TAKUTEA
REEF RESOURCES
BASELINE ASSESSMENT.

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Template A Common reef resources found at Takutea island.

SUMMARY.

The small uninhabited island of Takutea provides a unique example of a reef nature reserve. This report surveyed 17 reef resources of Takutea that are of social and biological importance. They include, Ariri, Belligerent Rock-shell, Etu, Karikao, Kina, Mangeongeo, Mapi, Matu Rori, Paua, Pupu, Popoto, Poreo, Rori Puakatoro, Rori Toto, Paua Kura Venus, Ungakoa, and Vana. Although the diversity of species is relatively high, many of the abundant resource types are not considered of high economic or food value.

The distribution of some species is affected by site factors. Generally, higher abundance is found on the intermediate zone between the windward and leeward areas (such as Aumatangi site). Some species are further affected in distribution depending on whether they are close to the reef (where there is high wave action) or further back. An example of one such species is the Paua (*Tridacna maxima*) which has the highest abundance at Aumatangi site, 20 meters from the reef edge.

The reef resource with the largest population size is the Kina (30 000), Ungakoa (14 000) and the Paua (11 000). There is only a relatively small (< 1 000) population of Etu, Matu Rori and Poreo. Some common species of sea urchin and sea cucumber found elsewhere in the Cook Islands were absent during the survey, they include Atuke, Avake, Rori Pua and Rori Matie.

The survey also coincided with a introduction of 200 Trochus (*Trochus niloticus*) to the island. It is hoped that the Trochus population may become established and in the future become a reserve stock for neighbouring Atiu island.

The sustainable harvest quota of Paua was estimated at 7 buckets of meat per year. This is based on the population structure of 11 200 Paua with a mean size of 9 cm. The harvest quota is 30% of the size range of Paua between 10-15 cm (from 50 – 100% fully mature). Those larger then 15 cm are to be left as brood stock. The quota also assumes that 200 Paua are the equivalent of a bucket of meat.

It is suggested that the Takutea Trustees consider extending the wildlife sanctuary to the reef life of Takutea. This is important to avoid over harvesting of its resources. It is up to the Trustees what form of Raui to be used, for example;

a. *A Raui that will ban outright the harvesting of all reef life. Or,*

b. *A Raui that will allow the harvesting of reef life only under approval and subject to a sustainable harvest quota being established first. For instance, the Raui on the Paua may be lifted once a year to allow a harvest of 7 buckets of Paua meat, from animals between 10–15 cm sizes. The Ministry of Marine Resources can assist the Trustees by determining the harvest quota before the harvest proceeds. Such a relationship has been established with Island Council in Aitutaki for the Trochus harvest.*

INTRODUCTION.

Takutea is a small sand cay (120 hectare) that rises approximately 6 meters above sea level. Although the island is unpopulated it has close social ties to neighbouring Atiu Island (22 kilometers south). Takutea was gifted to the British Crown in 1903 and since then has been referred to as "wildlife sanctuary". In 1950 the Aronga Mana of Atiu were appointed as the "Trustees for all the native land owners of Atiu and their descendents". The island is considered to be the most important sea bird breeding island in the Southern Cooks.

There is little documentation of reef resources of Takutea. An ongoing project of the Ministry of Marine Resources is to assess the reef resources (of biological and social significance) of the Cook Islands. The information collected will contribute to a nation-wide database of reef resource types and distributions in the Cook Islands. This has numerous scientific, educational and management implications. Specifically, this survey is intended to describe the common reef resource types, their distribution patterns and population size.

The Ministry was also requested by the Takutea Trustees to provide an estimate of a sustainable harvest for the Paua resource and to also consider some conservation options of the reef life.

GENERAL MATERIALS AND METHODS.

The survey of Takutea was undertaken during a visit in May 1998. Field staff comprised of Marine Resources personnel from Rarotonga. Staff from the Ministry of Outer Island Development (Agriculture dept) at Atiu, and other self employed persons also provided assistance.

Three sites on the fringing bench reef were surveyed for the distribution patterns and abundance of "reef resource" species. The survey site were, Taunganui, Aumatangi and Tautara (**Figure 1**). For the purpose of this study, reef resources are defined as any species of edible or potential commercial value.

At each survey site, four replicate line transects of 50 m length were placed perpendicular to the reef edge. Two observers would search a 2 m band on either side of the transect line and as they progress down the line would record the resource types and counts within 5 m length segments, (each 5 m section being equivalent to a "quadrant" of 20 m^2 area).

The Shannon-Weiner diversity index (Zar, 1984) was calculated at each site to measure the diversity of resources. If a reef site is dominated by only a few species then a low diversity index occurs. Accordingly, the distribution is not even and the index also becomes a measure of heterogeneity or evenness. The index also has a special test to compare whether the diversities of two sampled populations are the same (Hutcheson in Zar, 1984). The equations relating to diversity are appended in **Append. 1**.

The resource species were each examined statistically for density distribution patterns among the survey sites and with distance from the reef edge (in 5 m increments). A two-way ANOVA model was used which tested the two factors (1) site and (2) distance from reef. Where significant differences ($P < 0.05$) in density were found the data set was further examined *a posteriori* with Tukeys HSD test to differentiate between different subsets. To improve homoscedasity of variance

the raw data for some species was log + 1 transformed prior to statistical analysis. Reef species that rarely occur were not examined for distribution patterns as the statistical power of these tests would be unacceptably low.

A simple stratified assessment of the total population numbers for the various resources was calculated. The resource density from the three survey sites was pooled to calculate an overall mean and the population estimate derived as the product of the mean density and the area of reef habitat.

Statistical treatment of data was performed using *SPSS version 6* software package. Whenever possible, means are presented with the standard error (s.e), which is a measure of variability associated with the mean. Assuming normality of the data distribution, the standard error can be used to derive confidence intervals (CI) about the mean estimate. For instance, a 95% confidence interval provides a range of values for the estimated mean that has a 95% probability to encompass the true mean. The working equations for standard error and confidence intervals are appended in **Append. 1**.

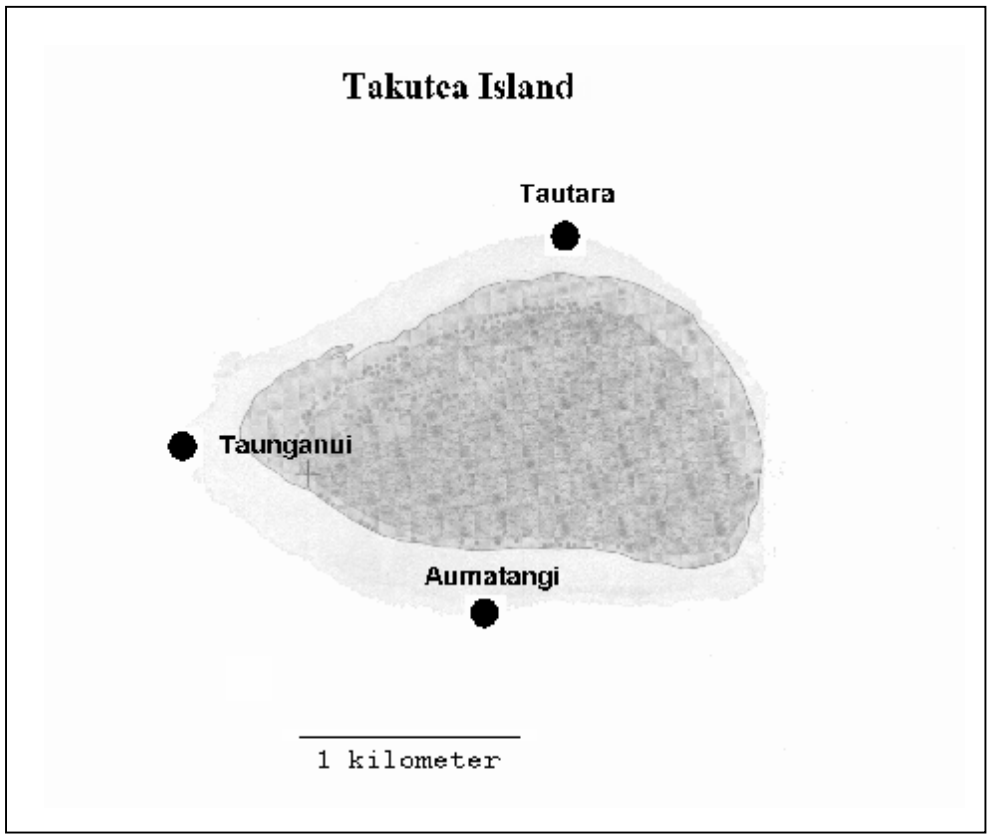

Figure 1 Map of Takutea island showing the three sample sites used in this survey.

RESULTS.

Resource Diversity.

There was a total of 17 reef resource species recorded at Takutea (refer to **Template A**). They include,
Ariri (Rough Turban-shell, *Turbo setosus*),
Belligerent Rock-shell, (*Thais armigera*),
Etu (Blue Starfish, *Linckia laevigata*),
Karikao, (Rose Mouthed Turban-shell, *Astrea rhodostoma*),
Kina (Pink Sea-urchin, *Echinometra mathaei*),
Mangeongeo, (Mollusc, Muricidae family, Drupa genus – most common species is the Mulberry drupe, *Drupa morum* and *Drupa ricinius ricinus*),
Mapi, (Star shaped limpet, *Patella flexuosa* and Chapman's limpet, *Patella chapum* and less common is the Cap limpet, *Patelloidea conoidalis*),
Matu Rori, (Soft Black Sea-cucumber, *Holothoria leucospilota*),
Paua, (Rugose Giant-clam, *Tridacana maxima*),
Paua Kura, (Prow Pitar Venus clam, *Pitar prova?*),
Popoto, (Mollusc, Conidae family – most common species are *Conus ebraeus*, *Conus eburneus* and *Conus chaldaeus*),
Poreo, (Cowrie sp., Cypraeidae family, *Cyprea tigris* most common species),
Pupu, (Mollusc, Muricidae family, Drupa genus – most common species is Grape drupe, *Morula uva* and Grandular drupe, *Morula grandulata*),
Rori Puakatoro, (Red Surf-fish, *Actinopyga mauritiana*),
Rori Toto, (Sandy Sea-cucumber, *Holothuria atra*),
Ungakoa, (Large Worm shell, *Dendropoma maxima*),
and Vana (Long Spine urchin, *Echinothrix diadema*).

There were 15 different reef species recorded at Taunganui site, 12 reef species were found at Aumatangi and a total of 14 reef species at Tautara (**Table 1**). The most common resource recorded was the Kina, a total of 206 animals were noted. Several species were rarely encountered, (less then 10 of these animals counted). These species include, Etu, Matu Rori, Poreo and Paua Kura.

The percentage of 20 meter quadrants which a resource was recorded may be an indication of how often one may expect to see the species (i.e "Occur" column, **Table 1**). And, since the Kina occurred in more then 30% of the quadrants surveyed, it is expected that there is a > 30% chance that this resource will be encountered on a trip to the reef. Similarly, resources which may be expected to be seen at the reef with a 20% to 30% probability include, Mangeongeo, Paua, Rori Toto and Ungakoa. The remaining resources have a < 20% probability of being encountered.

Table 1 The percentage occurrence and counts of reef resources at Takutea.

Site	Taunganui		Aumatangi		Tautara		Total	
Resource	Occur	Count	Occur	Count	Occur	Count	Occur	Count
Ariri	5%	8	2%	13	5%	7	**4%**	**28**
Etu	0%		0%		2%	1	**1%**	**1**
Karikao	11%	6	5%	2	5%	2	**7%**	**10**
Kina	50%	146	41%	54	9%	6	**33%**	**206**
Mangeongeo	18%	17	30%	20	25%	28	**24%**	**65**
Mapi	0%		0%		14%	42	**5%**	**42**
Matu Rori	5%	2	0%		0%		**2%**	**2**
Paua	23%	15	57%	78	5%	2	**28%**	**95**
Paua Kura	5%	4	0%		5%	3	**3%**	**7**
Popoto	7%	5	16%	16	18%	22	**14%**	**43**
Poreo	5%	2	2%	2	0%		**2%**	**4**
Pupu	9%	7	0%		14%	26	**8%**	**33**
Rock-shell	2%	2	16%	9	7%	3	**8%**	**14**
Rori Puakatoro	23%	11	23%	14	5%	2	**17%**	**27**
Rori Toto	27%	15	39%	25	5%	2	**23%**	**42**
Ungakoa	36%	78	11%	7	11%	10	**20%**	**95**
Vana	2%	1	18%	19	0%		**7%**	**20**

The diversity index, *H'* indicates that the most diverse site surveyed at Takutea was Tautara site (*H'* = 0.905) (**Table 2**) (Refer to General Materials and Methods, about diversity index). But the site with the most even spread of species numbers was Aumatangi, i.e evenness, *J'* = 0.834. The site with the least amount of reef diversity and evenness was Taunganui (*H'* = 0.758, *J'* = 0.645). This is because a large population of Kina skews the diversity in the area. A special statistical test to compare diversity concluded that the diversity between Taunganui and Tautara are significantly different ($P > 0.05$).

Table 2 Diversity index of resources at Takutea.

Test statistic	Taunganui	Aumatangi	Tautara
Diversity, *H'*	0.758	0.900	0.905
Maximum Diversity, H_{max}	1.176	1.079	1.146
Evenness, *J'*	0.645	0.834	0.790

Distribution Patterns.

The results of the distribution patterns of resources with distance from the reef and among sites have been portrayed (**Figures 2, 3** and **4**) to enable a representation of the reefs.

The statistical results are summarised in a tabular form (**Table 3**). A statistically significant (or positive) test can be thought of a 95% probability chance to be correct. For instance, if a

significantly high number of Mangeongeo are found at the 5 meter distance from the reef, then chances that this pattern is true has about a 95% probability. The animals with less then 10 animals were not analysed for distribution patterns because there were too few of these animals for test to have adequate statistical power.

The Kina, Ungakoa and Vana had distribution patterns that were significantly different ($P < 0.05$) among the three sites surveyed. There was a very low density of Kina at Tautara compared to Taunganui and Aumatangi sites. Tautara site is a raised bench reef that becomes exposed over low tides, and this probably makes it an unfavourable habitat for the Kina. The density of Ungakoa (which is burrowed into the rocks and has more protection from tidal exposure) was significantly greater at Taunganui then the other two sites. The greatest density of Vana was found at Aumatangi site. This is one of the few lagoonal areas and probably offers the best habitat for the Vana.

The Paua, Rori Puakatoro, Rori Toto and Belligerent Rock-shell had significant distribution patterns that were affected by both distance from the reef edge and sites. The greatest abundance of Paua was at Aumatangi site, close to the reef edge, compared to Taunganui site where there were more Paua further back. Similarly the greatest density of Rori Toto, Rori Puakatoro and Rock-shell occur at Aumatangi site, about 20 meters from the reef edge compared to further back at other sites.

The Karikao, Mangeongeo did not have any apparent distribution pattern affected by site or distance.

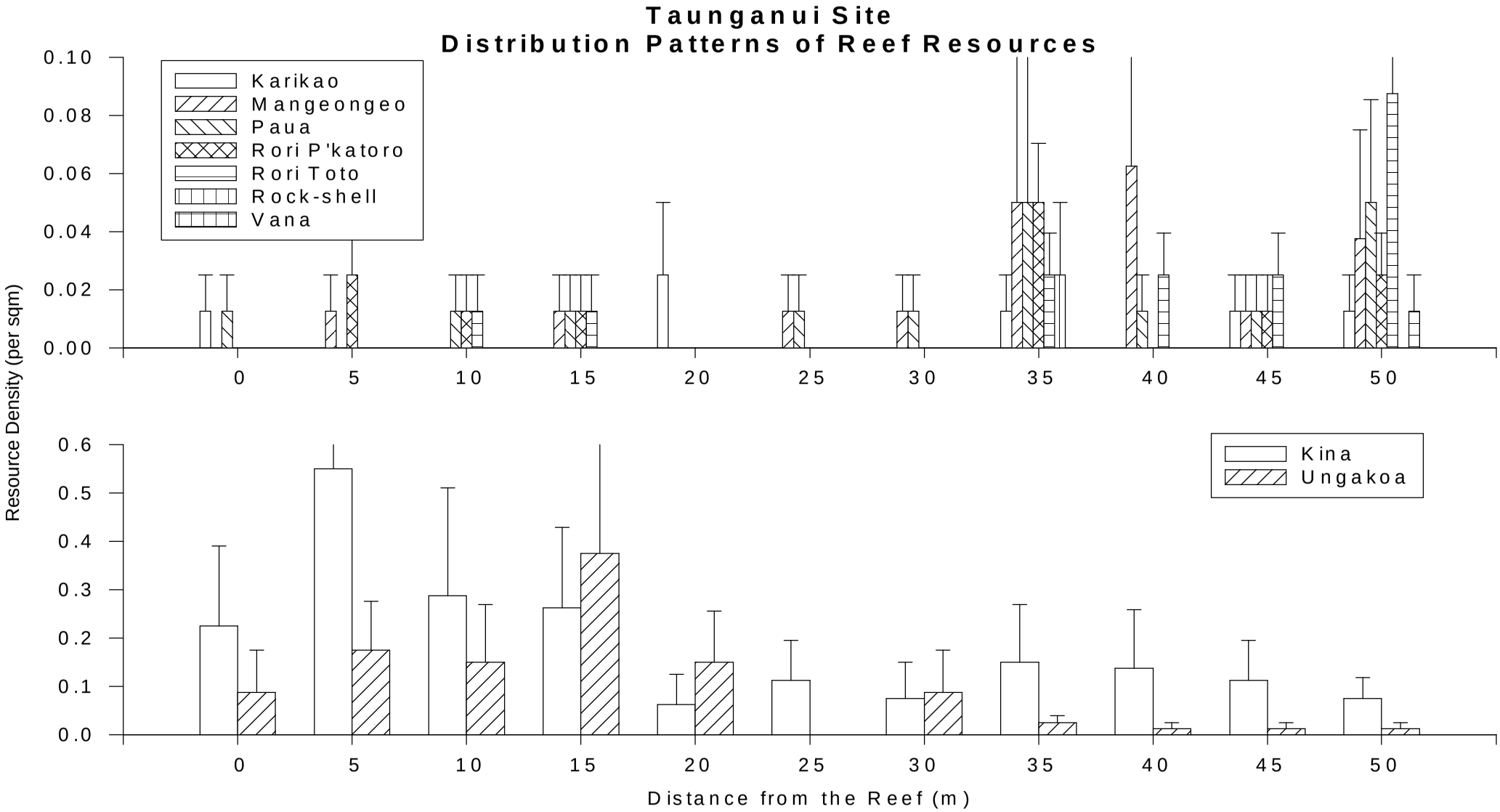

Figure 2 Graph of reef resources distribution patterns at Taunganui site.

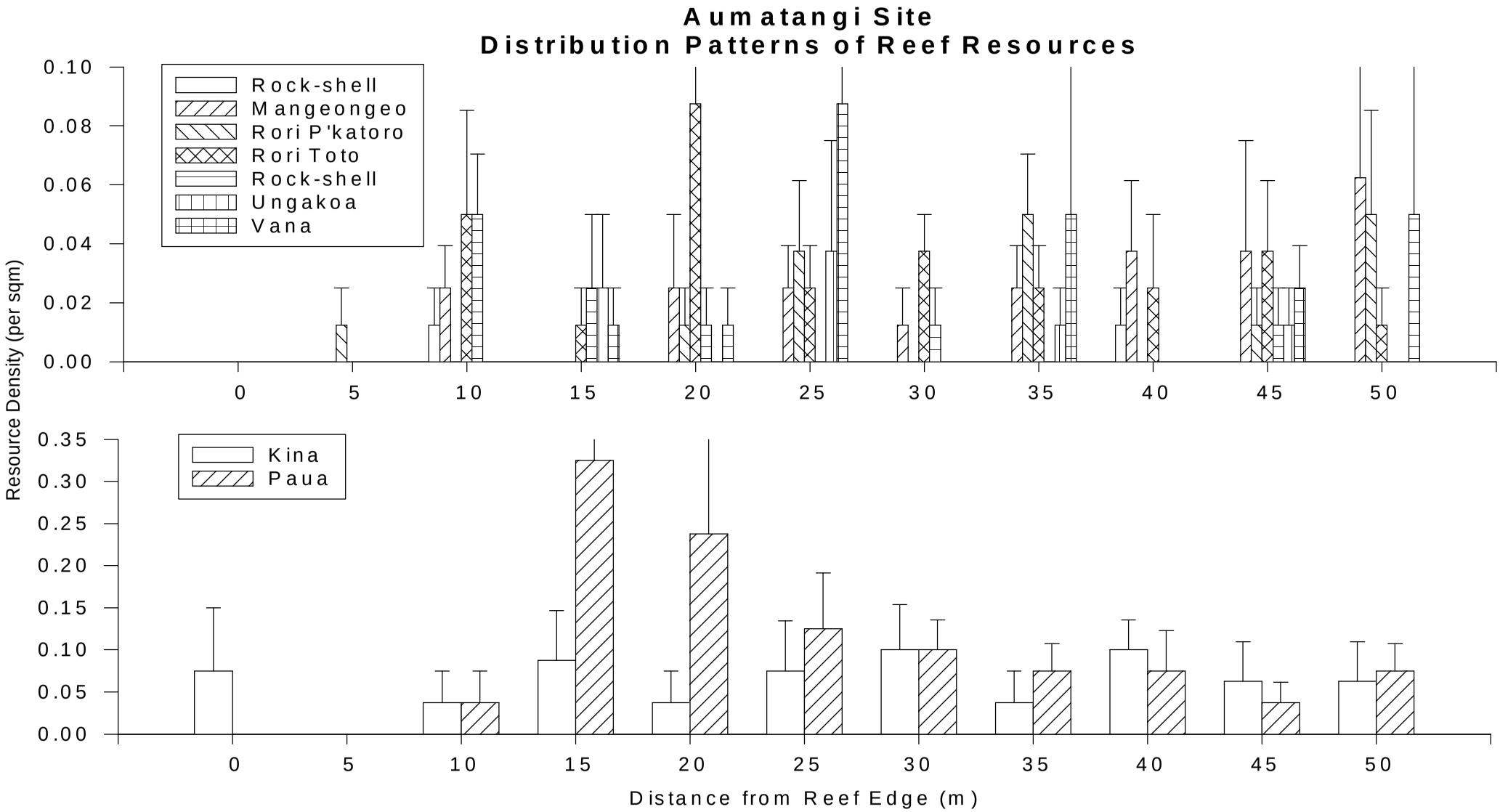

Figure 3 Graph of reef resources distribution patterns at Aumatangi site.

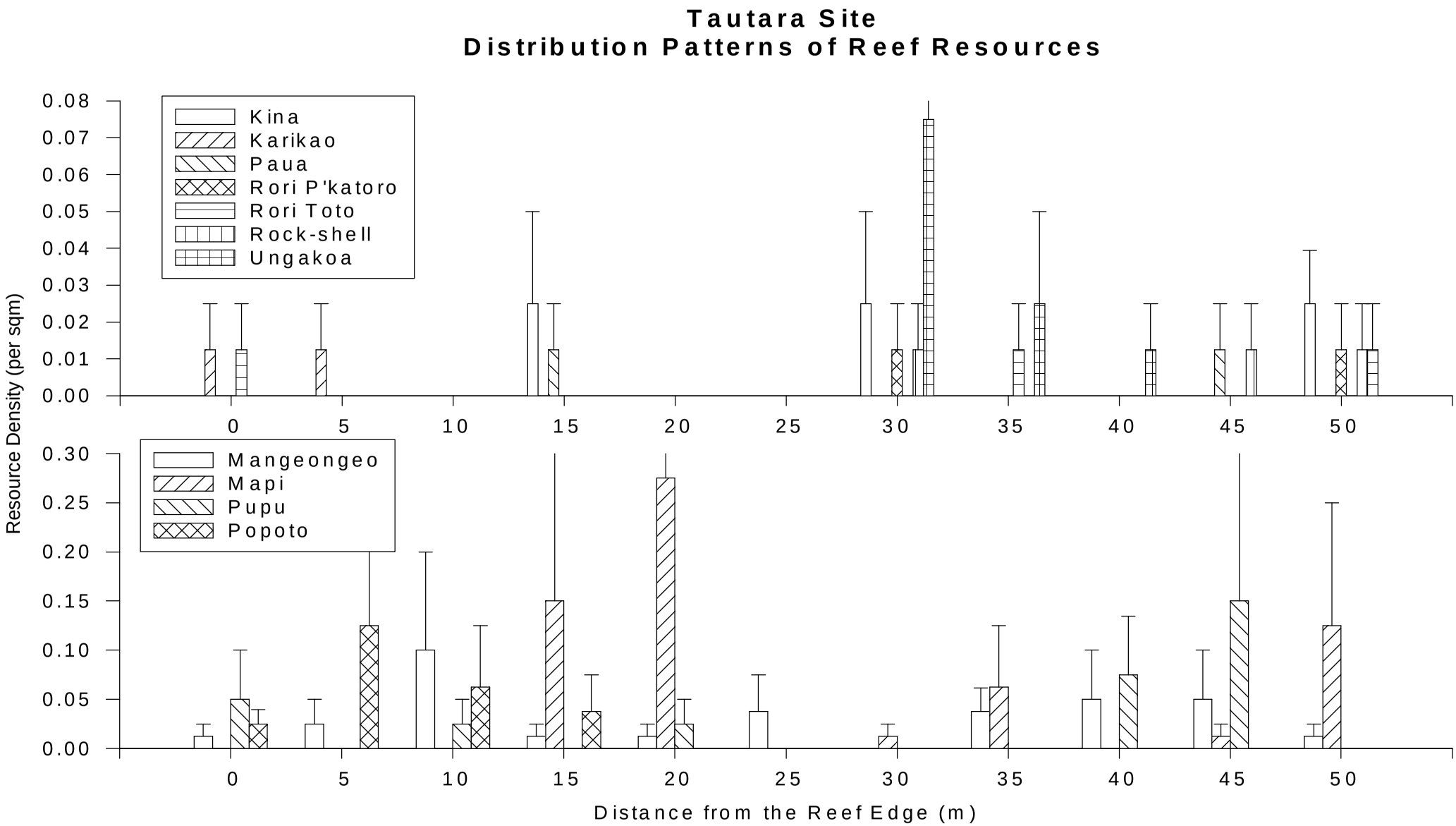

Figure 4 Graph of reef resources distribution patterns at Tautara site.

Table 3 Resource distribution patterns at Takutea survey sites and with distance from the reef edge.

Resource	Tests	Result	Density (per sq.m)	Conclusion
Ariri	Not done		Overall density = 0.009	-no density patterns with site or distance.
Etu	Not done		Overall density = 0.001	-no density patterns with site or distance.
Mapi	Not done		Overall density = 0.024	-no density patterns with site or distance.
Matu Rori	Not done		Overall density = 0.001	-no density patterns with site or distance.
Paua Kura	Not done		Overall density = 0.002	-no density patterns with site or distance.
Popoto	Not done		Overall density = 0.020	-no density patterns with site or distance.
Pupu	Not done		Overall density = 0.011	-no density patterns with site or distance.
Kina	2-way ANOVA Tukeys HSD	site = * distance = n.s	*Tautara* = 0.007 (subset 1) *Taunganui* = 0.186 (subset 2) *Aumatangi* = 0.064 (subset 2)	-*Tautara* density < *Taunganui* and *Aumatangi* density. -no difference in density with distance from reef edge.
Karikao	2-way ANOVA	site = n.s distance = n.s	Overall density = 0.003	-no density patterns with site or distance.
Mangeongeo	2-way ANOVA	site = n.s distance = n.s	Overall density = 0.026	-no density patterns with site or distance.
Paua	2-way ANOVA	site x distance = **	Overall density = 0.046	-highest densities occur at Aumatangi site, density greatest close to reef edge at Aumatangi and further back at Taunganui site.
Rori Puakatoro	2-way ANOVA	site x distance = *	Overall density = 0.011	-low densities occur at Tautara site, density greatest >20 m from reef at Taunganui and Aumatangi site.
Rori Toto	2-way ANOVA	site x distance = **	Overall density = 0.017	-greatest densities occur at Aumatangi site 20 m from reef, compared to 50 m from reef at Tautara site.
Rock-shell	2-way ANOVA	site x distance = *	Overall density = 0.005	-greatest densities occur at Aumatangi site.
Ungakoa	2-way ANOVA Tukeys HSD	site = * distance = n.s	*Tautara* = 0.062 (subset 1) *Taunganui* = 0.002 (subset 2) *Aumatangi* = 0.000 (subset 2)	-*Tautara* density > *Taunganui* and *Aumatangi* density. -no difference in density with distance from reef edge.
Vana	2-way ANOVA Tukeys HSD	site = * distance = n.s	*Aumatangi* = 0.025 (subset 1) *Taunganui* = 0.001 (subset 2) *Tautara* = 0.000 (subset 2)	- *Aumatangi* density > *Taunganui* and *Tautara* density. -no difference in density with distance from reef edge.

n.s = non significant difference found among levels of factor, P > 0.05. * = significant difference found between levels of factors, P < 0.05
** = highly significant difference found between levels of factors, P < 0.001. Unless indicated, no significant interactive effects between site and distance factors found.

Total Population Size.
The total population of resources was calculated based on the survey results of density of species per square meter and the area of reef (taken simply as the length of the reef and a 50 meter width) (**Table 4**).

The largest resource population is the Kina. The total population of Kina (plus or minus 95% Confidence Interval – see General Materials and Methods, for an explanation of confidence intervals), was 30 000 ± 78 000. Another resource of relatively high abundance is the Paua and Ungakoa, the population size of both animals was approximately 14 000 ± 45 000. Resources with a small total population (less then 1000) include Etu, Matu Rori and Poreo. The population estimates are graphed in **Figure 5**.

Table 4 Population size of reef resources at Takutea.

Resource	Density (Per Sq.m)	Std. Error	Abundance	95% C.I
Ariri	0.012	0.002	**4 200**	3 600
Etu	< 0.001	< 0.001	**200**	700
Karikao	0.004	0.002	**1 500**	2 600
Kina	0.086	0.051	**30 500**	78 400
Mangeo	0.027	0.004	**9 600**	6 300
Mapi	0.018	0.018	**6 200**	26 700
Matu Rori	0.001	0.001	**300**	1 300
Paua	0.040	0.029	**14 100**	44 800
Paua Kura	0.003	0.002	**1 100**	2 300
Popoto	0.018	0.006	**6 400**	9 500
Poreo	0.002	0.001	**600**	1 300
Pupu	0.008	0.003	**2 700**	4 000
Rock-shell	0.006	0.003	**2 100**	4 200
Rori P'ktoro	0.011	0.005	**4 000**	6 900
Rori Toto	0.018	0.008	**6 200**	12 700
Ungakoa	0.040	0.029	**14 100**	44 300
Vana	0.008	0.008	**3 000**	11 800

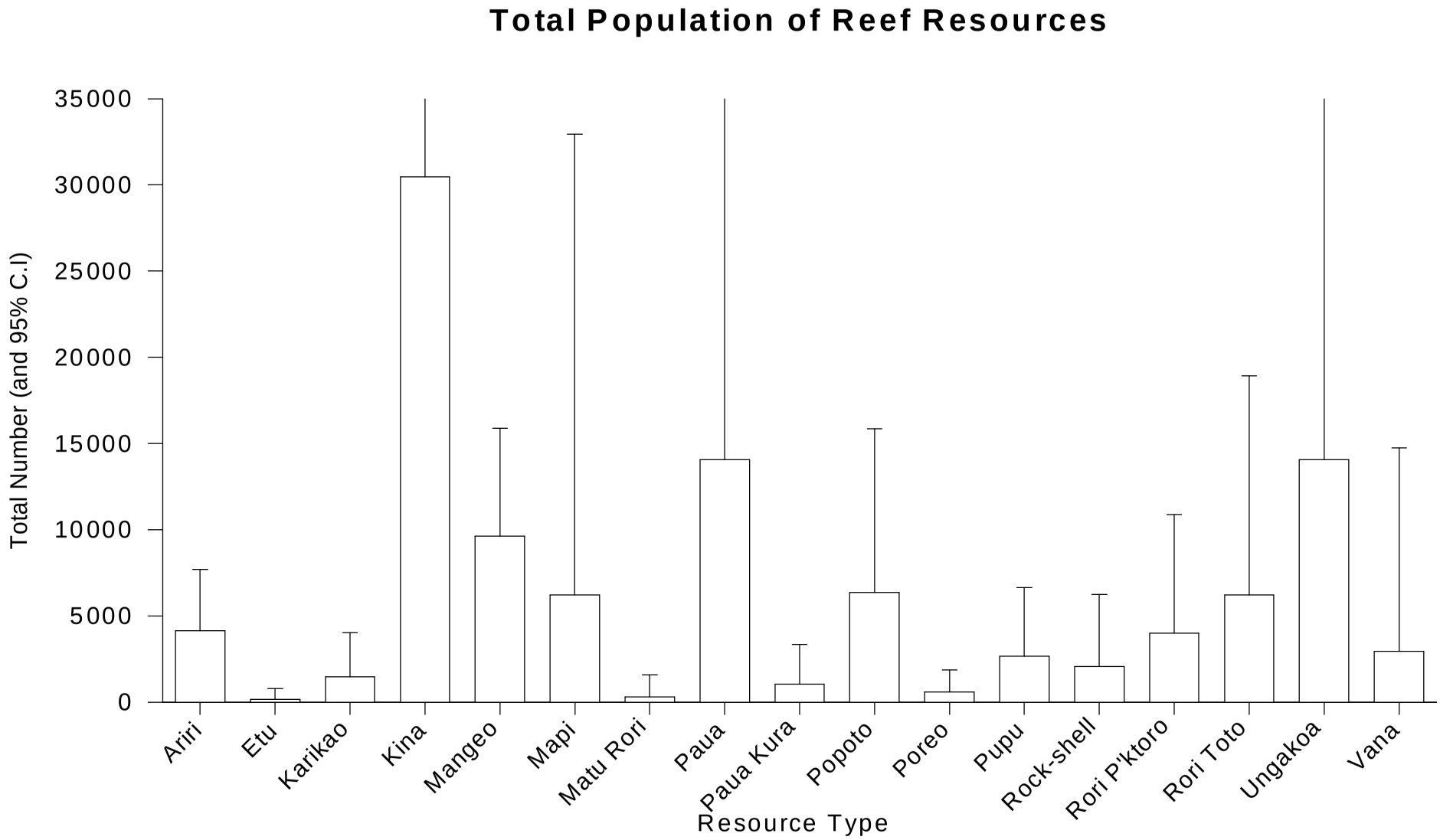

Figure 5 Population size of reef resources at Takutea.

DISCUSSION.

Many of the 17 resource types reported in survey are generally of low value in subsistence food or commercial terms. Of the three sites sampled, Tautara was found to have the highest diversity index and Aumatangi the most evenness of resource abundance.

The distribution patterns among the sites and with distance from the reef edge were examined statistically. Compared to Aumatangi and Taunganui sites, Tautara site was found to have significantly lower abundance of Kina, Ungakoa and Vana. Tautara is located on the leeward side of the island and a large proportion of the bench reef is exposed during low tides. This would present unfavourable conditions for these resources. Other site factors to take into consideration is, wave action (some species prefer a lot of wave surge, others do not), benthos type (rock, sand etc) and food (many invertebrates are herbivorous and prefer areas of algal cover).

The Paua, Rori Puakatoro, Rori Toto and Rock-shell had significant distribution patterns affected not only by site but also distance from the reef edge. The general pattern being that the highest abundance of animals occur at Aumatangi site at about 20 meters from the reef edge but further back from the reef at other sites.

The largest resource population is the Kina. The population size is approximately 30 000. The other sea urchin (Echinoderm) reported is the Vana (population size 3 000). Some common sea urchin species found else in the Cooks but absent from this survey include the Atuke (*Heterocentrotus mammillatus*) and Avake (*Tripneustes gratilla*). Another relatively large resource population is the Paua and the Ungakoa, the population size of both these animals is approximately 14 000. Only three Rori (Holothurian) species were found at Takutea. They include Matu Rori (300), Rori Puakatoro (4 000) and Rori Toto (6 000). There are two other species (Rori Pua, *Holothuria cinerascens* and Rori Matie, *Stichopus chloronotus*) that are common in the Cooks but were not observed during this survey.

There is only a relatively small population (< 1 000) of Etu. Matu Rori and Poreo. Although the number of Ariri was estimated to be 4 000, this may be an underestimate as the Ariri were unable to be counted right to the reef edge due to high wave action. This survey trip was conducted in conjunction with a Trochus (*Trochus niloticus*) transfer and it is hoped that the Trochus will multiply (they are closely related to the Ariri). In future, Takutea may act as a Trochus reserve for the island of Atiu (Trochus are valued for their shell and meat).

THE PAUA FISHERY.

This survey has revealed information of the Paua distribution and abundance patterns. The highest abundance of Paua is found at the Aumatangi area. And lesser abundant populations are located on the areas adjacent to Aumatangi. There are several possible reasons why Aumatangi area is a suitable habitat for the Paua.

(i) It has a small lagoon basin that acts as a buffer to dry exposure during low tides.

(iii) Since the area supports a relatively large body of water, the environmental conditions are more stable. Physical characteristics of the water column (particularly temperature and salinity) are not as variable as shallow parts of Takutea.

(ii) The area is adjacent to the prevailing currents and so wave surge action is moderate. This will improve the chance of successful settlement and recruitment. Wave action on the windward side is very turbulent while the leeward side often dry.

(iv) Few molluscivate fish species were observed at Aumatangi so that natural predation rates are probably low.

The distribution of Paua appears stratified into several zones. The first zone of high density occurs at Aumatangi area on the southern side in the area adjacent to a lagoon basin and where moderate wave action occurs. A second zone of medium density is found along the north western (leeward) side of the island at Taunganui site. The third zone of low Paua density occurs on the windward side of the island where there is high wave action and little reef cover. The densities of Aumatangi, Taunganui and Tautara are taken as representative of the high, medium and low densities, respectively. On the basis of this stratified design a population abundance of Paua can be estimated.

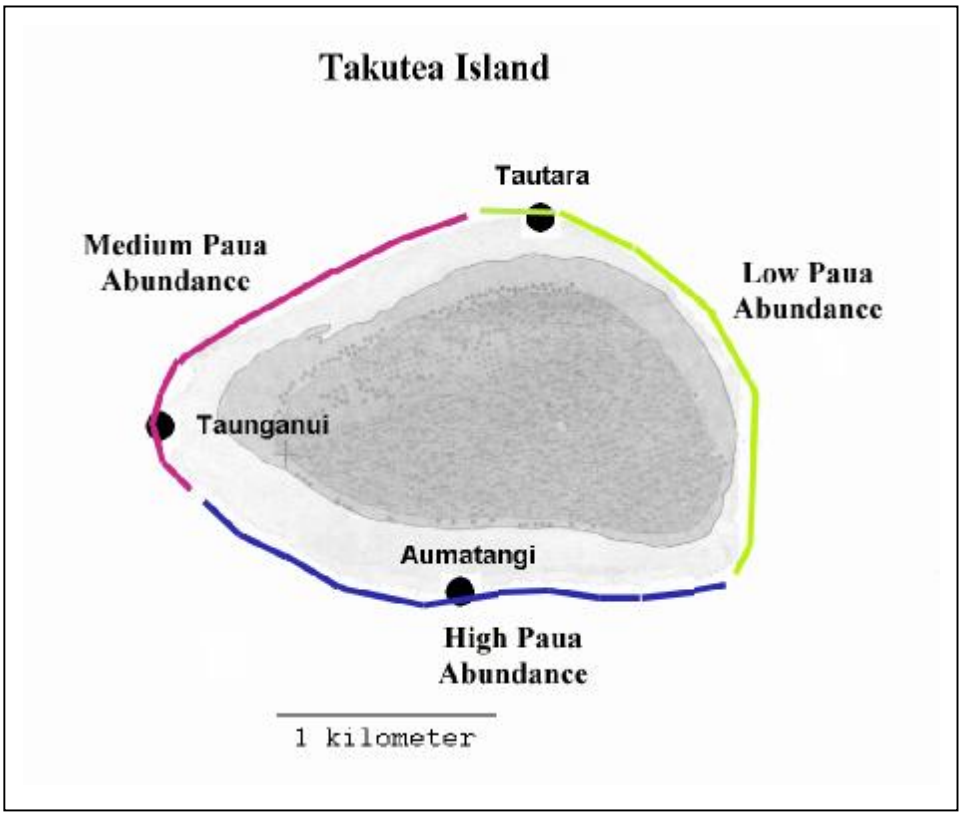

Figure 6 Map of Takutea island showing a stratified abundance of the Paua population.

Using a stratified technique the total population abundance of Paua is estimated to be 11 000 ± 32 000 animals (**Table 5**). The result is similar to the 14 000 estimate that was calculated earlier using a simple assessment.

Table 5 Stratified population assessment of Paua at Takutea.

Strata	Area (sqm)	Average Density	Std. Error	Abundance	95% C.I
High	90 000	0.099	0.076	**8 900**	21 700
Medium	115 000	0.017	0.020	**2 000**	7 400
Low	150 000	0.002	0.005	**300**	2 500
Total	355 000			**11 200**	31 600

A theoretical population structure can be developed based on a population structure of mean shell length of 9.1 cm and a standard deviation of 3.9 cm recorded in Aitutaki during the mid 80's (Sims and Howard, 1988). Assuming a normal population distribution of size length at Takutea to be similar to the Aitutaki survey the population structure of 11 200 Paua at Takutea can be determined (**Figure 7**) (Refer to **Appendix I** for equations of normal distribution).

To establish guidelines for a sustainable harvest it is necessary to consider some biological traits of the Paua. At 10-11 cm size, approximately 50% of the animals are mature, and 100% are mature by 14 cm and above (Lewis, 1988). To ensure that reproductive power of the population is retained it is suggested that the harvest quota per year be limited to 30% of the size range between 10 – 15 cm. The animals greater then 15 cm are fully mature and usually more fecundate (pers. observ.) then their smaller counterparts. This segment of the population should be left as natural brood stock.

Having determined our harvest quota (30% of size range between 10 – 15 cm) we can quantify the numbers of Paua that can be harvested. Based on the observations of McCormack (1997), there are approximately 200 Paua harvested per "bucket", (on that occasion, he estimated 30 buckets of meat, or 5,000 – 7,000 Paua were harvested from Takutea). Therefore,

a. The total population of Paua at Takutea = 11 200 Paua.

b. The total number of Paua between 10–15 cm size = 4 600 Paua.

c. The total number of Paua that can be harvested (@30%) = 1 400 Paua.

d. The total buckets of Paua that can be harvested (@200 Paua per bucket) = 7 Buckets.

IT IS RECOMMENDED THAT HARVEST OF PAUA BE LIMITED TO 7 BUCKETS PER YEAR.

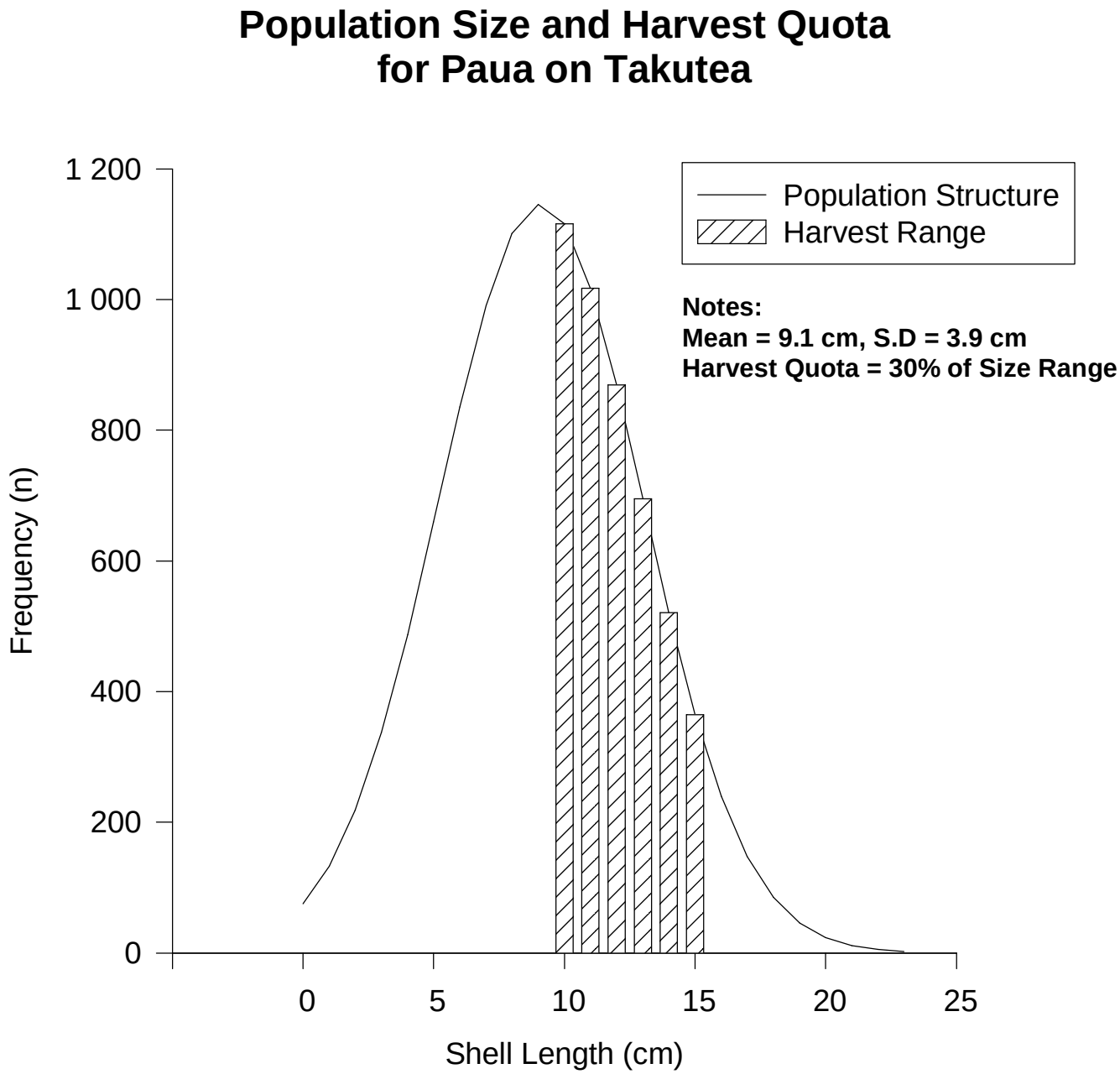

Figure 7 Population size structure of Paua on Takutea island. Also indicated is the harvestable size range of Paua (10 – 15 cm) (shaded region).

MANAGEMENT RECOMMENDATIONS.

Takutea is a rather unique island in the Cook group and since it is relatively free of harvest pressure it is a good example of a marine nature reserve.

However, the abundance of the reef resources on Takutea is relatively small and is vulnerable to over harvesting should heavy-handed attitudes prevail. We have seen how the once enormous population of Paua on the large reef of Aitutaki was quickly reduced, mostly over fished by unscrupulous attitudes. For instance, in 1988, there was 100 Paua in every 20 square meter area (Sims and Howard) on the reef, but today only 1 Paua is found per 20 square meters (Ponia, 1998).

It is recommended that the Trustees extend the wild life sanctuary of Takutea to the reef life of Takutea. It is up to the Trustees what form of Raui to be used, for example;

a. *A Raui that will ban outright the harvesting of all reef life. Or,*

b. *A Raui that will allow the harvesting of reef life only under approval and subject to a sustainable harvest quota being established first. For instance, the Raui on the Paua may be lifted once a year to allow a harvest of 7 buckets of Paua meat, from animals between 10–15 cm sizes. The Ministry of Marine Resources can assist the Trustees by determining the harvest quota before the harvest proceeds. Such a relationship has been established with Island Council in Aitutaki for the Trochus harvest.*

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APPENDICES

APPENDIX I

Diversity.

A. Shannon-Weiner diversity index, H' is

$$H' = \frac{n \log n - \sum_{(i=1)}^{(k)} f_i \log f_i}{n}$$

where, n = sample size; f_i = number of observations in category i.

B. Where maximum possible diversity for k categories is

$$H'_{max} = \log k$$

C. Evenness J' may be calculated as

$$J' = \frac{H'}{H_{max}}$$

D. The t -test of the null hypothesis that the diversity of two sampled populations is equal whereby

$$t \text{ statistic} = \frac{H'_1 - H'_2}{s_{H'1} - s_{H'2}}$$

where, $s_{H'1-H'2} = \text{sqrt}(s^2_{H'1} + s^2_{H'2})$ and $s^2_H = \frac{\sum f_i \log^2 f_i - (\sum f_i \log f_i)^2 / n}{n^2}$

E. *Standard Error s.e, or (variance of mean)*

Standard error, s.e = sqrt(standard deviation) / *n*
where ***n*** = number of samples.

F. *Confidence intervals, C.I (95% confidence)*

95% Confidence Interval (CI) = (s.e) $t_{2,0.05}n-1$
with ***t*** value derived from ***t* table** with ***n*** - 1 degrees of freedom.

G. Normal distribution with, frequency ($\mathbf{f_i}$) of size ($\mathbf{X_i}$), mean = μ, and standard deviation = σ.

$$Fi = \frac{1}{\sigma\sqrt{2\pi}} e^{-(Xi-\mu)2/2\sigma 2}$$

where p = 3.14159, and **e** = 2.71828

APPENDIX II.

a. Summary of ANOVA tests for distribution patterns.

Kina

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	14.90	158	.09		
SITE	3.61	2	1.81	19.15	.000
DISTANCE	.49	10	.05	.52	.873
SITE BY DISTANCE	1.49	20	.07	.79	.724

```
Multiple Range Tests:  Tukey-HSD test with significance level .050
 (*) Indicates significant differences which are shown in the lower triangle
                         G G G
                         r r r
                         p p p
                         3 2 1
     Mean      SITE
      .0344    Grp 3
      .2462    Grp 2      *
      .3997    Grp 1      * *
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Karikao

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	.92	158	.01		
SITE	.02	2	.01	1.71	.184
DISTANCE	.04	10	.00	.74	.682
SITE BY DISTANCE	.16	20	.01	1.36	.148

Mangeongeo

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	7.53	158	.05		
SITE	.05	2	.03	.54	.586
DISTANCE	.51	10	.05	1.06	.396
SITE BY DISTANCE	.37	20	.02	.39	.991

Paua

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	6.10	158	.04		
SITE	3.55	2	1.77	45.98	.000
DISTANCE	1.20	10	.12	3.10	.001
SITE BY DISTANCE	2.22	20	.11	2.88	.000

Rori Puakatoro

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	2.11	158	.01		
SITE	.18	2	.09	6.74	.002
DISTANCE	.53	10	.05	3.96	.000
SITE BY DISTANCE	.48	20	.02	1.80	.025

Rori Toto

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	2.88	158	.02		
SITE	.61	2	.30	16.65	.000
DISTANCE	.35	10	.03	1.89	.050
SITE BY DISTANCE	1.16	20	.06	3.18	.000

Belligerent Rock-shell

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	1.27	158	.01		
SITE	.08	2	.04	4.93	.008
DISTANCE	.13	10	.01	1.63	.103
SITE BY DISTANCE	.38	20	.02	2.33	.002

Ungakoa

```
Source of Variation          SS      DF        MS         F  Sig of F
 WITHIN+RESIDUAL           6.52     158       .04
 SITE                       .57       2       .28      6.90      .001
 DISTANCE                   .40      10       .04       .97      .470
 SITE BY DISTANCE           .84      20       .04      1.02      .444

Multiple Range Tests:  Tukey-HSD test with significance level .050
(*) Indicates significant differences which are shown in the lower triangle
                         G G G
                         r r r
                         p p p
                         2 1 3
     Mean      SITE
      .0000    Grp 2
      .0137    Grp 1
      .1158    Grp 3      * *
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Vana

```
Source of Variation          SS      DF        MS         F  Sig of F
 WITHIN+RESIDUAL           2.88     158       .02
 SITE                       .27       2       .14      7.42      .001
 DISTANCE                   .21      10       .02      1.14      .335
 SITE BY DISTANCE           .40      20       .02      1.10      .352

Multiple Range Tests:  Tukey-HSD test with significance level .050
(*) Indicates significant differences which are shown in the lower triangle
                         G G G
                         r r r
                         p p p
                         3 1 2
     Mean      SITE
      .0000    Grp 3
      .0068    Grp 1
      .0972    Grp 2      * *
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

b. Summary of mean density for sites and reef distances surveyed. (Site 1 = Taunganui, Site 2 = Aumatangi, Site 3 = Tautara. Distance 1 = 0 meters from reef edge, 2 = 5 m, 3 = 10 m, 4 = 15 m, 5 = 20 m, 6 = 25 m, 7 = 30 m, 8 = 35 m, 9 = 40 m, 10 = 45 m and 11 = 50 meters from reef edge).

Ariri

```
Value  Label                                  Mean
For Entire Population                        .0086

SITE          1.00                           .0091
SITE          2.00                           .0088
SITE          3.00                           .0082

DISTANCE      1.00                           .0219
DISTANCE      2.00                           .0406
DISTANCE      3.00                           .0031
DISTANCE      4.00                           .0278
DISTANCE      5.00                           .0000
DISTANCE      6.00                           .0000
DISTANCE      7.00                           .0000
DISTANCE      8.00                           .0000
DISTANCE      9.00                           .0000
DISTANCE     10.00                           .0000
```

DISTANCE	11.00	.0063

Etu

For Entire Population		.0005
SITE	1.00	.0000
SITE	2.00	.0000
SITE	3.00	.0014
DISTANCE	1.00	.0000
DISTANCE	2.00	.0063
DISTANCE	3.00	.0000
DISTANCE	4.00	.0000
DISTANCE	5.00	.0000
DISTANCE	6.00	.0000
DISTANCE	7.00	.0000
DISTANCE	8.00	.0000
DISTANCE	9.00	.0000
DISTANCE	10.00	.0000
DISTANCE	11.00	.0000

Kina

For Entire Population		.0702
SITE	1.00	.1864
SITE	2.00	.0635
SITE	3.00	.0068
DISTANCE	1.00	.0750
DISTANCE	2.00	.1375
DISTANCE	3.00	.0812
DISTANCE	4.00	.0944
DISTANCE	5.00	.0275
DISTANCE	6.00	.0525
DISTANCE	7.00	.0650
DISTANCE	8.00	.0529
DISTANCE	9.00	.0844
DISTANCE	10.00	.0594
DISTANCE	11.00	.0563

Karikao

For Entire Population		.0034
SITE	1.00	.0068
SITE	2.00	.0020
SITE	3.00	.0027
DISTANCE	1.00	.0094
DISTANCE	2.00	.0063
DISTANCE	3.00	.0031
DISTANCE	4.00	.0000
DISTANCE	5.00	.0050
DISTANCE	6.00	.0000
DISTANCE	7.00	.0000
DISTANCE	8.00	.0029
DISTANCE	9.00	.0063
DISTANCE	10.00	.0031
DISTANCE	11.00	.0031

Mangeongeo

For Entire Population		.0262
SITE	1.00	.0193
SITE	2.00	.0257
SITE	3.00	.0308
DISTANCE	1.00	.0063
DISTANCE	2.00	.0156
DISTANCE	3.00	.0563
DISTANCE	4.00	.0083
DISTANCE	5.00	.0150
DISTANCE	6.00	.0275
DISTANCE	7.00	.0075
DISTANCE	8.00	.0353
DISTANCE	9.00	.0469
DISTANCE	10.00	.0344
DISTANCE	11.00	.0438

Mapi

For Entire Population		.0238
SITE	1.00	.0000
SITE	2.00	.0000
SITE	3.00	.0623
DISTANCE	1.00	.0000
DISTANCE	2.00	.0000
DISTANCE	3.00	.0000
DISTANCE	4.00	.0667
DISTANCE	5.00	.1100
DISTANCE	6.00	.0000
DISTANCE	7.00	.0050
DISTANCE	8.00	.0294
DISTANCE	9.00	.0000
DISTANCE	10.00	.0031
DISTANCE	11.00	.0313

Matu Rori

For Entire Population		.0005
SITE	1.00	.0023
SITE	2.00	.0000
SITE	3.00	.0000
DISTANCE	1.00	.0000
DISTANCE	2.00	.0000
DISTANCE	3.00	.0000
DISTANCE	4.00	.0000
DISTANCE	5.00	.0000
DISTANCE	6.00	.0000
DISTANCE	7.00	.0000
DISTANCE	8.00	.0000
DISTANCE	9.00	.0000
DISTANCE	10.00	.0031
DISTANCE	11.00	.0031

Paua

For Entire Population		.0461
SITE	1.00	.0170
SITE	2.00	.1068

SITE	3.00	.0021
DISTANCE	1.00	.0031
DISTANCE	2.00	.0000
DISTANCE	3.00	.0125
DISTANCE	4.00	.1167
DISTANCE	5.00	.0950
DISTANCE	6.00	.0525
DISTANCE	7.00	.0425
DISTANCE	8.00	.0471
DISTANCE	9.00	.0406
DISTANCE	10.00	.0250
DISTANCE	11.00	.0500

Paua Kura

For Entire Population		.0018
SITE	1.00	.0045
SITE	2.00	.0000
SITE	3.00	.0021
DISTANCE	1.00	.0000
DISTANCE	2.00	.0000
DISTANCE	3.00	.0000
DISTANCE	4.00	.0083
DISTANCE	5.00	.0000
DISTANCE	6.00	.0000
DISTANCE	7.00	.0000
DISTANCE	8.00	.0000
DISTANCE	9.00	.0063
DISTANCE	10.00	.0063
DISTANCE	11.00	.0000

Pupu

For Entire Population		.0107
SITE	1.00	.0080
SITE	2.00	.0000
SITE	3.00	.0233
DISTANCE	1.00	.0250
DISTANCE	2.00	.0000
DISTANCE	3.00	.0156
DISTANCE	4.00	.0056
DISTANCE	5.00	.0150
DISTANCE	6.00	.0000
DISTANCE	7.00	.0000
DISTANCE	8.00	.0000
DISTANCE	9.00	.0188
DISTANCE	10.00	.0375
DISTANCE	11.00	.0063

Popoto

For Entire Population		.0196
SITE	1.00	.0091
SITE	2.00	.0162
SITE	3.00	.0295
DISTANCE	1.00	.0156
DISTANCE	2.00	.0625

DISTANCE	3.00	.0406
DISTANCE	4.00	.0417
DISTANCE	5.00	.0100
DISTANCE	6.00	.0050
DISTANCE	7.00	.0250
DISTANCE	8.00	.0059
DISTANCE	9.00	.0063
DISTANCE	10.00	.0063
DISTANCE	11.00	.0000

Rori Puakatoro

For Entire Population		.0107
SITE	1.00	.0125
SITE	2.00	.0182
SITE	3.00	.0021
DISTANCE	1.00	.0000
DISTANCE	2.00	.0094
DISTANCE	3.00	.0031
DISTANCE	4.00	.0028
DISTANCE	5.00	.0050
DISTANCE	6.00	.0150
DISTANCE	7.00	.0050
DISTANCE	8.00	.0353
DISTANCE	9.00	.0000
DISTANCE	10.00	.0094
DISTANCE	11.00	.0344

Rori Toto

For Entire Population		.0168
SITE	1.00	.0170
SITE	2.00	.0311
SITE	3.00	.0021
DISTANCE	1.00	.0063
DISTANCE	2.00	.0000
DISTANCE	3.00	.0156
DISTANCE	4.00	.0083
DISTANCE	5.00	.0350
DISTANCE	6.00	.0100
DISTANCE	7.00	.0150
DISTANCE	8.00	.0206
DISTANCE	9.00	.0188
DISTANCE	10.00	.0250
DISTANCE	11.00	.0281

Belligerent Rock-shell

For Entire Population		.0052
SITE	1.00	.0023
SITE	2.00	.0095
SITE	3.00	.0027
DISTANCE	1.00	.0000
DISTANCE	2.00	.0000
DISTANCE	3.00	.0125
DISTANCE	4.00	.0111
DISTANCE	5.00	.0050
DISTANCE	6.00	.0000

DISTANCE	7.00	.0100
DISTANCE	8.00	.0059
DISTANCE	9.00	.0000
DISTANCE	10.00	.0094
DISTANCE	11.00	.0031

Ungakoa

For Entire Population		.0243
SITE	1.00	.0023
SITE	2.00	.0000
SITE	3.00	.0623
DISTANCE	1.00	.0000
DISTANCE	2.00	.0000
DISTANCE	3.00	.0000
DISTANCE	4.00	.0667
DISTANCE	5.00	.1100
DISTANCE	6.00	.0000
DISTANCE	7.00	.0050
DISTANCE	8.00	.0294
DISTANCE	9.00	.0000
DISTANCE	10.00	.0063
DISTANCE	11.00	.0344

Vana

For Entire Population		.0099
SITE	1.00	.0011
SITE	2.00	.0250
SITE	3.00	.0000
DISTANCE	1.00	.0000
DISTANCE	2.00	.0000
DISTANCE	3.00	.0000
DISTANCE	4.00	.0028
DISTANCE	5.00	.0050
DISTANCE	6.00	.0350
DISTANCE	7.00	.0000
DISTANCE	8.00	.0235
DISTANCE	9.00	.0000
DISTANCE	10.00	.0125
DISTANCE	11.00	.0281