

Final Report
Overseas Development Administration
Fisheries Management Science Programme

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Multispecies responses of reef-fisheries to exploitation in the Indo-Pacific

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Contents

1. Objectives of the project	2
2. Work carried out in the period	2
3. Results	7
4. Implications of the results	51
5. Priority tasks for follow-up	59
6. Summary of financial expenditure	60

1. Objectives of the project

The objectives of the project were a. to appraise existing approaches to reef-fisheries stock assessment, b. to designate two suites of ecologically similar sites in different regions of the Pacific along which fishing intensity varies from very low to high levels, c. to use these gradients to characterise changes in species composition and actual catch at different fishing intensities, d. to test the hypothesis that fishing selects for species which are fast growing and maintain high recruitment at low stock sizes and e. to review the biological basis of surplus production models applied to multispecies fisheries on reefs and make specific recommendations about the areas investigated. One modification was made to the stated objectives and agreed with MRAG: one series of sites in the Pacific (Fiji) and one in the Indian Ocean (Seychelles) were studied rather than two series' of sites in the Pacific.

2. Work carried out in the period

Daniel Morton began work on the project in Newcastle from April to mid-June 1992. Simon Jennings joined the project on 1 June 1992 and departed for Fiji on 18 July. Nicholas Polunin made a preliminary visit to Fiji in early July and established institutional links with the Marine Studies Programme at the University of the South Pacific. Nicholas Polunin returned to Fiji in August 1992 and conducted the majority of the first phase visual census work with Simon Jennings. Following the departure of Nicholas Polunin in October 1992, Simon Jennings remained in Fiji to complete the visual census work and conduct a logbook assessment of the Fijian fisheries (location of sites in Figures 1-3). Simon Jennings returned to the United Kingdom in April 1993 and worked with Nicholas Polunin to analyse the visual census and fishery data.

Tony Beeching departed for Fiji in May 1993 to conduct a parallel study on the Suva reef fishery. He returned to the United Kingdom in July, writing-up some of his results as an MSc thesis and passing relevant data to Nicholas Polunin and Simon Jennings in order that they could complete their assessment of fishing effort and catch rates in the Suva fishery. Nicholas Polunin and Simon Jennings spent the remainder of 1993 preparing the results of the 1992-93 field work for publication.

Simon Jennings established working links with the Seychelles Fishing Authority in early 1994. He returned to the Pacific from January to March 1994, to conduct a second visual census study of target reef fishes in Fiji and to present the results of the project at the Regional Technical Fisheries Meeting in New Caledonia. From April to July 1994, Jennings worked in Seychelles (Figure 4) to determine whether the hypotheses formulated in Fiji could reasonably be applied to ecologically similar sites in Seychelles.

Andrew Cooke visited Fiji from May to July 1994 in order to collect information on local management of fishing grounds subject to high fishing pressure. From July 1994 until the end of the project, Nicholas Polunin and Simon Jennings collaborated to complete data analyses and draft book chapters and papers.

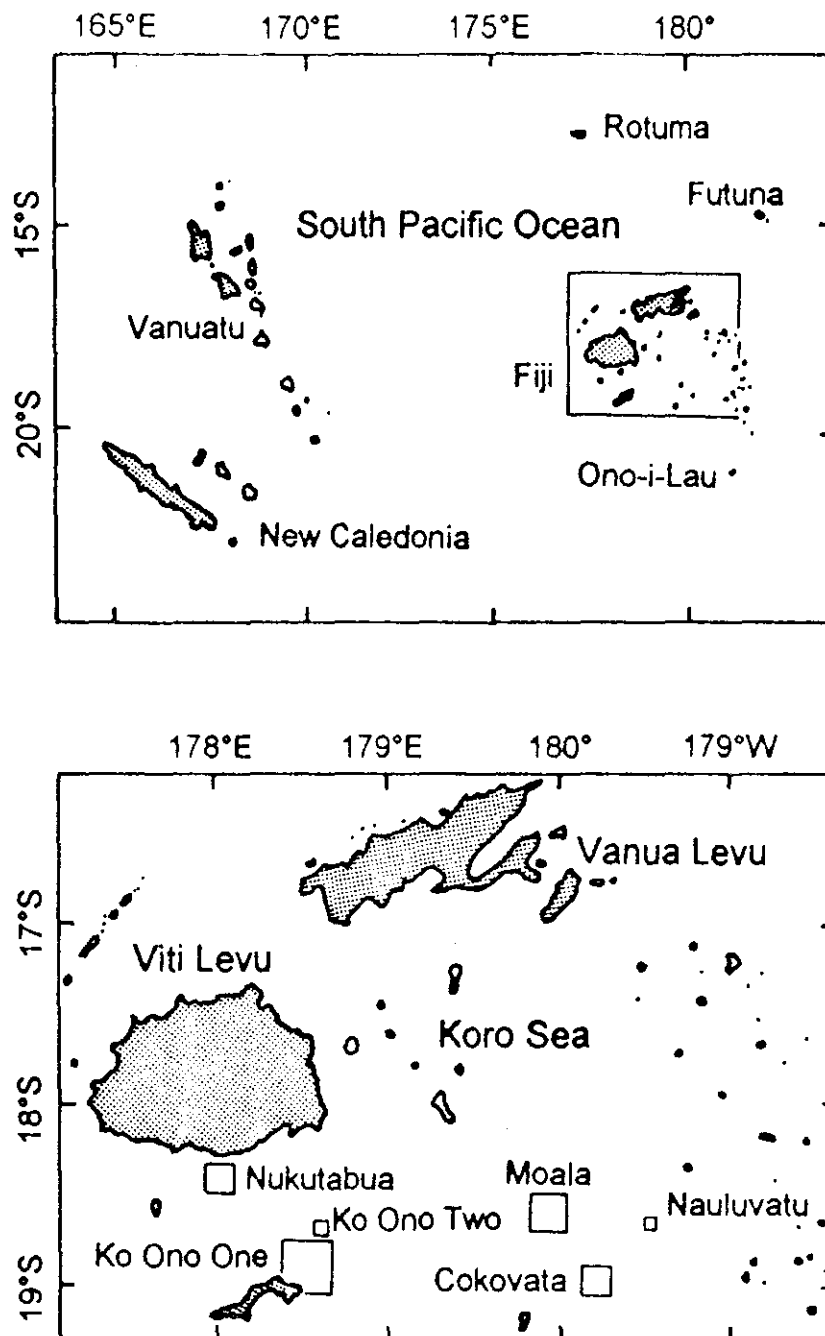


Figure 1. General location of the Fijian Islands (a) and the six *qoliqoli* selected for study (b) Boxes in 'b' indicate coverage of plans in Figures 2 and 3.

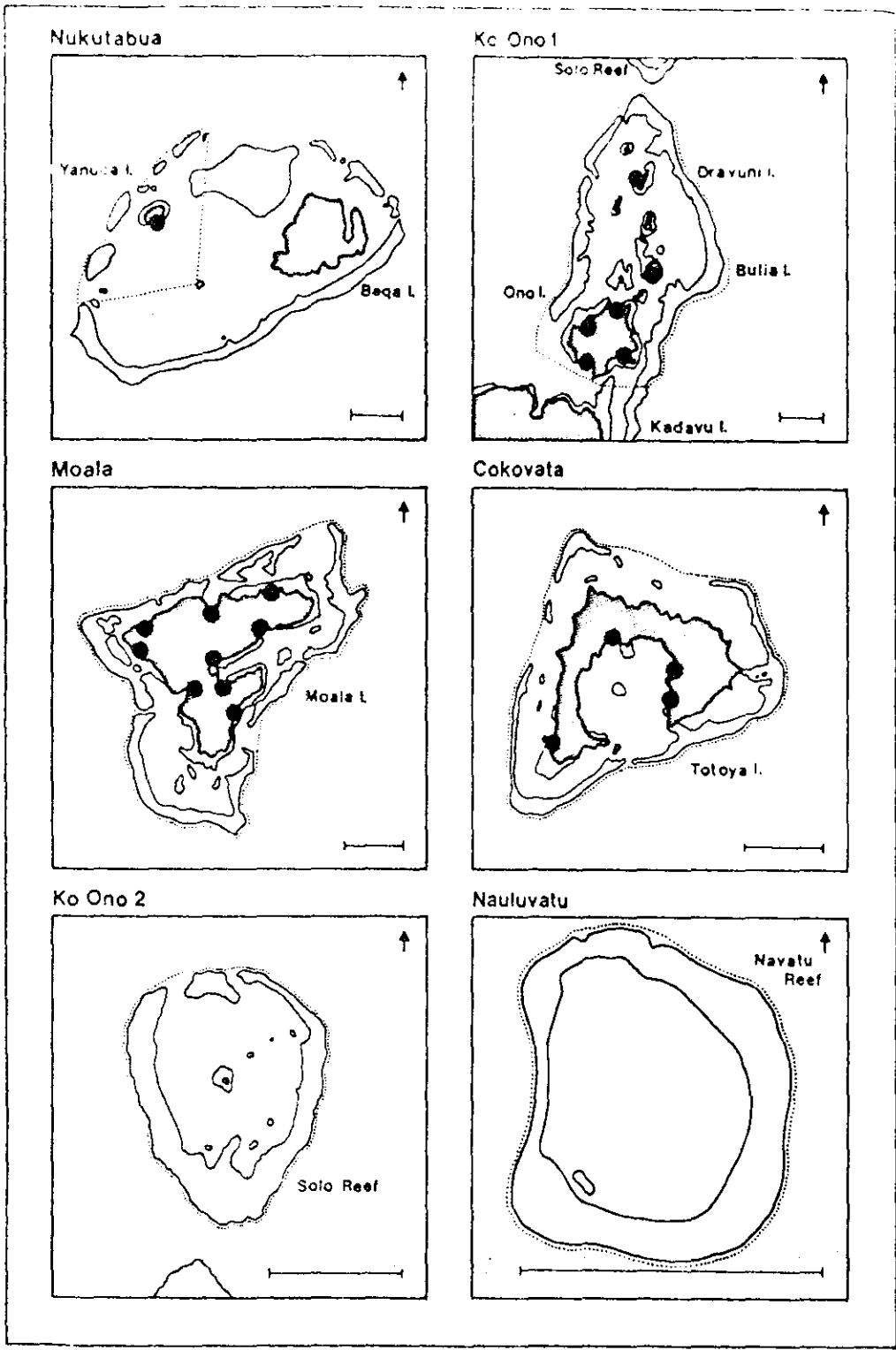


Figure 2. The six Fijian fishing grounds investigated during the present study. Land is shaded, unbroken lines show the position of major reefs and the limits of the *qoliqoli* are indicated by a broken line. The arrow points true North and the scale bar represents 5km. The positions of the main villages prosecuting the fishery are indicated by closed circles.

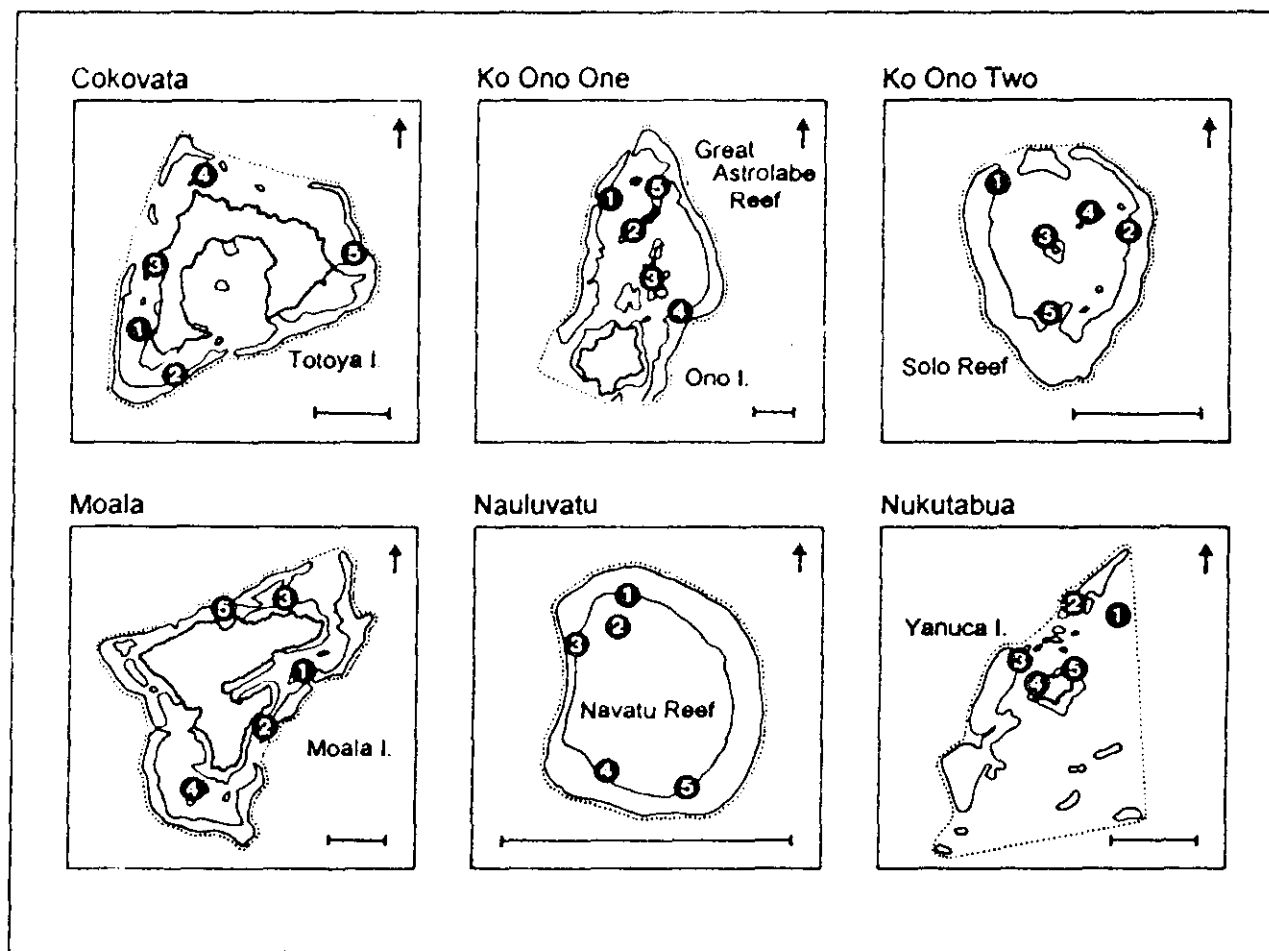


Figure 3. Location of survey sites (numbered) within the six Fijian *qoliqoli*. Land is shaded, unbroken lines indicate major reef areas, broken lines indicate *qoliqoli* boundaries, arrows point true north and scale bars represent 5km.

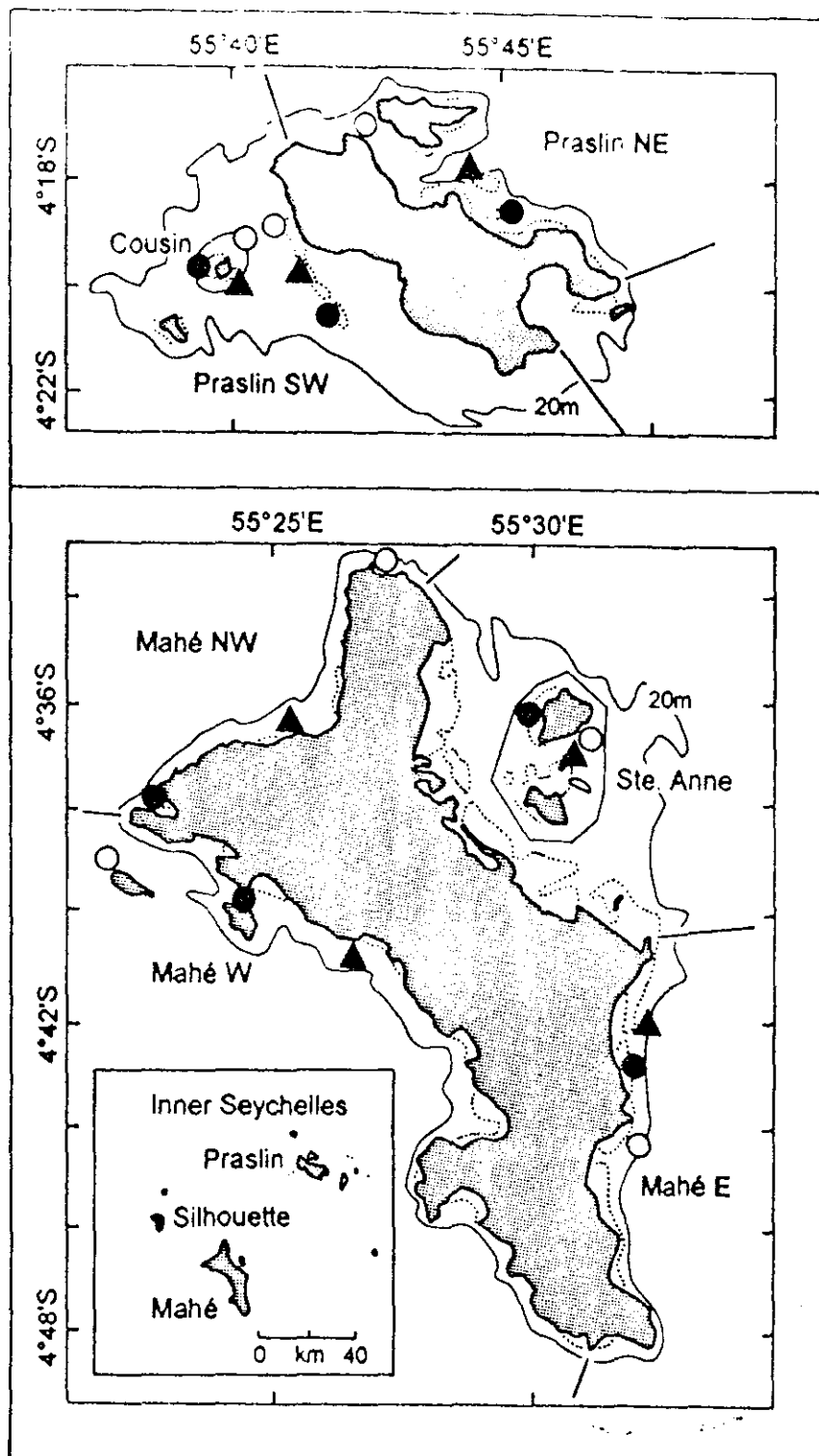


Figure 4. Location of the seven Seychelles' fishing grounds subject to different fishing intensities. Continuous lines bordering Ste. Anne and Cousin indicate boundaries of the reserves. Broken lines indicate fringing reefs. Habitat types: ●=1, well developed fringing reef with a carbonate framework. ○=2, coral growth on a granitic substrate in exposed locations. ▲=3, small rock and coral patch reefs on a predominantly sandy substrate.

3. Results

a. Appraisal of existing approaches to stock assessment.

In the forthcoming book 'Tropical Reef Fisheries' assembled during this project, Appeldoorn (in press) concludes that models currently used in assessment of inshore reef fisheries are simple because the underlying data are very limited. The prevailing techniques are single-species surplus production and yield-per-recruit models, relying on length-frequency or otolith analyses. The length-based methods involve assumptions which may not be valid. Otolith methods have the potential to be accurate, but are time-consuming and expensive. In either case there is the assumption that consequences of interspecies interactions are negligible. This project had the testing of multispecies effects of fishing as a major objective.

b. Designation of sites

Fiji

A voluntary logbook scheme was used to obtain information on fishing activities and the composition of catches in the Fijian fishing grounds where fish community structure would be examined (Table 1). Logbooks were distributed to a proportion of the households and boat fishers in six native fishing grounds (*qoliqoli*) (Nukutabua, Ko Ono 1, Moala, Cokovata, Ko Ono 2 and Nauluvatu) in the southern and eastern regions of the Fijian archipelago (Figures 1,2). The *qoliqoli* provided an excellent opportunity for the study of reef fisheries because they are used only by villagers with fishing rights and thus it was possible to study all fishing in the *qoliqoli* by monitoring fishing activities and landings in the villages with fishing rights.

To obtain estimates of the total catch and effort within *qoliqoli*, logbook catch and effort records were raised according to the proportion of the fleet sampled and the total frequency of shorefishing trips in each *qoliqoli*. This information was obtained from contemporaneous fleet size and shore fishing activity surveys (Table 2). CPUE for specific gears and species was calculated directly from fishing trips recorded in the logbooks.

One hundred and thirteen of the 172 logbooks issued were correctly completed and provided details of 1369 fishing trips on which the analyses were based. Acanthurids, lethrins and serranids dominated the estimated yield from all *qoliqoli* (Table 3). A relatively large proportion of the catch was sold from the *qoliqoli* close (within a few hours boat travel) to the major markets such as Suva on the mainland of Viti Levu. In general, a greater proportion of the lethrins and serranid catch was sold than that of other species.

In order to compare the yields from different *qoliqoli*, mean estimated yields of reef-associated fishes in different trophic groups were expressed in terms of the area of coral reef or rock reef in the *qoliqoli* (Table 4). Piscivores or macro-invertebrate feeders dominated the yield from all *qoliqoli* and planktivores were relatively unimportant. Herbivores and detritivores contributed to around 20% of yield in some *qoliqoli*. Tests for significant differences in yield within trophic groups were conducted using ANOVA with $\log_e(x+1)$ transformed data (Table 5). There were significant differences between yields of all trophic groups in all *qoliqoli* (Table 5). Total estimated yield was significantly higher in Moala and Cokovata than in Nukutabua and Ko Ono One (Table 5). The lowest yield was recorded from Ko Ono 2 and Nauluvatu. Annual yields ranged from 0.2 to 3.4 tonne km^{-2} *qoliqoli* year^{-1} and 0.3 to 10.2 tonne km^{-2} reef year^{-1} (Table 6).

Table 1. English translations of the questions included in the logbook survey in six Fijian *qoliqoli*. Beneath each of the questions, a series of possible responses was listed, and the fishers were asked to circle the most appropriate response. In addition, a space was always provided in which they could make an alternative response. The final question (12) required that fishers insert details of their catches in a prepared table. Logbooks were distributed to a proportion of the households and boat fishers in six *qoliqoli*. Heads of households were asked to record details of all shore fishing activity by members of their household, and boat fishermen were asked to record all activity on a specific boat. Logbooks were distributed for 30-day periods in October 1992, February 1993 and June 1993 to a random sample of those villagers who indicated that they wished to participate in the survey.

1. On which day of the month did the fishing trip begin?
2. What type of fishing gear were you using?
3. Which types of fish were you hoping to catch?
4. Were you fishing from a boat or from the shore?
5. Have you been fishing since you last completed a page of this logbook? If so, how many times?
6. How many people were fishing (in the boat) with you?
7. Were any of the people fishing with you also in possession of a logbook? If so, how many?
8. At what time of day did you start fishing?
9. For how many hours were you fishing (do not include time travelling to or from the fishing grounds)?
10. Where in the *qoliqoli* were you fishing?
11. At what depth were you fishing?
12. In the table below, please list the weight of each type of fish which you caught and indicate whether they were eaten in the village, sold outside the village or disposed of in some other way.

Table 2. Summary of the number of households, boats prosecuting the fishery, fishing activity and the proportion of fishing activities sampled by the voluntary logbook scheme in the six Fijian *qoliqoli*. na: not applicable.

<i>qoliqoli</i>	Nukutabua	Ko Ono 1	Moala	Cokovata	Ko Ono 2	Nauluvatu
households	32	106	328	145	na	na
boats	6	28	59	28	7	2
shorefishing trips (number month⁻¹)	255	753	3426	1740	na	na
mean number of shorefishing trips (number month⁻¹)	8.0	7.1	10.4	12.0	na	na
mean proportion of boats sampled (%)	71.4	26.2	10.7	38.1	40.0	100.0
mean proportion of shorefishing trips sampled (%)	12.0	1.6	1.7	2.9	na	na

Table 3. Yields from Fijian reef fisheries. Values are mean weights (tonnes 30 d⁻¹ ±SE). Values in parentheses indicate the amount of this yield which was sold outside the *qoliqoli*. Percentages indicate the contribution of the yield from individual families to the total yield. Percentages in parentheses indicate the proportion of yield within a family which was sold rather than being eaten in the fishing villages or disposed of by other means.

<i>qoliqoli</i>	Nukutabua		Ko Ono 1		Moala		Cokovata		Ko Ono 2		Nauluvatu	
family	yield	%	yield	%	yield	%	yield	%	yield	%	yield	%
Acanthuridae	1.05±0.472 (0.17±0.084)	16.4 (16.2)	1.89±0.506 (0.51±0.169)	8.4 (27.0)	3.42±0.478 (0.13±0.071)	9.3 (3.8)	2.01±0.038 (0.20±0.067)	9.0 (10.0)	0.14±0.099 (0.02±0.022)	5.7 (14.2)	0.02±0.009 (0)	5.9 (0)
Balistidae	0.04±0.020 (0)	0.6	0.01±0.001 (0)	0.1	0.40±0.155 (0.09±0.094)	1.1 (22.5)	0.09±0.054 (0)	0.4	0		0	
Carangidae	0.64±0.558 (0.01 ± 0.006)	10.0 (1.6)	1.12±0.116 (0.03±0.027)	2.7 (25.0)	1.50±0.336 (0.81±0.448)	4.1 (54.0)	0.77±0.060 (0.16±0.079)	3.5 (20.8)	0.01±0.007 (0.01±0.007)	0.4 (100.0)	0	
Haemulidae	0.06±0.023 (0.01±0.005)	0.9 (16.7)	0.81±0.336 (0.44±0.221)	3.6 (54.3)	0.44±0.163 (0.06±0.041)	1.2 (13.6)	0.38±0.039 (0.05±0.042)	1.7 (13.2)	0.16±0.131 (0.01±0.008)	6.5 (6.3)	0	
Holocentridae	0.01±0.001 (0)	0.2	0.1±0.008 (0.09±0.085)	0.4 (90.0)	0.17±0.091 (0)	0.5 (0)	0.02±0.018 (0)	0.1 (0)	0.01±0.006	0.4	0	
Labridae	0.16±0.103 (0.02±0.021)	2.5 (12.5)	0.10±0.095 (0.10±0.095)	0.4 (100.0)	1.22±0.881 (0.26±0.139)	3.3 (21.3)	0.78±0.292 (0.12±0.105)	3.5 (15.4)	0		0	
Lethrinidae	2.32±0.091 (1.20±0.155)	36.2 (51.7)	8.54±1.863 (5.38±2.078)	37.9 (63.0)	6.77±0.220 (1.13±0.531)	18.4 (16.7)	3.23±0.092 (0.63±0.433)	14.5 (19.5)	0.78±0.382 (0.53±0.270)	31.7 (67.9)	0.07±0.055 (0.05±0.040)	18.4 (71.2)
Lutjanidae	0.34±0.121 (0.14±0.080)	5.3 (41.2)	1.56±0.552 (0.61±0.292)	6.9 (39.1)	2.08±0.368 (0.51±0.252)	5.7 (24.5)	0.58±0.074 (0.08±0.038)	2.6 (13.8)	0.26±0.144 (0.06±0.040)	10.6 (23.1)	0	
Scaridae	0.20±0.116 (0.06±0.028)	3.1 (30.0)	1.14±0.505 (0.45±0.338)	5.3 (39.5)	1.28±0.655 (0.07±0.066)	3.5 (5.5)	0.89±0.102 (0.19±0.020)	4.0 (21.3)	0.15±0.113 (0.02±0.023)	6.1 (13.3)		

Table 3. continued

<i>qoliqoli</i> family	Nukutabua		Ko Ono 1		Moala		Cokovata		Ko Ono 2		Nauluvatu	
	yield	%	yield	%	yield	%	yield	%	yield	%	yield	%
Mullidae	0.06±0.022 (0)	0.9	0.33±0.267 (0)	1.3	1.94±0.248 (0.02±0.013)	5.3 (1.0)	1.52±0.536 (0.03±0.011)	6.8 (2.0)	0		0	
Scombridae	0.01±0.013 (0)	0.2	0.14±0.081 (0.05±0.050)	1.5 (35.7)	0.92±0.746 (0.78±0.778)	2.5 (84.5)	2.23±0.557 (0.36±0.251)	10.0 (16.1)	0.01±0.005 (0)	0.4	0	
Serranidae	0.77±0.137 (0.35±0.147)	12.0 (45.4)	4.30±0.456 (2.40±0.510)	19.1 (55.8)	7.38±1.60 (1.14±0.534)	20.1 (15.4)	2.68±0.935 (0.50±0.308)	12.0 (18.7)	0.63±0.259 (0.22±0.090)	25.6 (34.9)	0.21±0.184 (0.19±0.200)	71.6 (91.0)
Siganidae	0.18±0.084 (0.13±0.092)	2.8 (72.2)	0.41±0.102 (0.13±0.101)	1.8 (31.7)	0.92±0.220 (0.05±0.031)	2.5 (5.4)	0.41±0.050 (0.01±0.007)	1.8 (2.4)	0.01±0.006 (0)	0.4		
Unidentified species	0.36±0.205 (0.07±0.035)	5.6 (19.4)	1.06±0.618 (0.02±0.015)	4.7 (1.9)	5.92±0.444 (2.11±1.167)	16.1 (35.5)	3.70±0.681 (0.28±0.133)	16.6 (7.6)	0.04±0.032 (0)	1.6	0	
Other families	0.20±0.098 (0.03±0.025)	3.1 (15.0)	2.03±0.564 (1.05±0.688)	9.0 (51.7)	2.39±0.275 (0)	6.5	2.94±0.288 (0.19±0.148)	13.2 (6.5)	0.27±0.199 (0.01±0.010)	11.0 (3.7)	0	
Total	6.41±1.301 (2.18±0.265)		22.53±3.017 (11.26±1.869)		36.74±4.276 (7.16±3.609)		22.26±0.804 (2.79±1.110)		2.46±1.104 (0.88±0.352)		0.29±0.137 (0.24±0.223)	5.9 (74.9)

Table 4. Yields of reef associated fishes from Fijian *qoliqoli* ($\text{kg km}^{-2} \text{30d}^{-1} \pm \text{SE}$). Percentages indicate the yield of each trophic group as a proportion of the total yield of reef-associated fishes from each *qoliqoli*. Fishes were assigned to trophic groups on the basis of information provided by Hiatt & Strasburg (1960), Vivien (1973), Sano *et al* (1984), Parrish (1987), Myers (1989), Blaber *et al* (1990), Randall *et al* (1990).

<i>qoliqoli</i>	Nukutabua		Ko Ono 1		Moala		Cokovata		Ko Ono 2		Nauluvatu	
trophic group	yield	%	yield	%	yield	%	yield	%	yield	%	yield	%
piscivores	39±33.4	10.3	7±5.9	3.3	103±22.8	12.2	47±15.2	6.9	1±0.4	0.6	0	
planktivores	7±3.7	1.9	1±0.7	0.5	24±19.5	2.9	15±2.9	2.2	1±0.4	0.6	0	
herbivores/ detritivores	84±32.6	22.1	33±10.2	15.3	138±6.0	16.4	112±5.0	16.5	19±14.1	12.0	2±0.9	6.0
Macro- invertebrate feeders	28±5.1	7.4	15±6.6	7.1	116±19.7	13.8	109±22.7	16.1	13±10.5	8.0	0	
piscivores/ macro- invertebrate feeders	204±15.5	53.6	139±17.5	64.7	381±49.5	45.3	220±62.3	32.5	108±44.2	68.0	26±23.0	94.0
Unassigned	18±3.0	4.7	20±5.6	9.3	79±6.7	9.4	175±22	25.8	17±12.8	10.8	0	
Total	381±77.6		215±29.8		841±83.0		677±38.6		159±70.9		28±23.4	

Table 5. Analysis of variance and Welsch's test comparisons of the reef area specific yields of different trophic groups within six *qoliqoli*. Means indicated with the same letter were not significantly different ($p < 0.05$).

Group	F	df	p	Nukutabua	Ko Ono 1	Moala	Cokovata	Ko Ono 2	Nauluvatu
piscivores	8.87	5,12	<0.001	b	b.c	a	a.b	c	c
planktivores	6.06	5,12	<0.005	a	b	a	a	b	b
herbivores/ detritivores	8.31	5,12	<0.001	b	c	a.b	a	c	c
macro-invertebrate feeders	15.28	5,12	<0.001	a.b	b	a	a	b.c	c
piscivores/ macro-invertebrate feeders	21.18	5,12	<0.001	b	b	a	a	b	c
all groups	25.97	5,12	<0.001	a.b	b.c	a	a	c	d

Table 6. The effects of fish type (loosely reef-associated species or all species including pelagics) and area (rock/coral reef or all habitats) upon the calculated yield from Fijian *qoliqoli*. Fish were assigned to trophic groups on the basis of information provided by Hiatt & Strasburg (1960), Vivien (1973), Sano *et al* (1984), Parrish (1987), Myers (1989), Blaber *et al* (1990), Randall *et al* (1990).

<i>qoliqoli</i>	Nukutabua	Ko Ono1	Moala	Cokovata	Ko Ono2	Nauluvatu
Area (km²)						
reef only	16.8	103.9	42.6	29.6	15.5	10.7
total <i>qoliqoli</i>	85.4	289.7	130.1	124.6	42.9	19.4
Yield (t km⁻² y⁻¹)						
reef fish/ reef area	4.6	2.6	10.2	8.2	1.9	0.3
reef fish/ <i>qoliqoli</i> area	0.9	0.9	3.4	2.0	0.7	0.2

Line fishing (handline with single baited hook) dominated the time spent fishing from boat and shore in all *qoliqoli* except Nukutabua and Nauluvatu, where total fishing effort was relatively low (Figure 5). Spear fishing (spear-gun or pole-spear with rubber) accounted for much of the daily fishing time in boats but was relatively unimportant from the shore. Nets (gill nets and seine or drive nets) were widely used, but due to the great variety of fishing techniques used and not fully described in the logbooks, netting was treated as a single category. In many cases, the methods which were used for the greatest proportion of the time were not those which produced the highest multispecies mean CPUE (Figure 6).

Preliminary analyses of the factors affecting mean multispecies CPUE of reef-associated species in each *qoliqoli* indicated that the time (day, night), place (over coral, over sand), method (day or night fishing with net, line or spear) and purpose (for eating in village or sale) of fishing frequently had significant effects upon CPUE, but that season did not (ANOVA, $P < 0.05$). Accordingly, data from the three monthly surveys were pooled and the factors listed above were treated separately when rescaling fishing effort (Table 7). Two values deemed to be erroneous were removed when scaling factors were calculated. These values resulted from fishing events which were known to be atypical because gill nets were taken hurriedly from the village and used to encircle *Caranx* spp. which had been seen shoaling close to the shore. The villagers claimed that they had not used this technique on any other occasion from January 1992 to June 1993 and normal shore catches with nets were considerably lower. Of the recorded effort, 4.5% could not be rescaled with respect to one hour boat-based spearfishing over coral reefs and during the day to catch fish for sale because the relevant information was not reported by logbook respondents. This recorded effort was given a scaling value of 0.85 on the basis of a pooled CPUE calculation. Multispecies CPUE with all gears ranged from 1.40 kg hour⁻¹ in Moala to 4.82 kg hour⁻¹ at Nauluvatu (Table 8).

Mean CPUE for the valuable genera from high trophic levels which dominated the marketed boat catch (Table 9) rarely exceeded 1 kg hr⁻¹ except in Ko Ono 2 and Nauluvatu (Table 4). Comparison of the catch rates (ANOVA, $\sqrt{y+0.5}$ transformation, coupled with Welsch's test (Sokal & Rohlf, 1981), P critical = 0.05) indicated that, on the occasions when differences between *qoliqoli* and within gears were significant, only the one or two least intensively fished sites could be differentiated from the others on the basis of CPUE (Table 9). Night line fishing and day spear fishing were the only boat fishing techniques used to catch reef-associated fish over coral for sale in five or more of the *qoliqoli*.

In the *qoliqoli* where fishing effort was lowest the mean multispecies CPUE declined rapidly with increasing equivalent effort. However, CPUE was relatively stable in the more heavily fished sites (Figure 7). Such a pattern is not apparent in all multispecies reef fisheries (Figure 7).

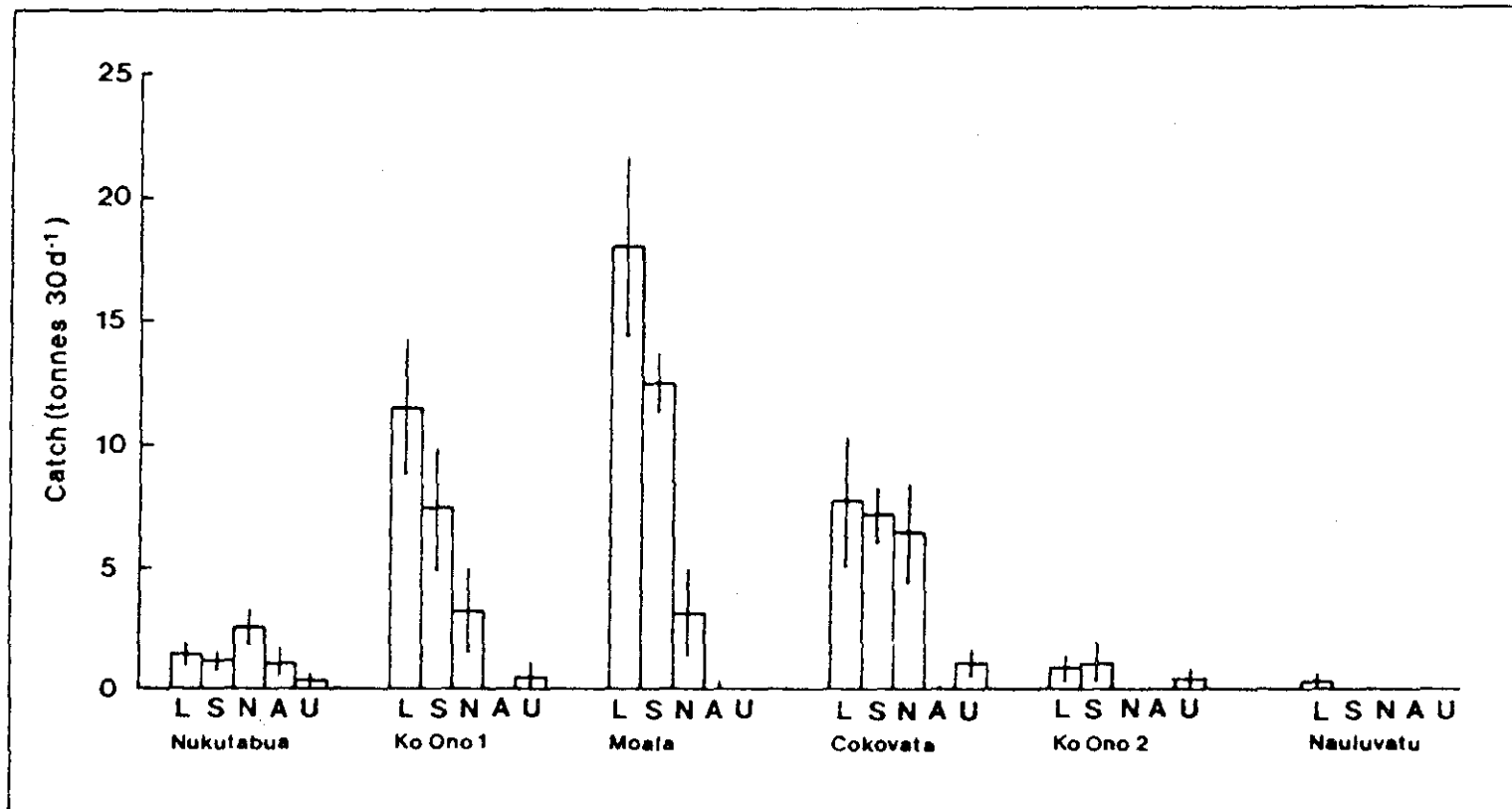


Figure 5. Estimated catches (\pm SE) with different fishing techniques in the six Fijian *qoliqoli*. L, Line (lure or bait); S, hand spear or spear gun; N, set (gill) net; A, actively fished (drag, seine or drive) net; U, method unreported or other methods used.

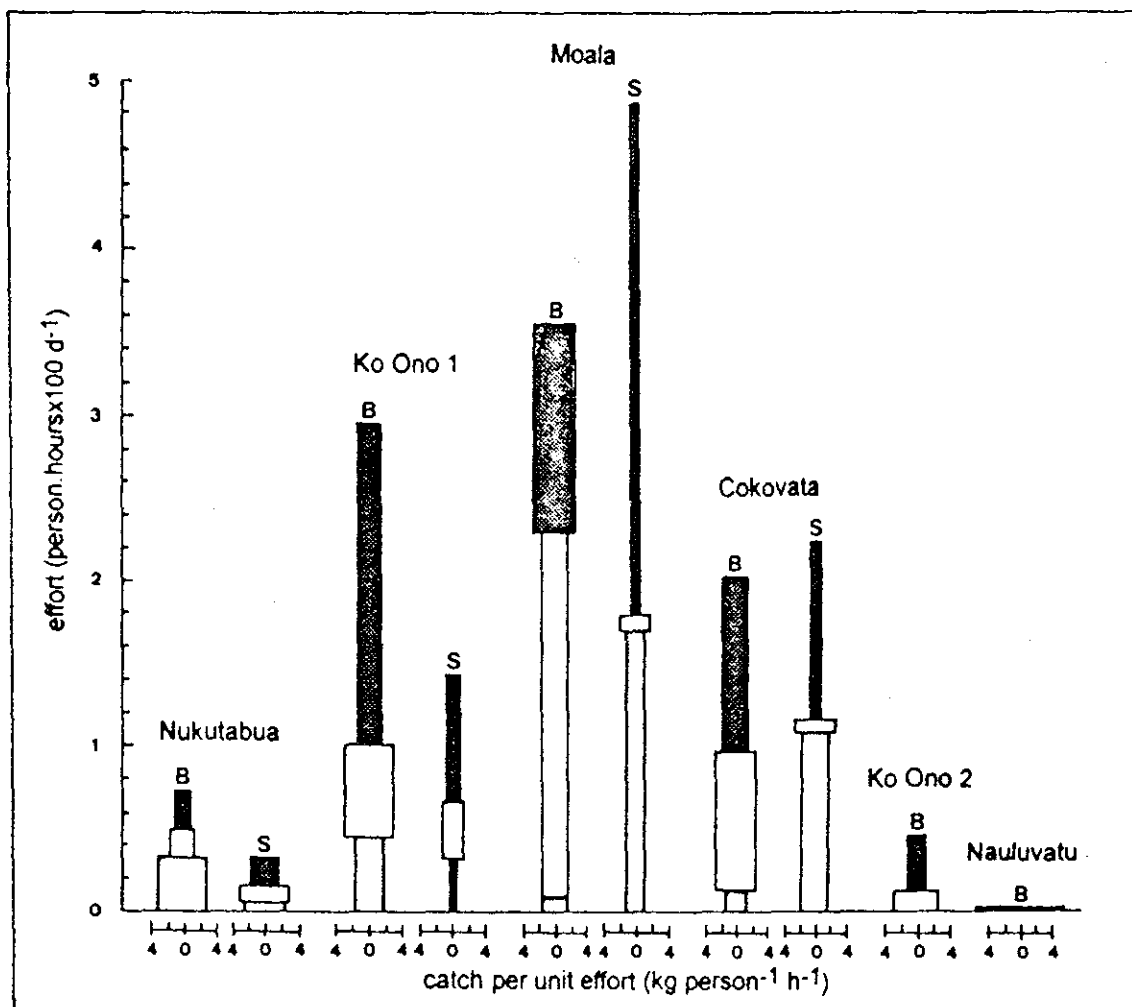


Figure 6. Mean catch rates of reef associated species for boat (B) and shore (S) fishing techniques and the estimated mean time for which they were employed in six Fijian *qoliqoli*. Dark stipple: handline fishing, Unshaded: Spear fishing, Light stipple: net fishing.

Table 7. Relative power of fishing techniques in use within Fijian reef fisheries with respect to boat based spear fishing over coral in the day to catch fish for sale (=1). n = number of logbook records for each technique. Parentheses indicate that factors were based on pooled records within Boat-Eat, Boat-Sell, Shore-Eat or Shore Sell categories because there were five or less records. The mean weight of the multispecies reef-associated catch during one hour of boat-based spear fishing over coral by day to catch fish for sale was treated as a single unit of fishing success. The equivalent effort (f^* , in hours) for each of a numbered series of other fishing techniques (i) which were used on more than five occasions (the minimum number of records which ensure that there is not a significant change in the variance of the mean CPUE when further records are included in the calculation) during the survey period was calculated as:

$$f_i^* = \left(\left(\sum_{j=1}^n b_j \right) / n \right) / \left(\left(\sum_{j=1}^n b_{i=1} \right) / n \right)$$

where, in *qoliqoli* j , $b_j = a_j / \left(\left(\sum_{i=1}^n a_i \right) / n \right)$ and $a_i = Y_w / f$

and $i=1$ is boat based spear fishing by day over coral to catch fish for sale, Y_w = yield in weight from each recorded fishing trip (kg), f = fishing effort during each recorded fishing trip (as h).

	Boat Fishing		Shore Fishing	
	To Eat	To Sell	To Eat	To Sell
Day Fishing Over Sand				
Line	0.37 n=43	0.33 n=7	(0.60) n=5	(0.70) n=2
Spear	0.81 n=12	(1.20) n=1	(0.60) n=1	- n=0
Net	0.85 n=5	(1.20) n=5	0.78 n=13	- n=0
Over Coral				
Line	0.64 n=133	0.45 n=56	0.44 n=144	0.37 n=6
Spear	1.18 n=153	1.00 n=44	0.45 n=28	(0.70) n=2
Net	2.09 n=40	0.67 n=26	0.39 n=98	0.40 n=6
Over other substrata				
Line	0.68 n=22	0.22 n=9	0.50 n=31	- n=0
Spear	0.61 n=22	- n=0	0.85 n=7	- n=0
Net	0.91 n=8	(1.20) n=4	0.42 n=27	(0.60) n=4

Table 7. continued

	Boat Fishing		Shore Fishing	
	To Eat	To Sell	To Eat	To Sell
Night Fishing				
Over Sand				
Line	0.86 n=25	0.43 n=30	(0.60) n=2	- n=0
Spear	(0.85) n=5	- n=0	(0.60) n=1	- n=0
Net	(0.85) n=2	- n=0	- n=0	- n=0
Over Coral				
Line	1.09 n=43	1.19 n=60	0.81 n=6	(0.70) n=3
Spear	0.35 n=73	0.92 n=16	(0.60) n=4	(0.70) n=2
Net	(0.85) n=3	- n=0	0.60 n=10	(0.70) n=4
Over other substrata				
Line	(0.85) n=3	1.23 n=20	- n=0	(0.70) n=4
Spear	0.86 n=15	(1.20) n=4	(0.60) n=1	(0.70) n=1
Net	- n=0	(1.20) n=2	(0.60) n=3	- n=0

Table 8. Catch, effort and area statistics for six Fijian Reef Fisheries. Effort: total estimated fishing effort, Yield: total estimated yield of reef-associated fish; Mean CPUE: CPUE based on total estimated fishing effort and total estimated yield; Total Area: Area of *qoliqoli*; Reef Area: area of coral or rocky reef based on sea-surface area; Scaled Effort: total estimated fishing effort expressed as hours equivalent to hours boat based spear fishing over coral by day to catch fish for sale.

	<i>qoliqoli</i>					
	Nukutabua	Ko Ono 1	Moala	Cokovata	Ko Ono 2	Nauluvatu
Effort (h yr ⁻¹)	39092	161329	310833	162381	16010	746
Yield (t yr ⁻¹)	77.8	271.8	435.9	243.8	30.0	3.6
Mean CPUE (kg h ⁻¹)	1.99	1.68	1.40	1.50	1.87	4.82
Total Area (km ²)	85.4	289.7 42.9	130.1	124.6	42.9	19.4
Total Reef Area (km ²)	16.8	103.9	42.6	29.6	15.5	10.7
Total Reef Area to 15m depth (km ²)	16.0	99.2	35.1	25.0	14.2	8.1
Scaled effort (h km ⁻² yr ⁻¹) (all methods)	2028	1121	4310	3582	739	72
Scaled effort (h km ⁻² yr ⁻¹) (excluding spear)	707	876	3212	2548	418	0
Scaled effort (h km ⁻² yr ⁻¹) (excluding line)	1436	484	1972	2066	421	72

Table 9. Catch per unit effort (kg hr^{-1}) for three fish genera caught from boats over coral in Fijian reef fisheries (mean \pm SD). Means marked with the same number of asterisks are not significantly different (Welsch Test, $P=0.05$). When no asterisks are shown the differences between means were not significant (ANOVA, $P<0.05$).

	<i>Qoliqoli</i>					
	Nukutabua	Ko Ono 1	Moala	Cokovata	Ko Ono 2	Nauluvatu
<i>Epinephelus</i> spp.						
Line-Day	0.10 \pm 0.260 n=33 **	0.25 \pm 0.345 n=73 *	0.49 \pm 0.603 n=21 *	0.44 \pm 0.615 n=50 *	0.26 \pm 0.176 n=12 *	- n=0
Line-Night	0.24 \pm 0.288 n=8 **	0.51 \pm 0.550 n=53 **	0.42 \pm 0.382 n=27 **	1.16 \pm 0.691 n=13 *	1.25 \pm 1.770 n=2 *	- n=0
Spear-Day	0.41 \pm 0.773 n=9 **	0.34 \pm 0.564 n=46 **	0.11 \pm 0.220 n=32 **	0.27 \pm 0.780 n=87 **	0.92 \pm 2.654 n=20 **	1.94 \pm 2.100 n=3 *
Spear-Night	0.19 \pm 0.240 n=9	0.57 \pm 0.687 n=4	0.08 \pm 0.154 n=31	0.26 \pm 0.801 n=44	0 n=1	- n=0
<i>Lethrinus</i> spp.						
Line-Day	0.29 \pm 0.305 n=33	0.22 \pm 0.335 n=73	0.28 \pm 0.639 n=21	0.29 \pm 0.459 n=50	0.69 \pm 1.375 n=12	- n=0
Line-Night	0.26 \pm 0.262 n=8 **	0.51 \pm 0.394 n=53 **	0.33 \pm 0.406 n=27 **	0.79 \pm 0.603 n=13 **	3.83 \pm 1.17 n=2 *	- n=0
Spear-Day	0.20 \pm 0.349 n=9 **	0 n=46 ***	0.09 \pm 0.150 n=32 ***	0.01 \pm 0.049 n=87 ***	0 n=20 ***	1.32 \pm 0.315 n=3 *
Spear-Night	0.34 \pm 0.404 n=9	0.04 \pm 0.08 n=4	0 n=31	0.14 \pm 0.597 n=44	0 n=1	- n=0
<i>Plectropomus</i> spp.						
Line-Day	0.13 \pm 0.359 n=33	0.07 \pm 0.194 n=73	0.02 \pm 0.074 n=21	0.04 \pm 0.282 n=50	0.06 \pm 0.106 n=12	- n=0
Line-Night	0 n=8	0.03 \pm 0.143 n=53	0 n=27	0 n=13	0 n=2	- n=0
Spear-Day	0.55 \pm 1.319 n=9 **	0.46 \pm 0.803 n=46 **	0.45 \pm 0.871 n=32 **	0.13 \pm 0.507 n=87 **	0.57 \pm 1.135 n=20 **	1.74 \pm 1.203 n=3 *
Spear-Night	0.04 \pm 0.110 n=9	1.08 \pm 0.475 n=4	0.54 \pm 1.030 n=31	0.51 \pm 1.18 n=44	0 n=1	- n=0

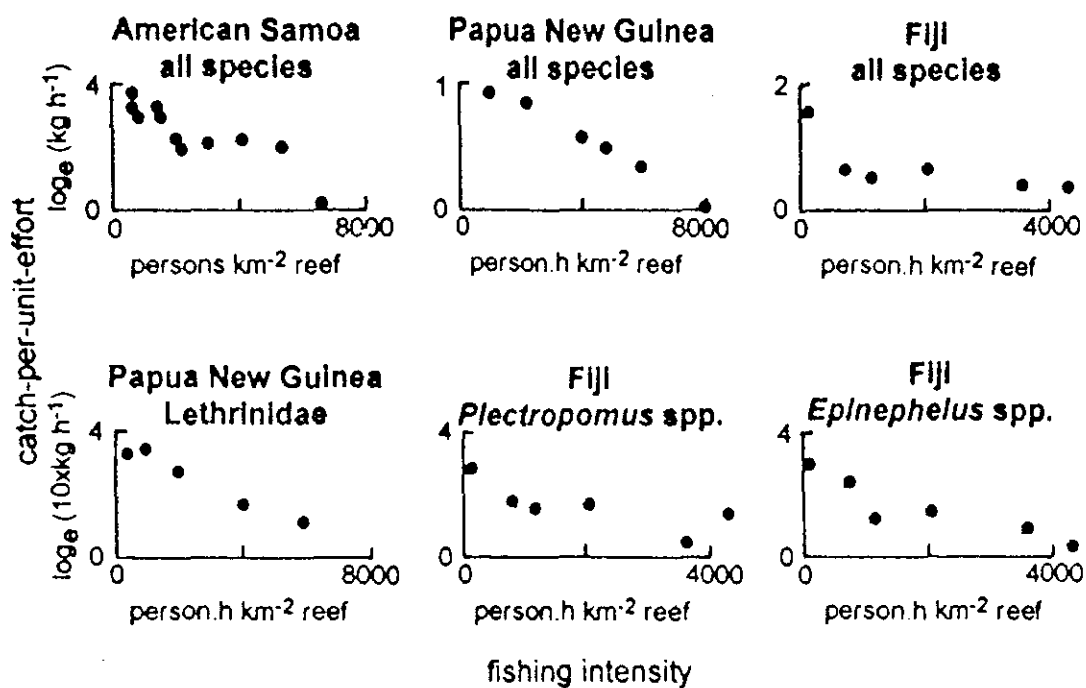


Figure 7. Relationships between catch-per-unit-effort and various indices of fishing intensity in reef fisheries (American Samoa, all species combined: redrawn from Munro & Williams (1985) treatment of data in Wass (1982); Papua New Guinea, all species combined: calculated from Lock (1986); Fiji, all species combined; Papua New Guinea, Lethrinidae (emperors): calculated from Lock (1986); Fiji, *Plectropomus* spp and *Epinephelus* spp. (day spear-fishery).

b. Designation of sites

ii. Seychelles

Fishing effort at sites in Seychelles was determined using information provided by the Seychelles Fishing Authority and Seychelles Division of Environment. Data from the 1992 Seychelles Fishing Authority censuses (Anon, 1993a) were used to estimate the monthly mean number of boats fishing with lines or traps (the methods used on inshore reefs) on a sea-area specific basis within each fishing ground. This provides a reasonable index of fishing intensity because the majority of small boats fish in areas relatively close to their landing sites and a similar proportion of the fleet use specific gear types in the different grounds (Anon, 1993a).

There are no records of the number of boats fishing or poaching in Ste. Anne, so the effective number of boats fishing was calculated from knowledge of the number of traps and lines licensed to local families (Seychelles Division of Environment, unpublished) and records of illegally positioned traps confiscated by wardens of the National Parks Service (Anon, 1993b). It was assumed i) that 50% of the traps set by poachers were confiscated, ii) that the ratio of trap to line fishing effort was 1:1 and iii) that a single boat with fishing power equivalent to those in other grounds would deploy four traps day⁻¹.

Areas of reef habitat (of the three types where fish counts were conducted) within each fishing ground were determined on the basis of sea-surface area using digitised navigational charts (UK Admiralty 722 & 742) or maps (OS Map Series Y851) and records of substrate type collected during diving surveys. Areas were measured using AutoCAD software; from the coast to the 20m isobath for grounds based on Seychelles Fishing Authority strata and to the reserve boundary at Ste. Anne and Cousin.

c. Population and ecosystem effects of fishing

i. Fiji

Primary target species

We investigated the effects of the measured fishing effort and catch rates upon the biomass and structure of shallow-water reef fish communities in the six sustainably fished Fijian fishing grounds (*qoliqoli*). There is good evidence to suggest that fishing effort in, and catch from, the *qoliqoli* has been relatively constant for at least 20 years because population growth has not exceeded 2%, there are no facilities for most villagers to store fish, there have been limited opportunities for the villagers to sell fish and fishes have always been captured because they provide the only adequate and regular supply of protein (Jennings & Polunin, in press a). Biomass was estimated by underwater visual census at five sites in each *qoliqoli* (Figure 3).

Quantitative estimates of the abundance and size of target-fishes in the six *qoliqoli* were made using an underwater visual census (uvc) technique. The methods followed those of Samoily (1992) and Samoily & Carlos (1992). Validation of the methodology and the benefits and disadvantages of the technique are discussed by Samoily (1992), Samoily & Carlos (1992). In this study, the method offered a number of advantages when compared with traditional transect counts. In particular, location of counts is easy to randomise, relatively short count durations increase the potential for replication in a given survey period, and push-pull effects due to diver presence are reduced due to the short period of time spent in a single census area (Samoily 1992, Samoily & Carlos 1992). Furthermore, net movements of target species do not bias counts as they would if transect techniques were used (Watson *et al.* in press).

Ninety-three diurnally active reef associated species which had been recorded in catches from the *qoliqoli* were selected for study (Table 10). Five census sites were selected randomly (within the constraints imposed by safe diving and boating practices) on shallow (<15m) lagoonal patch reef and back-reef areas in each *qoliqoli* (Figure 3). Sites were selected from areas which were regarded as reef by local fishers and would be recognised as reef when making measurements of reef area from charts and aerial photographs. No attempt was made to select reef areas with a high proportion of living coral. At each site, the abundance and size of target species $\geq 15\text{cm}$ fork length was estimated within 36 randomly positioned census areas of 7m radius by counting each individual and making an estimate of its length to the nearest 1 cm. The boundaries of each census area were estimated from as far above or to one side of the census area as the prevailing visibility permitted and counts of the most wary species began immediately. Species in each census area were recorded sequentially, the most active species being recorded first. When a count for one species was complete, all further movements of that species in or out of the census area were disregarded. The time required to complete a census was not standardised since this was dependent on the number and diversity of fish in the census area and the complexity of habitat to be searched. In practice, counts took 4-10 minutes. Following the count, a 7m line was laid to confirm the dimensions of the counting area. Accuracy of fish length estimation was maintained by practising with objects of known length at intervals throughout the study period and assessed using the methods of Polunin & Roberts (1993). All counts were conducted during daylight hours, from January to March 1994.

Habitat was described within the perimeter of each replicate count. When a count was complete, the percentage cover (based on plan view) of hard coral, rock, rubble and sand was estimated, the mean depth was recorded and the topographic complexity of the substrate was described using the six point scale of Polunin & Roberts (1993). The percentage cover of each substrate type, topographic complexity of the substrate and depth (Table 11) all differed significantly between *qoliqoli* (ANOVA, $p < 0.05$). However, in no instances were any of these factors significantly correlated ($p > 0.1$ for all factors) with the estimates of fishing effort in the *qoliqoli* and sites did not show any tendency to cluster into *qoliqoli* specific groups on the basis of their habitat characteristics (Figure 8). *Qoliqoli* subject to similar fishing intensity (Table 8) were not grouped in the same regions of the archipelago (Figure 1). Nauluvatu, the least intensively fished *qoliqoli* was closest to Moala, the most intensively fished (Table 8, Figure 1).

Estimates of fish length were converted to mass using published length: weight relationships (Wright & Richards 1985, Kulbicki *et al* 1993, Smith & Dalzell 1993). When a weight: length relationship for a given species was not available we used the relationship for a species with similar morphology (usually from the same genus). Eleven species were excluded from the analyses (Table 10) as they were not censused effectively using the visual census technique (Samoilys & Carlos 1992).

Characteristics of the reef habitat such as coral cover and reef size, height or topographic complexity may determine the abundance of reef fishes (e.g. Williams, 1991). However, since the analyses of habitat data indicated that similarities between sites in different *qoliqoli* were frequently greater than those within *qoliqoli* and that there were no consistent relationships between habitat type and fishing effort, habitat differences were unlikely to be solely responsible for the consistent and significant differences between biomass in the six *qoliqoli*.

Table 10. Fishes included in the census of reef fishes in Fijian *qoliqoli* and their trophic groups (dt, detritivore; hb, herbivore; iv, invertebrate feeder; ip, invertebrate feeder/ piscivore; om, omnivore; pi, piscivore; pk, planktivore). Fishes were assigned to trophic groups on the basis of information provided by Hiatt & Strasburg (1960), Vivien (1973), Sano *et al* (1984), Parrish (1987), Myers (1989), Blaber *et al* (1990), Randall *et al* (1990). An asterisk indicates species not included in the analyses because they were ineffectively censused (Samoilys & Carlos 1992; Jennings & Polunin in press b).

		Trophic Group
Acanthuridae	<i>Acanthurus lineatus</i> (Linnaeus, 1758)	hb
	<i>A. nigrofuscus</i> (Forsskål, 1775)	hb
	<i>A. olivaceus</i> Forster, 1801	hb
	<i>A. triostegus</i> (Linnaeus, 1758)	hb
	<i>Ctenochaetus striatus</i> (Quoy and Gaimard, 1825)	dt
	<i>Naso lituratus</i> (Forster, 1801)	hb
	<i>N. unicornis</i> (Forsskål, 1775)	hb
	<i>P. hepatus</i> (Linnaeus, 1766)	pk
	<i>Zebrasoma scopas</i> (Cuvier, 1829)	om
	<i>Z. veliferum</i> (Bloch, 1797)	om
Balistidae	<i>Balistapus undulatus</i> (Park, 1797)	iv
Haemulidae	<i>Plectorhinchus chaetodonoides</i> (Lacepède, 1801)	iv
	<i>P. gibbosus</i> (Lacepède, 1802)	iv
	<i>P. obscurum</i> (Günther, 1871)	iv
Labridae	<i>Bodianus axillaris</i> (Bennett, 1831)	iv
	<i>B. loxozonus</i> (Snyder, 1908)	iv
	<i>B. mesothorax</i> (Bloch and Schneider, 1801)	iv
	<i>Cheilinus digrammus</i> (Lacepède, 1801)	ip
	<i>C. fasciatus</i> (Bloch, 1791)	iv
	<i>C. trilobatus</i> Lacepède, 1801	iv
	<i>C. undulatus</i> Rüppell, 1835	iv
	<i>Coris aygula</i> Lacepède, 1801	iv
	<i>C. gaimard</i> (Bleeker, 1849)	iv
	<i>Epibulis insidiator</i> (Pallas, 1770)	ip
	<i>Gomphosus varius</i> Lacepède, 1801	iv
	<i>Hemigymnus fasciatus</i> (Bloch, 1792)	iv
<i>H. melapterus</i> (Bloch, 1791)	iv	
Lethrinidae	<i>Gnathodentex aurolineatus</i> (Lacepède, 1802)	iv
	<i>Gymnocranius grandoculis</i> (Valenciennes, 1830)	ip
	<i>Gymnocranius</i> sp.	ip
	<i>Lethrinus atkinsoni</i> Seale, 1909*	ip
	<i>L. erythracanthus</i> Cuvier, 1830*	ip
	<i>L. harak</i> (Forsskål, 1775)*	ip
	<i>L. nebulosus</i> (Forsskål, 1775)*	pi
	<i>L. obsoletus</i> (Forsskål, 1775)*	ip
	<i>L. olivaceus</i> Valenciennes, 1830*	pi
	<i>L. rubrioperculatus</i> Sato, 1978*	ip
	<i>L. xanthochilus</i> Kluzinger, 1870*	ip
<i>Monotaxis grandoculis</i> (Forsskål, 1775)	ip	
Lutjanidae	<i>Aprion virescens</i> Valenciennes, 1830	pi
	<i>Lutjanus argentimaculatus</i> (Forsskål, 1775)	pi
	<i>L. bohar</i> (Forsskål, 1775)	pi
	<i>L. fulviflamma</i> (Forsskål, 1775)	ip
	<i>L. fulvus</i> (Bloch and Schneider, 1801)	ip

Table 10. continued

	<i>L. gibbus</i> (Forsskål, 1775)	ip
	<i>L. kasmira</i> (Forsskål, 1775)	ip
	<i>L. monostigma</i> (Cuvier, 1828)	ip
	<i>L. russelli</i> (Bleeker, 1849)	ip
	<i>L. semicinctus</i> Quoy and Gaimard, 1824	ip
	<i>Macolor macularis</i> Fowler, 1931	pk
	<i>M. niger</i> (Forsskål, 1775)	pk
Mullidae	<i>Mulloides flavolineatus</i> (Lacepède, 1801)	ip
	<i>M. vanicolensis</i> (Valenciennes, 1831)	ip
	<i>Parupeneus barberinoides</i> (Lacepède, 1801)	iv
	<i>P. barberinus</i> (Lacepède, 1801)	iv
	<i>P. bifasciatus</i> (Lacepède, 1801)	ip
	<i>P. ciliatus</i> (Lacepède, 1801)	iv
	<i>P. cyclostomus</i> (Lacepède, 1801)	ip
	<i>P. indicus</i> (Shaw, 1803)	iv
	<i>P. multifasciatus</i> (Quoy and Gaimard, 1825)	iv
	<i>P. pleurostigma</i> (Bennett, 1830)	iv
Nemipteridae	<i>Scolopsis bilineatus</i> (Bloch, 1793)	iv
Scaridae	<i>C. bicolor</i> (Rüppell, 1829)	hb
	<i>H. longiceps</i> (Valenciennes, 1840)	hb
	<i>S. bleekeri</i> (de Beaufort, 1940)	hb
	<i>S. chameleon</i> Choat and Randall, 1986	hb
	<i>S. dimidiatus</i> Bleeker, 1859	hb
	<i>S. forsteni</i> (Bleeker, 1861)	hb
	<i>S. frenatus</i> Lacepède, 1802	hb
	<i>S. microrhinos</i> Bleeker, 1854	hb
	<i>S. niger</i> Forsskål, 1775	hb
	<i>S. oviceps</i> Valenciennes, 1840	hb
	<i>S. psittacus</i> Forsskål, 1775	hb
	<i>S. rubroviolaceus</i> Bleeker, 1847	hb
	<i>S. schlegeli</i> (Bleeker, 1861)	hb
	<i>S. sordidus</i> Forsskål, 1775	hb
Serranidae	<i>Cephalopholis argus</i> Bloch and Schneider, 1801	pi
	<i>C. leopardus</i> (Lacepède, 1801)*	ip
	<i>C. urodeta</i> (Bloch and Schneider, 1801)*	ip
	<i>Epinephelus caeruleopunctatus</i> (Bloch, 1790)	pi
	<i>E. cyanopodus</i> (Richardson, 1846)	ip
	<i>E. maculatus</i> (Bloch, 1790)	ip
	<i>E. malabaricus</i> (Bloch and Schneider, 1801)	ip
	<i>E. merra</i> Bloch, 1793*	ip
	<i>E. polyphkadion</i> (Bleeker, 1849)	ip
	<i>E. tauvina</i> (Forsskål, 1775)	ip
	<i>Gracila albomarginata</i> (Fowler and Bean, 1930)	ip
	<i>Plectropomus laevis</i> (Lacepède, 1802)	pi
	<i>P. leopardus</i> (Lacepède, 1802)	pi
	<i>Variola louti</i> (Forsskål, 1775)	pi
Siganidae	<i>Siganus doliatus</i> Cuvier, 1830	hb
	<i>S. spinus</i> (Linnaeus, 1758)	hb
	<i>S. vermiculatus</i> (Valenciennes, 1835)	hb

Table 11. Habitat characteristics at census sites in the six Fijian *qoliqoli* (mean \pm 1 SE).

	Nauluvatu	Ko Ono Two	Ko Ono One	Nukutabua	Cokovata	Moala
Hard Coral (%)	16.0 \pm 0.72	37.3 \pm 1.38	22.7 \pm 0.94	39.1 \pm 1.20	31.5 \pm 1.32	28.4 \pm 1.35
Rock (%)	30.2 \pm 1.46	24.7 \pm 1.28	25.6 \pm 1.18	27.6 \pm 1.15	35.3 \pm 1.64	31.9 \pm 1.36
Rubble (%)	25.5 \pm 2.28	25.0 \pm 1.46	38.8 \pm 2.09	22.5 \pm 1.33	18.2 \pm 1.35	32.6 \pm 2.29
Sand (%)	27.9 \pm 1.98	12.9 \pm 1.15	12.9 \pm 1.36	10.8 \pm 1.00	16.4 \pm 1.38	6.7 \pm 0.92
Depth (m)	6.0 \pm 0.20	5.7 \pm 0.16	6.9 \pm 0.16	7.0 \pm 0.17	6.8 \pm 0.18	6.3 \pm 0.16
Relief (see text)	3.0 \pm 0.11	3.3 \pm 0.05	3.1 \pm 0.05	3.4 \pm 0.05	3.4 \pm 0.04	3.3 \pm 0.06

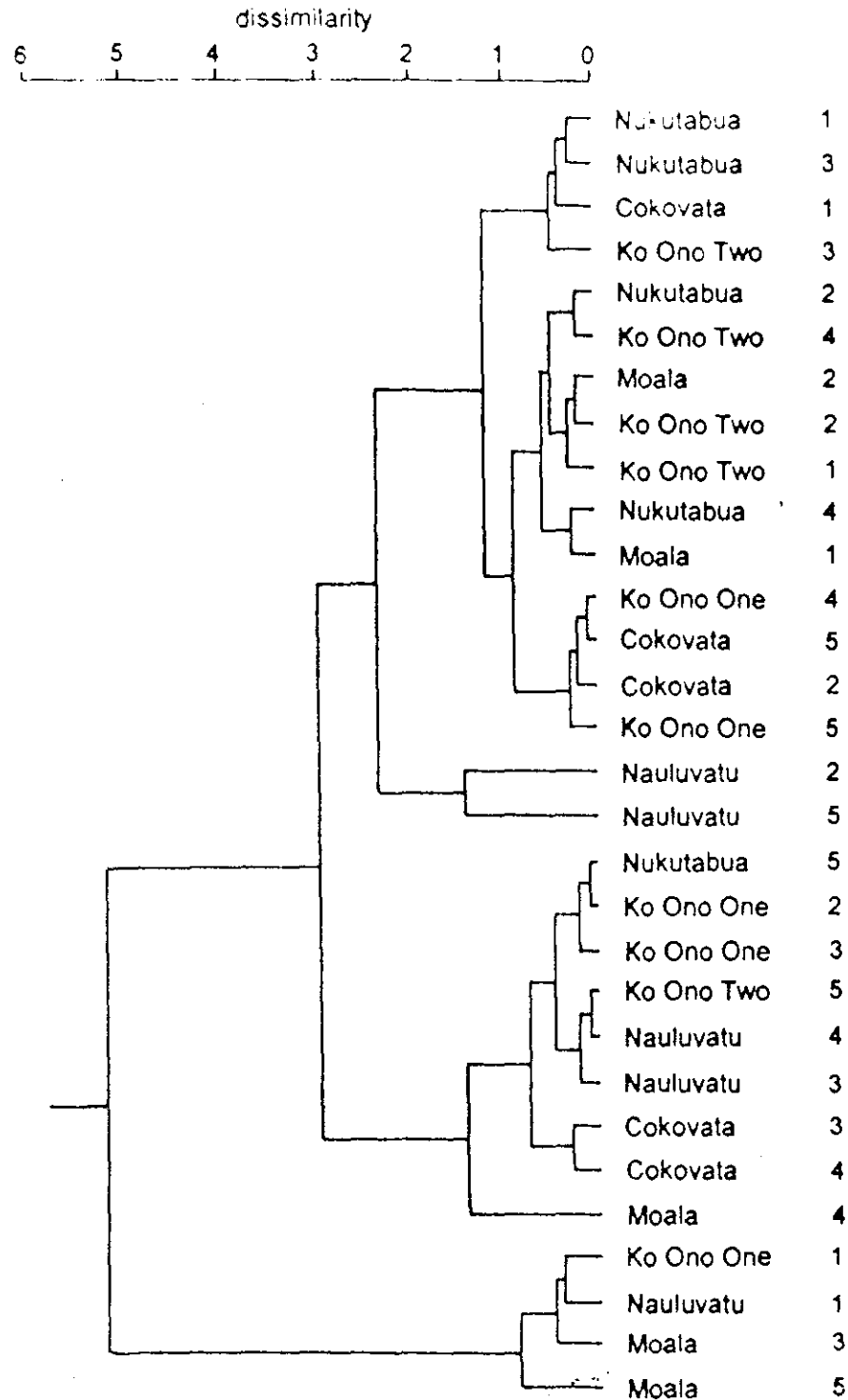


Figure 8. A dendrogram which shows the grouping of Fijian survey sites following hierarchical classification analysis of habitat variables. Relationships between all the habitat types within each site were investigated by subjecting the means of all replicate specific habitat indices ((depth (m), coral cover (%), rubble cover (%), rock cover(%), sand cover (%) and topographic complexity (6 point scale of Polunin & Roberts, 1993)) to an agglomerative hierarchical clustering procedure using the method of Ward (1963). All data were standardised to mean=0 and SD=1 before clustering.

Studies of recruitment processes on tropical reef reefs have confirmed that, as in temperate waters, spatial and temporal variations in recruitment contribute to the structuring of reef fish communities (e.g. Doherty, 1991). Long-term spatial differences in recruitment rates to different *qoliqoli* could have particularly marked effects on the biomass of their fish communities and contribute to much of the unexplained variance in biomass between sites. However, the observation that sites subject to similar fishing intensities were not grouped in geographic proximity (Moala and Cokovata, the most heavily fished sites, closest to Nauluvatu, where fishing intensity was lowest) and that the relationships between biomass and fishing intensity were consistent in a range of families with different life-history strategies, suggests that the significance of differences which we observed can reasonably be attributed to fishing effects.

The piscivorous and piscivorous/invertebrate feeding Lethrinidae, Serranidae and Lutjanidae (emperors, groupers and snappers) accounted for 35-40% of community biomass in the two least intensively fished *qoliqoli*, but for <25% of community biomass in the four *qoliqoli* fished more intensively. Conversely, the herbivorous Scaridae (parrotfishes) accounted for 19-22% of total biomass in the lightly fished *qoliqoli* and 31-39% elsewhere (Figure 9). In the two least intensively fished *qoliqoli*, area-specific annual catches of all target species, and six of the seven families which contributed most to total biomass, were less than 2% of the biomass estimates obtained by underwater visual census. In the *qoliqoli* where family specific or total annual catch rates exceeded 2-5% of the family specific or total biomass, family specific or total biomass was significantly higher than in *qoliqoli* where catch rates were less (Figure 10). Biomass differences within groups of *qoliqoli* where annual catch rates exceeded 2-5% of biomass were rarely significant (Table 12). Thus, at higher fishing intensities, the biomass of target fishes provided a poor index of relative fishing pressure. For Lethrinidae, Serranidae and Lutjanidae, fishing intensity and habitat type respectively accounted for 26-32% and 11-41% of the variance in biomass between sites (Table 13).

i. Fiji

All species

All diurnally active reef associated species ≥ 8 cm length were censused in the six *qoliqoli* (Figure 3) and at Suva reef from September 1992 to February 1993, in order to determine the effects of fishing on the composition and structure of the entire multispecies community. Methodology was similar to that described in the preceding section and is described below. At each site, the abundance and size of target species ≥ 8 cm fork length was estimated within 16 haphazardly positioned census areas of 7m radius by counting each individual and making an estimate of its length to the nearest 1cm. The boundaries of each census area were estimated from as far above or to one side of the census area as the prevailing visibility permitted and counts of the most wary species began immediately. Species in each census area were recorded sequentially, the most active species being recorded first. When a count for one species was complete, all further movements of that species in or out of the census area were disregarded.

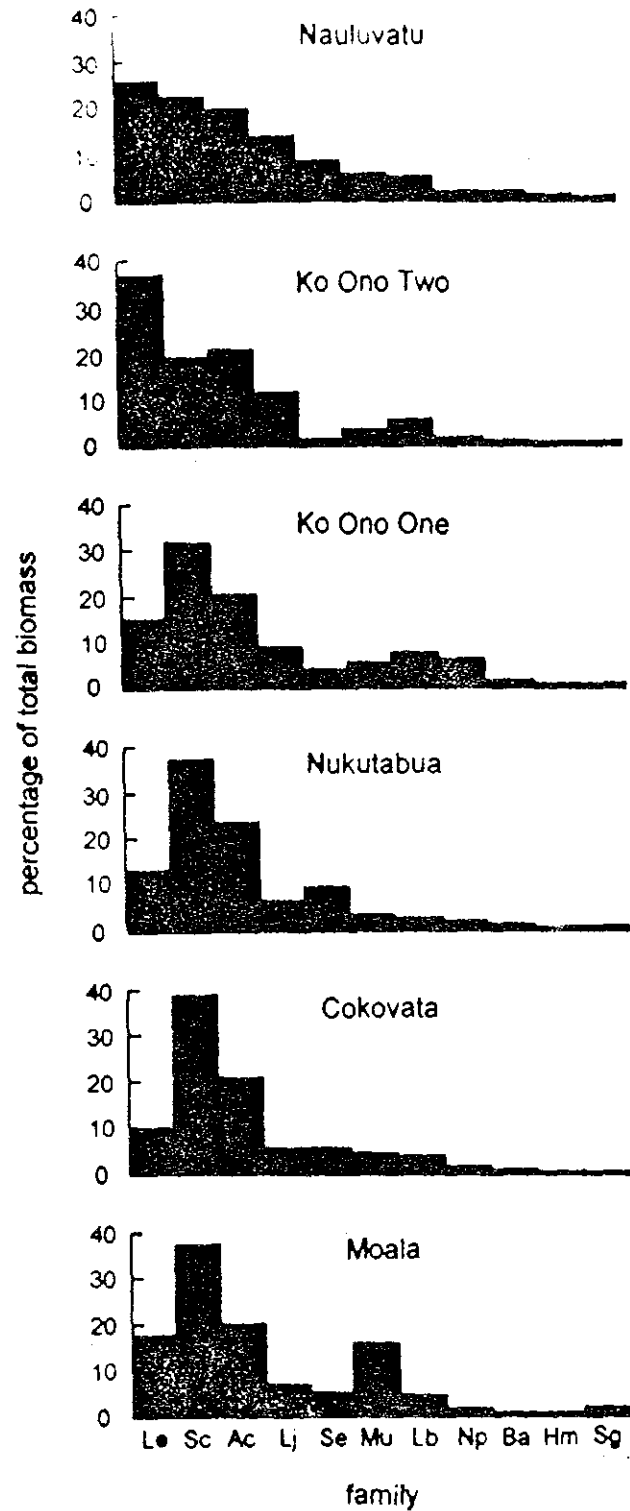


Figure 9. Percentage composition (by biomass) of the target reef fish community at the family level in the six Fijian *qoliqoli*. Family codes: Le, Lethrinidae; Sc, Scaridae; Ac, Acanthuridae; Lj, Lutjanidae; Se, Serranidae; Mu, Mullidae; Lb, Labridae; Np, Nemipteridae; Ba, Balistidae; Hm, Haemulidae; Sg, Siganidae.

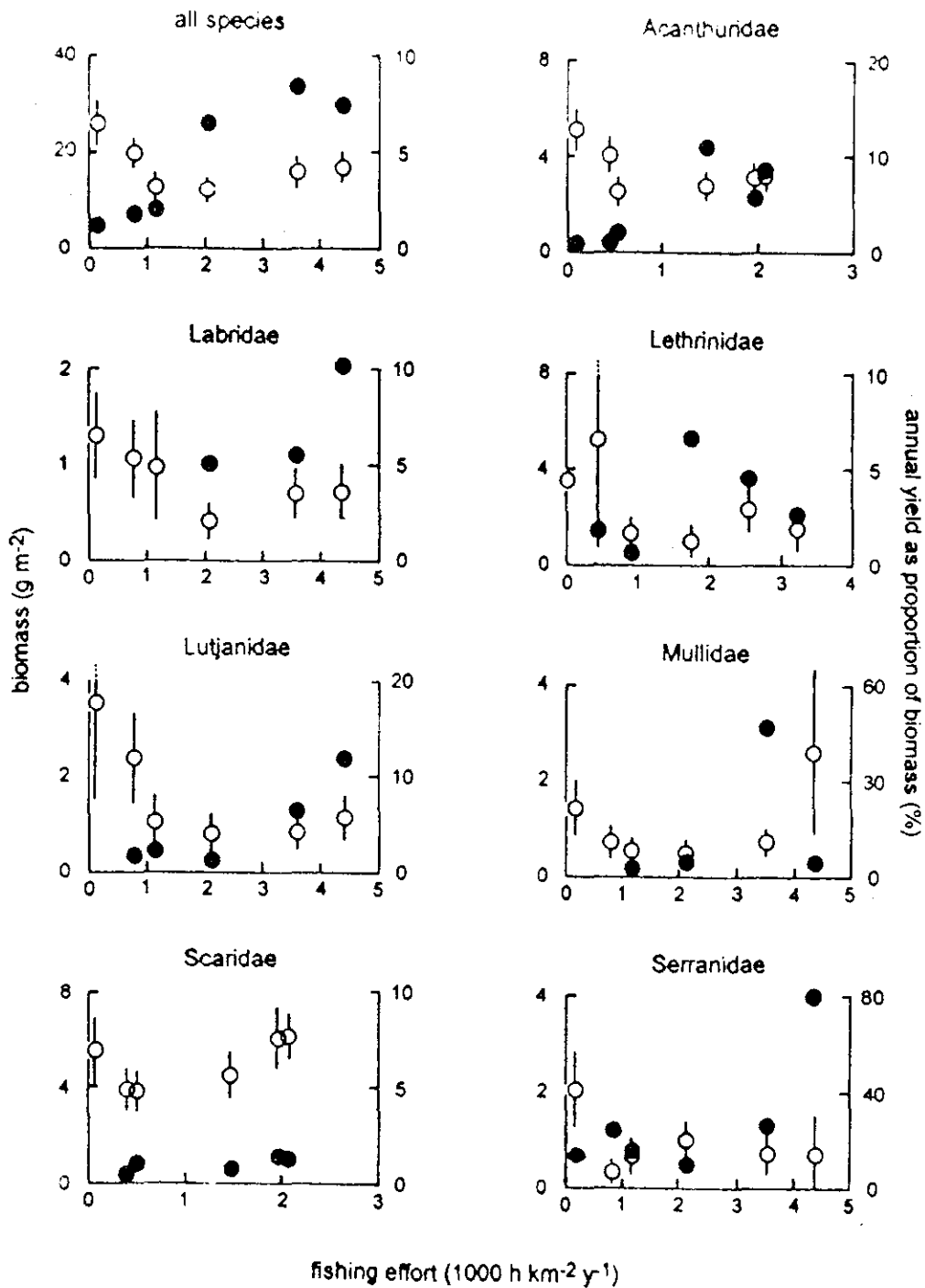


Figure 10. Relationships between biomass (open circles, mean \pm 95% CI) and yield ($\text{g m}^{-2} \text{y}^{-1}$) as a proportion of biomass (closed circles) for all species included in the census and for seven families of target reef fishes in Fijian *qoliqoli*.

Table 12. Results of Tukey's test comparisons between mean biomass by family in the six *qoliqoli*. Groups of means which do not differ significantly ($p < 0.05$) are linked. *Qoliqoli* codes: Nv, Nauluvatu; KT, Ko Ono Two; KO, Ko Ono One; Nk, Nukutabua; Ck, Cokovata; Mo, Moala.

all target species	<u>Nv</u> <u>KT</u> <u>MO</u> <u>Ck</u> <u>KO</u> <u>Nk</u>
Acanthuridae	<u>Nv</u> <u>KT</u> <u>Ck</u> <u>Mo</u> <u>Nk</u> <u>KO</u>
Labridae	<u>Nv</u> <u>KT</u> <u>KO</u> <u>Co</u> <u>Mo</u> <u>Ck</u>
Lethrinidae	<u>KT</u> <u>Nv</u> <u>Ck</u> <u>Mo</u> <u>KO</u> <u>Nk</u>
Lutjanidae	<u>Nv</u> <u>KT</u> <u>Mo</u> <u>KO</u> <u>Ck</u> <u>Nk</u>
Mullidae	<u>Mo</u> <u>Nv</u> <u>KT</u> <u>Ck</u> <u>KO</u> <u>Nk</u>
Scaridae	<u>Ck</u> <u>Mo</u> <u>Nv</u> <u>Nk</u> <u>KT</u> <u>KO</u>
Serranidae	<u>Nv</u> <u>Nk</u> <u>Mo</u> <u>Ck</u> <u>KO</u> <u>KT</u>

Table 13. The proportion of variance in family specific biomass explained by measures of fishing intensity and habitat structure. Multiple regression was used to determine the proportion of variance in biomass (log transformed) which could be attributed to characteristics of the habitat and catch rate. A forward selection procedure was adopted whereby variables were added sequentially to the regression equation until there was no significant improvement in the coefficient of determination.

	habitat	fishing intensity	total explained	total not explained
all species	0.24	0.12	0.36	0.64
Acanthuridae	0.24	0.16	0.40	0.60
Labridae	0.40	0.09	0.49	0.51
Lethrinidae	0.11	0.30	0.41	0.59
Lutjanidae	0.22	0.32	0.54	0.46
Mullidae	0.24	-	0.24	0.76
Scaridae	0.21	-	0.21	0.79
Serranidae	0.41	0.26	0.67	0.33

Following the fish census, habitat was described within the perimeter of the counting area. The percentage cover (based on plan view) of branching, small-head, massive and table hard corals, soft coral, rock, rubble and sand were estimated, the mean depth and aspect of the bottom were recorded and the topographic complexity of the substrate was described using the six point scale of Polunin & Roberts (1993). The sites did not show any tendency to cluster into *qoliqoli* specific groups on the basis of their habitat characteristics (Figure 11).

A biomass by species matrix was compiled using data from the census. Cluster analysis (Figure 12) provided no indication that *qoliqoli* subject to different fishing intensities had characteristic fish communities. Rather, as demonstrated by the census of target species, they were simply characterised by a loss of those species favoured by the fishers.

The demonstrable depletion of target species, most of which were large predators, allowed us to test for biodiversity effects of fishing both on target groups and on fishes which are not, or only lightly, exploited. Among the non-target groups, there were strong positive trends as a function of fishing effort in many cases, as exemplified by the parrotfishes (Fig. 13E). Among target predatory fishes, there were negative, but non-significant, trends with fishing effort in snappers and emperors (Fig. 13B and C).

ii. Seychelles

The visual census technique was also used to examine the effects of fishing on the diversity, biomass and trophic structure of Seychelles' reef fish communities. One hundred and thirty four species associated with three significantly different types of reef habitat were censused at one unfished ground and in six fishing grounds subject to different fishing intensities (Table 14, 15).

Fishes were counted and their lengths were estimated at three sites within each fishing ground. The sites were selected to include each of the three main types of fished reef habitat, *viz.*, 1, well developed fringing reef with a carbonate framework, 2, coral growth on a granitic substrate in exposed locations and 3, small (typically 3-7m circumference) rock and coral patch reefs on a predominantly sandy substrate. Counts were conducted by the same observer from 26 April to 12 June 1994. Sixteen replicate counts were completed at each site during daylight hours at depths of 3.0 to 13.0m below chart datum. Replicates were placed randomly within the constraints applied by the necessity for safe dive profiles and the proviso that the boundaries of adjacent counts should be separated by a minimum of 15m (to avoid bias due to push-pull effects in preceding counts; Samoilys, 1992).

Habitat was described both within the perimeter of each replicate count area and within the overall boundaries of the study site. When a count was complete the percentage cover (based on plan view) of sand, rubble, rock, massive coral, soft and branching coral was estimated and topographic complexity of the substrate was described using the 6 point scale of Polunin & Roberts (1993). An exposure index was calculated for each site by determining the 15° sectors (first sector beginning at true north) from which the site was fully exposed to an unobstructed wave fetch of 3km or more, and summing the product of the mean annual windspeed on Mahé (km hr^{-1}) and duration (hours) in each of these sectors (Seychelles Meteorological Office, unpublished data). The general seabed habitat at each site was described in terms of composition and profile. The number of counts in which the dominant underlying substrate consisted of carbonate framework, sand or granite was expressed as a proportion of the total

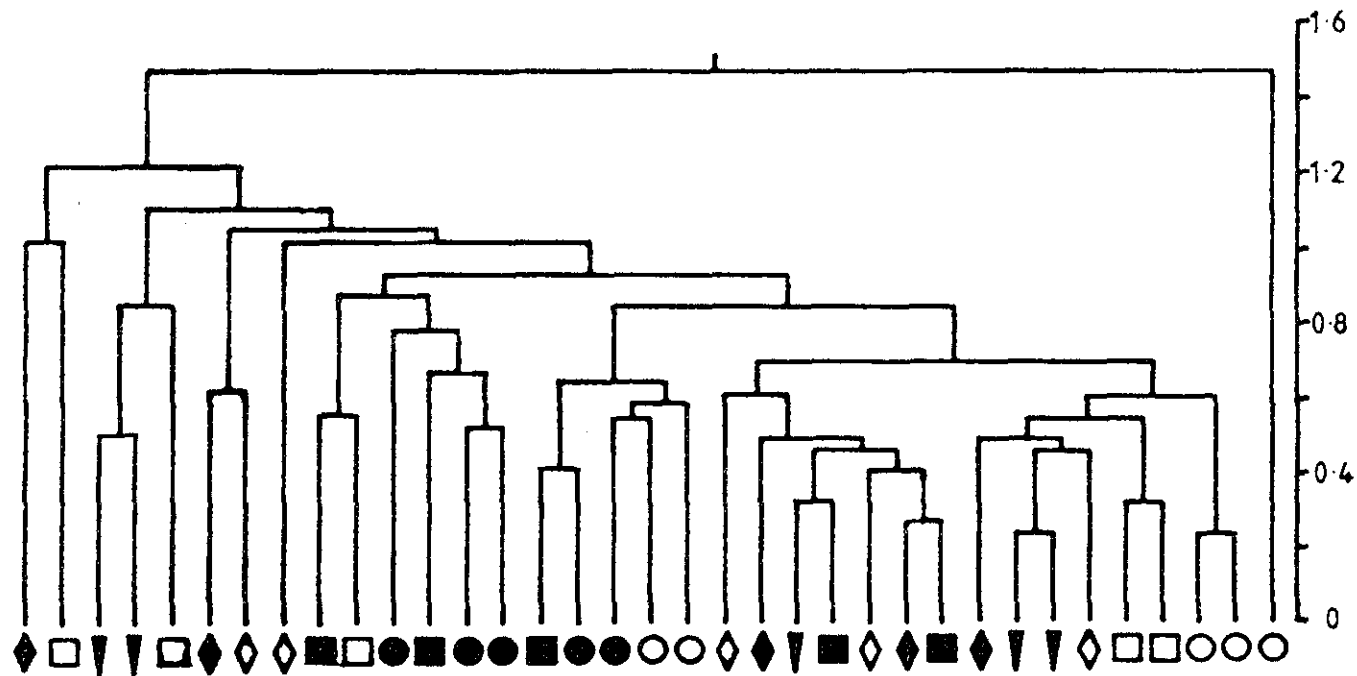


Figure 11. A dendrogram which shows the grouping of habitat types formed by hierarchical classification analysis. An examination of the relationships between habitats at the sites selected for study was made by subjecting the mean values of all site specific habitat indices (depth (m), coral cover (soft, branching, massive, small head (%)), rubble cover (%), rock cover (%), sand cover (%) aspect (°) and topographic complexity (6 point scale of Polunin & Roberts, 1993)) to an agglomerative hierarchical clustering procedure using the average linkage method (Sokal & Michener, 1958). *Qoligoli* codes: ○, Suva; ●, Nukutabua; □, Ko Ono One; ■, Moala; ◇, Cokovata; ◆, Ko Ono Two; ▼, Nauluvatu.

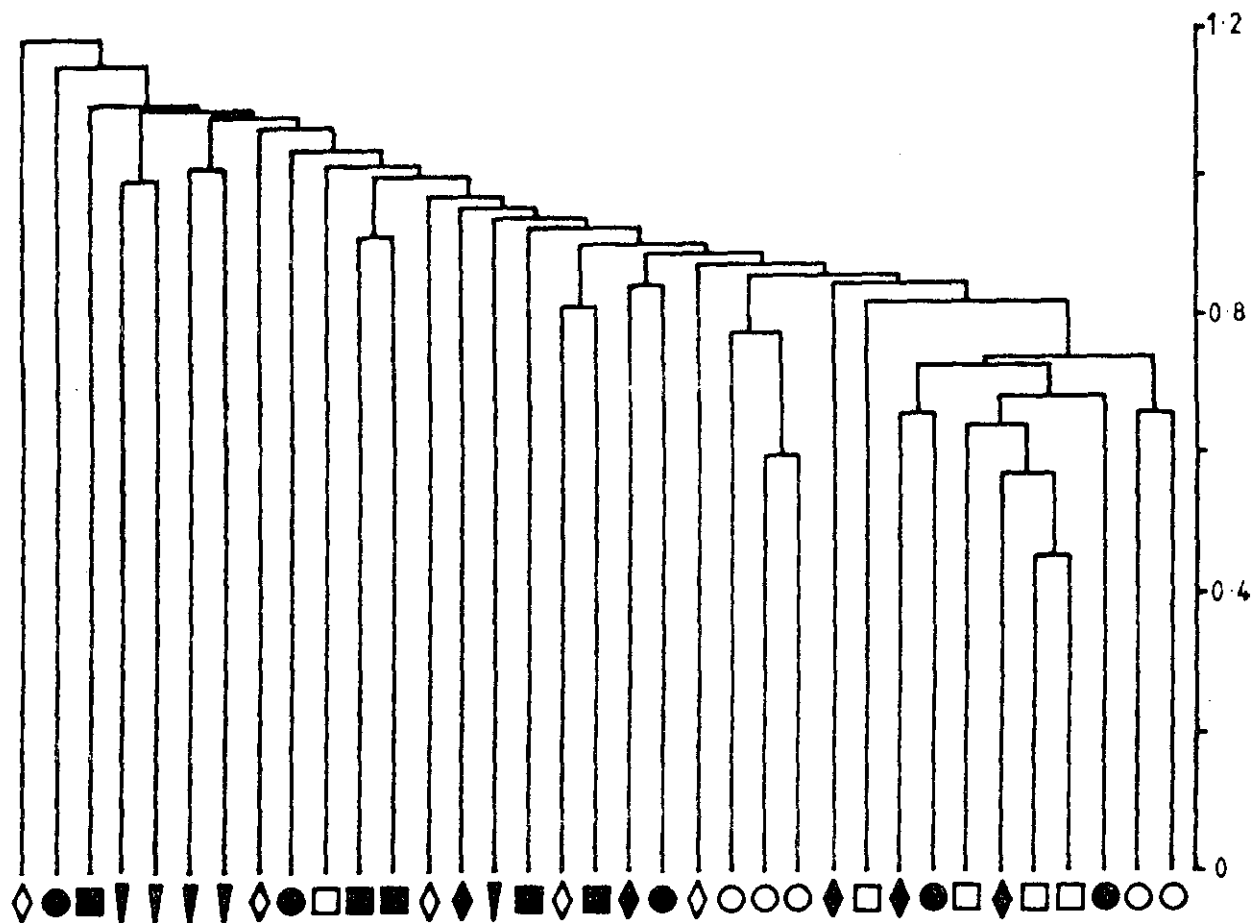


Figure 12. A dendrogram which shows the grouping of fish communities formed by hierarchical classification analysis. An examination of the relationships between fish communities at the sites selected for study was made by subjecting the mean site specific biomass estimates for all species censused ($\geq 8\text{cm}$ length) to an agglomerative hierarchical clustering procedure using the average linkage method (Sokal & Michener, 1958). *Qoliqoli* codes: ○, Suva; ●, Nukutabua; □, Ko Ono One; ■, Moala; ◇, Cokovata; ◆, Ko Ono Two; ▼, Nauluvatu.

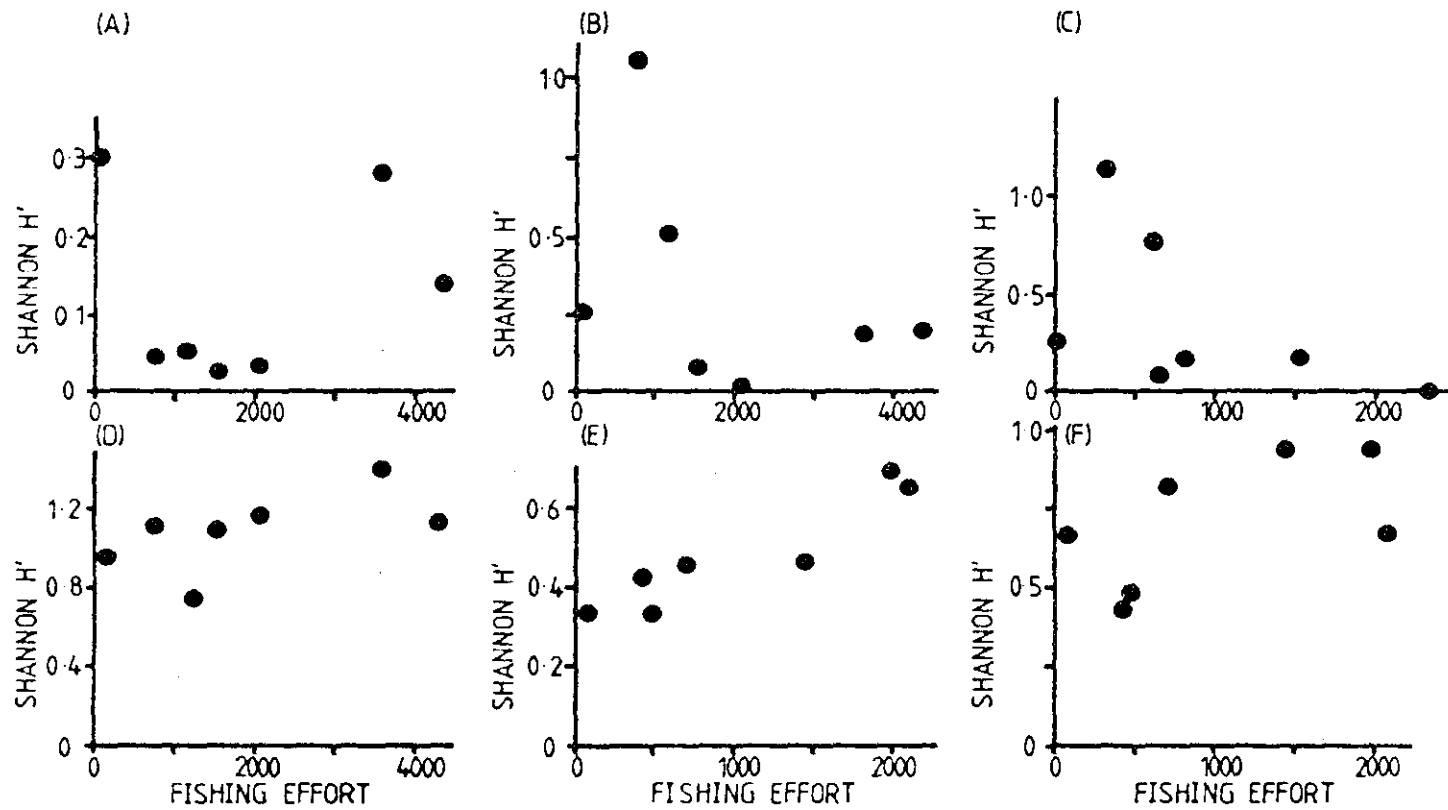


Figure 13. The relationships between diversity (Shannon H') and fishing effort for six families of reef fishes in Fijian *qoliqoli*. A, Serranidae (correlation not significant); B, Lutjanidae (ns); C, Lethrinidae (ns); D, Labridae (ns); E, Scaridae ($r=0.68$, $p<0.001$); F, Chaetodontidae ($r=0.39$, $p<0.05$).

Table 14. Fishing intensity indices for seven Seychelles' fishing grounds. Data from the 1992 Seychelles Fishing Authority boat censuses (Anon, 1993a) were used to estimate the monthly mean number of boats fishing with lines or traps (the methods used on inshore reefs) on a sea-area specific basis within each fishing ground. There are no records of the number of boats fishing or poaching in Ste. Anne, so the effective number of boats fishing was calculated from knowledge of the number of traps and lines licensed to local families (Seychelles Division of Environment, unpublished) and records of illegally positioned traps confiscated by wardens of the National Parks Service (Anon, 1993b). It was assumed i) that 50% of the traps set by poachers were confiscated, ii) that the ratio of trap to line fishing effort was 1:1 and iii) that a single boat with fishing power equivalent to those in other grounds would deploy four traps day⁻¹. Areas of reef habitat (of the three types where fish counts were conducted) within each fishing ground were determined on the basis of sea-surface area using digitised navigational charts (UK Admiralty 722 & 742) or maps (OS Map Series Y851) and records of substrate type collected during diving surveys. Areas were measured using AutoCAD software; from the coast to the 20m isobath for grounds based on Seychelles Fishing Authority strata and to the reserve boundary at Ste. Anne and Cousin.

Ground	Boats (mean no. fishing month⁻¹)	Reef area (km²)	Intensity Index (boats km⁻²)
Cousin	0	0.4	0
Ste. Anne	3.7	2.1	3.5
Mahé NW	25.9	2.7	19.9
Mahé W	27.0	4.6	11.7
Mahé E	45.2	9.0	10.0
Praslin SW	31.2	4.7	13.3
Praslin NE	20.2	5.7	7.0

Table 15. Species for which size and abundance estimates were obtained, the trophic groups to which they were assigned (co, corallivore; hb, herbivore; ip, invertebrate feeder and piscivore; iv, invertebrate feeder; om, omnivore; pi, piscivore; pk, planktivore; dt, detritivore), their maximum lengths (cm; from Smith and Heemstra, 1986, Randall, 1992 and pers. obs.) and their role in the artisanal fishery (***, primary target species caught by most of the fishing techniques in use; **, secondary target species caught using a limited number of techniques; * bycatch sometimes retained if caught; . species which have been observed in catches but which are not retained; from Seychelles Fishing Authority (unpublished data).

Acanthuridae

<i>Acanthurus leucosternon</i> Bennett, 1832	hb	23	.
<i>A. lineatus</i> (Linnaeus, 1758)	hb	38	*
<i>A. nigrofuscus</i> (Forsskål, 1775)	hb	21	.
<i>A. triostegus</i> (Linnaeus, 1758)	hb	27	*
<i>A. tenneti</i> Günther, 1861	hb	31	*
<i>Ctenochaetus binotatus</i> Randall, 1955	dt	22	.
<i>C. striatus</i> (Quoy and Gaimard, 1825)	dt	26	*
<i>C. strigosus</i> (Bennett, 1828)	dt	19	.
<i>Naso lituratus</i> (Forster, 1801)	hb	45	.
<i>Paracanthurus hepatus</i> (Linnaeus, 1766)	pk	31	.
<i>Zebrasoma scopas</i> (Cuvier, 1829)	om	19	*
<i>Z. desjardini</i> (Bennett, 1835)	om	40	.

Balistidae

<i>Sufflamen chrysopterus</i> (Bloch and Schneider, 1801)	iv	20	.
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Chaetodontidae

<i>Chaetodon auriga</i> Forsskål, 1775	iv	20	*
<i>C. guttatisimus</i> Bennett, 1823	iv	11	.
<i>C. kleinii</i> Bloch, 1790	co	12	.
<i>C. lineolatus</i> Cuvier, 1831	co	30	*
<i>C. lunula</i> Lacepède, 1803	iv	20	.
<i>C. madagaskariensis</i> Ahl, 1923	co	20	.
<i>C. trifascialis</i> Quoy and Gaimard, 1824	co	17	.
<i>C. trifasciatus</i> Park, 1797	iv	20	.
<i>C. zanzibariensis</i> Playfair, 1867	iv	15	*

Haemulidae

<i>Diagramma pictum</i> (Thunberg, 1792)	iv	90	**
<i>Plectorhinchus gibbosus</i> (Lacepède, 1802)	iv	70	***
<i>P. orientalis</i> (Bloch, 1793)	iv	55	***
<i>P. schotaf</i> (Forsskål, 1775)	iv	40	***

Labridae

<i>Anampses meleagrides</i> Valenciennes, 1840	iv	21	.
<i>Bodianus axillaris</i> (Bennett, 1831)	iv	20	.
<i>Cheilinus digrammus</i> (Lacepède, 1801)	pi	30	*
<i>C. fasciatus</i> (Bloch, 1791)	iv	36	*
<i>C. trilobatus</i> (Lacepède, 1801)	iv	40	**
<i>Coris formosa</i> (Bennett, 1834)	iv	60	*
<i>Epibulis insidiator</i> (Pallas, 1770)	ip	35	.
<i>Gomphosus caeruleus</i> Lacepède, 1801	iv	28	.
<i>Halichoeres cosmetus</i> Randall and Smith, 1982	iv	12	.
<i>H. hortulanus</i> (Lacepède, 1801)	iv	27	.

Table 15. continued

<i>H. marginatus</i> Rüppell, 1839	iv	17	.
<i>H. scapularis</i> (Bennett, 1831)	iv	20	.
<i>Hemigymnus fasciatus</i> (Bloch, 1792)	ip	45	*
<i>H. melapterus</i> (Bloch, 1791)	ip	50	*
<i>Labrichthys unilineatus</i> (Guichenot, 1847)	iv	17	.
<i>Labroides bicolor</i> (Fowler and Bean, 1828)	iv	14	.
<i>L. dimidiatus</i> Valenciennes, 1839	iv	12	.
<i>Macropharyngodon bipartus</i> Smith, 1957	iv	12	.
<i>Novaculichthys taeniourus</i> (Lacepède, 1801)	iv	25	.
<i>Stethojulis albovittata</i> (Bonnaterre, 1788)	iv	12	.
<i>Thalassoma hardwicke</i> (Bennett, 1828)	iv	18	.
<i>T. herbracium</i> (Lacepède, 1801)	iv	23	*
<i>T. lunare</i> (Linnaeus, 1758)	iv	27	*
Lethrinidae			
<i>Lethrinus concyliatus</i> (Smith, 1959)	ip	76	***
<i>L. enigmatus</i> undescribed	ip	40	***
<i>L. harak</i> (Forsskål, 1775)	ip	60	***
<i>L. lentjan</i> (Lacepède, 1802)	ip	40	***
<i>L. mahsena</i> (Forsskål, 1775)	ip	38	***
<i>L. mahsenoides</i> Valenciennes, 1830	ip	25	***
<i>L. nebulosus</i> (Forsskål, 1775)	ip	87	***
<i>L. obsoletus</i> (Forsskål, 1775)	ip	40	***
<i>L. olivaceus</i> Valenciennes, 1830	ip	100	***
<i>L. rubrioperculatus</i> Sato, 1978	ip	50	***
<i>Monotaxis grandoculis</i> (Forsskål, 1775)	iv	56	***
Lutjanidae			
<i>Aprion virescens</i> Valenciennes, 1830	pi	100	***
<i>Lutjanus argentimaculatus</i> (Forsskål, 1775)	pi	100	***
<i>L. bohar</i> (Forsskål, 1775)	pi	95	***
<i>L. fulviflamma</i> (Forsskål, 1775)	ip	30	***
<i>L. gibbus</i> (Forsskål, 1775)	ip	50	***
<i>L. kasmira</i> (Forsskål, 1775)	ip	30	**
<i>L. monostigma</i> (Cuvier, 1828)	ip	45	***
<i>L. rivulatus</i> (Cuvier, 1828)	ip	60	**
<i>L. russelli</i> (Bleeker, 1849)	ip	40	**
<i>Macolor niger</i> (Forsskål, 1775)	pk	70	**
Monacanthidae			
<i>Cantherines pardalis</i> (Rüppell, 1837)	iv	21	*
<i>Oxymonacanthus longirostris</i> (Bloch and Schneider, 1801)	co	10	.
Mullidae			
<i>Mulloides flavolineatus</i> (Lacepède, 1801)	ip	40	*
<i>P. barberinus</i> (Lacepède, 1801)	iv	50	*
<i>P. bifasciatus</i> (Lacepède, 1801)	ip	35	*
<i>P. ciliatus</i> (Lacepède, 1801)	ip	40	*
<i>P. cyclostomus</i> (Lacepède, 1801)	ip	50	*
<i>P. rubescens</i> (Lacepède, 1801)	ip	42	*
<i>P. macronema</i> (Lacepède, 1801)	iv	32	*

Table 15. continued

Nemipteridae			
<i>Scolopsis frenatus</i> (Cuvier, 1830)	iv	28	*
Pomacanthidae			
<i>Apolemichthys trimaculatus</i> (Lacepède, 1831)	iv	21	.
<i>Centropyge multispinis</i> (Playfair, 1867)	iv	12	.
<i>Pomacanthus imperator</i> (Bloch, 1787)	iv	40	*
<i>P. semicirculatus</i> (Cuvier, 1831)	iv	38	.
Pomacentridae			
<i>Ambyglyphidodon leucogaster</i> (Bleeker, 1847)	pk	14	.
<i>Chromis atripectoralis</i> Welander and Schultz, 1951	pk	14	.
<i>C. ternatensis</i> (Bleeker, 1856)	pk	11	.
<i>C. weberi</i> Fowler and Bean, 1928	pk	14	.
<i>Dascyllus trimaculatus</i> (Ruppell, 1828)	pk	14	.
<i>Neoglyphidodon melas</i> (Cuvier, 1830)	iv	18	.
<i>Plectroglyphidodon dickii</i> (Lienard, 1839)	om	11	.
<i>P. johnstonus</i> Fowler and Ball, 1924	om	10	.
<i>P. lacrymatus</i> Quoy and Gaimard, 1824	hb	12	.
<i>Pomacentrus trilineatus</i> Cuvier, 1830	hb	12	.
<i>Stegastes nigricans</i> (Lacepède, 1802)	hb	13	.
Scaridae			
<i>Calotomus carolinus</i> (Valenciennes, 1840)	hb	54	*
<i>Cetoscarus bicolor</i> (Rüppell, 1829)	hb	80	**
<i>Hipposcarus harid</i> (Forsskål, 1775)	hb	75	**
<i>Leptoscarus vaigiensis</i> (Quoy and Gaimard, 1824)	hb	35	*
<i>Scarus atrilunula</i> Randall and Bruce, 1923	hb	30	**
<i>S. caudofasciatus</i> (Gunther, 1862)	hb	70	**
<i>S. falcipinnis</i> Playfair, 1867	hb	47	**
<i>S. frenatus</i> Lacepède, 1802	hb	47	**
<i>S. ghobban</i> Forsskål, 1775	hb	75	**
<i>S. gibbus</i> Rüppell, 1829	hb	70	**
<i>S. globiceps</i> Valenciennes, 1840	hb	27	*
<i>S. niger</i> Forsskål, 1775	hb	35	**
<i>S. psittacus</i> Forsskål, 1775	hb	30	**
<i>S. rubroviolaceus</i> (Bleeker, 1849)	hb	75	**
<i>S. scaber</i> Valenciennes, 1840	hb	37	**
<i>S. sordidus</i> Forsskål, 1775	hb	35	**
<i>Scarus</i> sp	hb	38	**
<i>S. tricolor</i> Bleeker, 1847	hb	40	**
<i>S. viridifucatus</i> (Smith, 1956)	hb	33	*
Serranidae			
<i>Aethaloperca roga</i> (Forsskål, 1775)	ip	61	***
<i>Anyperodon leucogramma</i> (Valenciennes, 1828)	pi	50	**
<i>Cephalopholis argus</i> Bloch and Schneider, 1801)	pi	50	***
<i>C. leopardus</i> (Lacepède, 1801)	ip	20	**
<i>C. miniata</i> (Forsskål, 1775)	pi	41	***
<i>C. urodeta</i> (Bloch and Schneider, 1801)	ip	28	**
<i>Epinephelus caeruleopunctatus</i> (Bloch, 1790)	pi	60	***
<i>E. fasciatus</i> (Forsskål, 1775)	ip	35	***
<i>E. hexagonatus</i> (Bloch and Schneider, 1801)	ip	25	***
<i>E. merra</i> Bloch, 1793	ip	28	**
<i>E. spilotoceps</i> Schultz, 1953	ip	35	**
<i>E. tukula</i> Morgans, 1959	ip	200	***

Table 15. continued

Siganidae

<i>Siganus argenteus</i> (Quoy and Gaimard, 1825)	hb	37	***
<i>S. puelloides</i> Woodland and Randall, 1979	hb	35	**
<i>S. stellatus</i> Forsskål, 1775	hb	30	**
<i>S. sutor</i> (Valenciennes, 1835)	om	45	***

Zanclidae

<i>Zanclus cornutus</i> (Linnaeus, 1758)	iv	22	.
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number of replicate counts within each site and the minimum and maximum depth within each count area was recorded to provide a crude index of site rugosity.

Clustering of sites on the basis of their habitat characteristics (Figure 14) produced three significantly different groups ($p < 0.05$). The groups corresponded with the carbonate based coral reef (code 1), rock based coral reef (2) and patch reef (3) habitat types selected for study, with the exception of the carbonate based reef site in Mahé W (Fig 1) which clustered with the patch reefs on sandy substrate. Characteristics of the different habitat types are summarised in Table 16. The distribution of fishing intensity indices (Table 14) in relation to the geographic location of the grounds (Fig 1) indicates that grounds with similar fishing intensity were not grouped on the same islands or coasts of islands.

All lutjanid, lethriniid, chaetodontid, mullid and scarid species encountered during the survey were included in the census and their within-family diversity is shown in Figure 15. The number of lethriniid species recorded per count was significantly higher at the unfished ground in habitats 1 ($p < 0.005$) and 2 ($p < 0.001$) and the least intensively fished ground in habitat 3 ($p < 0.005$). Correlations between the number of lethriniid species per count and fishing intensity were significant in habitat 1 ($r = -0.77$, $p < 0.05$) but not in habitats 2 or 3 ($p > 0.05$). The number of lutjanid species recorded per count was higher in the unfished or least intensively fished grounds of all habitat types ($p < 0.05$) and correlations between species number and fishing intensity were significant at habitats 2 ($r = -0.88$, $p < 0.01$) and 3 ($r = -0.88$, $p < 0.05$) but not 1 ($p > 0.05$). Differences in the mean number of chaetodontid, mullid and scarid species were significantly different in all habitats ($p < 0.05$), with the exception of mullids in habitat 3 ($p > 0.05$). However, there were no significant correlations between fishing intensity and the mean number of chaetodontid, mullid or scarid species recorded per count (except for chaetodontids in habitat 2, $r = -0.82$, $p < 0.05$) and no indication of consistently higher numbers of these species at specific sites.

Twenty-five species each contributed more than 1% of the total recorded biomass, and their biomass at the different grounds is shown in Figure 16. The mean biomass of primary target species (Figure 16a) differed significantly between grounds ($p < 0.05$). The significance of decreases in the biomass of individual target species was generally attributable to differences between the unfished and /or most lightly fished site and all others. Thus, the biomass of *A. virescens* and *L. obsoletus* was significantly higher in the 2 least heavily fished sites and that of *L. bohar* significantly higher in the unfished site ($p < 0.05$). Similarly, in two of three habitat types the biomass of *C. argus* and *S. argenteus* was significantly higher in the unfished site ($p < 0.05$). For the ten species considered to be of secondary importance as target species (Figure 16b) the mean biomass at different grounds differed significantly only for *L. harak* in habitat 2 ($p < 0.05$), *L. fulviflamma* in habitat 3 ($p < 0.05$), *S. ghobban* (pooled data, $p < 0.05$) and *S. frenatus* (pooled data, $p < 0.01$). In addition, there was a significant negative correlation between the biomass of *S. frenatus* and fishing intensity ($r = -0.86$, $p < 0.01$). Differences between the biomass of the ten non-target and by-catch species in different grounds (Figure 16c) were frequently significant. However, there were no significant correlations between fishing intensity and mean biomass of these ten species ($p < 0.05$) and no trends indicating consistently higher biomass at specific sites.

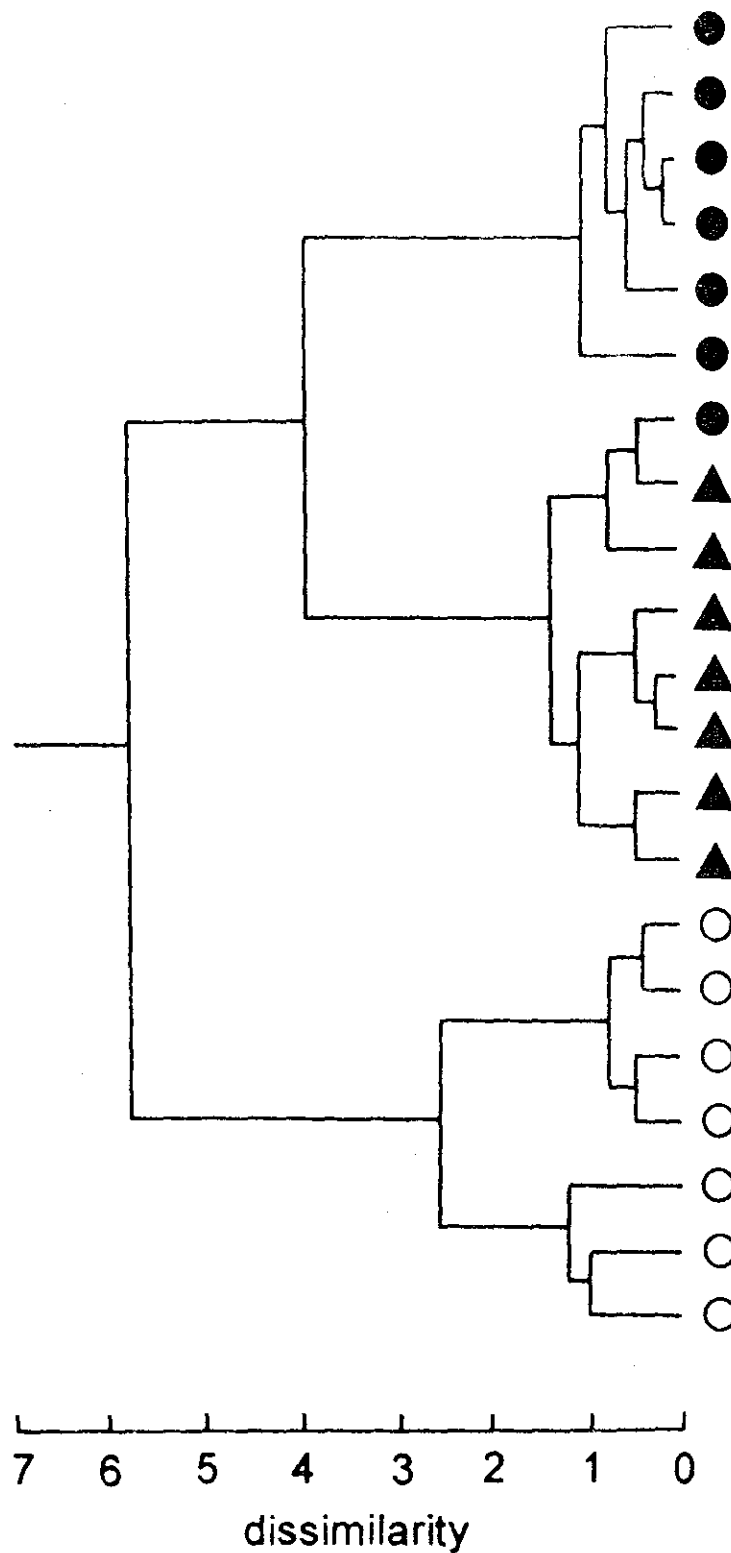


Figure 14. A dendrogram which shows the grouping of habitat types formed by hierarchical classification analysis. An examination of the relationships between habitats at the sites selected for study was made by subjecting the means of all replicate-specific habitat indices ((depth (m), coral cover (%), rubble cover (%), rock cover(%), sand cover (%)) and topographic complexity (6 point scale of Polunin & Roberts, 1993)) and the values of site specific habitat indices (exposure (Table 16), gross relief (Table 16), calcareous substrate (%), sandy substrate (%), rock substrate (%)) to an agglomerative hierarchical clustering procedure using the average linkage method (Sokal & Michener, 1958). All data were standardised to mean=0 and SD=1 before clustering. Habitat types: ●=1, well developed fringing reef with a carbonate framework. ○=2, coral growth on a granitic substrate in exposed locations. ▲=3, small rock and coral patch reefs on a predominantly sandy substrate.

Table 16. Characteristics of the habitat types in Seychelles' fishing grounds. Values are means \pm SD (n=112) unless indicated otherwise. *1, Expressed in relative terms where maximum possible value =1; *2, Expressed as the proportion of replicate counts in which a given substrate was dominant; *3, n=7. Habitat types: 1, well developed fringing reef with a carbonate framework; 2, coral growth on a granitic substrate in exposed locations; 3, small rock and coral patch reefs on a predominantly sandy substrate.

	Habitat 1	Habitat 2	Habitat 3
Coral Cover (%)	34.1 \pm 11.11	24.6 \pm 10.91	19.22 \pm 7.10
Sand Cover (%)	7.1 \pm 9.70	4.1 \pm 6.28	13.4 \pm 12.44
Rubble Cover (%)	32.7 \pm 20.4	25.0 \pm 25.25	22.1 \pm 13.15
Rock Cover (%)	13.4 \pm 12.50	40.3 \pm 28.73	30.5 \pm 10.36
Mean Depth (m)	5.8 \pm 0.61	7.1 \pm 1.55	6.8 \pm 1.23
Mean (Max-Min Depth) (m)	2.2 \pm 0.35	4.1 \pm 0.70	2.8 \pm 0.57
Habitat Complexity*1	0.62 \pm 0.039	0.64 \pm 0.069	0.65 \pm 0.053
Exposure*1*3	0.18 \pm 0.236	0.55 \pm 0.156	0.38 \pm 0.137
Calcareous substrate*2*3	0.86 \pm 0.152	0.09 \pm 0.087	0.44 \pm 0.051
Sand substrate*2*3	0.05 \pm 0.076	0.13 \pm 0.114	0.48 \pm 0.059
Rock substrate*2*3	0.09 \pm 0.134	0.79 \pm 0.157	0.08 \pm 0.059

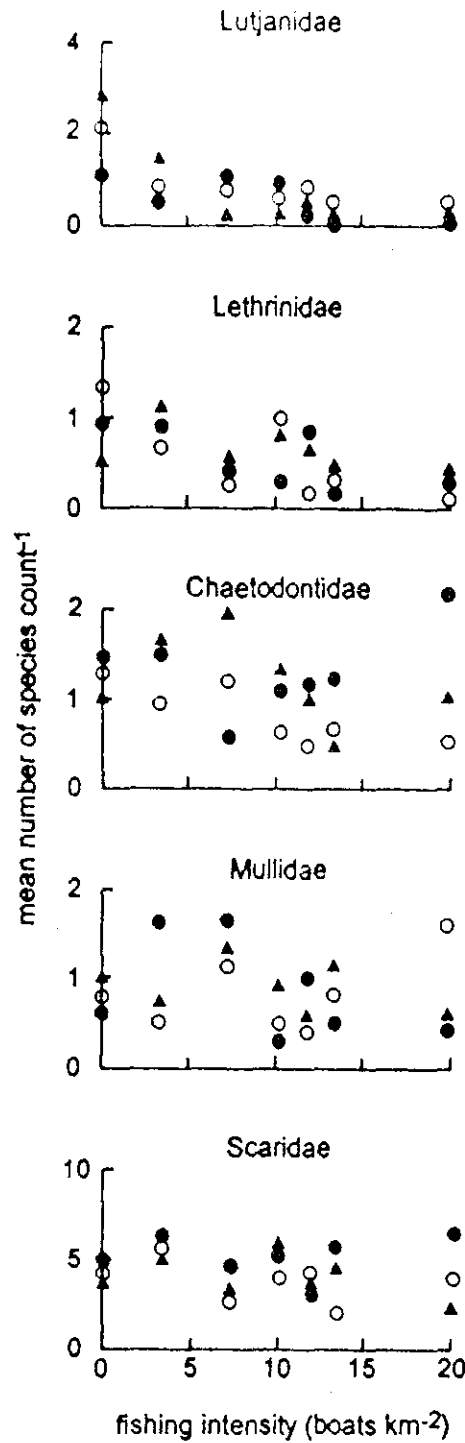


Figure 15. The relationship between the numbers of species recorded and fishing intensity within five families of reef fishes in Seychelles' fishing grounds. Habitat types: ●=1, well developed fringing reef with a carbonate framework. ○=2, coral growth on a granitic substrate in exposed locations. ▲=3, small rock and coral patch reefs on a predominantly sandy substrate.

Grounds

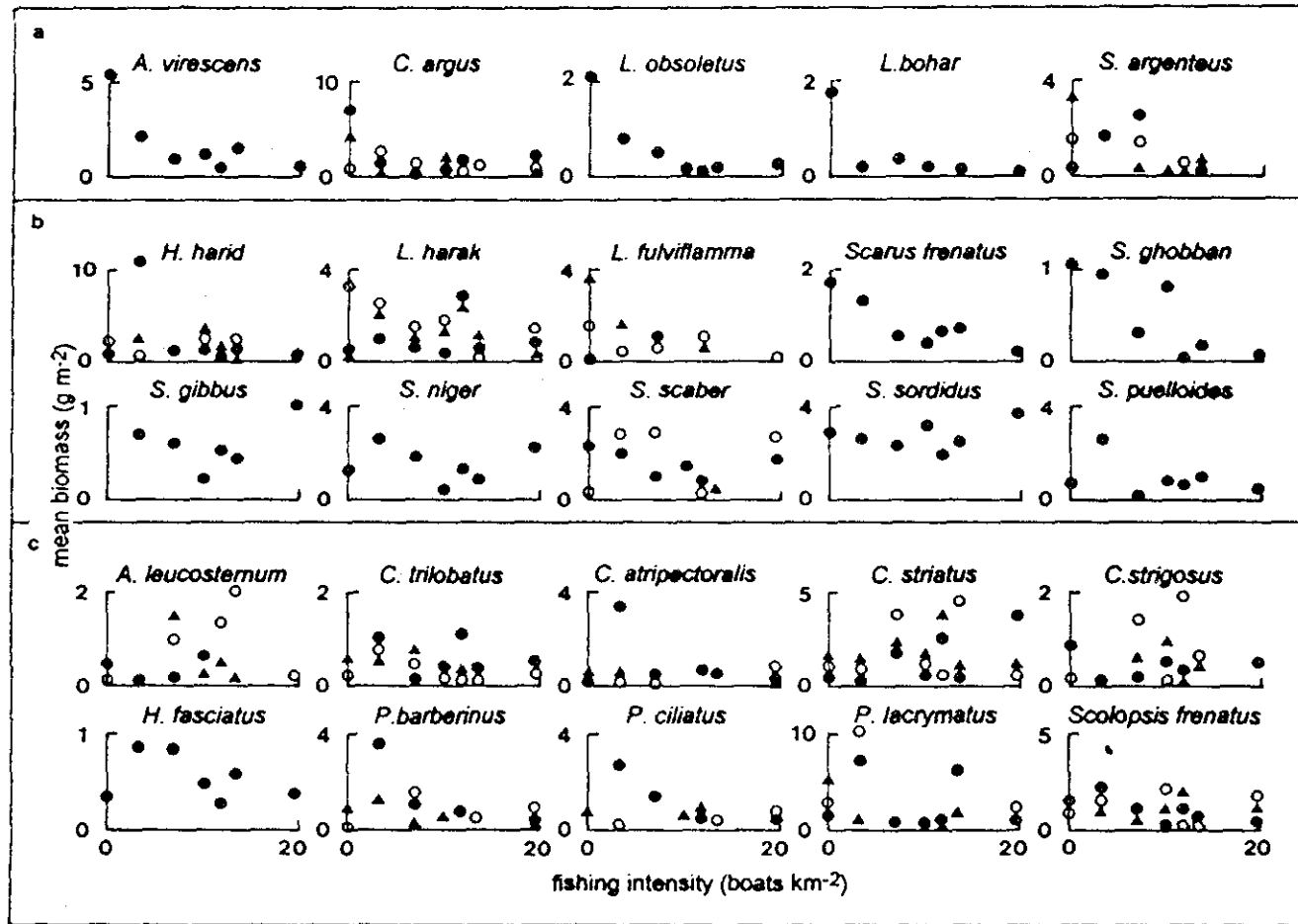


Figure 16. The relationship between biomass and fishing intensity for a. primary target species, b. secondary target species and c. species which are retained as bycatch or not fished in Seychelles reef fisheries. Mean values for replicates pooled across habitats are presented when interactions between grounds and habitats or differences between habitats were not significant (two-way crossed ANOVA, $p > 0.05$). In other cases symbols indicate habitat types. Habitat types: ●=1, well developed fringing reef with a carbonate framework. ○=2, coral growth on a granitic substrate in exposed locations. ▲=3, small rock and coral patch reefs on a predominantly sandy substrate.

The total biomass of all fish censused (Figure 17) was significantly higher in the unfished and least heavily fished site than at all others in all habitats ($p < 0.05$). Total biomass in habitats 1 and 3 was significantly correlated with fishing intensity ($r = -0.84$, $p < 0.05$; $r = -0.75$, $p < 0.05$) but not in habitat 2 ($p > 0.05$). Piscivore and invertebrate feeder/ piscivore biomass was significantly correlated with fishing intensity ($r = -0.76$, $p < 0.05$; $r = -0.85$, $p < 0.01$) and the biomass was significantly higher at the unfished and least intensively fished sites ($p < 0.05$). Differences between mean biomass in different grounds were significant ($p < 0.05$) for all other trophic groups (with the exception of invertebrate feeders in habitat 2 and planktivores in habitat 2). However, the only significant correlations between biomass and fishing intensity were for herbivores in habitat 2, invertebrate feeders in habitat 3 and corallivores in habitat 3 ($r = -0.76$, $p < 0.05$; $r = -0.74$, $p < 0.05$; $r = -0.81$, $p < 0.05$). For detritivores in all habitats the mean biomass at the unfished and least heavily fished site was in the lowest group of means which did not differ significantly ($p < 0.05$).

The biomass of fish which grow to a maximum size of less than 20 cm and which are rarely caught due to their small size and feeding strategy was not related to fishing intensity (Figure 18). The biomass of small detritivores, small omnivores and small planktivores was significantly different between grounds in all habitat types ($p < 0.05$) but there were no correlations with fishing intensity ($p > 0.05$). For small invertebrate feeding species, there were no significant differences between biomass in different grounds and no correlations between biomass and fishing intensity ($p > 0.05$).

Clearly, differences in the diversity, biomass or trophic structure of reef fish communities may be attributed to a number of factors and may not be persistent in space or time. However, there is a range of evidence to suggest that fishing effects were responsible for some of the significant trends observed. In particular, trends were examined across a range of seven grounds subject to different fishing intensities rather than using the paired (in space or time) comparisons which typified many previous studies. Whilst habitat characteristics such as coral cover, reef size, reef height, topographic complexity of the substrate, current flow and exposure have been shown to influence fish abundance (review Williams, 1991), the analysis of habitat data from the different grounds suggested that similarities within habitat types between fishing grounds are considerably greater than those between habitat types and within grounds. Furthermore, the distribution of fishing intensity indices in relation to geographic location of grounds indicated that grounds with similar fishing intensity were not grouped on the same islands or coasts of islands and, therefore, geographic trends in fish distribution were unlikely to lead to differences between fish populations which would be falsely attributed to fishing. Existing descriptions of the movements and migrations of many reef fish species (review Jennings & Lock, in press) suggest that only a relatively small proportion of fish would move between relatively large fishing grounds and thereby affect biomass estimates. However, given the proximity of individual grounds, the current flows on the Seychelles Bank (Seychelles Division of Environment, unpublished) and the duration of pelagic egg and larval phases in many reef fish (review Victor, 1991) it is reasonable to assume that fish populations within individual grounds are not predominantly self-recruiting.

18a 18b
3

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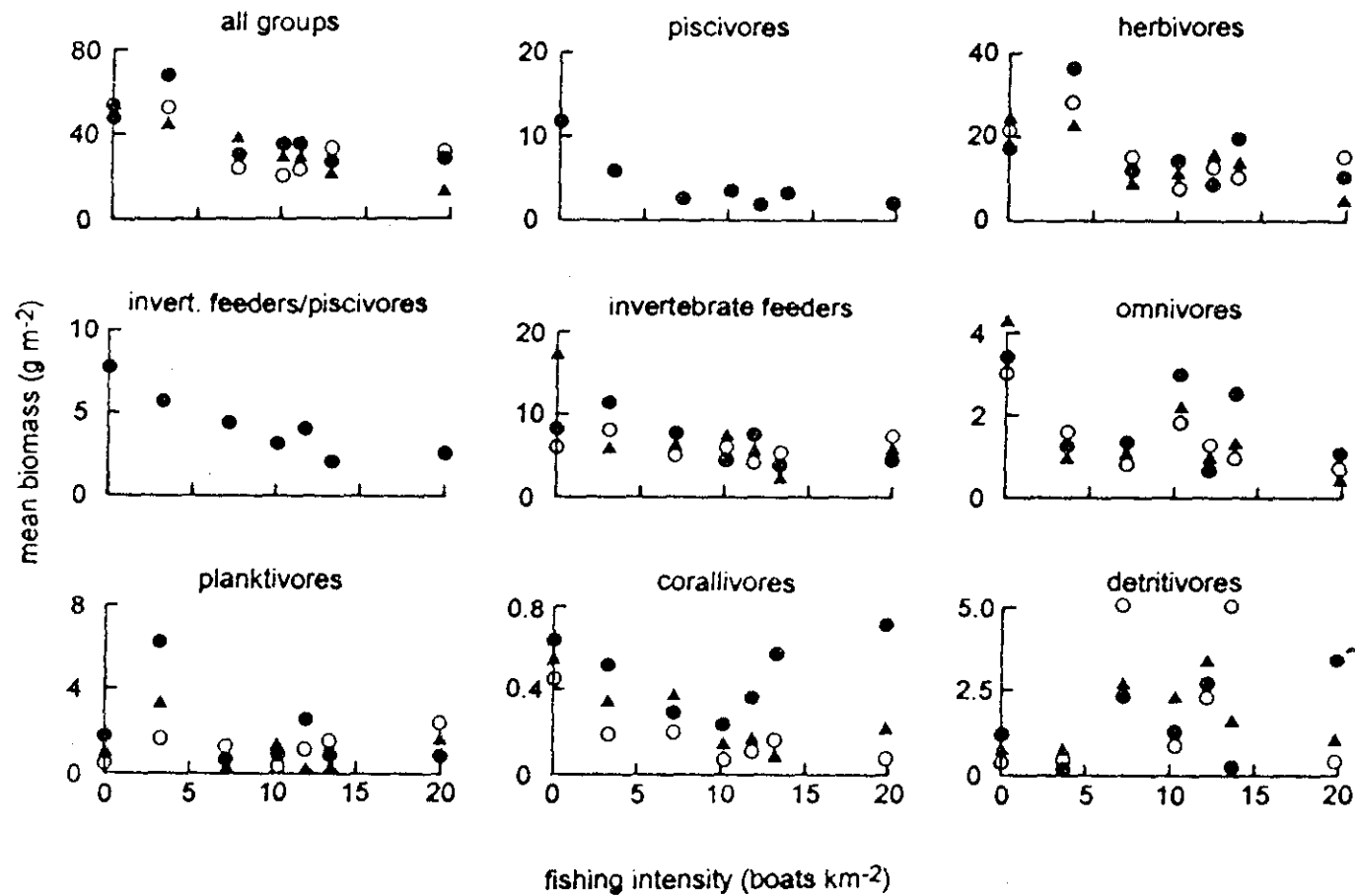


Figure 17. Relationships between biomass of trophic groups and fishing intensity in Seychelles reef fisheries. Mean values for replicates pooled across habitats are presented when interactions between grounds and habitats or differences between habitats were not significant (two-way crossed ANOVA, $p > 0.05$). In other cases symbols indicate habitat types. Habitat types: ●=1, well developed fringing reef with a carbonate framework. ○=2, coral growth on a granitic substrate in exposed locations. ▲=3, small rock and coral patch reefs on a predominantly sandy substrate.

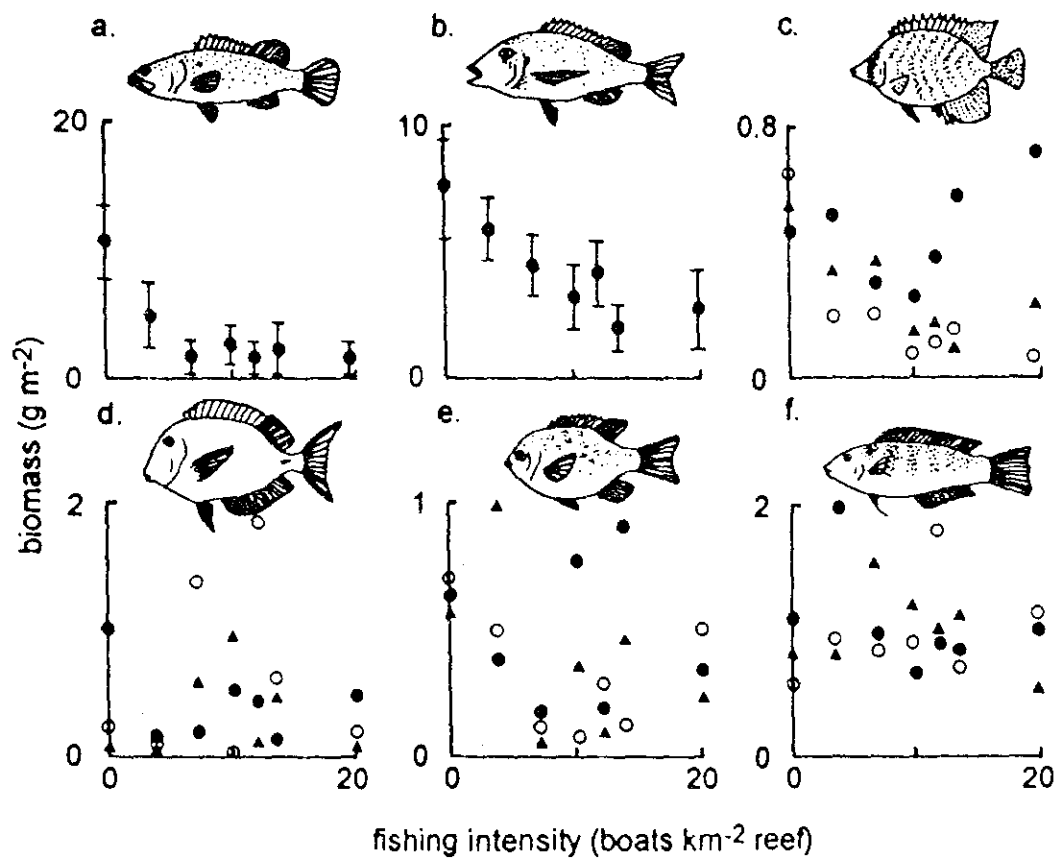


Figure 18. The relationship between biomass and fishing intensity for six trophic groups on Seychelles reefs. a, piscivores (mean±95% CI, n=48); b, invertebrate feeders and piscivores (mean±95% CI, n=48); c, corallivores of species with a maximum size <20cm total length (open circles, closed circles and triangles indicate means on three types of reef habitat, n=16); d, detritivores <20cm; e, omnivores <20cm; f, invertebrate feeders <20cm.

4. Implications of the results

i. Use of CPUE data in tropical fisheries assessment

The popularity of relatively inefficient fishing techniques suggests that certain assumptions which are often treated as implicit when analysing CPUE data may not be valid in reef fisheries such as these. Within a multigear fishery this has important repercussions for those who are developing yield models based on simplistic effort measures such as total numbers of people or total time fishing. In particular, fishers may only be forced to fish more intensively when they struggle to catch sufficient fish for their requirements and thus CPUE will apparently be maintained as more effort is being allocated per unit time.

ii. Surplus yield models for tropical reef fisheries stock assessment

The departure of relationships between CPUE and effort from linearity could have profound effects upon predictions of the sustainable yield in fisheries. We observed such departures in Fiji and they were suggested by the biomass and effort relationships in Seychelles. Variants of the surplus yield models developed by Graham (1935) and Schaefer (1954) still provide an attractive option for the provision of rapid interim predictions of sustainable yield in fisheries of limited economic or social significance which are unlikely to be selected for rigorous or immediate scientific study (Munro & Fakahau, 1993). They require simple inputs of catch and effort data, and, if necessary, these can be obtained from a number of sites subject to different fishing intensities, such as those considered in the present study (Caddy & Garcia 1983; Munro & Williams 1985). However, an underlying property of all symmetrical variants developed from the Schaefer (1954) model is that a linear relationship exists between CPUE and fishing effort (Kirkwood 1982). It is clear from the present study, and a range of studies in other regions, that such relationships often exhibit clear departures from linearity. In these cases, derivatives of the Pella & Tomlinson (1969) surplus production model would provide more appropriate estimates of sustainable yield since an additional parameter in their model permits the biomass regeneration function to adopt a range of different forms. The implication is that simple data inputs will no longer suffice here.

iii. The effects of fishing on community structure

The study provided empirical evidence that a given increase in fishing effort or catch rate will have a greater effect on the biomass and structure of an unfished community than on a community which is already exploited. This finding has important consequences for understanding fishing effects and for marine reserve management. If marine reserves are intended to protect the spawning stock biomass or community structure of target fishes then any fishing concessions or poaching activities which result in the annual removal of more than 2-5% of biomass will cause significant long-term decreases in biomass and changes to fish community structure. Explanations for this pattern of depletion include initial targeting of susceptible aggregations, such as are well known for groupers, or fishing down of stocks dominated by old fish.

The results from Seychelles support the findings of the Fiji study because they suggest that increases in effort within sustainably fished areas tend to have a smaller impact on biomass than starting to fish in an unfished system. The two factors which determine yield at a given biomass will be the rate of recruitment to the fishery and the growth of these recruits. On the basis of information available it is impossible to determine their relative significance. Biomass may not change across a range of fishing intensities because the fishers are consistently cropping the majority of those fish which recruit to the fishery. In addition, an increased rate of biomass regeneration (fish production) may compensate, in part, for the removal of fish by the fishery.

This possibility is compatible with the widely reported decreases in size that have been attributed to fishing since the form of fish growth trajectories is such that, within a population of given biomass, decreases in mean size are expected to lead to increases in mean production. An additional consequence of there being a greater proportion of the biomass in smaller fish of fewer dominant age classes may be that fluctuations in recruitment will have greater relative effects on the total stock biomass and thus lead to greater instability (variance) in population size. This may make fishing effects harder to detect in heavily fished areas.

iv. The sustainability of existing fishing practices

The study suggested that Fijian reefs and their associated shallow-water habitats had the capacity to sustain total yields of reef associated fishes of at least 3.4 tonne km⁻² *qoliqoli* year⁻¹ or 10.2 tonne km⁻² reef year⁻¹. At some of the sites examined, where yields were significantly less, there was some possibility of increasing yield whilst maintaining sustainability.

The result of the Seychelles study suggest that, despite decreases in total biomass, processes of recruitment and fish production are sufficient to allow yields to be maintained at existing fishing levels. The total catch of reef associated species landed by the small boat fishery off Mahé, Praslin and La Digue was 759 t in 1992 (Anon, 1993a) and the area (based on sea surface area) to 20m depth around these islands is approximately 170 km². Since the seabed in this area is often sand, rock, seagrass or rubble bottom and may not be fished as intensively as reef areas, but forms a habitat crudely comparable with those measured in other studies of area specific reef fish yields (Russ, 1991; Jennings and Polunin, in press, a). The mean yield from this area would be 4.5 t km² yr⁻¹, which suggests that, if this is a mean value, the fishing grounds studied represented a range of fishing intensities from unfished to close to the limits of sustainability (Russ, 1991). It should be emphasised, however, that the yields from heavily fished areas may only be maintained because larvae can recruit from adjacent and less heavily fished areas. Thus the collective effects of fishing must be considered and the study does not necessarily indicate that it is safe to increase effort to a theoretical maximum throughout the islands.

v. Evidence for the increased dominance of fast growing prey species

Whilst piscivory is one of the major processes of energy transfer within the reef ecosystem (Grigg *et al*, 1984; Parrish 1987; Norris & Parrish, 1988; Hixon, 1991) the present study provides no evidence for a consistent increase in the dominance of prey species following a significant reduction in the biomass of some of their predators. Thus detritivores, corallivores or small (<20cm maximum size) detritivores, omnivores, planktivores and invertebrate feeders are neither target nor retained bycatch species and yet, with the exception of a small response in some detritivores, there were no signs of increased biomass in grounds where predator populations had been reduced. Furthermore, the small responses observed did not compensate for the reduction in the biomass of target species, and total community biomass appeared to decrease significantly in response to fishing. Other studies of predation effects have also shown no marked responses in prey populations but have been hampered by the immigration of new piscivores to the study area and experimental artifacts or other extraneous factors which affect prey abundance (eg. Lassig, 1982; Stimson *et al*, 1982; Thresher, 1983; Doherty & Sale, 1985; Sphigel & Fishelson, 1991). However, in the present study there were significant differences between the biomass of the censused piscivorous and invertebrate-feeding/piscivorous species at the different grounds, although it is not clear how fishing has affected the density of cryptic piscivores such as muraenids or roving piscivores such as

carangids and some elasmobranchs. These species may play an important functional role in the ecosystem. Sudekum *et al* (1990) calculated the fish consumption of two carangid species on a Hawaiian reef and they consumed more fish per unit area than are characteristically removed by man from the most heavily fished reef areas (Russ, 1991). The lack of significant prey release may be a function of the complexity of trophic interactions within the reef ecosystem. Hixon (1991) suggested that diffuse predation may mask predator-prey relationships because the overall effect of all piscivores on the prey population is substantial and yet the impact of each species is minor. Bohnsack (1982) demonstrated significant decreases in the biomass of a few piscivorous species in a fished area and also found no convincing evidence for widespread changes in prey populations, whereas in an experiment at small spatial scale Caley (1993) removed all reef species likely to consume fish (with the exception of roving species) and provided evidence for increases in the abundance of some prey species.

The findings of the present study are important for fishery managers because they suggest that the intensive differential cropping of top predators will not necessarily lead to increases in the biomass or productivity of their prey. In enclosed lake fisheries there are examples of prey release following piscivore removal (Marten, 1979ab). However, these systems lack the complexity of trophic linkages between fish species which characterise reef ecosystems and the diversity of piscivorous species is considerably lower in lakes (Jones, 1982). There are implications of this for the detection of fishing effects, and also for fishing strategy. Absence of prey release suggests that for the situations which we have investigated, no single species or group of finfishes might be used to indicate high levels of fishing. On the matter of strategy, Munro & Williams (1985) and Grigg *et al* (1984) suggested that actively fishing piscivorous species may ensure that potential or actual catches of prey may be increased. It is unlikely that such a strategy would provide sufficient additional yield to be effective unless a very wide range of predators could be cropped - using a method, or methods, akin to the complex age, size and situation related feeding strategies of the piscivorous fishes. A fishing strategy of this type is likely to be impractical and more benefit may be derived from cropping prey species on the basis that they form a major proportion of total community biomass and are likely to be faster growing and more productive than species at higher trophic levels.

vi. Management of complex inshore reef fisheries

If the consequences of interspecies interactions are weak, as our findings indicate for these fisheries, then single-species models may be more feasible than has been commonly supposed (Polunin *et al*, in press). At the same time, even the simple models rely on growth and mortality analyses which may be inadequate. Under these circumstances, it is desirable to foster empirical approaches to assessment, as implied by the notion of 'adaptive' management. As part of such an approach, as well as an alternative basis to reliably maintaining the catch of reef fishers, detailed investigations of the dynamics of small closed areas are urgently needed.

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5. Priority tasks for follow-up

In order to be of value to fishery managers it is important that the results of this study are widely reported. The results of the study are, therefore, being disseminated through seminars, scientific publications and the book 'Tropical Reef Fisheries'.

Seminars

Jennings (February 1994) Catch-effort relationships and the management of Fijian reef fisheries. University of the South Pacific, Fiji.

Jennings (March 1994) Fishing effects and the management of Fijian reef fisheries. South Pacific Commission Regional Technical Meeting on Fisheries, New Caledonia.

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Jennings (November 1994) Catch-effort relationships and the management of tropical reef fisheries. Ministry of Agriculture, Fisheries and Food, Fisheries Laboratory, Lowestoft, United Kingdom.

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Reviews

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6. Summary of financial expenditure.

This summary was prepared by the Finance Office at the University of Newcastle upon Tyne and is appended to this report.



Finance Department
University of Newcastle
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Newcastle upon Tyne NE1 7RU
Director of Finance
D J Purvis BSc FCA

University Ref: R690/00493/01

**ODA Research Scheme
Fish Management Science**

Ref: No 10 Multi-species Responses of Reef Fisheries to Exploitation in the Pacific

Financial Statement of Expenditure and Receipts

Staff Costs	1992/93	£19,745.50	
	1993/94	£21,789.21	
	1994/95	£20,326.08	£61,860.79
Overheads	1992/93	£7,899.56	
	1993/94	£8,715.67	
	1994/95	£8,130.43	£24,745.66
Travel & Subsistence	1992/93	£9,400.54	
	1993/94	£8,223.61	
	1994/95	£1,757.25	£19,381.40
Other	1992/93	£5,939.00	
	1993/94	£4,439.00	
	1994/95	£1,526.09	£11,904.09
Materials	1992/93	£950.00	
	1993/94	£1,233.90	
	1994/95	£500.00	£2,683.90
Equipment	1992/93*	£2,248.89	
	1993/94	£4,109.58	£6,358.47
	1994/95		
Total Expenditure			£126,934.31
Income			£114,465.96
Balance outstanding			£12,468.35

Certified by

Margaret Elliott

Administrative Assistant, Research Services Unit

*Additional award for Equipment

9 February 1995