INSTITUTE OF APPLIED SCIENCES

THE UNIVERSITY OF THE SOUTH PACIFIC

CRISP-IRD/USP WORKSHOP
The Effectiveness of Different Taxonomic Survey Intensities Represented by Indicator Fish Species in Understanding the Effects of Designation on Fish Population Abundance in a Fijian Context

IAS TECHNICAL REPORT NO. 2007/1

by

James Comley
Ron Vave
Akuila Cakacaka
Semisi Meo
Alifereti Tawake
Marc Léopold
David Lecchini

February, 2007

CRISP-IRD/USP Workshop

An Examination of the Effectiveness of Different Taxonomic Survey Intensities Represented by Indicator Fish Species Used in Different Methodologies in Understanding the Effects of Marine Protected Area Designation on Fish Population Abundance in a Fijian Context

22nd November to 2nd December 2006

by

James Comley[1], Ron Vave[1], Akuila Cakacaka[1], Semisi Meo[1],
Alifereti Tawake[1], Marc Léopold[2], David Lecchini[2]

[1]Institute of Applied Sciences, University of the South Pacific
[2]Institut de recherché pour le développement, New Caledonia

Executive Summary

- This report presents data from the most comprehensive assessment undertaken on differing levels of ecological survey effort employed in Fiji.

- The four methods examined in order of increasing taxonomic complexity (number of variables or species observed) were FLMMA community monitoring, Reef Check†, Akuila Cakacaka's Masters thesis method† and that used by Coral Cay Conservation in Fiji†.

- All of these methods utilise a belt transect underwater visual census methodology with differing lengths of transects though for standardisation, all were set at 20m long by 5m wide by 5m high in this investigation.

- All methods employed a target species list.

- Of these target species lists, only the FLMMA methodology observed individuals from all of its target taxa; the other methodologies observed only 67, 70 and 59% of the species included on the target species list for the 'Reef Check method', 'Akuila's method' and the 'Coral Cay method' respectively.

- All five of the FLMMA variables (species) displayed significant differences between harvested and MPA sites with all being results being significant above the 99% confidence intervals.

- Only butterfly fish populations recorded by the 'Reef Check method' displayed significant differences. All six other encountered 'Reef Check' variables did not show significant differences between MPA and harvested samples.

- Four out of the fifty-seven observed species recorded using 'Akuila's method' showed significant differences between MPA and harvested samples, with one (*Chaetodon rafflesi*) being highly significantly different (99% Confidence Interval).

- Eight out of the eighty six observed species recorded using the 'Coral Cay method' showed significant differences, with five of these variables being highly significantly different (99% Confidence Interval)

- Only the FLMMA and 'Coral Cay method' exhibited significant differences between MPA and harvested samples when a multivariate analysis was undertaken to examine differences in the entire population across all the variables surveyed.

- Reducing the taxonomic resolution of the data collected using the 'Akuila's method' to Family level increased the power of this method to detect differences between MPA and harvested area data sets using both univariate and multivariate analysis techniques.

- In terms of explain the highest percentage of the differences between MPA and harvested site fish communities, Parrotfish and Emperors were the two most important taxa observed in the FLMMA method.

- Damselfish and the Wrasse family were the two most important taxa observed in the 'Coral Cay method' for describing the dissimilarity between MPA and harvested data sets.

- This study was isolated to only one geographic area and one coral reef habitat class and examined only one measure of MPA effectiveness. Additional studies will be needed to form a more Fiji-wide understanding of techniques to assess MPA effectiveness.

- This study, however, suggests that the use of an extensive indicator species list representing a high taxonomic complexity for assessing the effectiveness of MPAs may be less effective that a shorter list that has been selected by community members at a lower taxonomic resolution. Possible reasons for this include the infrequent observation of many target species in the more complex method and the consequent problems this creates in statistical analysis.

† Note that when reference is made to individual methods, these represent the target species or indicator lists used by each method only and are not intended to be a comparison of the method itself. Changes have been made to the prescribed method in terms of transect length, survey depth and replicate positioning. Accordingly, hereinafter in this document, all method names are given in inverted commas.

Introduction

The aims of the workshop conducted by CRISP-IRD with the scientific community represented by the University of the South Pacific conducted between the 22^{nd} November and 2^{nd} of December were as follows;

- To assess what survey techniques are used in Fiji by different partners
- To discuss the effectiveness of these
- To undertake basic training in marine life identification skills
- To undertake training in fish length estimates
- To make quantitative comparisons between different survey resolutions (community- scientific methodologies) to examine differences in MPA/ non-MPA benthic and fish community structure.
- To examine data analysis techniques that can be employed on various levels of data
- To identify areas of further capacity building needed amongst partners in Fiji.

Data collection

Twenty meter long transects were conducted both inside and outside of the Marine Protected Area at Muaivoso using each of the following target species or indicator lists (in increasing order of taxonomic complexity) used by the methods currently employed in Fiji for monitoring Marine Protected Area effectiveness.

- FLMMA community monitoring
- Reef Check†
- Akuila Cakacakas' Master thesis research methodology†
- Coral Cay Conservation†

The following table represents the number of transects conducted for each methodology.

Method	MPA surveys	Harvested surveys	Total surveys
FLMMA	30	29	59
'Reef Check'	29	29	58
'Akuila's method'	30	29	59
'Coral Cay'	30	29	59

The following figure provides a Geographic Information System output of the locations of starting points of both MPA and harvested site transects.

† Note that when reference is made to individual methods, these represent the target species or indicator lists used by each method only and are not intended to be a comparison of the method itself. Changes have been made to the prescribed method in terms of transect length, survey depth and replicate positioning. Accordingly, hereinafter in this document, all method names are given in inverted commas.

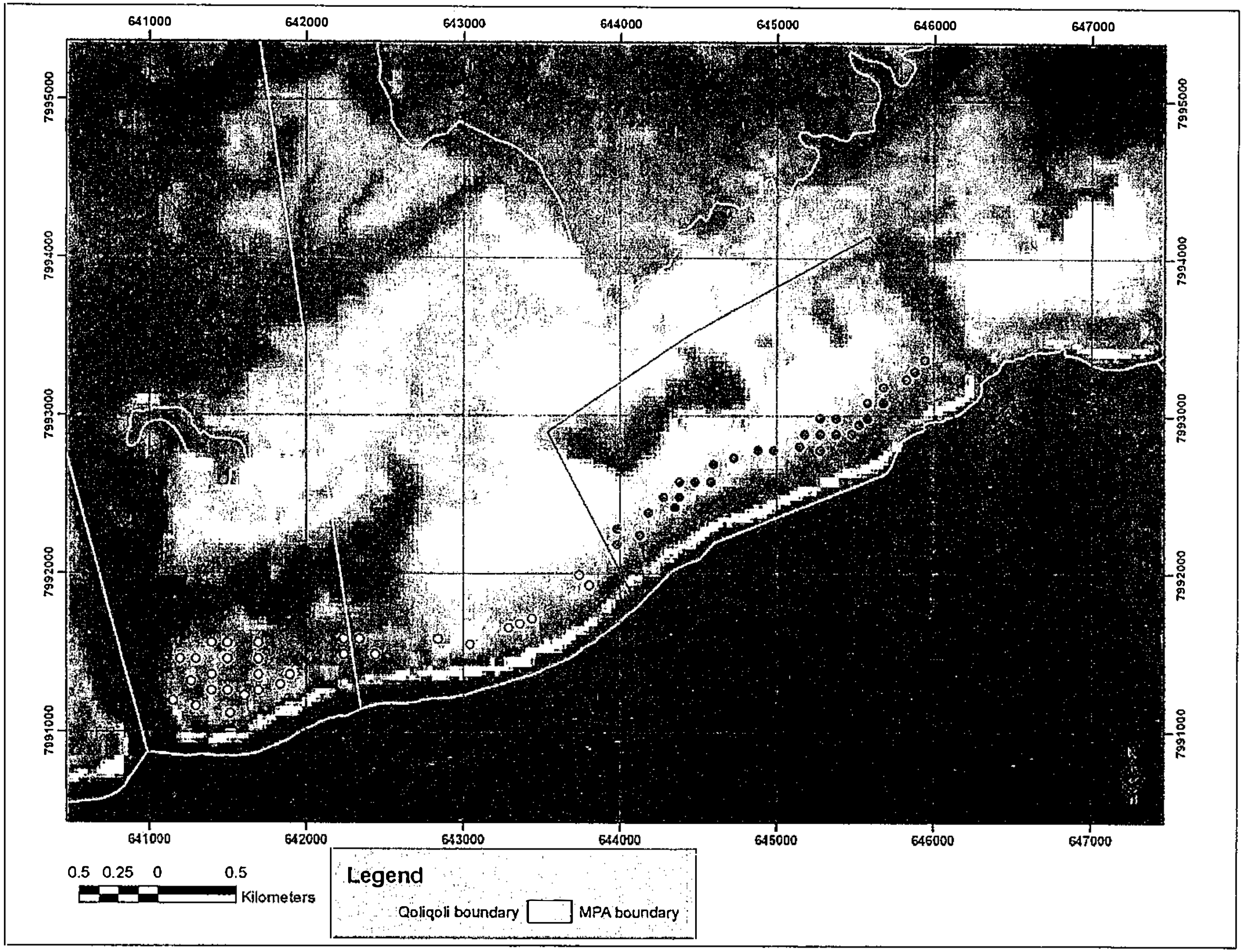

Figure 1. The location of both harvested and MPA survey sites conducted at Muaivoso

Results

Summary

Using the target species† list from each method which is appended to this report, the following number of target species from each list were encountered

Method	Number of target species on list	Number of target species encountered	% of target species list encountered
FLMMA	5	5	100
'Reef Check'	9	6	67
'Akuila's method'	82	57	70
'Coral Cay'	147	86	59

Both the number of species and sum of individuals from all species observed using each method both inside and outside the MPA is summarised below

	MPA surveys		Harvested area surveys	
Method	No species	Σ individuals	No species	Σ individuals
FLMMA	5	1331	5	463
'Reef Check'	6	216	4	95
'Akuila's method'	49	735	37	492
'Coral Cay'	74	2024	74	1204

Univariate statistics

A note: To be able to perform a powerful parametric univariate statistical test such as an ANOVA test, two assumptions about the data set must be made. Firstly the data must approximate a normal distribution where the distribution of data around the calculated mean is symmetrical. Secondly, the data must have a variance that approximates equality between populations.

Tests on both the normality of the datasets and also the homogeneity of variance showed that across all of the methods there were no variables (species) that displayed either a normal distribution or equal variance. Full results from the Anderson-Darling (Normality) and Levene's (Equal variance) tests are given in appendix II of this report.

According to these test statistics, the datasets are non-parametric and therefore whilst parametric tests such as one-way ANOVA and t-tests can be used, it is possible of encountering a type I error where the statistical test reveals there are statistical differences whereas in fact there are not differences.

Of the non-parametric tests that can be employed, the most powerful test that can be employed on non-normal data that does not have homogenous variance (as in the data collected here) is the Kruskal Wallis test.

† *The word species as used in this context is used to mean a functional taxonomic grouping that may or may not correspond to an individual species according to Linnaean taxonomic classification*

A Kruskal Wallis test has been performed on each of the species recorded by each method in this workshop. The null hypothesis under test is that there is no significant difference between the median values calculated for the fish population observed inside the Marine Protected Area when compared to that of the fish populations in the harvested or non-protected area.

The following tables show the test results statistics (H and p-values) for each comparison. In the case of the methods that have a higher number of species, the top twenty most significantly and closest to significantly different species are presented. P-values followed by a double asterisk (**) in the table shows that there is a significant difference between the MPA and harvested populations at a 99% confidence interval whilst those with a single asterisk indicate significant difference at the 95% confidence interval.

			Harvested			MPA		
Variable	H	P	Mean	SE Mean	SD Mean	Mean	SE Mean	SD Mean
Emperor (Kabatia)	16.30	0.000**	1.79	0.65	3.50	12.86	2.70	14.55
Grouper (Kawakawa)	16.12	0.000**	0.59	0.25	1.35	2.52	0.40	2.13
Goatfish (Ose)	10.07	0.002**	1.21	0.48	2.60	3.69	0.77	4.17
Parrotfish (Ulavi)	7.59	0.006**	6.69	1.04	5.57	15.55	2.32	12.52
Butterflyfish (Tivitivi)	7.20	0.007**	5.69	1.40	7.54	10.38	1.53	8.26

The results of Kruskal Wallis tests on data recorded using the FLMMA methodology

			Harvested			MPA		
Variable	H	P	Mean	SE Mean	SD Mean	Mean	SE Mean	SD Mean
Butterflyfish (Chaetodontidae)	5.48	0.019*	2.70	0.40	2.05	5.52	0.82	4.28
Other parrotfish (Scaridae) only >20 cm	2.25	0.134	0.07	0.05	0.27	0.04	0.04	0.19
Sweetlips (Haemulidae)	1.00	0.317	0.07	0.07	0.38	0.11	0.06	0.32
Snapper (Lutjanidae)	0.87	0.350	0.67	0.24	1.27	1.48	0.45	2.33
Grouper (Serranidae) only >30 cm	0.35	0.556	0.00	0.00	0.00	0.22	0.11	0.58
Moray eel (Muraenidae)	0.19	0.659	0.00	0.00	0.00	0.04	0.04	0.19

The results of Kruskal Wallis tests on data recorded using the 'Reef Check methodology'

			Harvested			MPA		
Variable	H	P	Mean	SE Mean	SD Mean	Mean	SE Mean	SD Mean
Chaetodon rafflesi	6.57	0.010**	0.00	0.00	0.00	0.07	0.07	0.38
Acanthurus triostegus	5.93	0.015*	0.00	0.00	0.00	0.04	0.04	0.19
Epinephelus merra	5.62	0.018*	0.00	0.00	0.00	0.18	0.10	0.55
Chaetodon vagabundus	4.08	0.043*	0.04	0.04	0.19	0.00	0.00	0.00
Scarus chamelon	3.51	0.061	0.32	0.22	1.19	0.29	0.14	0.76
Epinephelus hexagonatus	3.11	0.078	0.00	0.00	0.00	0.21	0.16	0.83
Lethrinus atkinsoni	3.11	0.078	0.39	0.19	0.99	1.00	0.26	1.39
Lutjanus fulvus	3.11	0.078	0.00	0.00	0.00	0.29	0.18	0.94
Leptoscarus vaganiensis	2.18	0.140	0.18	0.10	0.55	0.21	0.12	0.63
Balistapus undulatus	2.04	0.154	1.50	0.43	2.29	3.07	0.59	3.11
Centropyge flavissimus	2.04	0.154	0.75	0.22	1.17	1.50	0.29	1.55
Chaetodon flavissimus	2.04	0.154	2.79	0.42	2.20	2.57	0.30	1.57
Pomacanthus imperator	2.04	0.154	0.11	0.08	0.42	0.25	0.12	0.65
Parupeneus indicus	1.98	0.159	0.00	0.00	0.00	0.07	0.05	0.26
Parupeneus barberinus	1.37	0.242	0.21	0.09	0.50	0.29	0.12	0.66
Lethrinus harak	1.06	0.303	0.00	0.00	0.00	0.25	0.16	0.84
Rhinecathus aculeatus	1.04	0.307	0.00	0.00	0.00	0.04	0.04	0.19
Acanthurus maculiceps	1.00	0.317	0.11	0.08	0.42	0.04	0.04	0.19
Acanthurus nigricaudus	1.00	0.317	0.11	0.11	0.57	0.00	0.00	0.00
Acanthurus scopas	1.00	0.317	0.07	0.07	0.38	0.00	0.00	0.00

The results of Kruskal Wallis tests on data recorded using 'Akuila's methodology'

			Harvested			MPA		
Variable	H	P	Mean	SE Mean	SD Mean	Mean	SE Mean	SD Mean
Honeycomb Grouper sp.	10.39	0.001**	0.14	0.07	0.35	0.86	0.20	1.09
Humbug dascyllus	10.37	0.001**	0.00	0.00	0.00	5.07	2.39	12.86
Emperor	9.96	0.002**	0.24	0.11	0.58	1.66	0.45	2.44
Butterflyfish	13.65	0.001**	1.55	0.39	2.08	4.93	0.94	5.04
Convict Surgeonfish	7.04	0.008**	0.83	0.25	1.36	2.00	0.36	1.93
Vagabond Butterflyfish	6.13	0.013*	0.41	0.16	0.87	1.14	0.23	1.25
Multibarred Goatfish	5.38	0.02*	0.00	0.00	0.00	0.17	0.07	0.38
Goatfish	3.86	0.047*	0.21	0.09	0.49	0.48	0.12	0.63
Threespot dascyllus	3.8	0.051	0.62	0.37	1.99	1.28	0.41	2.19
Damselfish	3.25	0.071	11.55	3.47	18.70	20.62	4.77	25.67
Brownbarred Goby	3.11	0.078	0.10	0.06	0.31	0.00	0.00	0.00
Blue-Green Chromis	3.01	0.083	0.62	0.29	1.57	0.07	0.07	0.37
Grouper	2.92	0.087	0.03	0.03	0.19	0.17	0.07	0.38
Blue-devil Damselfish	2.88	0.09	4.17	2.24	12.04	6.41	1.76	9.45
Redfin Butterflyfish	2.86	0.091	0.07	0.07	0.37	0.31	0.14	0.76
Halfmoon Triggerfish	2.67	0.102	0.17	0.07	0.38	0.10	0.10	0.56
Ringtail Surgeonfish	2.67	0.102	0.17	0.17	0.93	0.38	0.17	0.90
Half-and-half Goatfish	2.12	0.146	0.10	0.08	0.41	0.24	0.09	0.51
Dusky Damselfish	2.04	0.154	0.07	0.05	0.26	0.00	0.00	0.00
Porcupine	2.04	0.154	0.00	0.00	0.00	0.07	0.05	0.26

The results of Kruskal Wallis tests on data recorded using the 'Coral Cay methodology'

In order to assess if reducing the taxonomic resolution on one of the more complicated methodologies would result in a return to increased differences between MPA and harvested sites, the data collected using Akuila's method was modified. Each of the target species recorded were converted to Family level differentiation.

The following table represents the result of a Kruskal-Wallis test conducted to examining potential significant differences between the abundances of fish Families in MPA and harvested data sets.

Variable	H	P	Mean Harvested	SE Mean Harvested	SD Mean Harvested	Mean MPA	SE Mean MPA	SD Mean MPA
Serranidae	7.30	0.007**	0.39	0.19	0.99	1.21	0.27	1.45
Scaridae	4.67	0.031*	1.36	0.67	3.56	3.04	1.18	6.27
Chaetodontidae	5.35	0.037*	3.93	0.53	2.80	5.64	0.67	3.53
Mullidae	1.07	0.048*	0.86	0.32	1.72	0.64	0.19	1.03
Pomacanthidae	3.11	0.078	0.00	0.00	0.00	0.29	0.18	0.94
Acanthuridae	2.65	0.104	2.96	0.80	4.21	5.00	1.23	6.49
Lethrinidae	2.02	0.156	1.54	0.65	3.43	2.68	0.84	4.42
Haemulidae	1.00	0.317	0.00	0.00	0.00	0.04	0.04	0.19
Lutjanidae	0.70	0.404	0.18	0.10	0.55	0.46	0.22	1.17
Balistidae	0.56	0.453	0.82	0.24	1.25	0.54	0.20	1.07
Nemipteridae	0.13	0.721	0.46	0.31	1.67	0.43	0.21	1.10
Siganidae	0.02	0.877	3.36	1.10	5.84	1.89	0.50	2.64
Labridae	0.01	0.914	2.93	0.58	3.09	3.71	0.75	3.98

The results of Kruskal Wallis tests on data recorded using 'Akuila's methodology' and then subsequently degraded to Family level.

The following table summarises the univariate analysis performed on the data. The relative power of each method is demonstrated by the percentage of target variables that were found to be both 99% and 95% statistically different between MPA and harvested data sets.

Method	No. of species on target species list	% target species list encountered	% target species list highly significant (99% CI)	% target species list significant (95% CI)
FLMMA	5	100	100	100
'Reef Check'	9	67	0	11
'Akuila's method'	82	70	1	5
'Coral Cay'	147	59	3	5
'Akuila's Family-level'	N/a	N/a	7	31

Multivariate statistics

In addition to the univariate Kruskal Wallis test that were performed, multivariate analyses of similarity tests (ANOSIM) were also performed. These tests conducted in the Plymouth Routines in Multivariate Ecological Research (PRIMER) package take data pooled from all of the variables (species) from transects inside the MPA and compare them against the data from the harvested (non-MPA) area.

This form of multivariate test is distribution-independent and does not make assumptions of the data being normally distributed or having homogenous variance.

The following table shows the Global R test values and their associated probabilities. P-values followed by a double asterisk (**) in the table shows that there is a significant difference between the MPA and harvested populations at a 99% confidence interval whilst those with a single asterisk indicate significant difference at the 95% confidence interval. In addition, the simplified version of 'Akuila's method' with target species reduced to target Families was also analysed.

Method	Global R	P-value
FLMMA	0.176	0.001**
'Reef Check'	0.044	0.107
'Akuila's method'	0.032	0.086
'Coral Cay'	0.051	0.024*
'Akuila's Family-level'	0.073	0.039*

Using the multivariate package used to undertake the ANOSIM analysis, it is also possible to examine which variables (species) contribute the most to the differences (and similarities) between the data sets collected from the MPA and harvested samples.

In the following table, the top eight species that contribute most to the differences between MPA and harvested datasets are outlined together with their mean abundances, average dissimilarities, the dissimilarity divided by the Standard Deviations around the mean values and most importantly the contribution each variable makes towards the overall differences between MPA and harvested data sets.

Whilst a table is presented for each methodology, it should be stressed that as there is only a proven statistical difference between the FLMMA, 'Coral Cay' and 'Akuila's' Family level data sets, the results for the other data sets are intended to be exploratory only.

Method	Species	Mean (Harvested)	Mean (MPA)	Mean dissimilarity	Dissimilarity/ SD	Contribution to inter-group dissimilarity (%)
FLMMA	Parrotfish (Ulavi)	6.7	15.6	21.4	1.3	32.4
	Emperor (Kabatia)	1.8	12.9	18.4	1.1	27.9
	Butterflyfish (Tivitivi)	5.7	10.4	16.2	1.2	24.5
	Goatfish (Ose)	1.2	3.7	5.7	1.1	8.5
'Reef Check'	Butterflyfish	3.7	5.7	30.1	1.7	62.2
	Other parrotfish	0.9	1.5	13.2	1.0	27.3
	Moray Eel	0.1	0.1	2.1	0.3	4.4
'Coral Cay'	Damselfish	11.6	20.6	18.1	1.3	22.2
	Wrasse	4.9	6.7	7.1	1.1	8.8
	Blue devil	4.2	6.4	6.5	0.8	8.0
	Humbug dascyllus	0.0	5.1	4.2	0.5	5.2
	Parrot Fish	1.8	3.9	2.9	0.6	3.6
	Convict	0.8	2.0	2.7	0.8	3.3
	Butterflyfish	0.7	2.6	2.3	0.9	2.9
	Emperor	0.2	1.7	2.3	0.6	2.8
'Akuila's method'	*Chlorurus sordidus*	2.6	3.0	8.9	1.0	11.8
	Siganus spinus	3.1	1.8	8.4	0.7	11.1
	Acanthurus triostegus	1.5	3.1	7.6	1.2	10.0
	Leptoscarus vaganiensis	1.2	1.7	6.0	0.6	8.0
	Chaetodon citrinellus	2.8	2.6	5.8	0.9	7.7
	Lethrinus harak	0.5	1.6	4.0	0.6	5.3
	Chaetodon vagabundus	0.8	1.5	3.9	0.9	5.2
	Ctenochaetus striatus	0.9	1.3	3.5	0.6	4.6
'Akuila's Family level'	Acanthuridae	3.0	5.0	10.7	1.2	16.1
	Chaetodontidae	3.9	5.6	10.5	1.1	15.9
	Labridae	2.9	3.7	9.8	1.1	14.8
	Siganidae	3.4	1.9	8.7	0.8	13.2
	Scaridae	1.4	3.0	8.4	0.7	12.7
	Lethrinidae	1.5	2.7	6.8	0.8	10.3
	Serranidae	0.4	1.2	3.3	0.9	5.0
	Balistidae	0.8	0.5	2.5	0.8	3.8

Discussion

Of the methods and given the time investment needed to train observers on the survey techniques, the one that appears to have maximum return is the FLMMA method as this method is the only method in which all of the target taxa on the target list were observed in this investigation.

All of the methods show differences between both the species number and the total abundance of individuals across all species between MPA and harvested survey sites.

As is common with many ecological datasets, the data collected in this assessment were found not to possess a normal distribution. The datasets for each variable (species) examined across all the methodologies had a 'skewed distribution' with zero counts being by far the most commonly occurring.

Accordingly, the datasets were non-parametric and a Kruskal-Wallis formal test was conducted on each variable (species) from each method in turn to examine the magnitude and any significance of differences between observed populations inside and outside the Marine Protected Area.

The most successful method in terms of identifying significant differences between MPA and harvested survey sites was the FLMMA method. All five of the variables monitored in this method showed highly significant differences (99% C.I.).

The second most successful was the 'Coral Cay method' where eight of the monitored variables exhibited significant differences. Interestingly, the majority of these variables were not at the individual species level but instead were at either a higher taxonomic level or were at the Family level.

From the multivariate tests undertaken comparing the entire population across all variables between MPA and harvested data sets, only the FLMMA and 'Coral Cay method' showed significant differences.

To assess the viability of undertaking 'complex' surveys and then post-hoc reducing the complexity of the data analysed, data collected at species level using 'Akuila's method' which was then reduced to Family-level data was analysed. This analysis showed that by reducing the taxonomic resolution greatly increased the power of the methodology to detect differences in MPA and harvested population data using both uni and multivariate statistical methods.

There are a number of factors that may have contributed to the success in the FLMMA methodology demonstrating the effects of the establishment of the MPA in the Muaivoso site at which the surveys in this workshop were undertaken.

Firstly, when compared to all of the other methodologies, each of the target species in the FLMMA methodology were observed consistently. By contrast, many of the target species in the other methodologies were observed on the surveys infrequently. Accordingly, the standard deviations of the datasets for each of these variables were large and the consequent power of the statistical tests undertaken was greatly reduced.

Secondly, when undertaking the multivariate tests, all of the populations in both MPA and harvested samples except those observed using the FLMMA method comprised of many variables that each had only one or two individuals. This would have an effect of reducing the intra-group similarity thereby making it more difficult for the multivariate testing method to determine statistical differences in the inter-group dissimilarities.

Finally, the FLMMA method employed target species that were chosen by the local community who instigated the MPA. In turn, the community choose indicators to be species that were frequently harvested. This would have the effect of exacerbating the effect of the establishment of the MPA on the fish populations present.

This study was undertaken on the MPA and harvested area of the qoliqoli around Muaivoso. An attempt was made to minimise the impact of variables other than the MPA/harvest site variable. One of the greatest variables that was controlled for was the impact of different benthic habitat types. The survey sites in both the MPA and the harvested area were chosen to represent a lagoonal habitat with sand and patchy hard substrate.

Therefore, when concluding from the results of this study, it is important to realise that they are taken only from one habitat type in one locality in Fiji and it may be that in more diverse areas (such as on the reef slope) some of the more complex methodologies would be more appropriate.

Conclusions

- The data collected in this workshop and then its subsequent analysis have revealed that the most effective methodology for assessing the difference in fish population abundance between MPA and harvested areas is the FLMMA method.

- Indeed, the study has shown that some of the more complicated methodologies that include a greater number of target fish at a finer taxonomic level reduces the power of the datasets to be able to show significant differences between MPA and harvested fish populations

- This study is based on one site only- the qoliqoli affront of Muaivoso. It is also based on only one habitat type- the habitat lagoonal habitat immediately behind the flat reef crest platform. Therefore the results of this study should be taken as being site and habitat specific. As discussed, the findings of this study may not be as relevant in other geographic areas in Fiji and in different reef habitats.

- Finally, this investigation has examined the impact of the establishment of an MPA on the abundance of the fish populations. This is only one possible component of the measure of success of an MPA. Factors such as fish population diversity and biomass were not examined in this investigation and in order to examine these success indicators, different methodologies would be required and would in turn have their own levels of successfulness and efficiency in detecting effects.

Plans for future work

Following a debriefing and discussion session held at the University of the South Pacific on the 8th of January 2007, it was decided that a number of options for follow-up work would be discussed.

These plans include the following;

- To include an estimate of biomass in some of the methods trialled in this investigation. As discussed in this document, the surveys conducted thus far examine only one component of MPA effectiveness; the overall abundance of fish populations. In order to combine biomass estimates into a further survey programme would necessitate a training and validation session on fish-length estimates being conducted for the partners involved in the study.

- To examine this range of methodologies over different coral reef habitat types. As discussed, the results of this study are applicable to one specific habitat type. If this were to be undertaken, it would be essential to examine the habitat distribution in the proposed study area to ensure that habitat types both inside and outside the MPA be directly comparable allowing any difference in fish populations to be attributed to the presence of an MPA.

- To integrate the findings of this study with the work currently being undertaken by post-graduate students enrolled at USP

- To replicate the aims of this survey at sites along the Coral Coast.

Appendix- target indicator species lists

FLMMA method

Family	Genus	Species	Variable
Lethrinidae	*Lethrinus*	*ALL SPECIES*	Emperor (Kabatia)
Serranidae	*Epinephelus*	*ALL SPECIES*	Grouper (Kawakawa)
Mullidae	*Parupeneus*	*indicus*	Goatfish (Ose)
Scaridae	*Scarus*	*ALL SPECIES*	Parrotfish (Ulavi)
	Chlorurus	*sordidus*	
Chaetodontidae	*ALL GENERA*	*ALL SPECIES*	Butterflyfish (Tivitivi)

'Reef Check' method

Family	Genus	Species	Variable
Chaetodontidae	*ALL GENERA*	*ALL SPECIES*	Butterflyfish
Scaridae	*ALL GENERA*	*ALL SPECIES*	Other parrotfish only >20 cm
Haemulidae	*ALL GENERA*	*ALL SPECIES*	Sweetlips
Lutjanidae	*ALL GENERA*	*ALL SPECIES*	Snapper
Serranidae	*ALL GENERA*	*ALL SPECIES*	Grouper only >30 cm
Muraenidae	*ALL GENERA*	*ALL SPECIES*	Moray eel

'Akuila's method

Family	Genus	Species	Variable
Acanthuridae	*Acanthurus*	*auranticavus*	Acanthurus auranticavus
Acanthuridae	*Acanthurus*	*fowleri*	Acanthurus fowleri
Acanthuridae	*Acanthurus*	*grammoptilus*	Acanthurus grammoptilus
Acanthuridae	*Acanthurus*	*lineatus*	Acanthurus lineatus
Acanthuridae	*Acanthurus*	*maculiceps*	Acanthurus maculiceps
Acanthuridae	*Acanthurus*	*nigricaudus*	Acanthurus nigricaudus
Acanthuridae	*Acanthurus*	*olivaceus*	Acanthurus olivaceus
Acanthuridae	*Acanthurus*	*triostegus*	Acanthurus triostegus
Serranidae	*Cephalopholis*	*argus*	Cephalopholis argus
Chaetodontidae	*Chaetodon*	*auriga*	Chaetodon auriga
Chaetodontidae	*Chaetodon*	*auriga*	Chaetodon auriga
Chaetodontidae	*Chaetodon*	*citrinellus*	Chaetodon citrinellus
Chaetodontidae	*Chaetodon*	*ephippium*	Chaetodon ephippium
Chaetodontidae	*Chaetodon*	*kleinii*	Chaetodon kleinii
Chaetodontidae	*Chaetodon*	*lunula*	Chaetodon lunula
Chaetodontidae	*Chaetodon*	*lunulatus*	Chaetodon lunulatus
Chaetodontidae	*Chaetodon*	*pelewensis*	Chaetodon pelewensis
Chaetodontidae	*Chaetodon*	*plebius*	Chaetodon plebius
Chaetodontidae	*Chaetodon*	*rafflesi*	Chaetodon rafflesi
Chaetodontidae	*Chaetodon*	*reticulatus*	Chaetodon reticulatus
Chaetodontidae	*Chaetodon*	*trifaciatus*	Chaetodon trifaciatus

'Akuila's method (continued)

Family	Genus	Species	Variable
Chaetodontidae	*Chaetodon*	*vagabundus*	Chaetodon vagabundus
Labridae	*Cheilinus*	*trilobatus*	Cheilinus trilobatus
Labridae	*Chelinus*	*chlorourus*	Chelinus chlorourus
Scaridae	*Chlorurus*	*sordidus*	Chlorurus sordidus
Acanthuridae	*Ctenochaetus*	*marginatus*	Ctenochaetus marginatus
Acanthuridae	*Ctenochaetus*	*striatus*	Ctenochaetus striatus
Dasyatidae	*Dasyatis*	*kuhlii*	Dasyatis kuhlii
Diodontidae	*Diodon*	*holocanthus*	Diodon holocanthus
Muraenidae	*Echidna*	*delicatula*	Echidna delicatula
Serranidae	*Epinephelus*	*areolatus*	Epinephelus areolatus
Serranidae	*Epinephelus*	*hexagonatus*	Epinephelus hexagonatus
Serranidae	*Epinephelus*	*merra*	Epinephelus merra
Serranidae	*Epinephelus*	*taunvina*	Epinephelus taunvina
Lethrinidae	*Gymnocranius*	*euanus*	Gymnocranius euanus
Muraenidae	*Gymnothorax*	*sp*	Gymnothorax sp
Muraenidae	*Gymnothorax*	*undulatus*	Gymnothorax undulatus
Chaetodontidae	*Heniochus*	*acuminatus*	Heniochus acuminatus
Chaetodontidae	*Heniochus*	*diphreutes*	Heniochus diphreutes
Hemiramphidae	*Hyporhamphus*	*dussumieri*	Hyporhamphus dussumieri
Lethrinidae	*Lethrinus*	*atkinsoni*	Lethrinus atkinsoni
Lethrinidae	*Lethrinus*	*harak*	Lethrinus harak
Lethrinidae	*Lethrinus*	*lentjan*	Lethrinus lentjan
Lethrinidae	*Lethrinus*	*microdon*	Lethrinus microdon
Lethrinidae	*Lethrinus*	*nebulosus*	Lethrinus nebulosus
Lethrinidae	*Lethrinus*	*obsoletus*	Lethrinus obsoletus
Lethrinidae	*Lethrinus*	*rubrioperculatus*	Lethrinus rubrioperculatus
Lutjanidae	*Lutjanus*	*bohar*	Lutjanus bohar
Lutjanidae	*Lutjanus*	*ehrenbergii*	Lutjanus ehrenbergii
Lutjanidae	*Lutjanus*	*fulvus*	Lutjanus fulvus
Lutjanidae	*Lutjanus*	*kasmira*	Lutjanus kasmira
Family	*Genus*	*Species*	Variable
Lutjanidae	*Lutjanus*	*semicinctus*	Lutjanus semicinctus
Mullidae	*Mulloidichthys*	*flavlineatus*	Mulloidichthys flavlineatus
Acanthuridae	*Naso*	*unicornis*	Naso unicornis
Labridae	*Novaculichthys*	*taeniourus*	Novaculichthys taeniourus
Mullidae	*Parupeneus*	*barberinoides*	Parupeneus barberinoides
Mullidae	*Parupeneus*	*barberinus*	Parupeneus barberinus
Mullidae	*Parupeneus*	*indicus*	Parupeneus indicus
Mullidae	*Parupeneus*	*multifasciatus*	Parupeneus multifasciatus
Haemulidae	*Plectorhinchus*	*picus*	Plectorhinchus picus
Haemulidae	*Plectorhinchus*	*vitatus*	Plectorhinchus vitatus
Serranidae	*Plectropomus*	*pessuliferus*	Plectropomus pessuliferus
Pomacanthidae	*Pomacanthus*	*imperator*	Pomacanthus imperator
Pomacanthidae	*Pomacanthus*	*semicirculatus*	Pomacanthus semicirculatus
Balistidae	*Rhinecanthus*	*rectangulus*	Rhinecanthus rectangulus
Balistidae	*Rhinecathus*	*aculeatus*	Rhinecathus aculeatus
Scaridae	*Scarus*	*chamelon*	Scarus chamelon

'Akuila's method (continued)

Family	Genus	Species	Variable
Scaridae	*Scarus*	*dimidiatus*	Scarus dimidiatus
Scaridae	*Scarus*	*ghobban*	Scarus ghobban
Scaridae	*Scarus*	*globiceps*	Scarus globiceps
Nemipteridae	*Scolopsis*	*bilineatus*	Scolopsis bilineatus
Nemipteridae	*Scolopsis*	*temporalis*	Scolopsis temporalis
Nemipteridae	*Scolopsis*	*trilineatus*	Scolopsis trilineatus
Siganidae	*Siganus*	*doliatus*	Siganus doliatus
Siganidae	*Siganus*	*javus*	Siganus javus
Siganidae	*Siganus*	*punctatus*	Siganus punctatus
Siganidae	*Siganus*	*randalli*	Siganus randalli
Siganidae	*Siganus*	*spinus*	Siganus spinus
Siganidae	*Siganus*	*vermiculatus*	Siganus vermiculatus
Balistidae	*Sufflamen*	*chrysopterus*	Sufflamen chrysopterus
Synancejidae	*Synanceia*	*verrucosa*	Synanceia verrucosa
Acanthuridae	*Zebrasoma*	*scopas*	Zebrasoma scopas

'Coral Cay' method

Family	Genus	Species	Variable
Acanthuridae	*Acanthurus*	*triostegus*	Convict Surgeonfish
Acanthuridae	*Acanthurus*	*blochii*	Ringtail Surgeonfish
Acanthuridae	*ALL GENERA*	*ALL SPECIES*	Surgeonfish
Acanthuridae	*Ctenochaetus*	*ALL SPECIES*	Bristletooth Surgeonfish
Aulostomidae	*ALL GENERA*	*ALL SPECIES*	Trumpetfish
Balistidae	*ALL GENERA*	*ALL SPECIES*	Triggerfish
Balistidae	*Balistapus*	*undulatus*	Orangestriped Triggerfish
Balistidae	*Balistoides*	*conspicillum*	Clown Triggerfish
Balistidae	*Rhinecanthus*	*lunula*	Halfmoon Triggerfish
Balistidae	*Rhinecanthus*	*aculeatus*	Picasso Triggerfish
Balistidae	*Rhinecanthus*	*verrucosus*	Blackbelly Picassofish
Balistidae	*Sufflamen*	*bursa*	Scythe Triggerfish
Blennidae	*ALL GENERA*	*ALL SPECIES*	Blenny
Chaetodontidae	*ALL GENERA*	*ALL SPECIES*	Butterflyfish
Chaetodontidae	*Chaetodon*	*vagabundus*	Vagabond Butterflyfish
Chaetodontidae	*Chaetodon*	*trifasciatus*	Redfin Butterflyfish
Chaetodontidae	*Chaetodon*	*auriga*	Threadfin Butterflyfish
Chaetodontidae	*Chaetodon*	*baronessa*	Eastern Triangle Butterflyfish
Chaetodontidae	*Chaetodon*	*trifascialis*	Chevroned Butterflyfish
Chaetodontidae	*Chaetodon*	*kleinii*	Kleins Butterflyfish
Chaetodontidae	*Chaetodon*	*rafflesii*	Latticed Butterflyfish
Chaetodontidae	*Chaetodon*	*ephippium*	Saddled Butterflyfish
Cirrhitidae	*ALL GENERA*	*ALL SPECIES*	Hawkfish
Diodontidae	*Diodon*	*hystrix*	Porcupine Pufferfish
Ephippidae	*ALL GENERA*	*ALL SPECIES*	Spadefish / Batfish
Gobiidae	*Amblygobius*	*phalaena*	Brownbarred Goby
Gobiidae	*Amblygobius*	*sphynx*	Sphynx Goby
Gobiidae	*ALL GENERA*	*ALL SPECIES*	Gobies
Holocentridae	*ALL GENERA*	*ALL SPECIES*	Squirrelfish / Soldierfish

'Coral Cay' method (continued)

Family	Genus	Species	Variable
Labridae	*Cheilinus*	*fasciatus*	Red-banded Wrasse
Labridae	*ALL GENERA*	*ALL SPECIES*	Wrasse
Labridae	*Cheilio*	*inermis*	Cigar Wrasse
Labridae	*Epibulus*	*insidiator*	Sling-jaw Wrasse
Labridae	*Gomphosus*	*varius*	Bird Wrasse
Labridae	*Halichoeres*	*hortulanus*	Checkerboard Wrasse
Labridae	*Halichoeres*	*prosopeion*	Twotone Wrasse
Labridae	*Hemigymnus*	*melapterus*	Blackedged Thicklip Wrasse
Labridae	*Labroides*	*dimidiatus*	Cleaner Wrasse
Labridae	*Novaculichthys*	*taeniourus*	Rockmover Wrasse
Labridae	*Thalassoma*	*hardwicke*	Sixbar Wrasse
Labridae	*Thalassoma*	*jansenii*	Jansens Wrasse
Labridae	*Thalassoma*	*lunare*	Crescent Wrasse
Lethrinidae	*Lethrinus*	*ALL SPECIES*	Emperors
Lutjanidae	*Lutjanus*	*gibbus*	Paddletail Snapper
Monacanthidae	*ALL GENERA*	*ALL SPECIES*	Filefish
Mullidae	*ALL GENERA*	*ALL SPECIES*	Goatfish
Mullidae	*Parupeneus*	*multifasciatus*	Multibarred Goatfish
Mullidae	*Parupeneus*	*barberinoides*	Half-and-half Goatfish
Family	*Genus*	*Species*	Variable
Mullidae	*Parupeneus*	*trifasciatus*	Two-barred Goatfish
Mullidae	*Parupeneus*	*barberinus*	Dash-and-dot Goatfish
Muraenidae	*ALL GENERA*	*ALL SPECIES*	Moray Eel
Nemipteridae	*Scolopsis*	*ALL SPECIES*	Spinecheek
Nemipteridae	*Scolopsis*	*bilineata*	Twoline Spinecheek
Ostraciidae	*ALL GENERA*	*ALL SPECIES*	Trunk / Box / Cowfish
Pinguipedidae	*ALL GENERA*	*ALL SPECIES*	Sandperch
Pomacanthidae	*Centropyge*	*bispinosa*	Dusky Angelfish
Pomacanthidae	*Centropyge*	*bicolor*	Bicolour Angelfish
Pomacanthidae	*Centropyge*	*flavissima*	Lemonpeel Angelfish
Pomacanthidae	*Pomacanthus*	*semicirculatus*	Semicircle Angelfish
Pomacanthidae	*ALL GENERA*	*ALL SPECIES*	Angelfish
Pomacentridae	*Abudefduf*	*ALL SPECIES*	Sergeant sp.
Pomacentridae	*Amblyglyphidodon*	*aureus*	Golden Angelfish
Pomacentridae	*Chromis*	*viridis*	Blue-Green Chromis
Pomacentridae	*Chromis*	*ALL SPECIES*	Other Chromis species
Pomacentridae	*Chromis*	*retrofasciata*	Black Bar Chromis
Pomacentridae	*Chrysiptera*	*cyanea*	Blue Devil Chromis
Pomacentridae	*Dascyllus*	*aruanus*	Humbug dascyllus
Pomacentridae	*Dascyllus*	*trimaculatus*	Threespot dascyllus
Pomacentridae	*Dascyllus*	*flavicaudus*	Black Damselfish
Pomacentridae	*Dascyllus*	*reticulatus*	Reticulated dascyllus
Pomacentridae	*Amphiprioninae*	*ALL SPECIES*	Anemone fish
Pomacentridae	*ALL GENERA*	*ALL SPECIES*	Damselfish
Scaridae	*ALL GENERA*	*ALL SPECIES*	Parrot Fish
Scaridae	*Cetoscarus*	*bicolor*	Bicolour Parrotfish
Serranidae	*Epinephelus*	*merra*	Honeycomb Grouper
Serranidae	*ALL GENERA*	*ALL SPECIES*	Groupers

'Coral Cay' method (continued)

Family	Genus	Species	Variable
Serranidae	*Plectropomus*	*laevis*	Saddleback/ Chinese coral Snapper
Siganidae	*Siganus*	*doliatus*	Pencil-streaked Rabbtfish
Siganidae	*ALL GENERA*	*ALL SPECIES*	Rabbitfish
Syngnathidae	*ALL GENERA*	*ALL SPECIES*	Pipefish
Synodontidae	*ALL GENERA*	*ALL SPECIES*	Lizardfish
Tetraodontidae	*Canthigaster*	*ALL SPECIES*	Toby
Tetraodontidae	*Canthigaster*	*solandri*	Spotted Pufferfish
Tetraodontidae	*ALL GENERA*	*ALL SPECIES*	Puffer
Zanclidae	*Zanclus*	*cornutus*	Moorish Idol