
| INTERACTIONS | | | | |
| AB | 12 | 0.289 | 1.95 | 0.045 |
| RESIDUAL | 62 | 0.148 | | |

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Multiple Range Tests for Abundance by Strata

Method: 95.0 percent Tukey HSD

| Strata | Count | LS Mean | Homogeneous Groups |
|---|---|---|---|
| 6 | 16 | 4.24 | X |
| 5 | 25 | 4.39 | XX |
| 2 | 16 | 4.69 | XX |
| 4 | 14 | 4.79 | X |
| 3 | 11 | 4.82 | X |

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Multiple Range Tests for Abundance by Depth

Method: 95.0 percent Tukey HSD

| Depth | Count | LS Mean | Homogeneous Groups |
|---|---|---|---|
| 25 | 17 | 4.34 | X |
| 15 | 25 | 4.57 | XX |
| 35 | 22 | 4.58 | XX |
| 45 | 18 | 4.85 | X |

**Table 7.** Stratum size (km$^2$; represents area within 10 fathom contour), mean density of reef fish (100 m$^2$), and population estimate of reef fish in the proposed Tinian Marine Sanctuary.

| Strata | Stratum Size | Mean Density | Population Estimate |
|---|---|---|---|
| 2 | 0.628 | 141 | 886,909< **887,891** <888,873 |
| 3 | 0.658 | 124 | 813,182< **813,633** <814,084 |
| 4 | 0.986 | 127 | 1,254,741< **1,255,359** <1,255,977 |
| 5 | 1.265 | 84 | 1,064,710< **1,065,176** <1,065,642 |
| 6 | 0.759 | 72 | 543,930< **544,234** <544,538 |

**Table 8.** Sample size comparison per stratum from sampled (simple proportional allocation) versus optimal allocation.

| Strata | Proportional Allocation | Optimal Allocation |
|---|---|---|
| 2 | 16 | 29 |
| 3 | 16 | 14 |
| 4 | 24 | 24 |
| 5 | 27 | 22 |
| 6 | 16 | 10 |

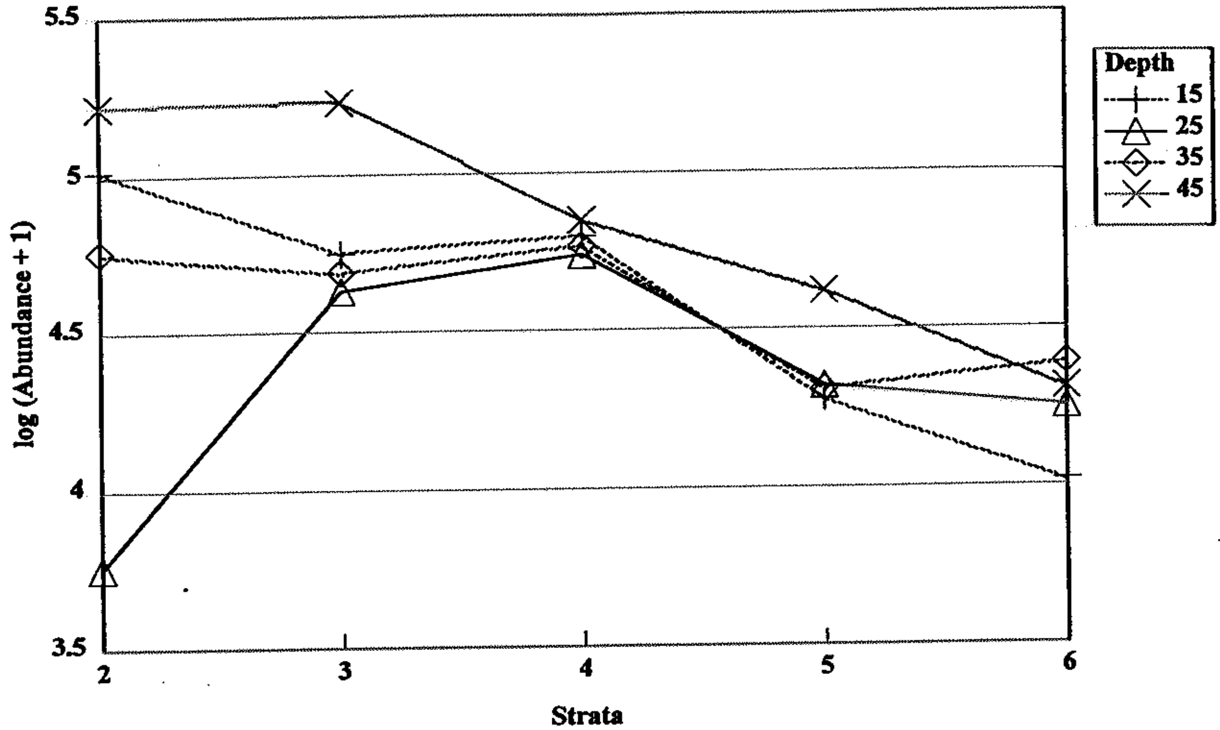


**Figure 7.** Interaction plot for log (Abundance + 1).

significant exception was stratum 2, where the sample size would have been nearly doubled using optimal allocation.

## DISCUSSION

Results of this survey in the proposed Tinian Marine Sanctuary indicated some interesting trends. ANOVA results for rugosity indicated significant differences between stratum 4 and strata 2, 6, and 5. The inverse relationship of the tested variables to rugosity indicated that rugosity was highest in strata 2, 6, and 5. The 25 and 15-foot depth ranges were found to be significantly greater than the 35-foot depth range.

For coral cover ANOVA results found a significant difference for both depth and strata, but further analysis was prohibited by a complex significant interaction, depicted in Figure 6. In general, the 15 and 25-foot depth strata had the highest coral cover, although coral cover was very low in strata 5 for all depths (especially 25 foot depth) and in strata 6 for all but the 15-foot depth. The locations of strata 5 and 6 are near and south of the harbor entrance, where visibility was typically low from the presence of suspended sediment. This sediment was observed to have covered a considerable amount of coral and hard rock during the survey period. The low percent coral cover was also in contrast to the medium to high rugosity documented in strata 5 & 6, respectively (Tables 1 & 2; Figures 4 & 5). The Commonwealth of the Northern Mariana Islands Division of Environmental Quality (DEQ) provided sedimentation rate data from Tinian to the DFW. Sedimentation rates from the DEQ Taga beach, Tachonga beach, and Unai Babui (located on the Northwest coast of Tinian, outside the boundaries of the proposed sanctuary) stations are shown in Figure 8 below. Sedimentation rates from Taga and Tachonga beaches reflect sedimentation rates in strata 5 & 6, respectively, as those stations are located within the respective strata. The Tachonga station, placed at 10 meters (33 feet), recorded the lowest average sedimentation rate of all Tinian stations from May 1998 to May 1999. The Taga beach station, placed at 5 meters (16.5 feet), recorded the highest average sedimentation rate of all Tinian stations for the period May 1998 to May 1999. The high sedimentation rate from the Taga beach station may be the origin of some sedimentation observed on the bottom in stratum 5. The sediments collected in the traps were not distinguished between terrestrial or oceanic origin (J. Olesch, DEQ, pers. comm.).

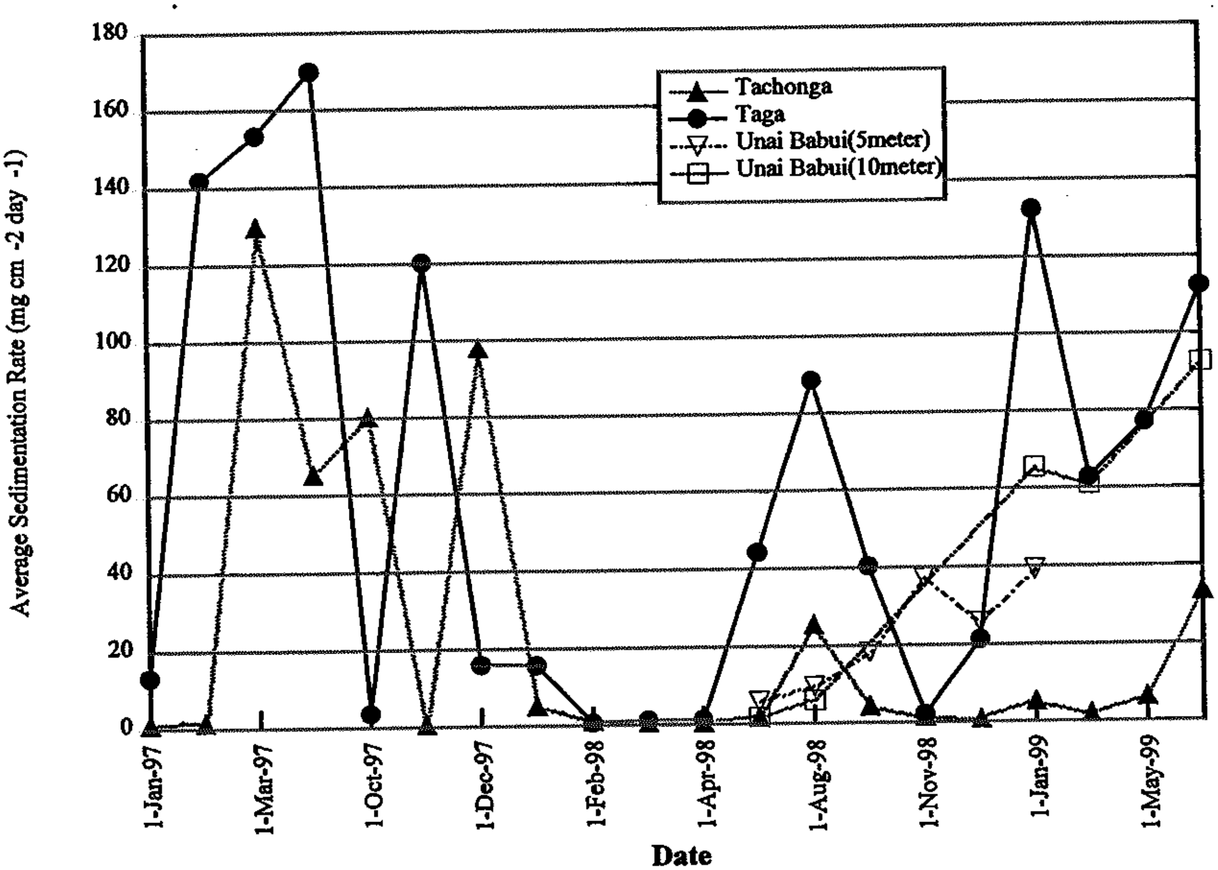


**Figure 8.** Average sedimentation rates from selected stations on Tinian.

Both strata and depth were found to have significant effects on abundance, where strata 2, 3, and 4 were found to be significantly different from strata 5 & 6 (Table 6). Strata 5 & 6 are closest to the harbor area, and were also found to have low % percent coral cover but medium to high rugosity. Regression analysis from this study found no correlation between abundance and rugosity or percent coral cover, in part due to the medium to high rugosity values recorded in strata 5 & 6 (Table 1; Figures' 4 & 5). The mean number of fish was highest in the 45-foot depth strata, which equated with results from Friedlander and Parrish (1998) on a Hawaiian coral reef. Depth ranges of strata were not equivalent between the Hawaiian study and this study, and in other similar strata no equitability or similar trend(s) could be discerned.

Friedlander and Parrish (1998) found the representation of habitat complexity provided by rugosity to have useful predictive capability with respect to dependent variables including abundance. In that study they also found types of substratum including algal and coral cover to have little predictive effect with respect to fish abundance. In this study rugosity was found to have no predictive capability with regard to abundance, in contrast to the Hawaiian study. Intuitively, an increase in the spatial heterogeneity of the benthic environment should have a positive effect on fish abundance, as fish prefer structure. High habitat complexity should correlate not only with greater fish abundance, but also a higher fish richness and diversity, due to greater habitat diversity. A reason why the correlation did not apply in this study might be related to fishing pressure, as the area proposed by the sanctuary was that which was found to have received the greatest scuba/spear fishing pressure in Tinian (DFW 1994; Trianni 1998). The effect of fishing pressure on fish observation along transect lines in a particular area may result in under-estimation of real abundance, as fish may be more prone to seek cover than in unexploited areas.

The composition of food fish documented in this study were similar to that derived from the sampling of commercial catches in Tinian (DFW 1994; Trianni 1998), although not directly comparable because Tinian commercial catch composition data were from night fishing. In contrast to the commercial catch composition data very few Mullidae (goatfish) were observed, and no Lethrinids (emperors), the later of which comprised 19% of the commercial Tinian night catch from 1995-96 (Trianni 1998). One caveat when using transects is that they have a tendency to under-represent large and/or roving predators such as emperors (Samoilys and Carlos 1992). To that extent, Lutjanids (snappers) also appeared to be under-represented in the data. Although transects will tend to under-represent these families or members thereof, the absence of emperors and the presence of only two snappers in over 12,000 $m^2$ of coverage (99 transects) appears to be significant. In contrast, 12 transects conducted at Pagan Island in August 1999 documented 24 emperors and 22 snappers in 1,500 $m^2$ of coverage. Being a desired food fish it is therefore probable that these families of fish have been considerably exploited within the proposed sanctuary.

The percentage of terminal phase parrotfish from this survey was observed to be 31%, which was considerably lower than the percentage sampled from commercial operations in Tinian of 68% in 1992-93 and 53% in 1995-96. These percentages are not directly comparable because fishers will tend to target the larger, brilliantly colored males. Data collected from Pagan Island in August 1999 found 50% of the parrotfish observed to be terminal phase males.

The inclusion of the wrasse family in the food fish category for this study may be inappropriate, since, unlike other food fish families such as the surgeon/unicorn fish, only a few select species of wrasse are taken as food fish.

With respect to non-food fish, densities were lower in strata 5 & 6 also (Table 4). One conspicuous observation was the relatively low density of Chaetodontids (butterflyfish) observed in the sanctuary (Table 4). The mean density of 0.6 butterflyfish observed per 125 $m^2$ in the Tinian sanctuary contrasted to the mean density from Pagan of 4.7 per 125 $m^2$. The sample size from Pagan was very small in comparison to that from Tinian, and less random in nature. Because many species of butterflyfish are dependent upon coral as a food source or as cover (Reese 1981), the percent coral cover would be important in any comparison. The mean percent coral cover recorded in Pagan was 39.8%, which was similar to the mean percent coral cover for strata 2 and 4 (44.7% and 39.8%, respectively), and greater than strata 3, 5, and 6 (Table 1). The habitat in strata 2 & 4 would then be more appropriate for the comparison of butterflyfish mean density to the habitat sampled in Pagan. In strata 2 & 4, the mean densities of butterflyfish were 1.0 and 0.5, respectively, lower than the density recorded from Pagan. This is surprising because stratum 2 contains some of the most luxuriant coral growth in the Mariana Islands.

Unfortunately, rugosity data from Pagan was deleted from analysis when it was discovered after returning to Saipan that the measurement chain had been broken during sampling, resulting in data unreliability. The data from Pagan may have served to elucidate whether or not rugosity has predictive capability with respect to fish abundance in the Mariana Islands.

## CONCLUSION

The area comprising the proposed Tinian Marine Sanctuary appears to have experienced considerable fishing pressure. Although data from this survey are not entirely conclusive in that regard, data from other sources tend to reinforce that supposition. The recovery of fish stocks from unrestricted fishing pressure forms the primary rationale behind establishing the sanctuary. The original House Bill for the proposed sanctuary states that certain types of fishing activity will be allowed; specifically for seasonal fisheries including the atuali and mahanak runs. It is here suggested that no fishing of any kind be allowed, or that specific limitations on total take be established for atuali and mahanak, to prevent overfishing that would be contrary to the concept of the sanctuary.

Certain strata within the proposed sanctuary boundaries were found to have high percentages of coral cover, suggesting a potential for the establishment of dive sites. The habitat comprising stratum 2 contains the 'Two Coral Head' dive site, one of the most popular dive sites in Tinian, which includes some of the most luxuriant coral growth in the Marianas. With a relatively high percent coral cover, stratum 4 could be considered as an area for the establishment of new or additional dive sites.

The presence of medium to high mean rugosity and low mean percent coral cover in strata 5 & 6 appear to be contradictory (Table 1; Figures' 4 & 5). It would be expected that ample rugosity would provide sufficient surface area for coral settlement and growth, but the data did not reflect this in strata 5 & 6. Qualitative observations in those strata during the study indicated that considerable sediment was present in the water column and on the bottom. High sedimentation rates for stratum 5 were corroborated by data supplied by the DEQ. The presence of the sediment was most likely derived from the combination of the harbor proper and the consequent current flow, the extensive beach areas found within all or part of those strata, the large sandy patch between the patch and outer reefs in stratum 6, and possibly from terrestrial sources. With regard to the large sandy patch it has been stated that a jet-ski operation will be granted access to that area. This is not recommended because the benthic disturbance that will result from consistent jet-ski activity will result in increased suspended sediment that will subsequently be carried by the current and settle out on areas otherwise suitable to coral settlement and growth.

The collection of baseline estimates of fish abundance and coral cover in the proposed sanctuary will serve as benchmarks to which future surveys can be compared in order to gauge the effectiveness of sanctuary designation. The total area within the proposed sanctuary boundaries includes what would be considered prime coral reef habitat and habitat that has the potential to improve if fishing pressure and other human-induced activities are properly mitigated. Legislation should, therefore, also include strict guidelines for non-fishing activities such as harbor dredging and terrestrial runoff.

Following official designation of the Tinian Marine Sanctuary, a similar survey utilizing the same statistical design and collecting the same basic data should be conducted every two years in order to measure any significant changes to fish abundance and coral cover. The time frame allotted to the first survey was less than 10 working days, which required staff to make three dives per day, a physically challenging task. Adhering to a proper statistical sampling design is oftentimes difficult, yet absolutely necessary in order to collect meaningful data.

It is recommended that more time be allotted for subsequent surveys, in order to ensure that at least the same sampling scheme can be successfully emulated. Otherwise, comparative analysis will be prohibited. With estimates of means and variances for fish populations within each strata future surveys will be able to incorporate stratified random sampling utilizing an optimal allocation design. This will enhance use of survey resources.

Expansion of data collection can occur so long as it does not detract from the original sampling scheme and data objectives. As long as adequate time is allotted in future surveys, specific identification of fish, coral, and other life forms can be considered, as well as size estimation for commercially important species.

## LITERATURE CITED


Cochran, W.G. 1977. Sampling Techniques. 3rd ed. John Wiley & Sons, New York, NY. 428 p.

DFW Technical Report 94-02. 1994. Biological analysis of the nearshore reef fish fishery of Saipan and Tinian, Commonwealth of the Northern Mariana Islands, Division of Fish and Wildlife, 124 pp.

Dowdy, S. and S. Wearden. 1991. Statistics for research. John Wiley & Sons, Second Edition. 629 pp.

Elliot, J.M. 1977. Some methods for the statistical analysis of benthic invertebrates. 2nd ed. Sci. Pub. No. 25 Freshwater Biological Association, Ferry House, U.K. 159 p.

Friedlander, A.M. and J.D. Parrish. 1998. Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. J. Exp. Mar. Biol. and Ecol. 224, 1-30.

Samoilys, M. and G. Carlos. 1992. Development of an underwater visual census method for assessing shallow water reef fish stocks in the South West Pacific. Australian Centre for International Agricultural Research, Project PN 8545, 100 pp.

Shaw, R.G. and T. Mitchell-Olds. 1993. ANOVA for unbalanced data: an overview. Ecology 74(6): 1638-1645.

Trianni, M. 1998. Summary and further analysis of the nearshore reef fishery of the Northern Mariana Islands. Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife Technical Report 98-02, 64 pp.


## PERSONNEL COMMUNICATIONS

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