NOAA Technical Memorandum NMFS

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SEPTEMBER 1990

UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT AND NATIONAL MARINE FISHERIES SERVICE WORKSHOP ON TROPICAL FISH STOCK ASSESSMENT, 5-26 JULY 1989, HONOLULU, HAWAII

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Acknowledgments

The United States Agency for International Development and the National Marine Fisheries Service Workshop on Tropical Fish Stock Assessment was co-sponsored by the Honolulu Laboratory, Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, and the Hawaii Institute of Marine Biology, School of Ocean and Earth Science and Technology, University of Hawaii. Funds for the workshop were provided by the United States Agency for International Development (879-0009-1-80038).

INTRODUCTION AND SUMMARY OF METHODS AND RESULTS FROM THE TROPICAL STOCK ASSESSMENT WORKSHOP

Jeffrey J. Polovina, Ronald A. Benco, Albert H. Carlot, Esperance Cillaurren, Paul Dalzell, Ned Howard, Donald Kobayashi, Tevita F. Latu, Paul Lokani, Gianandar Nath, Helen Pitiale, Apesai Sesewa, Richard Shomura, Taniela Sua, Gideon Tiroba, and Sosaia Tulua

A 3-week workshop was convened to assist fishery scientists from selected Pacific island countries in analyzing their research and commercial catch and effort data on deepwater snappers. Workshop participants came from the Cook Islands, Fiji, Kingdom of Tonga, Papua New Guinea, Solomon Islands, Tuvalu, Vanuatu, and Western Samoa. The ultimate objectives of the analyses were to estimate the maximum sustainable yield (MSY) and the fishing effort that achieves the MSY for deepwater snappers in each country. As a simplifying step, all analyses treated this multispecies resource as a single group by combining all species.

Since the deepwater snapper fisheries in all of the Pacific islands represented at the workshop are undeveloped or very recently developed, no long-term time series of catch and effort data are available to apply to production models. An alternate approach estimates unexploited exploitable standing stock (N_0) from the depletion of an area, typically a small seamount or island, and then estimates MSY as a fraction of the unexploited exploitable biomass (B_0; Polovina and Ralston 1986). To estimate N_0 from a depletion or intensive fishing study, two analytical models are used. If the depletion has occurred during a short time period so that the number of fish added by recruitment or removed by natural mortality is a minimal part of the population, then the Leslie model (Ricker 1975) is used. This model estimates catchability (q) and N_0 by regressing catch (expressed in numbers of fish) per unit effort (CPUE), against the cumulative number of fish caught. However, if the period covered by the depletion is long enough so that recruitment and natural mortality may have a significant impact on the population, then the Allen model (Sainsbury 1984) is used to estimate catchability (q) and N_0. The Allen model requires an estimate of natural mortality (M); it estimates q and mean recruitment (R) by regressing catch on two variables: effort and the product of effort with adjusted cumulative catch. Generally when the period covered by the depletion study is less than 9 months, then the Leslie model is used; when the period exceeds 9 months, then the Allen model is used. For the depletion and MSY analyses, whenever an estimate of M is required, two values (M = 0.25/year and 0.50/year) are used to represent a range from the published literature on deepwater snappers (Ralston 1987).

Once estimates of N_0 are obtained from either the Leslie or Allen model, they are adjusted for the habitat area of the depletion site by dividing N_0 by the length (in nautical miles) of the 200 m isobath. The estimates of N_0 are converted to B_0 by multiplying N_0 by mean fish weight.

Estimates of MSY are computed with three approaches: the Gulland method, which estimates MSY as $0.5MB_0$; the Pauly method, which estimates MSY as $2.3(w)^{-0.26}$, where w is the mean (in grams) of the asymptotic weight and the weight at the onset of sexual maturity (Pauly 1983); and a method based on the Beverton-Holt equation in which MSY is estimated as a fraction of B_0 with the fraction as a function of parameters, including M/K, where K is the von Bertalanffy growth constant, and age at recruitment to the fishery (t_r) (Beddington and Cooke 1983). The parameter M/K is estimated at 2.0, based on estimates for M and K for deepwater snappers from the literature (Ralston 1987). The estimated age at recruitment to the fishery is 3 years for Vanuatu and 4 years for all of the other study areas. For each country, an MSY estimate is computed as the product of the MSY range per nautical mile of 200 m isobath and the total length of the 200 m isobath.

Fishing mortality (F) is estimated from catchability, which is estimated from the depletion analyses for each country. The value of q from each depletion analysis is multiplied by the length of 200 m isobath to obtain a standardized q. The mean of all standardized q values from within a country is multiplied by the total fishing effort and then divided by the total length of the 200 m isobath to estimate annual F, which can be interpreted: When F equals M, then fishing effort is optimal to produce MSY; when F exceeds M, then fishing effort is excessive.

The results of 18 depletion analyses from the workshop are presented in Table 1. Table 2 presents a summary of the estimated unexploited exploitable biomass per nautical mile of 200 m isobath from the depletion analyses by seamount and island grouping. Except for a few outliers, most estimates of B_0 cluster around the median values of 2.7 metric tons (t)/nmi for seamounts and 0.7 t/nmi for islands. Since the seamounts are smaller than the islands and have a steeper slope, the difference in the estimates of B_0/nmi between seamounts and islands may, to some extent, be due to the concentration of biomass over the smaller habitat areas available at seamounts.

The ratios of MSY to B_0 by the Beverton and Holt, Gulland, and Pauly models have a range of about 10 to 30% (Table 3). For an M of 0.25, based on the Gulland estimate, a lower bound of MSY estimated at 9% B_0 is obtained. Conversely, using the Beverton and Holt equation and an M of 0.5 or using the Pauly method, which depends only on fish weight, estimates MSY at about 30% B_0. Thus, the range of 10 to 30% B_0 is estimated to include the true value of MSY.

Table 4 presents the MSY estimate for each country. For Tonga, current landings from the seamounts are almost twice the upper bound of the estimated MSY, and F is about equal to M. This result suggests that fishing effort is at the level which produces MSY and, once the fishery at the seamounts reaches its equilibrium level, the catches and CPUE will be substantially lower. However, if new seamounts are found, the higher catches may be sustained for a longer time. In Western Samoa, the

Table 1. Summary of results of depletion analyses

COUNTRY / Area	Type	Principal Species	Nautical Miles of 200 meter isobaths	(Method) Number of Fish / nmi		Fish Mean Wgt (Kg.)	Unexploited Biomass / nmi (Tonnes)		Recruitment R/nmi/year	
MARIANAS		Pristipomoides zonatus		(Leslie)			(Leslie)			
Pathfinder Reef	Seamount	P. auricilla	3.00	1354		1.5	2.0			
		P. flavipinnis								
		Etelis carbunculus								
TONGA		P. filamentosus		(Allen)			(Allen)		(Number of fish)	
		P. flavipinnis		M=.25	M=.50		M=.25	M=.50	M=.25	M=.50
801	Seamount	Etelis coruscans	5.00	616	554	4.4	2.7	2.4	197	344
901	Seamount	E. carbunculus	6.80	614	351	4.4	2.7	1.5	137	202
903	Seamount		35.00	547	608	4.4	2.4	2.7	118	265
1004	Seamount		1.20	1927	1233	4.4	8.5	5.4	493	762
FIJI SEAMOUNTS		Etelis coruscans		(Leslie)			(Leslie)			
Taveuni	Seamount	E. carbunculus	3.10	333		7.5		2.5		
Napuka	Seamount		4.20	507		7.5		3.8		
Kadavu	Seamount		18.00	200		7.5		1.5		
Savusavu	Seamount		7.90	189		6.5		1.2		
GRID 147	Seamount		13.10	931		7.5		7.0		
FIJI SHELF										
Nasilai to Ovalau	Island		50.00	94		7.5		0.7		
Ovalau to MoonReef	Island		42.00	95		7.5		0.7		
MoonReef to Ellington	Island		40.00	75		7.5		0.6		
GRID 482	Island		40.00	73		7.5		0.5		
VANUATU									Recruitment	
		Etelis carbunculus		(Allen)			(Allen)		R/nmi/year - tonne	
		E. coruscans		M=.25	M=.50		M=.25	M=.50	M=.25	M=.50
Paama	Island	E. radiosus	28.00	1277	1100	1.8	2.3	1.1	0.30	0.37
Ambae	Island	Lutjanus malabarius	62.00	389	167	1.8	0.7	0.3	0.10	0.13
PAPUA NEW GUINEA		P. multidens		(Leslie)			(Leslie)			
Schoutten Islands	Island	P. filamentosus	33.00	121		2		0.2		
Kavieng	Seamount	E. carbunculus	0.25	416		2		3.3		
		Wattsia mosambitus								
		L. malabaricus								
		Paracaesia stonei								

Table 2. Length of 200m isobaths and Bo/nmi of 200m isobath for all depletion analyses

	Nautical Miles	Unexploited Biomass / nmi.
SEAMOUNTS		
Kavieng	0.25	3.30
1004	1.20	8.50
Pathfinder	3.00	2.00
Tavenui	3.10	2.50
Napuka	4.20	3.80
801	5.00	2.70
901	6.80	2.70
Savusavu	7.90	1.40
GRID 147	13.10	7.00
Kadavu	18.00	1.50
903	35.00	2.40
		2.70 = Median
ISLAND		
Paama	28.00	2.30
Schoutten Islands	33.00	0.20
MoonReef to Ellington	40.00	0.60
GRID 482	40.00	0.55
Ovalau to MoonReef	42.00	0.70
Nasilai to Ovalau	50.00	0.70
Ambae	62.00	0.70
		0.70 = Median

Table 3. Ratios of MSY to Bo for the three methods

	MSY/B M=.25	MSY/B M=.5
Gulland (1/2m)	0.13	0.25
Beverton-Holt when m/k = 2		
age at recruitment = 3 years	0.06	0.18
age at recruitment = 4 years	0.09	0.28
Pauly (2.3w)^-.26		
Marianas	0.34	
Papua New Guinea	0.28	
Western Samoa	0.27	
Vanuatu	0.32	
Tonga	0.28	

Table 4. Estimates of MSY, 1988 Landings, and F for deepwater snappers at selected Pacific Island countries

COUNTRY	Estimated MSY (Tons/yr)	1988 Landings (Tons/yr)	1988 Estimated F (fishing mortality per year
TONGA	77 - 222	391	0.38
WESTERN SAMOA	17 - 50	25	(*)
FIJI current fishing area of 500 nmi of 200m habitat now being fished	70 - 200	300	0.12
FIJI potential fishing area of 3000 nmi	426 - 1280	0	0
PAPUA NEW GUINEA	170 - 270	0	0
VANUATU	113 - 190	40	.07

(*) No estimate of q available to estimate F deepwater snapper resource is already close to MSY, but some increase is possible. The fishery in Fiji is currently fishing only about 20% of the estimated 3,000 nmi of 200 m isobath. Thus, Fiji has the potential to increase catches if this unfished habitat has populations of deepwater snappers. However, if the fishery remains only within the habitat currently fished, catches will decline perhaps by 50%. The level of fishing effort may be a little lower than the level which produces MSY. Papua New Guinea has no appreciable landings of deepwater snappers, but a potential exists with MSY in the range of 170 to 270 t/year. Vanuatu's landings represent only one-third to one-fifth of the potential MSY, as indicated by the current landings and level of F; therefore, the potential exists for greater landings.

A point worth emphasizing is that the results from this workshop represent preliminary estimates of future MSY based on estimates of unexploited biomass and certain mathematical models that project the response of the populations to exploitation. The MSY estimates represent a sustainable equilibrium level, which is lower than the catches that can be obtained in the early stages of the fishery. As the fishery in each country develops, these preliminary estimates of MSY can be improved from a time series of catch and fishing effort data recorded by island.

This workshop also examined the utility of length-frequency data to estimate relative fishing mortality but found that size-frequency samples from the commercial catches do not provide very accurate indicators of fishing mortality, perhaps because of fish size and depth relationships and size-specific targeting by fishermen.

Finally, this workshop focused on the dynamics of the resource and did not consider the dynamics of the fishing operations. In some countries, market conditions and economics of other fisheries may limit fishing for deepwater snappers so that the MSY level is not achieved. In other instances, the distances from port to some of the deepwater snapper grounds may also limit fishing effort below the level resulting in MSY.

CITATIONS

Beddington, J. R., and J. G. Cooke.
1983. The potential yield of fish stocks. FAO Fish. Tech. Pap. 242, 47 p.

Pauly, D.
1983. Some simple methods for the assessment of tropical fish stocks. FAO Fish. Tech. Pap. 234, 52 p.

Polovina, J. J., and S. Ralston.
1986. An approach to yield assessment for unexploited resources with application to the deep slope fishes of the Marianas. Fish. Bull., U.S. 84:759-770.

Ralston, S.
1987. Mortality rates of snappers and groupers. Pages 375-404 *in* J. J. Polovina and S. Ralston (editors), Tropical snappers and groupers: biology and fishery management. Westview Press, Boulder.

Ricker, W. E.
1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191, 382 p.

Sainsbury, K. J.
1984. Optimal mesh size for tropical multispecies trawl fisheries. J. Cons. int. Explor. Mer 41:129-139.

ASSESSMENT OF DEEPWATER BOTTOMFISH STOCKS AROUND THE FIJIAN REPUBLIC

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INTRODUCTION

During the late 1970s, the Fisheries Division of the Republic of Fiji started experimental fishing surveys, using handlines, which established the presence of a variety of deep-sea snappers and associated species in Fijian waters. The snappers, which constitute the majority of the catch, belong primarily to the lutjanid subfamily Etelinae, whose natural habitat is found at depths of 50-400 m.

The commercial development of this fishery was slow, as deepwater snappers were not commonly known to local markets. Initially only one or two fishing vessels (9 m long) were in operation; they were designed by the Food and Agriculture Organization of the United Nations and used Samoan hand reels. As early as 1985, the catch was mainly used by the tourist industry. The deep-sea snapper (bottomfish) industry began to grow rapidly when Fiji began exporting to the Hawaiian market. The prices varied, but the activity was profitable enough to encourage the expansion of the fleet to as many as 15 boats. Some larger vessels using hydraulic reels also were constructed. The modifications were designed to increase productivity. The only existing information concerning Fijian bottomfish stocks has been a study by Lewis et al. (1988), who summarized existing growth and mortality data, described the development of the fishery, and reported initial length frequencies, catch rates, and species composition data. During 1985, a resource survey was conducted in the waters between Fiji and Tuvalu by the Japanese International Cooperation Agency, which estimated the biomass of the total demersal fish population in Fijian waters at 4,900 metric tons (t) (in Lewis et al. 1988). This estimate included many species not exploited by the deep-sea snapper fishery.

From 1985 to 1986, the deep-sea snapper fishery was concentrated on nine seamounts and eight coastal slopes around Fiji. Some of these fishing areas have begun showing signs of decreases in catch and catch per unit effort (CPUE). The declines in catch led some fishermen to turn to alternative sources of income, bringing about the development of an extensive longline fishery for tuna and other pelagic species. Some of the concerned fishermen turned to the Fisheries Division of the Ministry of Primary Industries for advice and information on the continued exploitation of the deep-sea snapper resource. These fishermen have cooperated with the Fisheries Division in an effort to obtain the information necessary for the assessment of the resource's potential by submitting their logbooks for evaluation and their catch for biological sampling.

At present, the snapper fishery is based principally in the southeastern portion of the Fijian Archipelago: about 60% of the harvest comes from the coastal slopes and 40% from the seamounts. The principal fishing grounds are on the windward sides of both slopes and seamounts.

MATERIALS AND METHODS

The data used in this study were obtained from two sources: catch records and dockside samples of the catch of commercial fishing vessels. In the dockside sampling program, the entire catch from 39 trips by the Fijian bottomfish fleet was classified by species, counted, and measured. The fishermen were interviewed to determine the area fished, so that the volume and size structure of the catch could be evaluated on a regional basis. The other portion of the data was obtained from records kept in the logbooks of the commercial fleet and compiled by the central management of that fleet.

Data from the dockside sampling program were processed in the following manner. The average fork length of the catch per trip was estimated for each species from the length data, and the corresponding weight estimated by using information from the literature concerning the relationship between weight and length for each species. For the majority of the species sampled, these estimates were obtained from Brouard and Grandperrin's (1985) report for Vanuatu. There were three species for which this information was not available for an area as nearby as Vanuatu: Estimates from Hawaii (Uchiyama et al. 1984) were used for *Pristipomoides filamentosus* and *P. zonatus*, whereas the length-weight relationship from French Polynesia (Wrobel 1985) was used for *P. auricilla*. Finally, no weight-length relationship in the literature was available for *Etelis radiosus*. Accordingly, the relationship for *E. coruscans* (Brouard and Grandperrin 1985) was used as a rough approximation. In this manner, the total weight of the catch for all trips was estimated and then summarized by trip and species for the regions where fishing had been reported. Length frequencies were estimated by species for the total catch and on a regional basis.

Aggregated catch and effort records and length-frequency subsamples were collected at dockside from the commercial fleet by the Fisheries Division. Unexploited exploitable biomass was estimated from areas where heavily depleted stocks were fished, by applying the Leslie model (Polovina 1986). Of the fishing trips sampled, sufficient data were available for two grid regions for these estimates. Average length, converted to weight as previously described, was used to convert the estimated number of fish in the area to estimated total biomass for the dockside samples. Com mercial records were given in units of biomass (metric tons) and thus needed no conversion. The length of the 200 m isobath (i.e., the primary depth targeted by fishermen for these species) was used to convert the total biomass estimates to estimated biomass (in metric tons) per nautical mile at this depth.

The unexploited biomass for the estimated length of the 200 m isobath around the Fijian Islands was calculated on the basis of these values for the two habitat types. Since the biomass estimates per nautical mile were significantly different for slopes, as opposed to seamounts, the total biomass for these habitats was estimated separately by using the average of the values obtained for the five seamounts and four slope areas for which sufficient data were available. The seamounts were considered 40% of the 3,000 nmi presently estimated for this region; the slopes constituted the other 60%.

The upper and lower limits for the estimates of the maximum sustainable yield (MSY) of this total biomass were obtained by two methods. The lower limit of the ratio of equilibrium yield to unexploited recruited biomass was estimated by the Beverton and Holt (1957) yield per recruit equation using the lower bound of 0.25 for M, a ratio of $M/K = 2.0$ for snappers and groupers (Ralston 1987), and an estimated age at recruitment (t_r) of 4 years (Polovina and Ralston 1986). The upper limit of MSY was obtained from the Pauly (1983) model, which estimates MSY as $2.3(w)^{-0.26}$, where w equals the mean (in grams) of the asymptotic weight and the weight at the onset of sexual maturity. Using average figures from the literature for these weights, the Pauly equation predicts the MSY as 28% of the unexploited biomass. This upper bound also corresponds to the value obtained from the Beverton and Holt method with $M = 0.5$. The lower and upper limits of the MSY were then set at 0.09*B and 0.28*B, where B equals the biomass estimated for the total number of nautical miles of habitat area. We have included this range of estimates of MSY and provided an index of both total biomass and minimum and maximum MSY under a series of possible ranges of the 200 m isobath where fishing may be feasible.

To determine fishing mortality (F), catchability (q) was estimated as the slope of the depletion curve for the Leslie model. The value of q was multiplied by the length of the 200 m isobath to obtain a standardized q per nautical mile that could be averaged between all of the areas for which a depletion curve was estimated. The mean of these standardized q values was multiplied by the total fishing effort divided by the length of the 200 m isobath exploited during the fishing experiment to give an estimate of annual F. When F is equal to M, fishing effort is considered optimal to produce MSY, whereas when F exceeds M, fishing effort is excessive.

RESULTS

Figure 1 shows a map of the Fijian Archipelago and notes the recognized sampling areas used in the logbooks of fishermen. The areas for which total biomass per nautical mile was estimated are marked with cross-hatching. Commercial catch reports were submitted on the basis of land formations rather than by grid areas. The seamount formations sampled in these reports are also indicated in Figure 1. The slope areas mentioned are located on the eastern coast of the largest Fijian island, Viti Levu, from the region slightly north of Suva to the coast of Rakiraki. These correspond to grid areas 398, 399, 482, and 481.

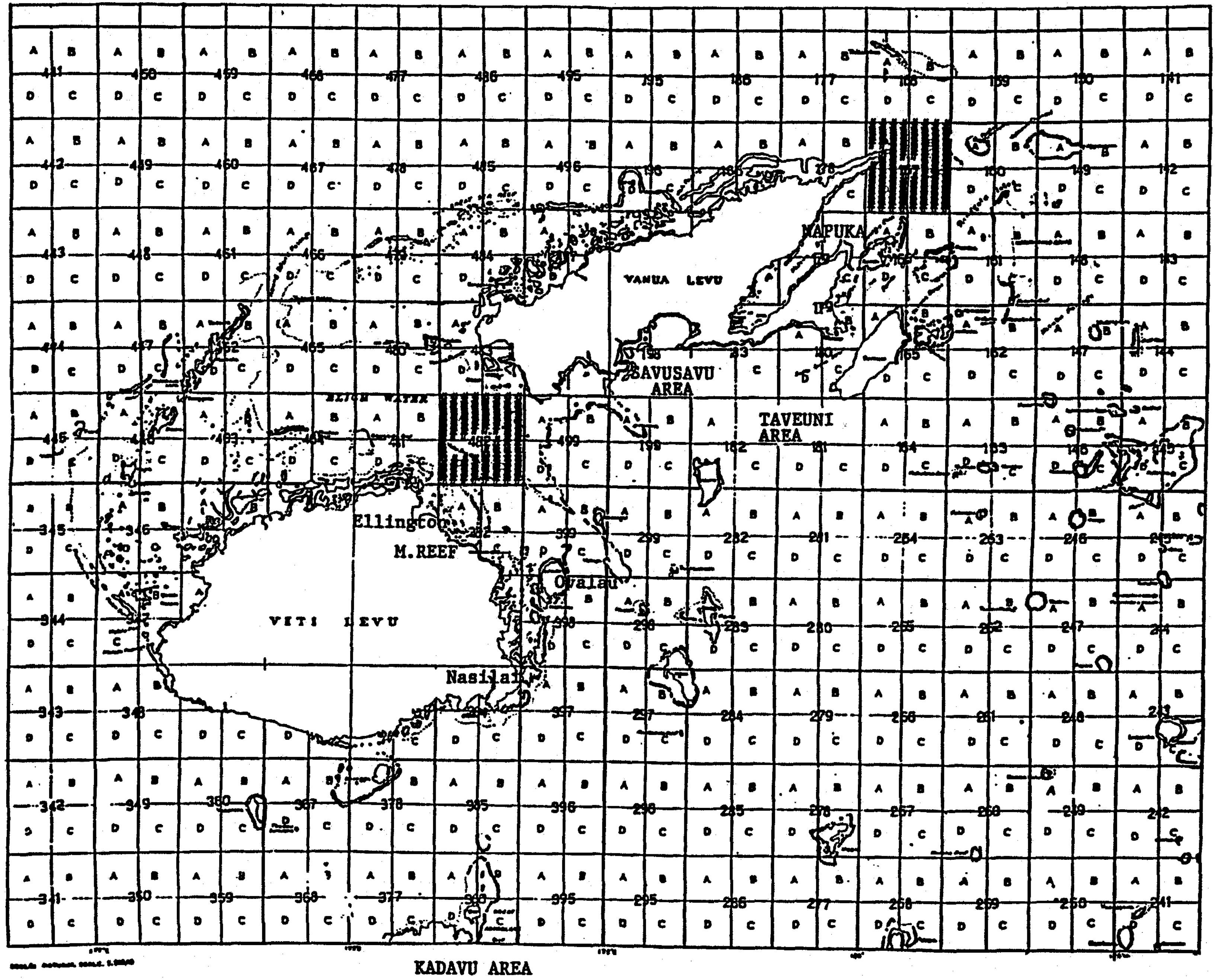


Figure 1.--Map of the Fijian Archipelago, showing the grid pattern for exploratory fishing.

The data collected through the dockside sampling program are summarized in Appendix A. Sampling was carried out from May through October 1987, and a total of 44.8 t of bottomfish were sampled. The average catch per trip was 1,332 kg or 382 fish; this information is summarized on a regional basis in Appendix B. The contribution by weight of each species also is summarized on a trip-by-trip basis in Appendix A and by grid area in Appendix B. Table 1 summarizes the total number of fish and their weight in the catch sampled for the entire sampling period.

Figure 2A and B summarizes composition (percent number and percent weight) of the total catch of the six major commercial groups at each grid area. A considerable diversity can be noted in species composition from one region to another, which must certainly affect the exploitable biomass and renewal rates on a regional basis. This is important to keep in mind when considering the fisheries potential of the resource as a whole.

The size composition, on the other hand, was not found to be significantly different between the various regions. Figure 3A-E shows the size composition of the five major commercial species sampled from all regions, subgrouped into slopes versus seamounts. The size range present in the catch was quite similar in the two habitat types for both *Aphareus rutilans* and *Paracesio kusakari*, although there were notable differences in the modal size classes. *Etelis carbunculus*, *E. coruscans*, and *Pristipomoides filamentosus* were apparently somewhat larger on the seamounts than on the slopes. These differences may be due to differences in the depths fished, which however were not recorded. In the case of *P. filamentosus*, the apparent differences may also be attributable to differences in sample size or random sampling.

The depletion studies yielded the biomass estimates per nautical mile (Table 2). These results were quite comparable with the data obtained from catch records and dockside samples from grid areas 167 (a seamount) and 482 (a coastal slope). Therefore, the average biomass estimates per nautical mile (in Table 2) are from the five seamounts and four slope regions sampled. The difference is that the estimates from commercial catch records are made on the basis of the slope of a line drawn between two points only--the initial and final CPUE and cumulative catches in metric tons. Conversely, the biomass estimates from the sampling data are linear regressions of CPUE and cumulative catch in numbers of fish per trip, converted to metric tons on the basis of the weight calculated for the average length sampled in each grid. Figure 4A and B shows the fit of the two regression lines to the data. The slope, intercept, and correlation coefficient of each line are in Table 2, along with the slopes for the estimates made from the catch records.

Table 3 summarizes the estimated fishing mortality during 1987, based on two hypothetical lengths of the 200 m isobath exploited during that period. This table also summarizes the estimates of total biomass of bottomfish for the entire Fijian Archipelago, based on several possible lengths (3,000, 2,000, and 1,000 nmi) of the 200 m isobath exploited.

Table 1.--Species key and index of overall abundance.

Abreviation Used	Common Name In Use	Scientific Name	FREQUENCY (Num)	FREQUENCY (kg)	RELATIVE ABUNDANCE Numerical	RELATIVE ABUNDANCE By Weight
E car	Ehu	Etelis carbunculus	4985	17702.8	34.39	40.02
E cor	Onaga	Etelis coruscans	4457	13046.2	30.74	29.49
E rad		Etelis radiosus	112	444.1	0.77	1.00
P flav	O'Pakapaka	Pristipomoides flavipinnis	374	287.3	2.58	0.65
P fila	O'Pakapaka	Pristipomoides filamentosus	682	996.5	4.70	2.25
P mult	O'Pakapaka	Pristipomoides multidens	239	363.3	1.65	0.82
P aur	O'Pakapaka	Pristipomoides auricilla	17	25.4	0.12	0.06
P zon	Flower	Pristipomoides zonatus	71	102.7	0.49	0.23
P typus	O'Pakapaka	Pristipomoides typus	224	53.6	1.55	0.12
A rut	Lehi	Aphareus rutilans	1160	6001.2	8.00	13.57
Pa.ston	Bedford	Paracesio stonei	138	276.7	0.95	0.63
Pa.kus	Bedford	Paracesio kusakari	971	3037.3	6.70	6.87
E mor	Cod	Epinephelus morrhua	59	145.8	0.41	0.33
W. mos	Bream	Wattsia mossambica	1008	1754.9	6.95	3.97
		Total Catch	14497	44237.8		

(Data from dockside samples)

Table 2.--Summary of biomass estimates from 1987-88 CPUE and cumulative catch by the Leslie (1952) method.

	ESTIMATES FROM CATCH RECORDS							DOCKSIDE SAMPLING GRID AREAS SAMPLED	
	SEAMOUNTS				COASTAL			Seamount	Coastal
Region ->	Taveuni	Napuka	Kadavu	Savusavu	Nasilei to Ovalau	Ovalau to Moon Reef	Moon Reef to Ellington	167	482
Initial CPUE	0.40	0.45	0.40	1.00	0.60	0.60	0.70	589	724
	tons/trip ---------->				tons/trip ---------->			No fish/trip -->	
Final CPUE	0.10	0.00	0.15	0.25	0.20	0.00	0.20	409	192
Average Wt. (kg)	7.5	7.5	6.5	7.5	7.5	7.5	7.5	3.8	3.6
Cumulative Catch	6.0 tons	18.0 tons	17.0 tons	8.0 tons	25.0 tons	30.0 tons	15.0 tons	4338 No.Fish	1970 No.Fish
Estimated Initial Biomass	8.0	18.0	27.2	10.7	35.3	30.0	21.9	12191 No.Fish	2915 No.Fish
Estimated length 200m isobath	3.14 nmi	4.20 nmi	18.00 nmi	7.90 nmi	50.00 nmi	42.00 nmi	40.00 nmi	13.083 nmi	40 nmi
Biomass per nmi	2.55 t/nmi	4.29 t/nmi	1.51 t/nmi	1.35 t/nmi	0.71 t/nmi	0.71 t/nmi	0.55 t/nmi	3.541 t/nmi	0.262 t/nmi
Average biomass (tons/nmi)	SEAMOUNTS (N = 5)		2.648		SLOPES (N = 4)		0.558		
Regression Parameters:									
-Slope (q)	0.050	0.025	0.015	0.094	0.016	0.020	0.033	0.050	0.331
Y Intercept								614	965
Coef.Correlation								0.803	0.709

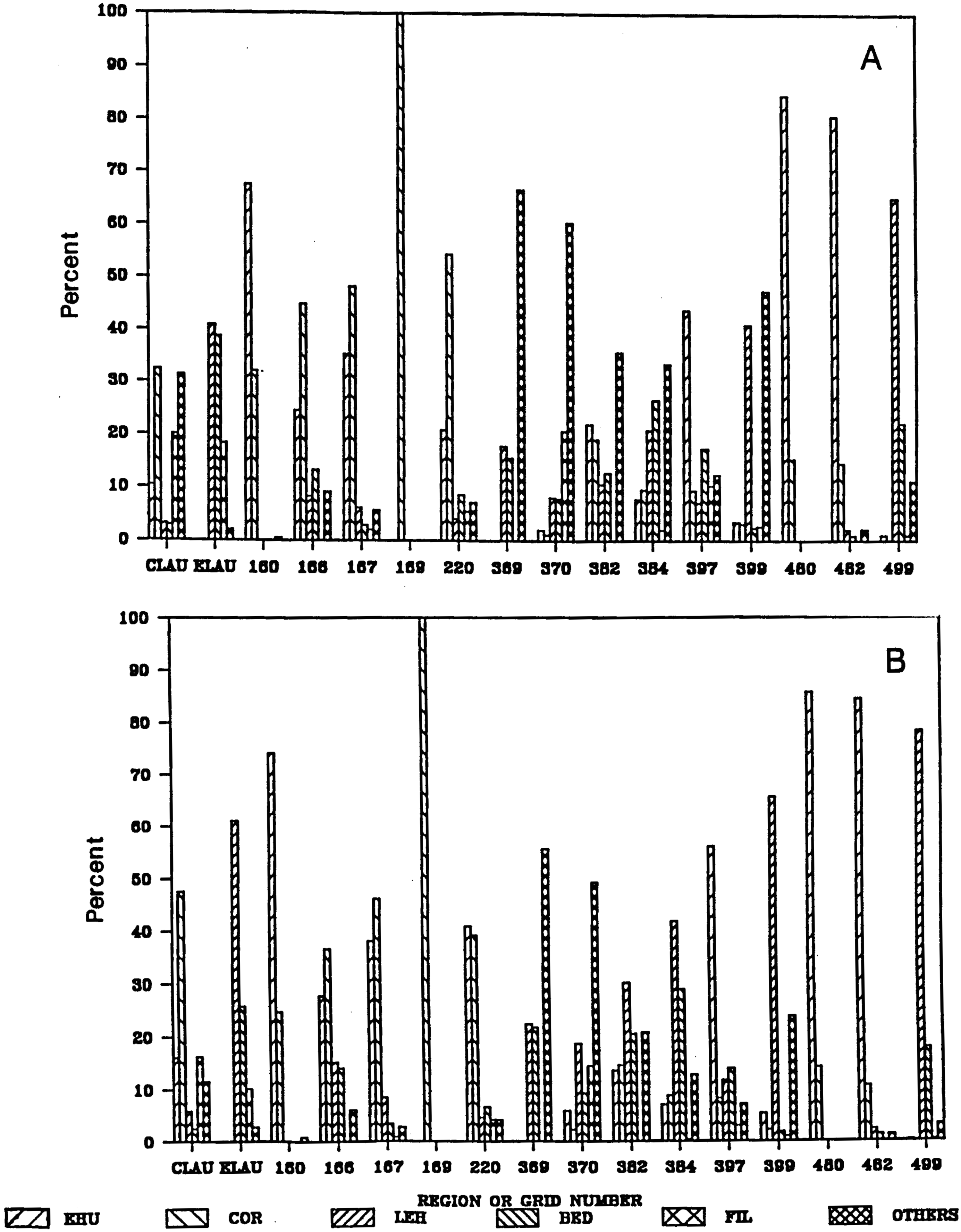


Figure 2.--Composition of the total catch of six major commercial groups of bottomfishes, by area of capture, in the Fijian Archipelago in 1987: A. Percent number. B. Percent weight. Regions and grid areas are depicted.

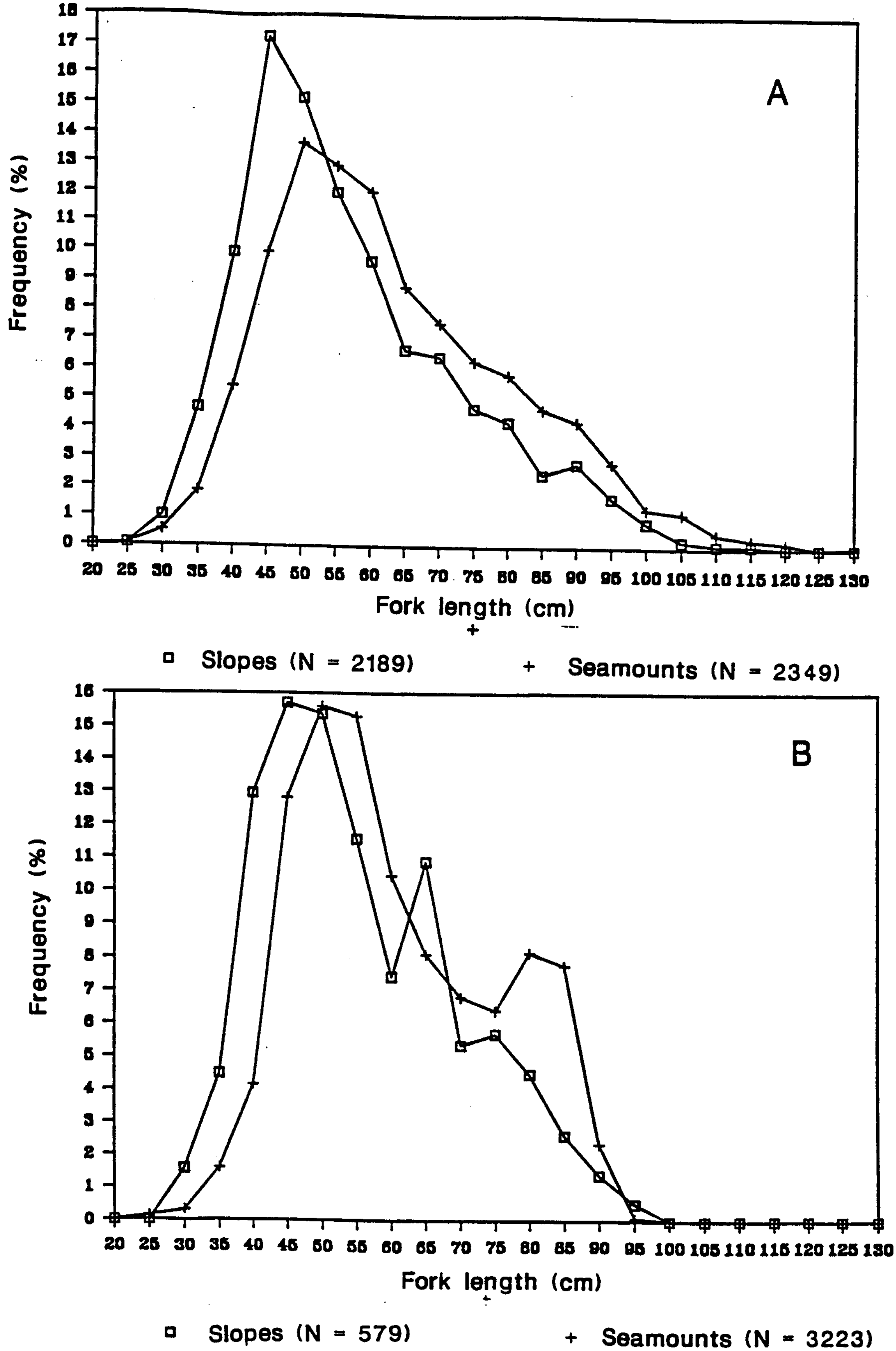
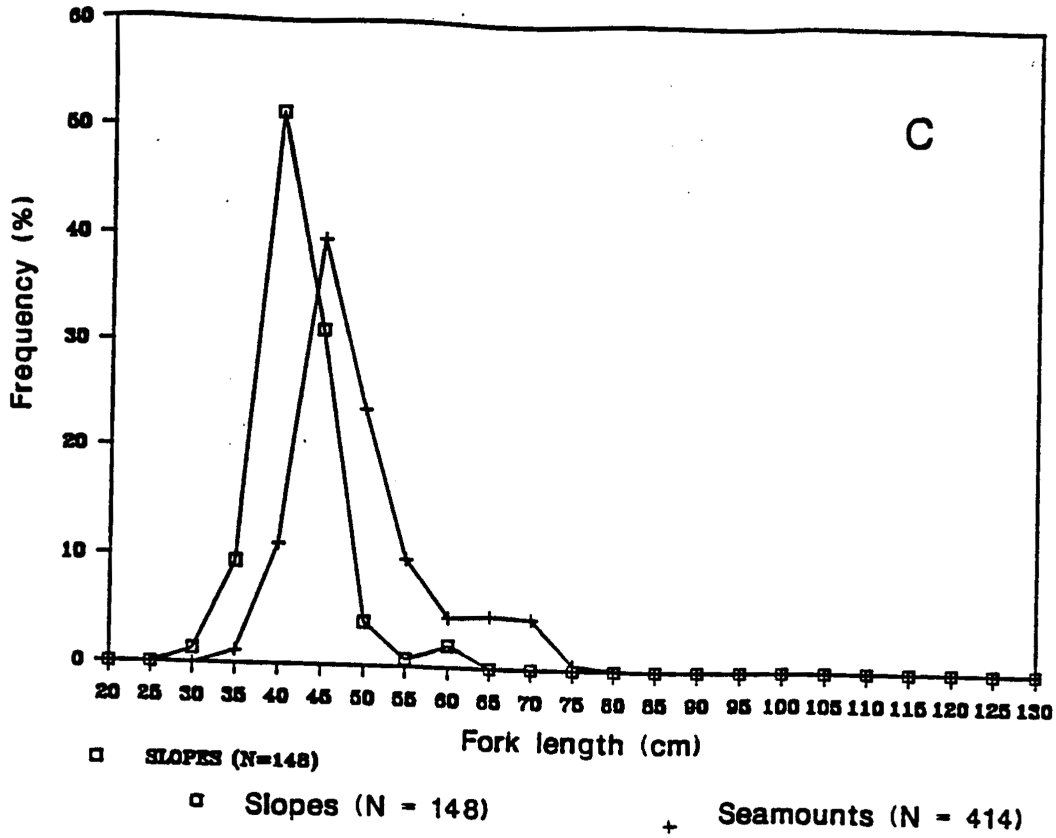


Figure 3.--Length frequency of bottomfishes captured on the slopes and seamounts of the Fijian Archipelago in 1987: A. Etelis cabunculus. B. E. coruscans. C. Pristipomoides filamentosus. D. Aphareus rutilans. E. Paracesio kusakari.



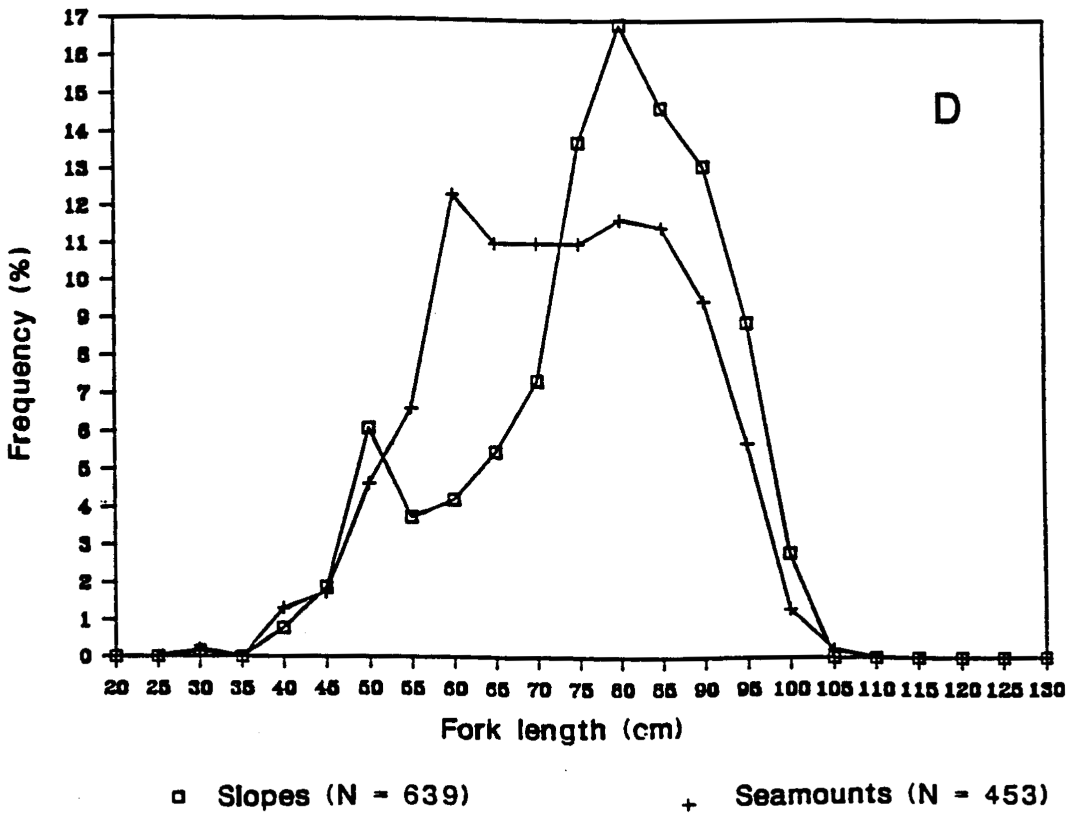


Figure 3.--Continued.

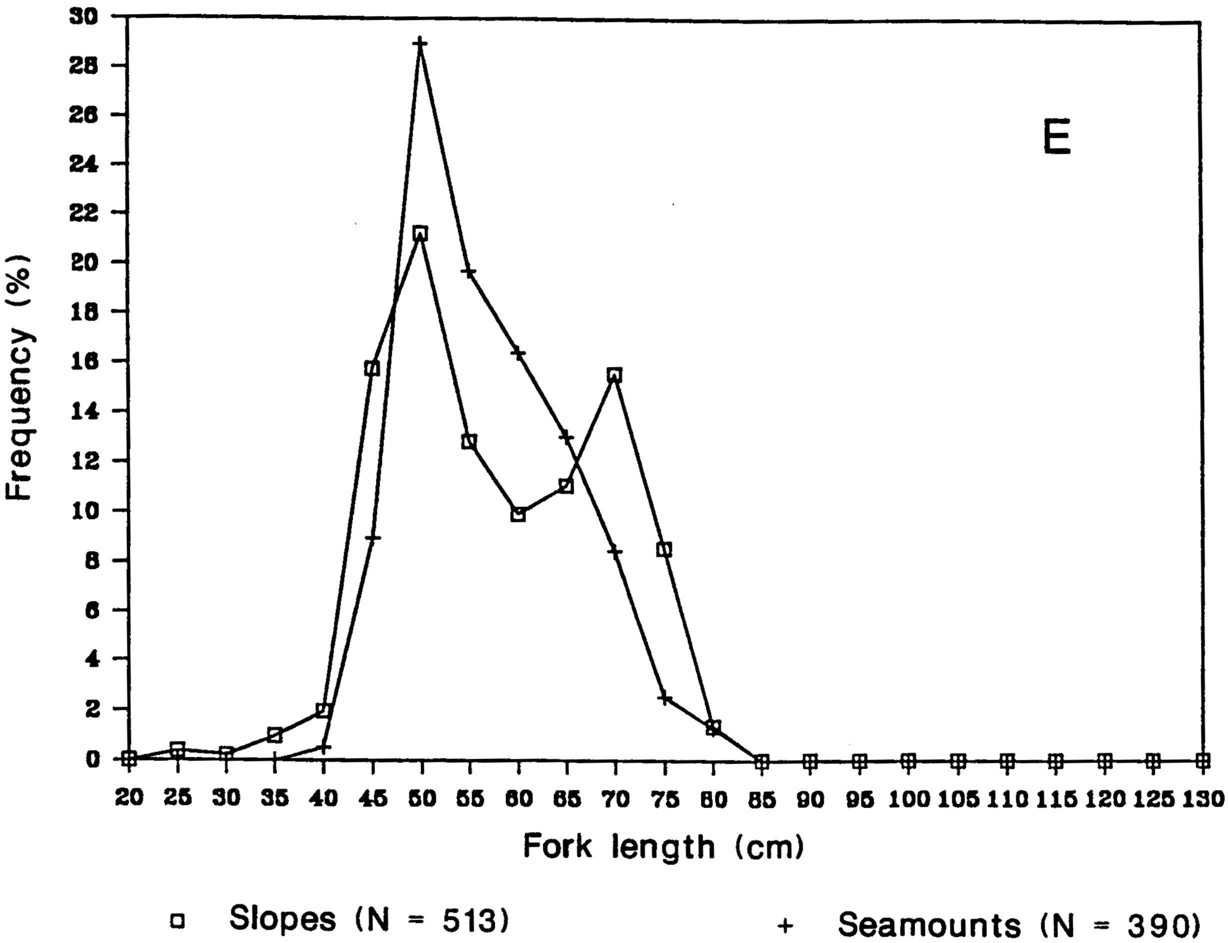


Figure 3.--Continued.

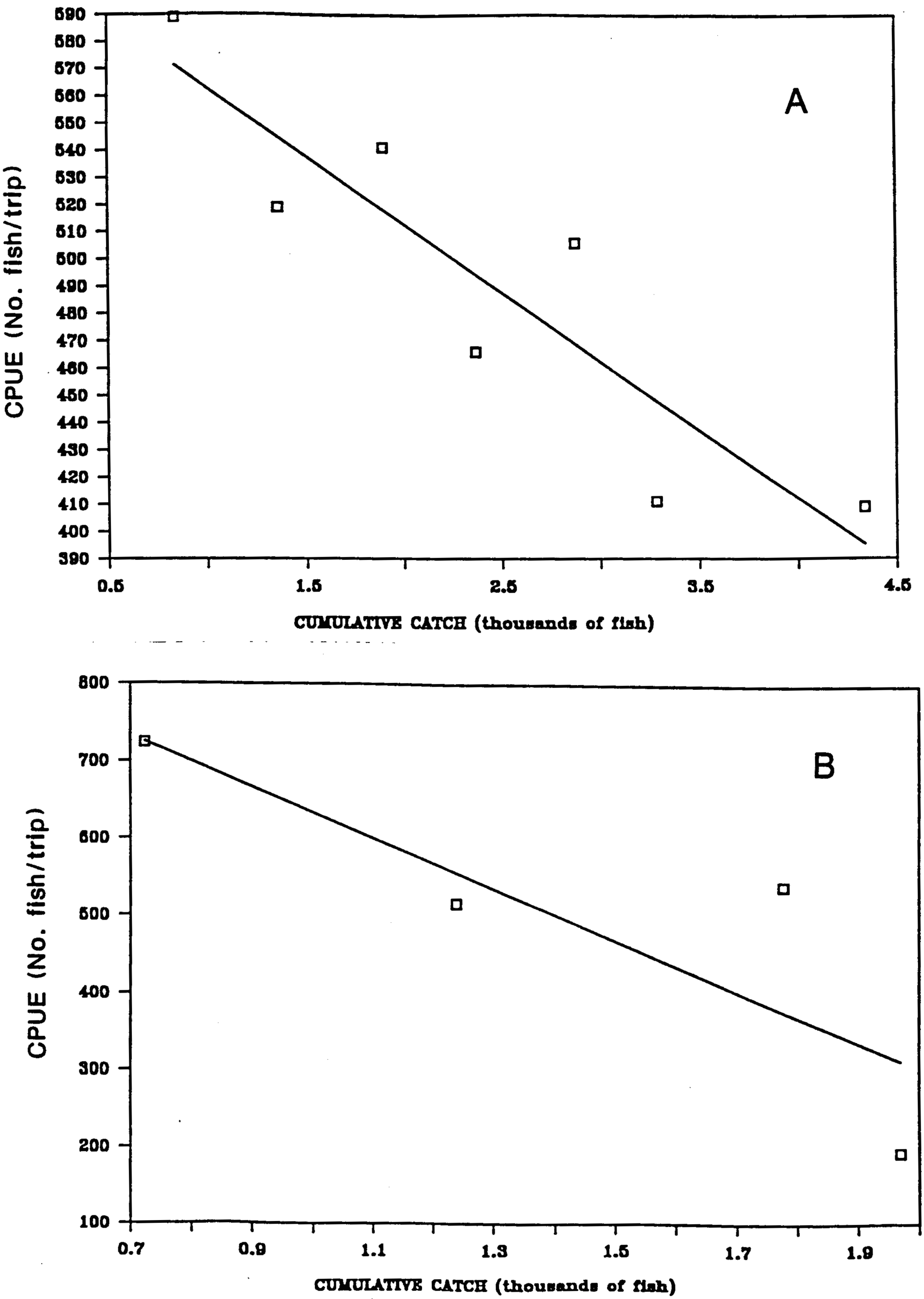


Figure 4.--Regressions of catch per unit effort (CPUE) on the cumulative catch of bottomfishes from the Fijian Archipelago: A. Grid 167. B. Grid 482. Grids are depicted in Figure 1.

Table 3.--Summary of estimates of fishing mortality and maximum sustainable yield from estimates of catchability and biomass per nautical mile.

Seamount	q	q/nmi	OVERALL ESTIMATES OF FISHING MORTALITY
Taveuni	0.050	0.157	
Napuka	0.025	0.105	
Kadavu	0.015	0.265	ESTIMATED F FOR
Savusavu	0.094	0.741	MINIMUM AND MAXIMUM
		0.209	ESTIMATES OF 1987
C/slope			PORTION OF 200 m
Nasilai-Ovalau	0.016	0.800	ISOBATH UNDER EXPLOITATION
Ovalau-M.reef	0.020	0.840	
Mreef- Ellington	0.033	1.333	F = 0.122
		0.987	
Grid 482	0.331	13.240	
Grid 167	0.050	0.654	
		6.947	ESTIMATED TOTAL BIOMASS
Overall q/nmi*		0.612	
*Less Grid 482			

ESTIMATED MSY IN TONNES UNDER VARIOUS POSSIBLE EXPLOITABLE PORTIONS OF 200 m ISOBATH

	Bev-Holt (1966)	Pauly (1988)
3000nmi	376	1171
2000nmi	251	780
1000nmi	125	390
500nmi	63	195

Present Level of Exploitation
200-300 tons/yr

If 3000 nmi present are exploitable

Seamounts	Slopes	Total
3178	1004	4181

If only 2000 nmi exploitable

Seamounts	Slopes	Total
2118	669	2787

If only 1000 nmi exploitable

Seamounts	Slopes	Total
1059	335	1394

If only 500 nmi exploitable

Seamounts	Slopes	Total
530	167	697

Using these lengths, the resultant estimates of MSY are given for two models (Beverton and Holt 1957; Pauly 1983). The Beverton and Holt model predicts that 9% of the total biomass is exploitable over a sustained period, whereas the Pauly model holds that up to 28% of this biomass can in fact be exploited. The values in Table 3 give an idea of the range of possible estimates of MSY, the significance of which will be discussed.

DISCUSSION AND CONCLUSIONS

This report provides an index of the development of a new and highly diverse fishery in Fiji, for which further studies will determine future trends. The object of this study is to help put into perspective the present levels of catch with regard to what can be expected as large and old fish are removed from the population and the catches are reduced to size groups that are more representative of the levels of biomass that can be sustained. In any fishery, the initial catches are large, but it is dangerous to project that these levels can be maintained. Such extrapolation leads to overinvestment in a fleet that may later begin to deteriorate as fishermen must deal with reduced profits due to extended search time for a limited catch.

Currently, 200-300 t of bottomfish are caught from a habitat of about 500 nmi of 200 m isobath. The MSY for this habitat is estimated to be in the range of 63 to 195 t. This is the long-term estimated yield after the early stage of fishing down the area. Thus, if the fishing does not expand to new habitat, a 50% decline in CPUE will occur, and an expansion of the fleet is not advisable. If the entire 3,000 nmi is indeed exploitable, then a range of 376 to 1,171 t/year is estimated for MSY, and there is still some room for growth in the fishery. The estimated F of 0.122 is well below the assumed natural mortality (M) of 0.25, which indicates that the stocks are probably not overexploited.

This analysis suggests a number of areas for future work. First, we believe that one of the most valuable investments of research time and effort would be an evaluation of the actual exploitable length of the 200 m isobath around Fiji. Such a study would not necessarily require the use of a research vessel. Considerable information could be obtained through interviews with commercial fishermen who have already spent considerable time exploring this area around Fiji. Questions to be asked in interviews might include the characteristics of the habitat and oceanographic conditions that allow handlines to be positioned and operated safely and effectively, as well as the reasons for the concentration of catch and effort on the northeastern slopes of islands and seamounts. The map in Figure 1 might be used in interviews, and the fishable habitat classified with respect to the recognized grid areas. This information would allow a more accurate estimate of the exploitable biomass and MSY to be made.

Sampling effort in the future might be measured more accurately. Weaknesses in the effort data collected during 1987 are that effort was recorded only on a trip basis and no information was kept with regard to the numbers of days and reels fished, nor any other information that might have provided a more sensitive index of the variation in fishing effort. The depths fished were not registered either, so only a rough indication of the actual fishing grounds is available. Accordingly, a series of assumptions had to be made about the amount of each grid area actually exploited, in order to draw any conclusions from the data.

Considerable effort was expended in measuring individual fish during dockside sampling as well. In some cases, several thousand fish were measured, when probably a smaller number would have provided an adequate estimate of the size structure of the catch. As seen, only limited conclusions could be drawn from these data. Since the size structure was fairly consistent between regions, measuring such a large number of fish is unnecessary. The present sample is considered sufficient to represent the size structure at the beginning of the fishery. At some point in the future, another sample should be made to assess any changes, but should be limited to the minimum that establishes the modal size classes and overall range of the catch. Inferences about mortality and growth from commercial length frequencies have limited application since the commercial catch is not representative of the overall size structure of the population, because of depth stratification of different-sized fish on the fishing grounds and the apparent selectivity of the gear for large fish (whether by behavioral mechanisms of the fish or selection of fishing areas where large fish can be captured). Therefore, we recommend that the effort of fisheries research be directed towards the elaboration of a more representative record of catch, effort, and the actual fishing areas.

ACKNOWLEDGMENTS

We thank both the United States Agency for International Development and the Director of the National Marine Fisheries Service for funding and arranging for us to attend this workshop. We thank M. Kimberly Smith for supervising the data processing and analysis. We are grateful to Jeffrey J. Polovina and Richard S. Shomura for reviewing and commenting our manuscript.

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CITATIONS

Beverton, R. J. H., and S. J. Holt.
1957. On the dynamics of exploited fish populations. Fish. Invest. London 2, 533 p.

Brouard, F., and R. Grandperrin.
1985. Deep-bottom fishes of the outer reef slope in Vanuatu (English). South Pac. Comm., 17th Regional Tech. Meeting, Noumea, New Caledonia, 127 p.

Leslie, P. H.
1952. The estimation of population parameters obtained by means of the capture-recapture method. II. The estimation of total numbers. Biometrika 39:363:388.

Lewis, A. D., A. Sesewa, and T. Adams.
1988. The Fiji deep-water snapper fishery - its development and management requirements. South Pac. Comm., Workshop Inshore Fish. Res., Noumea, New Caledonia, 14 p.

Pauly, D.
1983. Some simple methods for the assessment of tropical fish stocks. FAO Fish. Tech. Pap. 234:1-52.

Polovina, J. J.
1986. A variable catchability version of the Leslie model with application to an intensive fishing experiment on a multispecies stock. Fish. Bull., U.S. 84:423-428.

Polovina, J. J., and S. Ralston.
1986. An approach to yield assessment for unexploited resources with application to the deep slope fishes of the Marianas. Fish. Bull., U.S. 84:759-770.

Ralston, S.
1987. Mortality rates of snappers and groupers. Pages 375-404 *in* J. J. Polovina and S. Ralston (editors), Tropical snappers and groupers: biology and fisheries management. Westview Press, Boulder.

Uchiyama, J. H., S. H. Kuba, and D. T. Tagami.
1984. Length-weight and standard length-fork length relationships of deepsea handline fishes of the Northwestern Hawaiian Islands. Pages 209-225 *in* R. W. Grigg and K. Y. Tanoue (editors), Resource investigations in the Northwestern Hawaiian Islands. University of Hawaii, Honolulu, UNIHI-SEAGRANT-MR-84-01, Vol. 2.

Wrobel, L.
1985. La peche profonde en Polynesie Francaise. EVAAM, Ministere de la Mer, 82 p.

Appendix A.--Data summary from fishing trips sampled by the Fisheries Division of the Republic of Fiji in May-October 1987. For abbreviations, see Species Key in Table 1.

Trip No.	Date	Area or grid#	Total Catch Est.Wt (kg)	Total Catch No. Fish	Average Wt All Spp (kg)	E car	E cor	E rad	P flav	P fila	P mult	P aur	P zon	P typus	A rut	Pa.ston	Pa.kus	E mor	W. mos
1	19-May	397	1219.1	554	2.20	0.00	6.94	0.00	3.96	7.99	0.00	0.00	1.07	0.00	30.36	0.09	37.23	0.94	11.42
2	21-May	397	2047.3	592	4.22	89.69	9.03	0.60	0.00	0.00	0.25	0.00	0.00	0.00	0.43	0.00	0.00	0.00	0.00
3	26-May	382	1266.7	496	2.55	18.23	20.16	0.00	0.14	0.00	3.29	0.00	0.00	0.00	24.06	4.98	17.63	0.90	10.61
4	29-May	482	1527.4	495	3.09	94.34	3.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	0.00	0.00	0.00	0.00
5	02-Jun	382	795.8	244	3.60	6.37	5.80	8.47	0.00	0.00	8.00	0.00	0.00	0.00	40.26	0.00	25.24	2.42	3.43
6	06-Jun	487	1627.1	515	3.16	90.33	9.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	05-Jun	499	334.4	100	3.34	0.15	0.00	0.00	0.15	0.30	1.87	0.00	0.60	0.00	78.45	0.60	17.87	0.00	0.00
8	13-Jun	220	1538.8	443	3.47	52.36	22.08	0.00	1.12	1.24	0.00	0.39	0.00	0.00	8.89	0.00	13.49	0.08	0.35
9	13-Jun		517.3	188	2.75	26.16	26.41	0.00	0.00	0.00	14.13	0.00	0.00	0.00	33.30	0.00	0.00	0.00	0.00
10	13-Jun	C/LAU	723.7	184	3.93	14.86	65.48	0.00	4.98	0.86	0.00	0.00	0.47	0.00	6.68	0.00	4.28	0.41	1.98
11	16-Jun	482	1394.2	539	3.40	88.66	10.47	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	30-Jul	220	1115.2	367	4.10	33.13	44.63	1.50	0.58	15.95	0.00	0.00	0.68	0.00	2.10	0.00	0.00	1.42	0.00
13	30-Jun	E/LAU	409.4	98	8.38	0.00	0.00	2.81	0.00	10.16	0.00	0.00	0.00	0.00	61.07	0.00	25.96	0.00	0.00
14	08-Aug	C/LAU	641.5	251	2.56	17.58	27.36	0.00	1.27	33.84	0.00	2.34	4.65	0.00	5.00	0.00	0.45	7.15	0.37
15	24-Aug	160	2079.2	624	3.99	74.28	24.88	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	01-Jul	370	918.9	605	1.52	12.45	3.15	0.00	5.20	0.00	0.00	0.00	0.77	5.84	12.77	1.33	1.58	2.19	54.73
17	15-Jul	220	1381.4	398	4.88	18.67	57.27	2.13	0.43	1.18	0.00	0.00	0.13	0.00	5.10	0.00	8.79	0.00	6.31
18	16-Jul	220	933.5	236	3.96	64.63	34.90	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	30-Jun	167	1069.7	253	4.23	78.46	21.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	17-Jul	370	983.4	612	1.61	0.00	0.00	0.00	2.18	28.40	0.00	0.44	0.00	0.00	24.91	0.00	16.75	1.05	26.28
21	21-Jul	167	1484.9	484	3.41	11.71	42.75	0.40	3.87	1.56	1.51	0.00	0.00	0.00	34.30	0.00	3.90	0.00	0.00
22	30-Jul	480	1032.0	515	2.00	99.98	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	04-Aug	167	1791.0	537	3.34	12.49	43.66	0.00	1.78	5.10	3.83	0.00	0.00	0.00	29.68	0.00	3.46	0.00	0.00
24	24-Aug	384	104.4	36	2.90	71.76	28.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	01-Sep	384	425.4	107	5.61	0.00	8.88	11.93	0.00	0.00	7.95	0.00	0.00	0.00	56.63	0.00	14.60	0.00	0.00
26	01-Oct	399	1988.8	600	4.15	5.39	2.26	0.67	0.00	0.94	1.55	0.00	0.00	0.00	65.67	2.10	1.81	0.00	19.60
27	03-Sep	167	1669.0	541	3.28	74.25	25.22	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	05-Sep	369	232.8	90	8.60	0.00	0.00	6.04	0.00	0.00	0.00	0.00	3.87	0.00	22.46	0.00	21.83	0.00	45.80
29	25-Jun	482	615.3	192	6.89	35.28	30.47	1.38	0.00	0.00	5.29	0.00	0.00	0.00	15.25	0.00	10.66	1.18	0.51
30	08-Sep	384	1557.2	500	3.25	4.64	7.42	2.63	0.00	0.48	0.90	0.00	0.78	0.00	40.86	2.04	34.86	0.00	5.38
31	12-Sep	167	1452.4	486	3.71	76.39	22.91	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	18-Sep	166	1354.8	355	4.73	28.01	36.37	3.05	0.00	0.00	0.00	0.00	0.00	0.00	15.32	3.03	14.22	0.00	0.00
33	19-Sep	167	2343.1	518	5.07	6.55	79.36	1.18	0.00	0.00	0.45	0.00	0.72	0.00	3.84	2.06	5.84	0.00	0.00
34	22-Sep	166	10.6	8	9.52	0.00	86.01	13.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35	29-Sep	370	34.9	15	2.33	0.00	45.22	0.00	0.00	0.00	29.14	0.00	0.00	0.00	0.00	25.63	0.00	0.00	0.00
36	10-Jul	167	1749.2	447	4.66	43.87	29.46	3.09	0.00	0.00	1.36	0.00	0.00	0.00	6.74	1.52	13.97	0.00	0.00

Appendix A.--Continued.

Trip No.	Date	Area or grid#	Total Catch: Est.Wt (kg)	Total Catch: No. Fish	Average Wt All Spp (kg)	Percent contribution to total weight of catch by species: E car	E cor	E rad	P flav	P fila	P mult	P aur	P zon	P typus	A rut	Pa.ston	Pa.kus	E mor	W. mos
37	12-Aug	167	1917.5	644	2.98	59.06	40.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	06-Aug	167	1250.5	409	3.06	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	06-Oct	169	1217.2	407	2.99	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Totals --->			44755.0	14685	17838	13183	444	287	996	436	25	103	54	6173	277	3037	146	1755	0
Percent of total weight -->					39.86	29.46	0.99	0.64	2.23	0.98	0.06	0.23	0.12	13.79	0.62	6.79	0.33	3.92	0.00
Average weight by species all trips -->						3.54	2.92		0.77	1.46	1.50	1.49	1.45	0.24	5.21	2.01	3.13	2.47	1.74

Appendix B.--Summary catch and effort by fishing areas for samples of Fijian bottomfish, May-October 1987.

Grid or Area	Grid or Area	No Trips	Freq. Sampled (%)	# Fish	Total Wt. (kg)	Avg.Wt (kg)	% Catch by Weight	# Fish	Total Wt. (kg)	Avg.Wt (kg)	% Catch by Weight	# Fish	Total Wt. (kg)	Avg.Wt (kg)	% Catch by Weight
				Etelis carbunculus				**Etelis coruscans**				**Aphareus rutilans**			
397	397	2	5.26	501	1836.3	3.67	56.22	107	269.4	2.52	8.25	80	378.9	4.74	11.60
382	382	2	5.26	162	281.6	1.74	13.65	142	301.6	2.12	14.62	78	625.2	8.02	30.31
482	482	4	10.53	1403	4363.9	3.11	84.51	251	551.8	2.20	10.69	34	119.3	3.51	2.31
499	499	1	2.63	1	0.5	0.52	0.15	0	0.0		0.00	65	262.3	4.04	78.45
220	220	4	10.53	299	2036.4	6.81	40.98	783	1954.2	2.50	39.33	59	230.7	3.91	4.64
C/LAU	C/LAU	2	5.26	50	220.3	4.41	16.14	157	649.3	4.14	47.56	15	80.4	5.36	5.89
E/LAU	E/LAU	1	2.63	0	0.0		0.00	0	0.0		0.00	40	250.0	6.25	61.07
160	160	1	2.63	421	1544.5	3.67	74.28	200	517.3	2.59	24.88	0	0.0		0.00
370	370	3	7.89	25	114.4	4.58	5.91	13	44.7	3.44	2.31	99	362.3	3.66	18.70
167	167	9	23.68	1526	5639.0	3.70	38.29	2076	6810.8	3.28	46.25	264	1248.8	4.73	8.48
480	480	1	2.63	436	1031.9	2.37	99.98	79	172.0	2.18	16.67	0	0.0		0.00
384	384	3	7.89	50	147.1	2.94	7.05	61	182.8	3.00	8.76	134	877.2	6.55	42.03
399	399	1	2.63	21	107.3	5.11	5.39	19	45.0	2.37	2.26	246	1306.0	5.31	65.67
369	369	1	2.63	0	0.0		0.00	0	0.0		0.00	16	52.3	3.27	22.46
166	166	2	5.26	89	379.5	4.26	27.79	163	501.9	3.08	36.75	30	207.5	6.92	15.20
169	169	1	2.63	1	0.0	0.00	0.00	406	1217.2	3.00	100.00	0	0.0		0.00
Total	Total	38		4985	17702.8			4457	13046.2			1160	6001.2		
				Pristipomoides filamentosus				**P. multidens**				**P. flavipinnis**			
397	397			118	97.4	0.83	2.98	2	5.0	2.52	0.15	57	48.3	0.85	1.48
382	382			0	0.0		0.00	85	105.3	1.24	5.11	4	1.7	0.43	0.08
482	482			0	0.0		0.00	26	32.5	1.25	0.63	0	0.0		0.00
499	499			1	1.0	1.01	0.30	8	6.2	0.78	1.87	1	0.5	0.51	0.15
220	220			78	213.2	2.73	4.29	0	0.0		0.00	34	34.0	1.00	0.68
C/LAU	C/LAU			97	223.3	2.30	16.36	0	0.0		0.00	48	44.2	0.92	3.24
E/LAU	E/LAU			18	41.6	2.31	10.16	0	0.0		0.00	0	0.0		0.00
160	160			0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
370	370			255	279.3	1.10	14.42	5	10.2	2.03	0.53	64	69.2	1.08	3.57
167	167			86	114.6	1.33	0.78	64	125.2	1.96	0.85	105	89.3	0.85	0.61
480	480			0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
384	384			13	7.5	0.58	0.36	31	47.9	1.54	2.29	57	0.0		0.00
399	399			16	18.6	1.16	0.94	18	30.9	1.72	1.55	0	0.0		0.00
369	369			0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
166	166			0	0.0		0.00	0	0.0		0.00	4	0.0		0.00
169	169			0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
Total	Total			682	996.5			239	363.3			374	287.3		

Appendix B.--Continued.

Grid or Area	# Fish	Total Wt. (kg)	Avg.Wt (kg)	% Catch by Weight	# Fish	Total Wt. (kg)	Avg.Wt (kg)	% Catch by Weight	# Fish	Total Wt. (kg)	Avg.Wt (kg)	% Catch by Weight
	Pristipomoides typus				**Pristipomoides auricilla**				**Paracesio stonei**			
397	0	0.0		0.00	0	0.0		0.00	1	1.1	1.13	0.03
382	0	0.0		0.00	0	0.0		0.00	26	63.1	2.43	3.06
482	0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
499	0	0.0		0.00	0	0.0		0.00	1	2.0	2.02	0.60
220	0	0.0		0.00	5	6.0	1.21	0.12	0	0.0		0.00
C/LAU	0	0.0		0.00	8	15.0	1.88	1.10	0	0.0		0.00
E/LAU	0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
160	0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
370	224	53.6	0.24	2.77	4	4.3	1.08	0.22	12	21.2	1.76	1.09
167	0	0.0		0.00	0	0.0		0.00	39	74.7	1.92	0.51
480	0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
384	0	0.0		0.00	0	0.0		0.00	19	31.7	1.67	1.52
399	0	0.0		0.00	0	0.0		0.00	20	41.8	2.09	2.10
369	0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
166	0	0.0		0.00	0	0.0		0.00	20	41.1	2.05	3.01
169	0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
Total	224	53.6			17	25.4			138	276.7		
	Paracesio kusakari				**Wattsia mossambicus**				**Epinephelus morrhua**			
397	199	453.9	2.28	13.89	64	139.2	2.18	4.26	5	11.4	2.29	0.35
382	94	424.2	4.51	20.57	110	161.7	1.47	7.84	14	30.7	2.19	1.49
482	16	65.6	4.10	1.27	4	3.1	0.78	0.06	4	7.2	1.81	0.14
499	22	59.8	2.72	17.87	0	0.0		0.00	0	0.0		0.00
220	123	329.1	2.68	6.62	44	92.6	2.10	1.86	6	17.1	2.84	0.34
C/LAU	14	33.8	2.42	2.48	8	16.7	2.09	1.22	16	48.9	3.05	3.58
E/LAU	38	106.3	2.80	25.96	0	0.0		0.00	0	0.0		0.00
160	0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
370	96	179.2	1.87	9.25	416	761.3	1.83	39.30	14	30.5	2.18	1.57
167	123	501.0	4.07	3.40	0	0.0		0.00	0	0.0		0.00
480	0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
384	170	604.9	3.56	28.99	65	83.8	1.29	4.02	0	0.0		0.00
399	14	36.1	2.58	1.81	244	389.8	1.60	19.60	0	0.0		0.00
369	14	50.8	3.63	21.83	53	106.6	2.01	45.80	0	0.0		0.00
166	48	192.7	4.01	14.11	0	0.0		0.00	0	0.0		0.00
169	0	0.0		0.00	0	0.0		0.00	0	0.0		0.00
Total	971	3037.3			1008	1754.9			59	145.8		

Appendix B.--Continued.

Grid or Area	# Fish	Total Wt. (kg)	Avg.Wt (kg)	% Catch by Weight	# Fish	Total Wt. (kg)	Avg.Wt (kg)	% Catch by Weight
	Pristipomoides zonatus				**Etelis radiosus**			
397	10	13.0	1.30	0.40	2	12.3	6.15	0.38
382	0	0.0		0.00	25	67.4	2.69	3.27
482	0	0.0		0.00	3	20.5	6.85	0.40
499	1	2.0	1.99	0.60	0	0.0		0.00
220	6	9.4	1.57	0.19	7	46.1	6.59	0.93
C/LAU	22	33.2	1.51	2.43	0	0.0		0.00
E/LAU	0	0.0		0.00	2	11.5	5.76	2.81
160	0	0.0		0.00	3	17.5	5.83	0.84
370	5	7.0	1.41	0.36	0	0.0		0.00
167	12	16.8	1.40	0.11	24	106.9	4.45	0.73
480	0	0.0		0.00	0	0.0		0.00
384	10	12.2	1.22	0.58	33	91.8	2.78	4.40
399	0	0.0		0.00	2	13.3	6.67	0.67
369	5	9.0	1.80	3.87	2	14.1	7.03	6.04
166	0	0.0		0.00	9	42.8	4.75	3.13
169	0	0.0		0.00	0	0.0		0.00
Total	71	102.7			112	444.1		

Appendix B.--Continued.

Grid or Area	Total Wt. of Catch (kg)	Total No. Fish	Avg.Wt. Per Area All Spp.	CPUE PER GRID AREA kg/trip	No. fish/trip	
397	3266.4	1146	3.2	1858	573	
382	2062.5	740	2.9	1073	370	
482	5164.1	1741	3.6	1577	435	
499	334.4	100	3.3	334	100	
220	4968.8	1444	4.1	1479	361	
C/LAU	1365.2	435	3.1	683	218	
E/LAU	409.4	98	8.4	821	98	
160	2079.2	624	4.0	2492	624	
370	1937.2	1232	1.6	646	411	
167	14727.2	4319	3.7	1775	480	
480	1032.0	515	2.0	1032	515	
384	2087.0	643	3.6	777	214	
399	1988.8	600	4.2	2492	600	
369	232.8	90	8.6	774	90	
166	1365.5	363	4.8	877	182	
169	1217.2	407	3.0	1217	407	
				OVERALL AVERAGE CPUE		
Total	44237.8	14497 <-Totals		1332	382	<---Total Catch
			3.1 <--Averages			

*Not weighted.
Note: Catch from an unknown grid is not included.

Appendix C.--Regional representation by weight and numbers of the major bottomfish groups.

Grid area	or Grid area	or EHU Weight	No.	ONAGA Weight	No.	LEHI Weight	No.	BEDFORD Weight	No.	O'PAKAPAKA Weight	No.	ALL OTHERS Weight	No.
397	397	1836	501	269	107	379	80	454	199	97	118	230	141
382	382	282	162	302	142	625	78	424	94	0	0	430	264
482	482	4364	1403	552	251	119	34	66	16	0	0	63	37
499	499	1	1	0	0	262	65	60	22	1	1	11	11
220	220	2036	299	1954	783	231	59	329	123	213	78	205	102
C/LAU	C/LAU	220	50	649	157	80	15	34	14	223	97	158	102
E/LAU	E/LAU	0	0	0	0	250	40	106	38	42	18	12	2
160	160	1544	421	517	200	0	0	0	0	0	0	18	3
370	370	114	25	45	13	362	99	179	96	279	255	957	744
167	167	5639	1526	6811	2076	1249	264	501	123	115	86	413	244
480	480	1032	436	0	79	0	0	0	0	0	0	0	0
384	384	147	50	183	61	877	134	605	170	8	13	267	215
399	399	107	21	45	19	1306	246	36	14	19	16	476	284
369	369	0	0	0	0	52	16	51	14	0	0	130	60
166	166	380	89	502	163	208	30	193	48	0	0	84	33
169	169	0		1217	406	0	0	0	0	0	0	0	0
Total													
	Grid or												
	Area	Frequency (%)											
	C/LAU	56.22	43.72	8.25	9.34	11.60	6.98	13.89	17.36	2.98	10.30	7.06	12.30
Grid or	E/LAU	13.65	21.89	14.62	19.19	30.31	10.54	20.57	12.70	0.00	0.00	20.84	35.68
Area	160	84.51	80.59	10.69	14.42	2.31	1.95	1.27	0.92	0.00	0.00	1.23	2.13
397	166	0.15	1.00	0.00	0.00	78.45	65.00	17.87	22.00	0.30	1.00	3.22	11.00
382	167	40.98	20.71	39.33	54.22	4.64	4.09	6.62	8.52	4.29	5.40	4.13	7.06
482	220	16.14	11.49	47.56	36.09	5.89	3.45	2.48	3.22	16.36	22.30	11.57	23.45
499	369	0.00	0.00	0.00	0.00	61.07	40.82	25.96	38.78	10.16	18.37	2.81	2.04
220	370	74.28	67.47	24.88	32.05	0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.48
C/LAU	382	5.91	2.03	2.31	1.06	18.70	8.04	9.25	7.79	14.42	20.70	49.42	60.39
E/LAU	384	38.29	35.33	46.25	48.07	8.48	6.11	3.40	2.85	0.78	1.99	2.80	5.65
160	397	99.98	84.66	0.02	15.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
370	399	7.05	7.78	8.76	9.49	42.03	20.84	28.99	26.44	0.36	2.02	12.81	33.44
167	480	5.39	3.50	2.26	3.17	65.67	41.00	1.81	2.33	0.94	2.67	23.92	47.33
480	482	0.00	0.00	0.00	0.00	22.46	17.78	21.83	15.56	0.00	0.00	55.70	66.67
384	499	27.79	24.52	36.75	44.90	15.20	8.26	14.11	13.22	0.00	0.00	6.14	9.09
399	169	0.00		100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ESTIMATION OF THE UNEXPLOITED BIOMASS AND MAXIMUM SUSTAINABLE YIELD FOR THE DEEP REEF DEMERSAL FISHES IN PAPUA NEW GUINEA

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ABSTRACT

Estimates of biomass and maximum sustainable yield (MSY) for deep reef fish stocks in Papua New Guinea (PNG) were made from depletion studies at a seamount and an island site. Biomass was estimated to be 3,331 kg/nmi of 200 m isobath at the seamount and 191 kg/nmi of 200 m isobath at the island site. The potential MSY was calculated based on different empirical relationships that required either an estimate of natural mortality rate or growth and sexual maturation parameters. Possible ranges of total MSY of deep reef stocks for the entire PNG are given, and the limitations of the present estimates are discussed.

INTRODUCTION

Fishing for snappers and groupers in deep (>80 m) water beyond the reef slope was first introduced to Papua New Guinea (PNG) by the South Pacific Commission during exploratory surveys of West New Britain in 1979 (Fusimalohi and Crossland 1980). The principal gear employed was a Samoan design of wooden hand reel that has since become popular throughout the South Pacific. Other areas surveyed were Kavieng (Malcomson and Richards 1984), Port Moresby, Milne Bay, Manus (Sundberg and Richards 1982), Kieta (Anonymous 1985), Kupiano (Anonymous 1985; Sundberg and Richards 1984), Huon Gulf (Richards and Kaobe 1985), the Wewak Turubu area (Chapau 1986), and Aitape (Chapau unpubl. data). Despite these surveys, the introduction of deepwater fishing using Samoan-type, wooden hand reels in PNG has had little success. Deepwater snappers are, however, occasionally landed by subsistence fisherman in some areas of the country. A small artisanal fishery in the Turubu area of East Sepik Province was developed in 1983-85 and landed a peak catch of 15.0 metric tons (t) in 1984 (Chapau 1986). This fishery has since collapsed because of socioeconomic problems.

Previous studies of the PNG deepwater snapper and grouper resources have not addressed the question of the size of these resources. Recent studies of seamounts in the Marianas have shown that short-term depletion of the limited stocks on seamounts can provide information on the biomass of these fishes. The present paper reports on the analysis of depletion fishing for deepwater snappers in the Schouten Islands of East Sepik Province and at a pinnacle seamount near Kavieng in New Ireland Province (Fig. 1). The aim of these two studies was to obtain basic biological data and catch and effort information and to estimate the maximum sustainable yield (MSY) for these stocks in an attempt to determine the size of the PNG deep reef resources.

STUDY AREA

The Schouten Islands consist of four volcanic islands situated off the northern coast of PNG (lat. 2°30'S, long. 144°20'E) in the East Sepik Province (see Fig. 1). The islands are about 50 km from the Sepik River, the longest in PNG and one of the world's major tropical river systems. The Sepik River discharges 10,963 m^3/s of water into the sea (Coates 1985) and likely influences the hydrology of the sea around the Schouten Islands. At times of heavy flooding, silt flumes reach the islands.

The Kavieng Pinnacle is situated at Kavieng (lat. 2°30'S, long. 150°40'E) in New Ireland Province (Fig. 1). The pinnacle is a truncated cone, with a basal diameter of about 340 m and an apical diameter of 100 m. It rises to 70 m from a depth of 140 m. The 90 m isobath of the pinnacle is estimated to be 0.25 nmi. Unlike the Schouten Islands, no major river systems discharge into the sea in the vicinity of Kavieng.

METHODS

A three-hook, Samoan-type, wooden hand reel for vertical handlining (Fusimalohi and Crossland 1980) was used for fishing at the Schouten Islands and the Kavieng Pinnacle. Fishing was conducted throughout 1986 at the Schouten Islands and for 11 weeks in 1982 at the Kavieng Pinnacle. The catch was recorded by weight and numbers; effort was recorded in line-hours.

The sampling methods are described in Lokani (1988) for the Schouten Islands and in Sundberg and Richards (1984) for the Kavieng Pinnacle. Basic biological data recorded for fish landed from the Schouten Islands

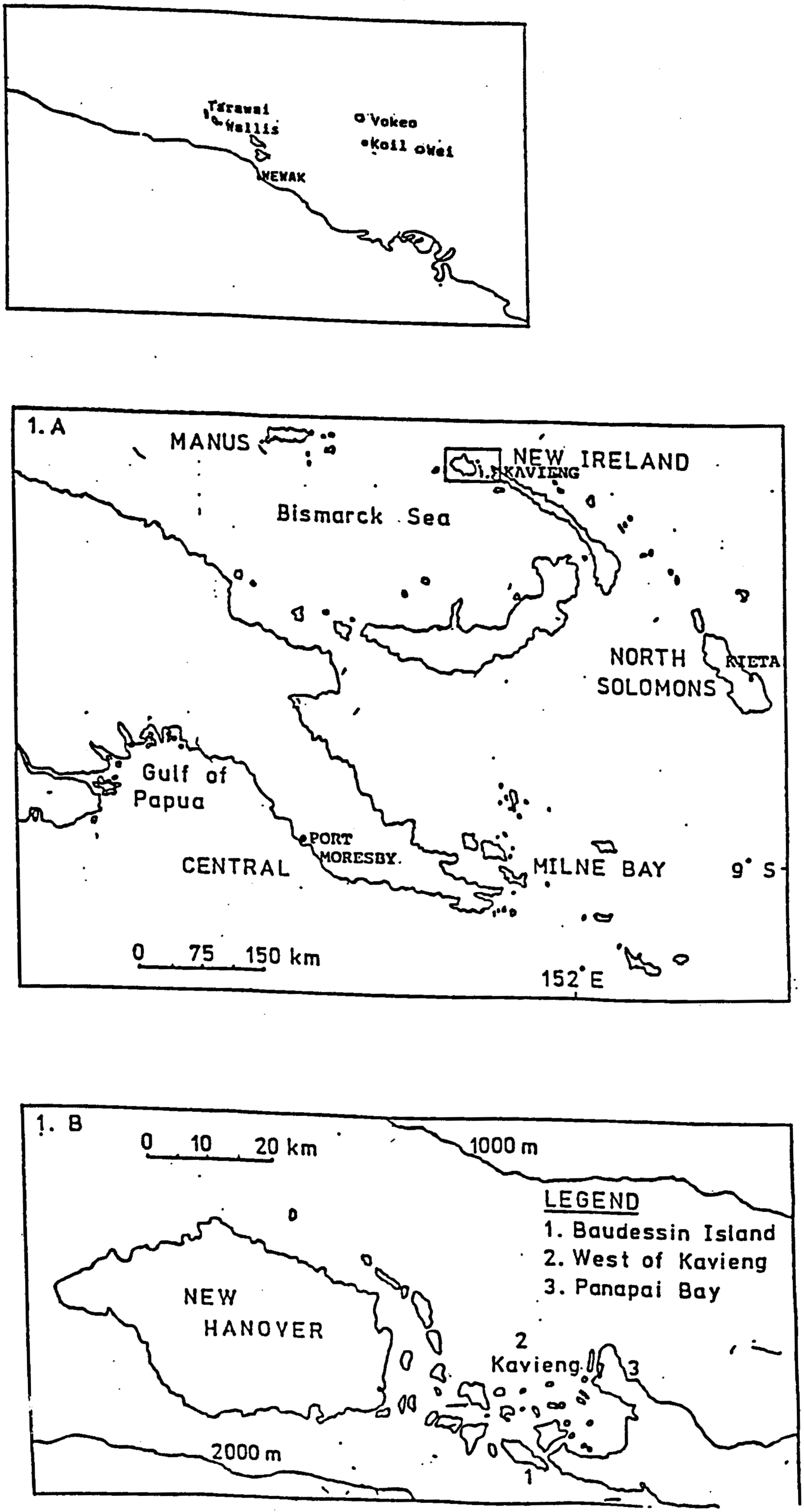


Figure 1.--Location of the study areas in Papua New Guinea.

included length to the nearest 10 mm, weight to the nearest 20 g, and gonad weight to the nearest 0.001 g. A gonadosomatic index (GSI) was computed for the six most common species in the catch from the Schouten Islands:

$$\mathrm{GSI} = \frac{\text{Gonad weight x 100}}{\text{Fish weight}} .$$

The depletion method of Leslie (in Ricker 1975) was used with the catch and effort data from the Schouten Islands and the Kavieng Pinnacle to determine virgin biomass (B_∞) at both locations. This model expresses catch per unit effort (CPUE) as a linear function of the cumulative catch (Polovina 1986) when catchability is constant and both natural mortality and recruitment are negligible. The model takes the form

$$C_t = qf(N_1 - C_1 - C_2 - \ldots - C_{t-1}),$$

and

$$\frac{C_t}{f_t} = qN_1 - q(C_1 + C_2 + \ldots C_{t-1}).$$

If depletion does indeed occur, then a plot of CPUE versus cumulative catch should yield a straight line with a negative slope, the value of which is q. Allen (1966) proposed a variant of the simple depletion model where catches occur over longer time periods and natural mortality (M) and recruitment (R) must be considered.

$$C_i = qf_i \quad \frac{R}{1-e^{-m}} \quad - \quad C_1 e^{-(i-1)m} + \ldots C_{i-1} e^{-m} + C_i/2 \quad ,$$

which can be rearranged in the form of a multiple regression equation:

$$C_i = Af_i + Bf_i \; X_i ;$$

where $A = qR/(1-e^{-m})$,

$B = q$, and

$$X_i = C_1 e^{-(i-1)m} + C_2^{-(i-2)m} + C_i/2.$$

When M is unknown, different values of natural mortality can be iterated to give the best fit of the model to catch and effort data.

The length-frequency data for the common species in the Schouten Islands were used to generate indexes of growth and mortality parameters. An approximation of the asymptotic length (L_∞) of the von Bertalanffy growth function (VBGF) was estimated:

$$L_\infty = \frac{L_{\max}}{0.95} .$$

Beverton and Holt (1957) showed that when fish growth can be described by the VBGF, then the total mortality rate (Z) can be determined:

$$Z = K \frac{(L_\infty - L)}{(L - L_c)} ,$$

where L_c is length at full recruitment and L is mean length of all fishes more than L_c. When K is not known, then

$$\frac{Z}{K} = \frac{L_\infty - L}{L - L_c} .$$

When fishing mortality (F) is zero, then as $Z = F + M$, the above equation generates indexes of the natural mortality rate. Estimates of potential MSY were made from two methods. Gulland (1971) suggested that the potential MSY might be determined given a knowledge of virgin biomass (B_∞) and natural mortality rate:

$$MSY = 0.5\ M\ B_\infty .$$

Alternatively, Pauly (1982) proposed that the MSY could be obtained from a knowledge of asymptotic weight (W_∞) and weight at sexual maturity (W_{mat}):

$$MSY = 2.3\ W^{-0.26}$$

where $W = (W\infty + W_{mat})/2$.

RESULTS

Depletion Studies

A summary of the data on catch and fishing effort at the Schouten Islands is given in Table 1. The initial 3 months of fishing are excluded from the analysis since they represent the learning effect of fishing at this location. A plot of CPUE versus cumulative catch is in Appendix A. The regression line gives a $q = 0.0006$ and a B_∞ of 3,156 fish. The average weight of fish captured at Schouten Islands is 2.0 kg (Lokani 1988); thus, B_∞ is 6,312 kg. Polovina et al. (1985) have suggested expressing deep reef fish biomass as a function of the length of the 200 m isobath in nautical miles. At the Schouten Islands, the length of the 200 m isobath is 33 nmi; thus, the standing stock of deepwater reef fish is 191.3 kg/nmi of 200 m isobath.

The catch and effort data from the Schouten Islands are also used in conjunction with the Allen depletion model. Natural mortality estimates of 0.25 and 0.5/year are assumed to represent the ranges of M for deepwater snappers based on Ralston (1987). The outputs of the model are, in each instance, not greatly different from those of the Leslie model. The

Table 1.--Catch, effort, catch per unit effort (CPUE), and cumulative catch for Schouten Islands.

Month	Effort (line-hours)	Catch (No.)	CPUE	Cumulative catch (No.)
Jan.	252	66	0.26	66
Feb.	84	106	1.26	172
Mar.	80	100	1.25	272
May.	196	275	1.40	547
Jun.	194	232	1.20	779
Jul.	161	310	1.93	1,089
Aug.	396	351	0.89	1,440
Sep.	156	196	1.26	1,636
Feb.	64	60	0.94	1,696
Mar.	116	47	0.41	1,743
Apr.	196	142	0.72	1,885

catchability coefficient with either M estimate is around 0.0006; using this coefficient to determine B_∞ from the largest CPUE gives values similar to that from the Leslie model.

For the catch (in weight) and effort data from the Kavieng Pinnacle (Table 2), the Allen model was again used. Although this model gave a good fit, the regression produced positive estimates of q, and this approach was therefore discontinued. The Leslie model fitted to the Kavieng data (Appendix B) gives a q of +0.00319 and a B_∞ of 832 kg of fish. With fishing in this instance at 90 m and the length of this isobath being 0.25 nmi, the biomass is an estimated 3,331.3 kg/nmi.

Length-Weight Equations

The relationship between length and weight is important in fishery studies since a knowledge of this relationship can preclude the continued collection of individual fish weight during sampling. The length-weight equation takes the form

$$W_t = aL^b ,$$

where a and b are constants of the curve. The value of b usually lies between 2 to 4 but is often close to 3. An estimate of $b = 3$ suggests isometric growth, while $b \neq 3$ suggests allometric growth. The equation can be easily fitted by making a double logarithmic transformation:

Table 2.--Catch, effort, catch per unit effort (CPUE), and cumulative catch for Kavieng Pinnacle.

Trip	Effort (line-hours)	Catch (kg)	CPUE	Cumulative catch (kg)
1	24	54.48	2.27	54.48
2	57	98.61	1.73	153.09
3	54	139.32	2.58	292.41
4	24	40.80	1.70	333.21
5	30	55.50	1.85	388.71
6	54	50.22	0.93	438.93
7	48	75.36	1.57	514.29
8	57	19.38	0.34	533.67
9	48	43.20	0.90	576.87
10	21	5.46	0.26	582.33
11	24	21.84	0.91	604.17

Table 3.--Length-weight relationships obtained from length-weight regressions.

Species	$W = aL^b$
Etelis carbunculus	$W = 5.32 \times 10^{-8} L^{2.8}$
Lutjanus malabaricus	$W = 5.84 \times 10^{-8} L^{2.8}$
Paracaesio stonei	$W = 2.18 \times 10^{-6} L^{2.2}$
Pristipomoides filamentosus	$W = 3.30 \times 10^{-5} L^{2.8}$
P. multidens	$W = 9.11 \times 10^{-8} L^{2.8}$
Wattsia mossambicus	$W = 3.63 \times 10^{-6} L^{2.2}$

$$Log_e\ W_t = Log_e a + b\ Log_e L,$$

which is a simple linear equation.

The length-weight equations for the six most common species in the Schouten Islands are given in Table 3 and, where possible, are compared with those estimated by Richards (1987) for the Kavieng area.

Lengths and Weights at First Maturity

The lengths at first maturity for the six most common species in the catch from the Schouten Islands (Table 4) are determined by plotting GSI values on the respective lengths. The different data points are plotted in Appendix C. In each case, the minimum length at first maturity could be determined and then easily converted into weight via the length-weight equation.

M/K Ratios and Natural Mortality Rates

The length-frequency data for the six most common species in the Schouten Islands are in Appendix D. Estimates of the *M/K* ratio could be computed from these data (see also Table 5), with the exception of *Etelis carbunculus*, which exhibits a bimodal rather than unimodal distribution--a phenomenon is apparent for this species in catches from Vanuatu, Tonga, and Western Samoa. To convert the *M/K* ratios to actual natural mortality rates, it is necessary to obtain values of *K*. Growth studies were not made in this instance; however, empirical values of *K* have been generated for four of the species by using the method of Pauly and Munro (1983):

$$\emptyset' = log_{10}K + 2log_{10}\ L_\infty,$$

The dimensionless parameter $\emptyset'$ permits comparative data on growth data to be used to generate values of *K* when only L_∞ is known or could be approximated.

Estimates of growth for *Pristipomoides multidens*, *P. filamentosus*, and *Lutjanus malabaricus* are available from the literature (Brouard and Grandperrin 1985; Ralston and Williams 1988). With these $\emptyset'$ estimates, *K* for these species could be computed, and hence, *M* computed.

Yield Estimates

The Gulland (1971) Method

The range of *M* estimates for the Schouten Islands is assumed to represent deep bottomfish species in the northern PNG region. The mean value of $M = 0.39$ is used in conjunction with the Gulland equation $0.5\ M\ B_\infty = \text{MSY}$; the outputs for both the Schouten Islands and Kavieng Pinnacle are given in Table 6.

Table 4.--Summary of data used to compute percentage of unexploited biomass.

Species	L_{max}	L_∞	W_∞ (g)	L_{mat}	W_{mat}	W_∞+W_{mat}/2	N	W_∞+W_{mat}/2 * N
Etelis carbunculus	97.0	102.1	14,163.9	61.0	3,348.0	8,756.0	158.0	1,383,448.0
Lutjanus malabaricus	54.0	56.8	3,010.2	36.0	832.0	1,925.0	146.0	281,050.0
Paracaesio stonei	79.0	83.2	5,790.7	40.0	3,473.0	3,473.0	148.0	514,004.0
Pristipomoides filamentosus	57.9	60.9	2,506.0	34.0	481.0	1,493.0	94.0	140,342.0
P. multidens	61.5	64.7	6,761.6	30.0	786.0	3,773.8	376.0	1,418,948.8
Wattsia mossambicus	47.4	50.0	3,145.1	31.0	1,100.0	2,123.0	279.0	592,317.0
Total							1,201.0	4,330,109.8

Note: Length infinity estimated from L_{max}/0.95.

The Pauly (1982) Method

A range of W_{mat} and W_∞ values were available for the six most common species in the catch from Schouten Islands. With these values, it is possible to estimate W. These values are then averaged, taking the number of fish in the catch as a weighting factor to give a W of 3,605 g. Inputting this into the equation B_∞ 2.3 $W^{-0.26}$ permits the estimation of MSY at both locations (Table 6).

DISCUSSION

Similar depletion studies from around the Pacific are presented in companion papers in this volume, as are the estimates of B_∞ per nautical mile of 200 m isobath. The data for the Kavieng Pinnacle are expressed in terms of the 90 m isobath, the depth at which fishing took place. The results for this location are, however, comparable with those from the rest of the South Pacific where estimates of B_∞ range from 1 to 8 t/nmi of 200 m isobath. The biomass estimate for the deep reef stocks from the Schouten Islands is the lowest encountered in the South Pacific (see contributions in this volume), but an estimate of 0.3 t/nmi of 200 m isobath has been reported for Ambae Island in Vanuatu by Carlot and Cillaurren (1990). In general, the concentration of fish stocks around seamounts apparently is greater than around island shelves. Seamounts offer only a limited habitat surface and thus may concentrate the available or unexploited exploitable

Table 5.--Summary of data used to compute M/K ratio from the Beverton and Holt (1957) mean length equation.

Species	L_{∞} (cm)	L_c (cm)	Mean(L) (cm)	M/K	M
Lutjanus malabaricus	56.8	43.5	49.1	1.38	0.46[a]
Paracaesio stonei	83.2	41.8	51.5	3.27	
Pristipomoides filamentosus	60.9	38.9	50.0	0.98	0.32[b]
P. multidens	64.7	48.0	55.1	1.35	0.39[c]
Wattsia mossambicus	50.0	39.4	43.0	1.94	

[a]K = 0.37/year computed from (phi-prime) estimate for *L. malabaricus* from Vanuatu (Brouard and Grandperrin 1985).

[b]K = 0.27/year computed from (phi-prime) estimate for *P. filamentosus* from the Marianas (Ralston and Williams 1988).

[c]K = 0.25/year computed from (phi-prime) estimate for *P. multidens* from Kavieng Pinnacle (Richards 1987).

Table 6.--Summary of estimates of exploitable biomass and maximum sustainable yield for Schouten Islands and the Kavieng Pinnacle.

Area	B_{∞} (No.)	B_{∞}(wt) (kg)	B_{∞}/nmi 200 m isobath (kg)	Maximum sustainable yield			
Schouten Islands	3,156.2	6,312.3[a]	191.3	53.7[b]	37.3[c]	1,726[d]	1231[e]
Kavieng Pinnacle	216.5	832.8	3,331.3	932.8[b]	649.6[c]	227[d]	162[e]

[a]B_{∞}(wt) computed from mean fish weight of 2 kg.

[b]Pauly method (W = 3.6 kg): kilograms per nautical miles 200 m isobath.

[c]Gulland method: kilograms per nautical miles 200 m isobath.

[d]Pauly method: absolute value in kilograms.

biomass. Around islands, the extensive habitat areas act to diffuse the available biomass, and thus both CPUE and biomass estimates are lower than at seamounts.

The total coastline length of PNG is about 10,500 km or 5,000 nmi (Frielink 1983). This might be used as an approximation of the length of the 200 m isobath. If the data from the Schouten Islands are representative of the general shelf area, then the national, annual MSY from deep reef demersal stocks might be expected to range from 170 to 270 t/year. This range is very low, given the size of PNG and the MSY estimates from other Pacific islands. Therefore, the estimate for the Schouten Islands may represent a lower limit of production. The average virgin biomass around other Pacific islands is 0.7 t/nmi of 200 m isobath (based on other contributions in this volume), which gives a predicted MSY range of 682 to 980 t/year when applied to PNG.

The uncertainty in the estimate of MSY for deep reef species is due to the limited information on biomass. Taking the average between MSY estimates for the Kavieng Pinnacle and the Schouten Islands would probably be incorrect given the highly concentrated nature of seamount stocks, and would result in extremely high biomasses when expressed in nautical miles of isobath. It might be argued that the catches at the Schouten Islands are not representative of the entire PNG and perhaps are influenced by the proximity of a major river. However, catch rates from fishing virgin deep reef stocks in different areas of the PNG were 1.2-5.4 kg/line-hour, with a mean of 3.6 kg/line-hour. The average catch rate from the Schouten Islands over the period of this study was 3.2 kg/line-hour. The estimate of 700 to 1,000 t of deep reef fishes for the PNG is probably a reasonable upper limit for MSY, but it should be clearly understood that the estimate is based on comparative studies from elsewhere.

ACKNOWLEDGMENTS

We thank our respective governments for nominating us to attend the workshop which generated this report. We are also very grateful to the United States Agency for International Development for financial support to attend the workshop and to Paul Dalzell, Jeffrey J. Polovina, and Richard S. Shomura for their help in the analysis and interpretation of the data. We also thank Ronald A. Benco and Donald R. Kobayashi for their assistance with microcomputer keypunching and analysis.

CITATIONS

Allen, K. R.
1966. Some methods for estimating exploited populations. J. Fish. Res. Board Can. 23:1553-1574.

Anonymous.
1985. Deepwater bottom fishing survey of Kieta, North Solomons Province, April 27-May 11, 1985. Unpubl. manuscr., var. pag.

Beverton, R. J. H., and S. J. Holt.
1957. On the dynamics of exploited fish populations. Fish. Invest. Ser. II, Mar. Fish. G. B. Minist. Agric. Fish. Food 19:1-53.

Brouard F., and R. Grandperrin.
1985. Deep-bottom fishes of the outer reef slope in Vanuatu. South Pacific Commission, 17th Regional Technical Meeting on Fisheries. South Pacific Commission, Noumea, New Caledonia, p. 127.

Carlot, A. H., and E. Cillaurren.
1990. Yield assessment of the deep bottomfish fishery in Vanuatu. (This volume.)

Chapau M. R.
1986. Development of deep sea fishing in the East Sepik Province, Papua New Guinea. Pages 357-359 *in* J. L. Maclean, L. B. Dizon, and L. V. Hosillos (editors), The First Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines.

Coates, D.
1985. Fish yield estimates for the Sepik River, Papua New Guinea, a large floodplain system east of "Wallace's Line." J. Fish Biol. 27:431-443.

Frielink, A. B., Jr.
1983. Coastal fisheries in Papua New Guinea's tuna fishery. Mar. Fish. Rev. 45(10/12):47-59.

Fusimalohi, T., and J. Crossland.
1980. Report on the South Pacific Commission deepsea fisheries development project in west New Britain, Papua New Guinea. South Pacific Commission, Noumea, New Caledonia.

Gulland, J. A.
1971. The fish resources of the ocean. Fishing News Books, Ltd., Surrey, England, 225 p.

Lokani, P.
1988. The deep sea reel fishing on the outer islands of East Sepik Province. Unpubl. manuscr., 16 p.

Malcomson, L., and A. H. Richards.
1982. Deepsea bottom fishing by National Fisheries College students near Kavieng, New Ireland.

Pauly, D.
1982. Studying single dynamics in a multispecies context. Pages 33-70 *in* D. Pauly and G. I. Murphy (editors), Theory and management of

tropical fisheries. ICLARM Conf. Proc. 9. International Center for Living Aquatic Resources Management, Manila, Philippines and Div. Fish. Res., Commonw. Sci. Indust. Res. Organ., Cronulla, Australia.

Pauly D., and J. L. Munro.
1984. Once more on the comparison of growth in fish and invertebrates. Fishbyte 2(1):21.

Polovina, J. J.
1986. An approach to yield assessment for unexploited resources with application to the deep slope fishes of the Marianas. Fish. Bull., U.S. 84:759-770.

Polovina, J. J., R. B. Moffitt, S. Ralston, M. P. Shiota, and H. A. Williams.
1985. Fisheries resource assessment of the Mariana Archipelago 1982-85. Mar. Fish. Rev. 47(4):19-25.

Ralston, S.
1987. Mortality rates of snappers and groupers. Pages 375-404 *in* J. J. Polovina and S. Ralston (editors), Tropical snappers and groupers: biology and fishery management. Westview Press, Boulder.

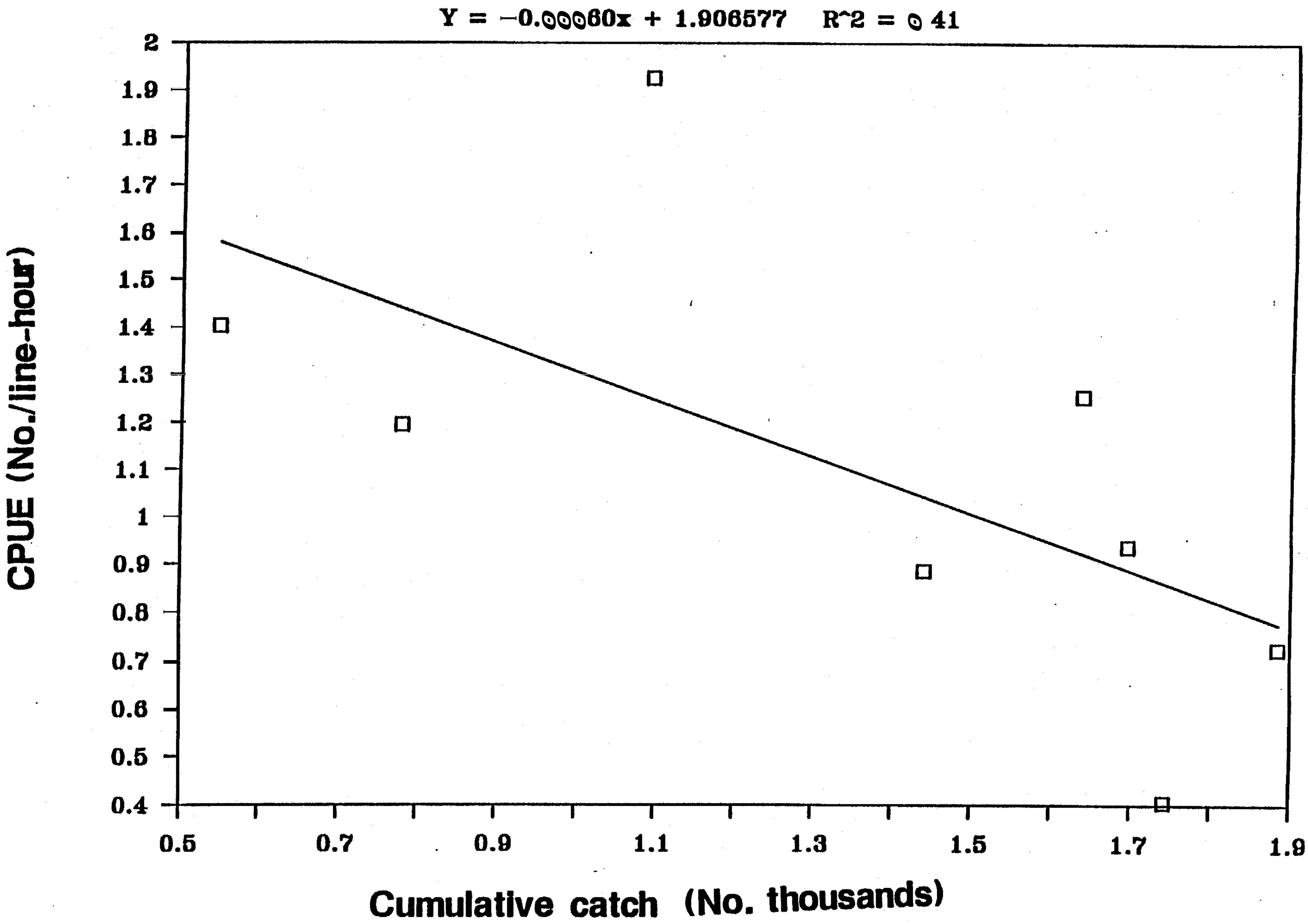
Ralston, S. V., and H. A. Williams.
1988. Depth distributions, growth, and mortality of deep slope fishes from the Mariana Archipelago. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SWFC-113, 47 p.

Richards, A. H.
1987. Aspects of the biology of some deepwater bottomfish in Papua New Guinea with special reference to *Pristipomoides multidens* (Day). Report No. 87-01, 31 p.

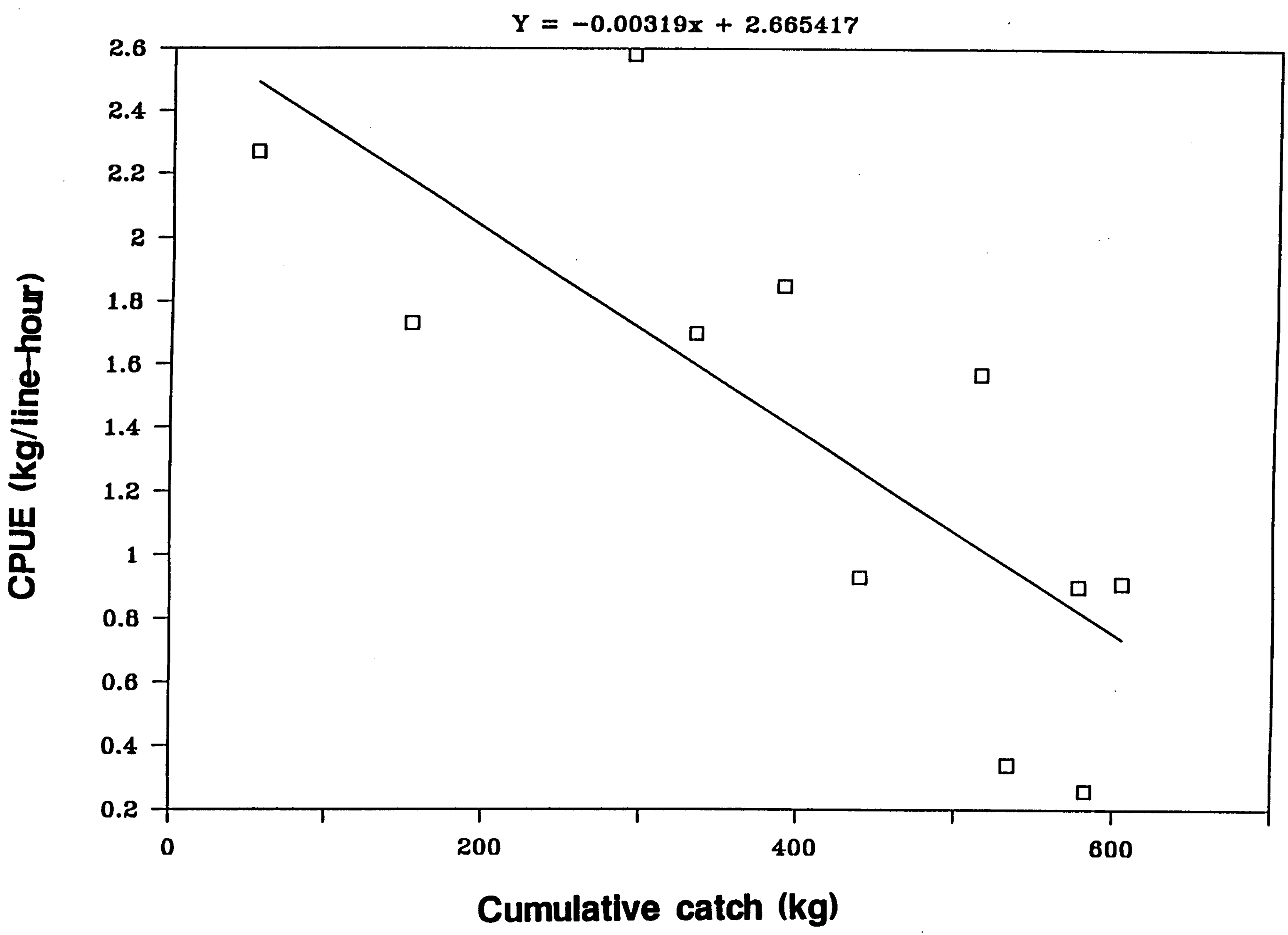
Richards, A. H., and J. Kaobe.
1985. Deepwater bottom fishing survey - Fly islands to Morobe station, Huon Gulf. Unpubl. manuscr., var. pag.

Ricker, W. E.
1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191, 382 p.

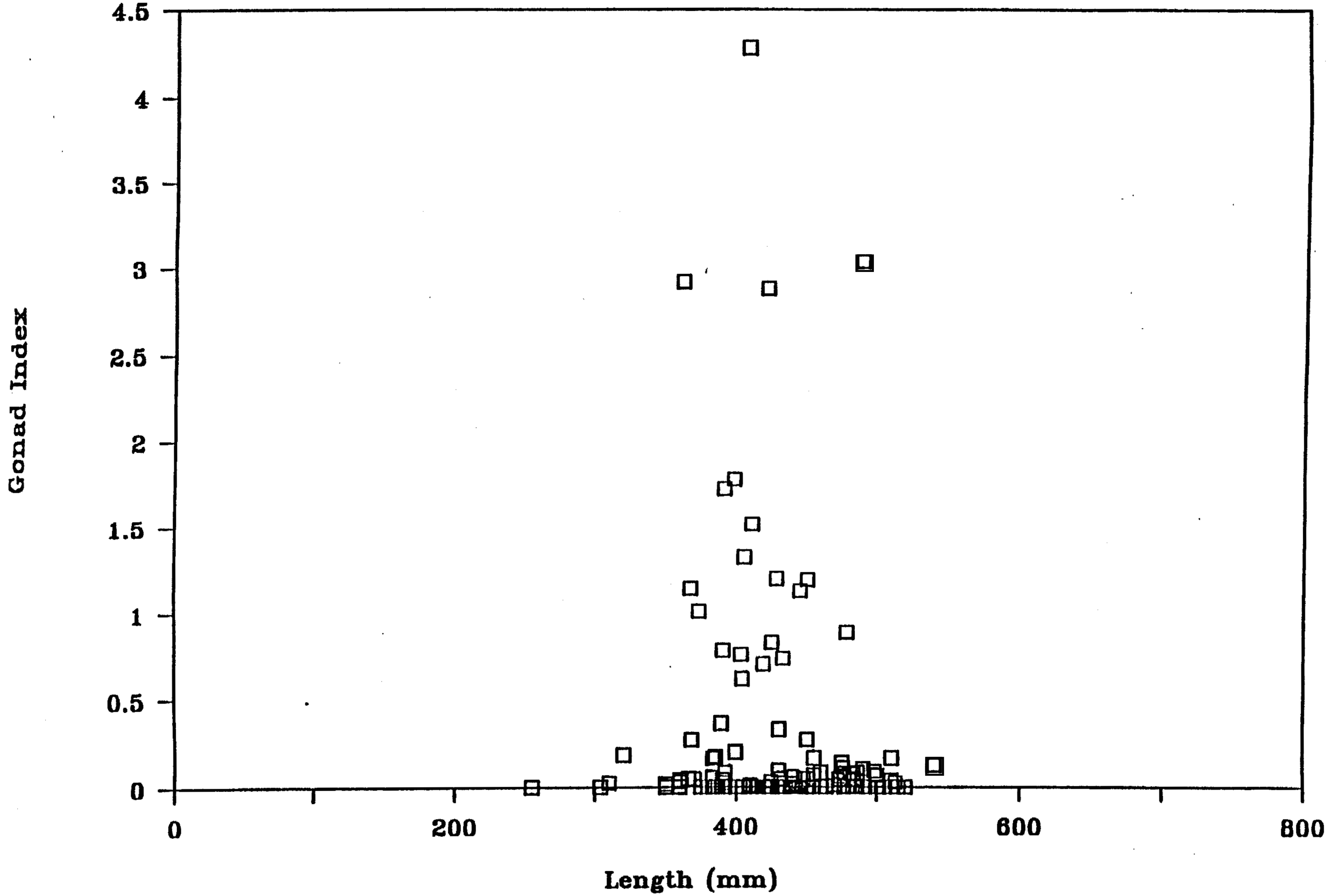
Sundberg, P., and A. Richards.
1984. Deep-sea bottom handline fishing in Papua New Guinea: a pilot study. Papua New Guinea J. Agric. For. Fish. 33:55-62.



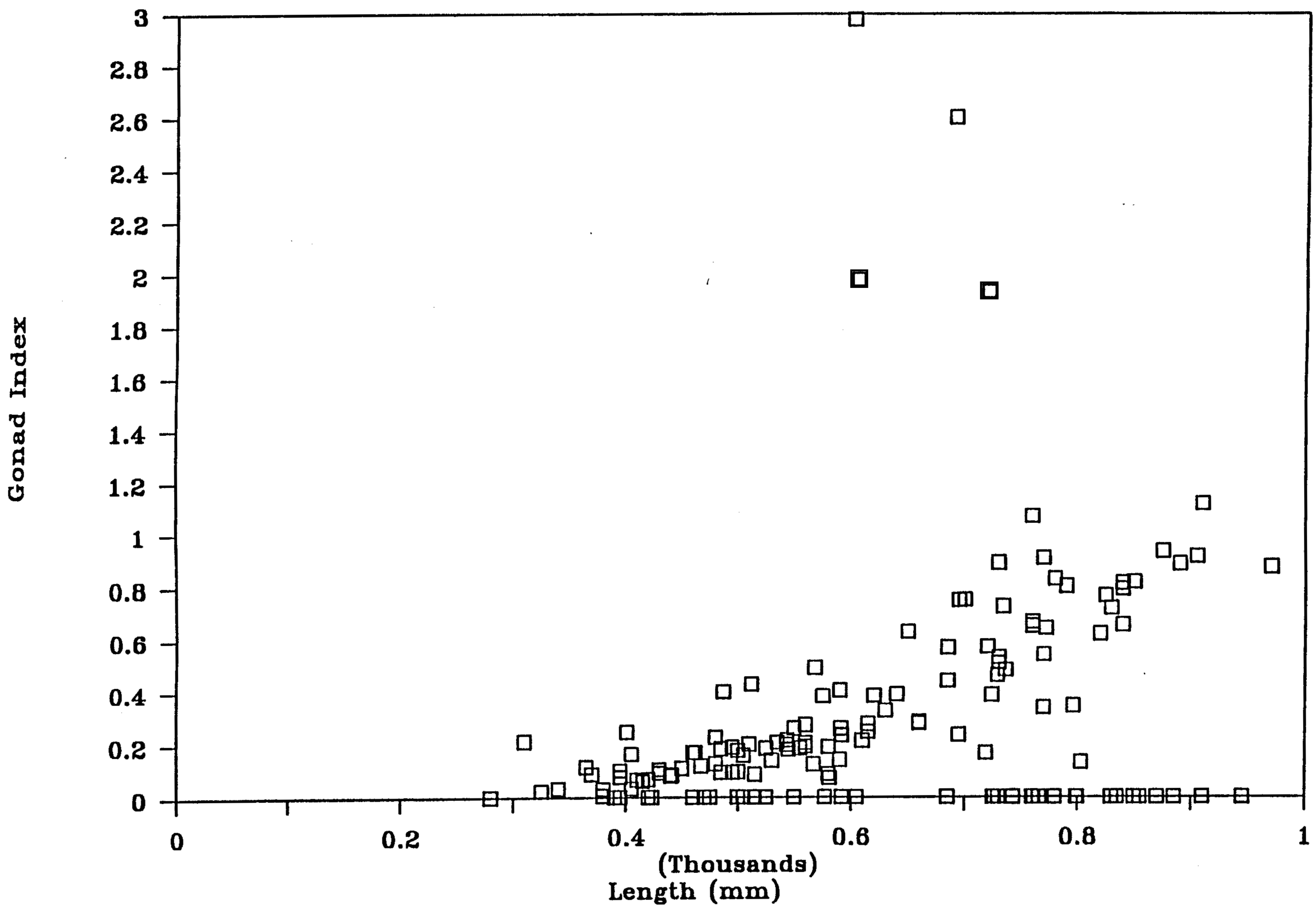
Appendix A.--Catch per unit effort (CPUE) as a function of cumulative catch at Schouten Islands.



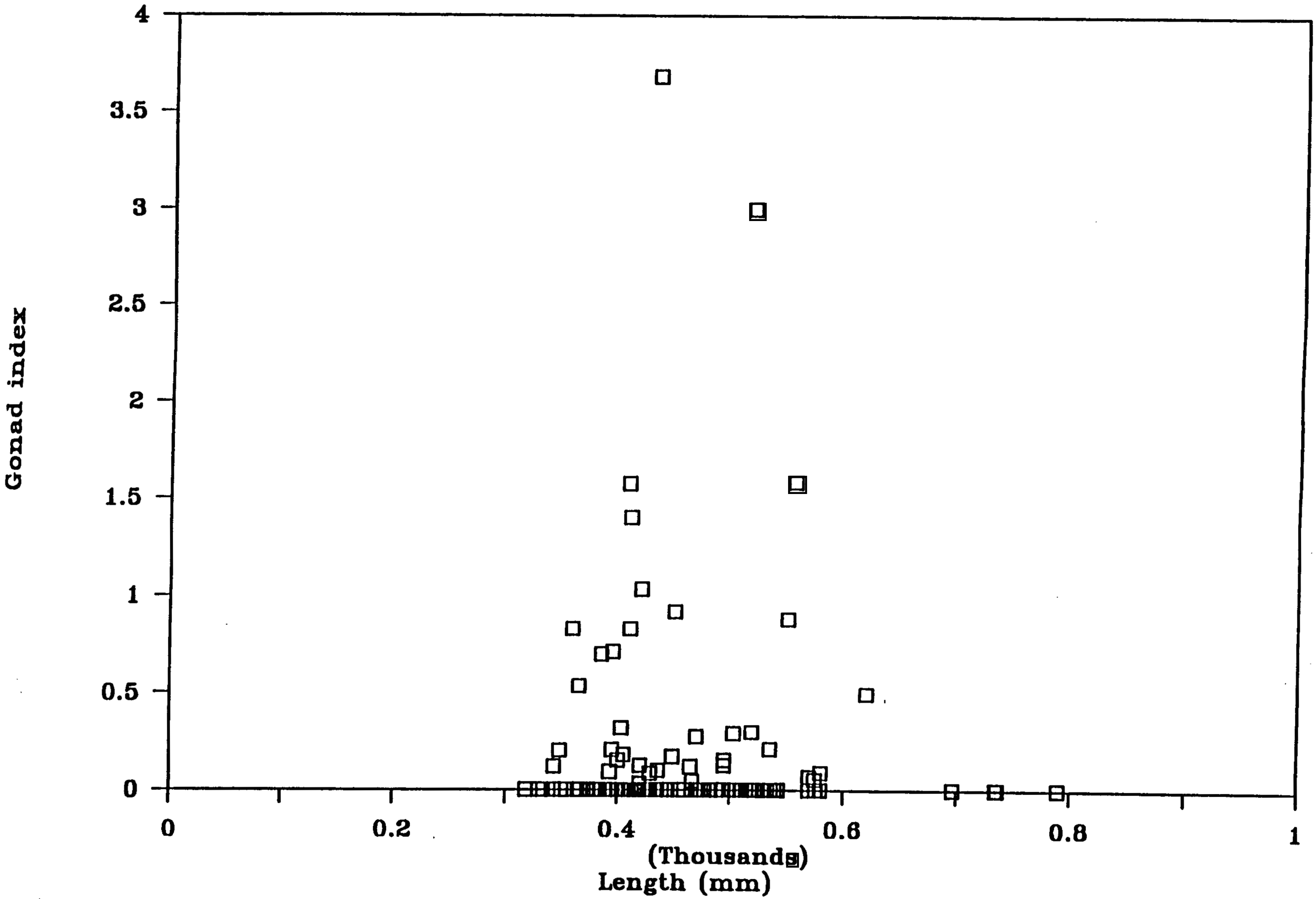
Appendix B.--Catch per unit effort as a function of cumulative catch at Kavieng.



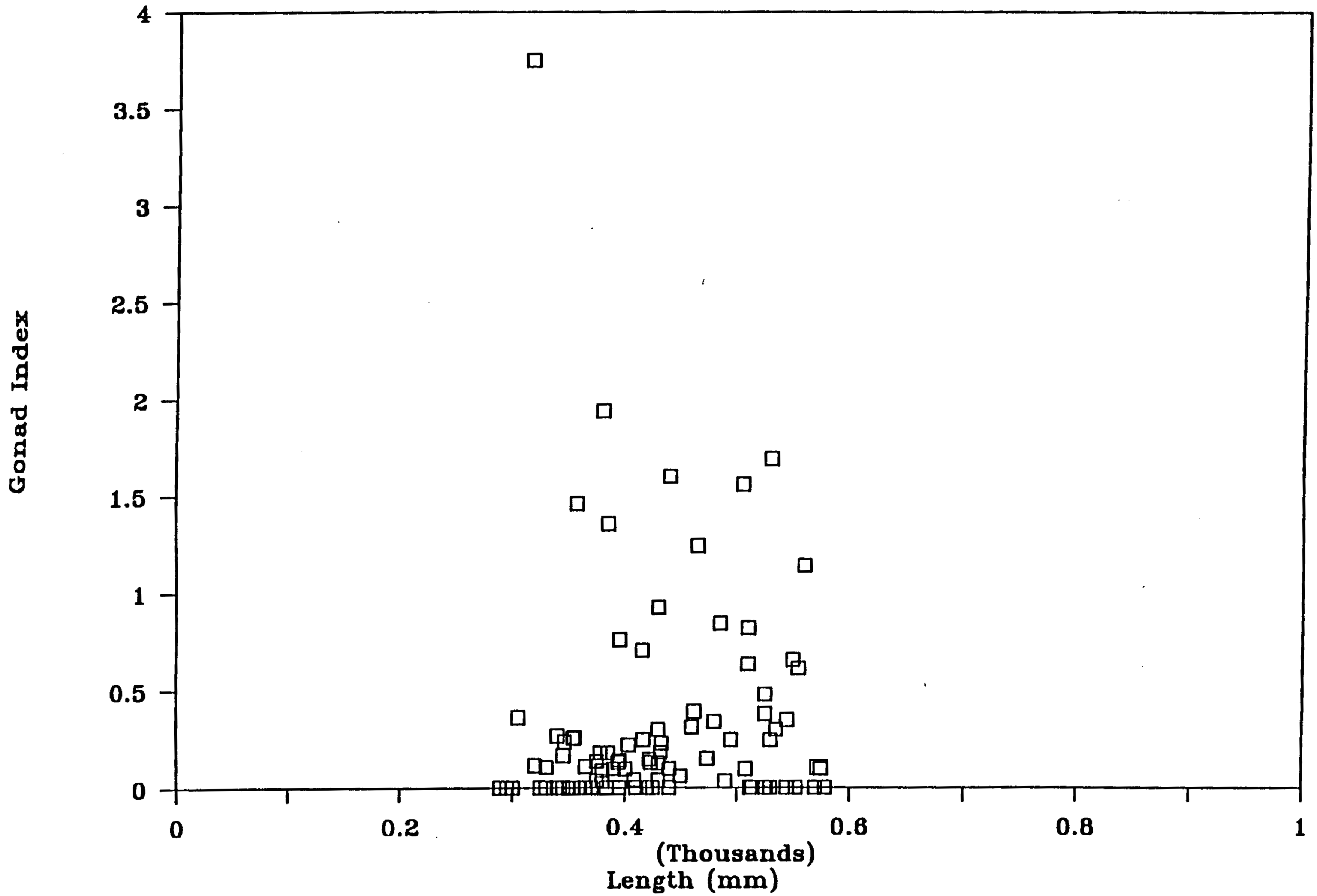
Appendix C.--Gonadosomatic index (GSI) as a function of length from Schouten Islands. *Lutjanus malabaricus*.



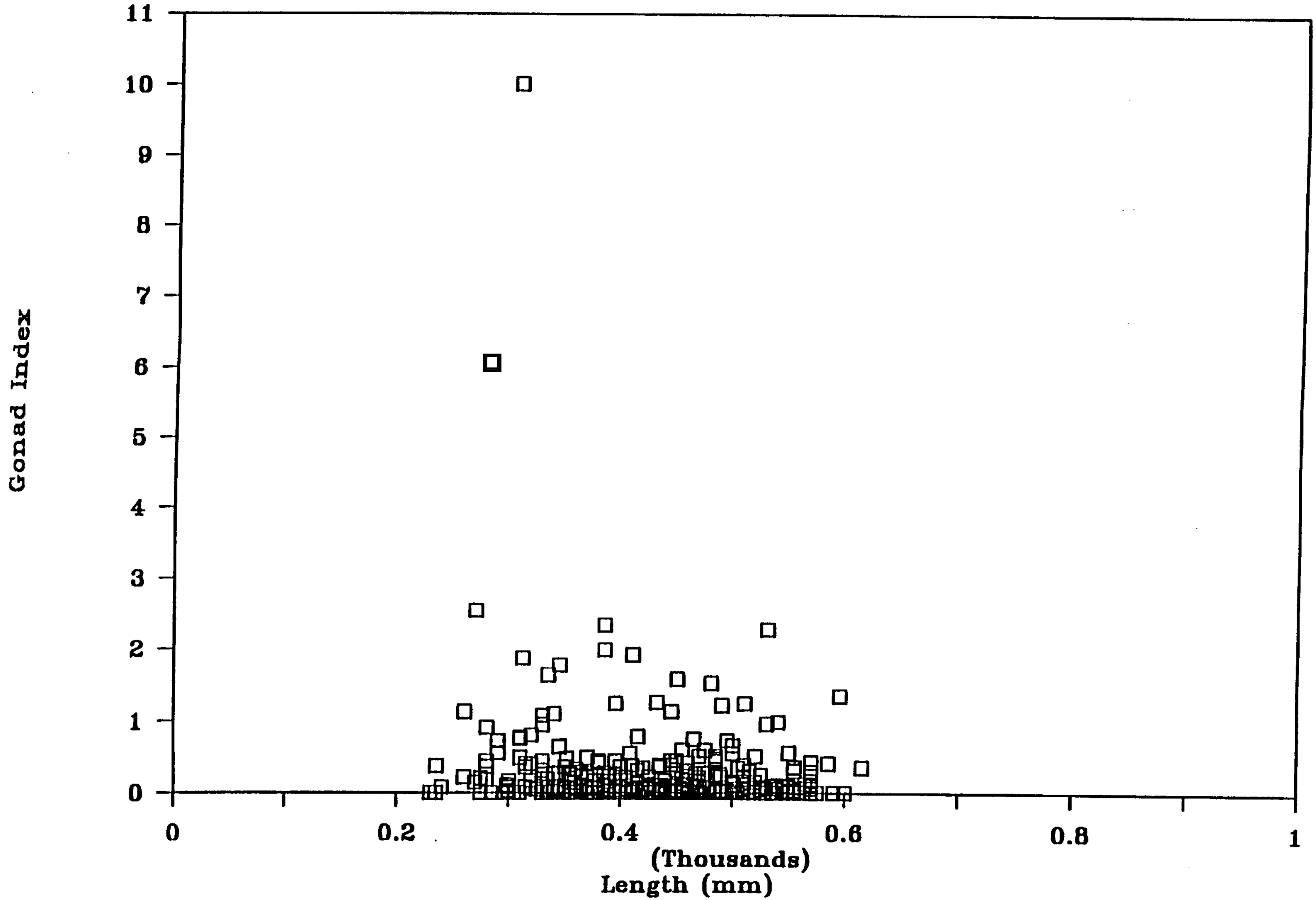
Appendix C.--Continued. *Etelis carbunculus*.



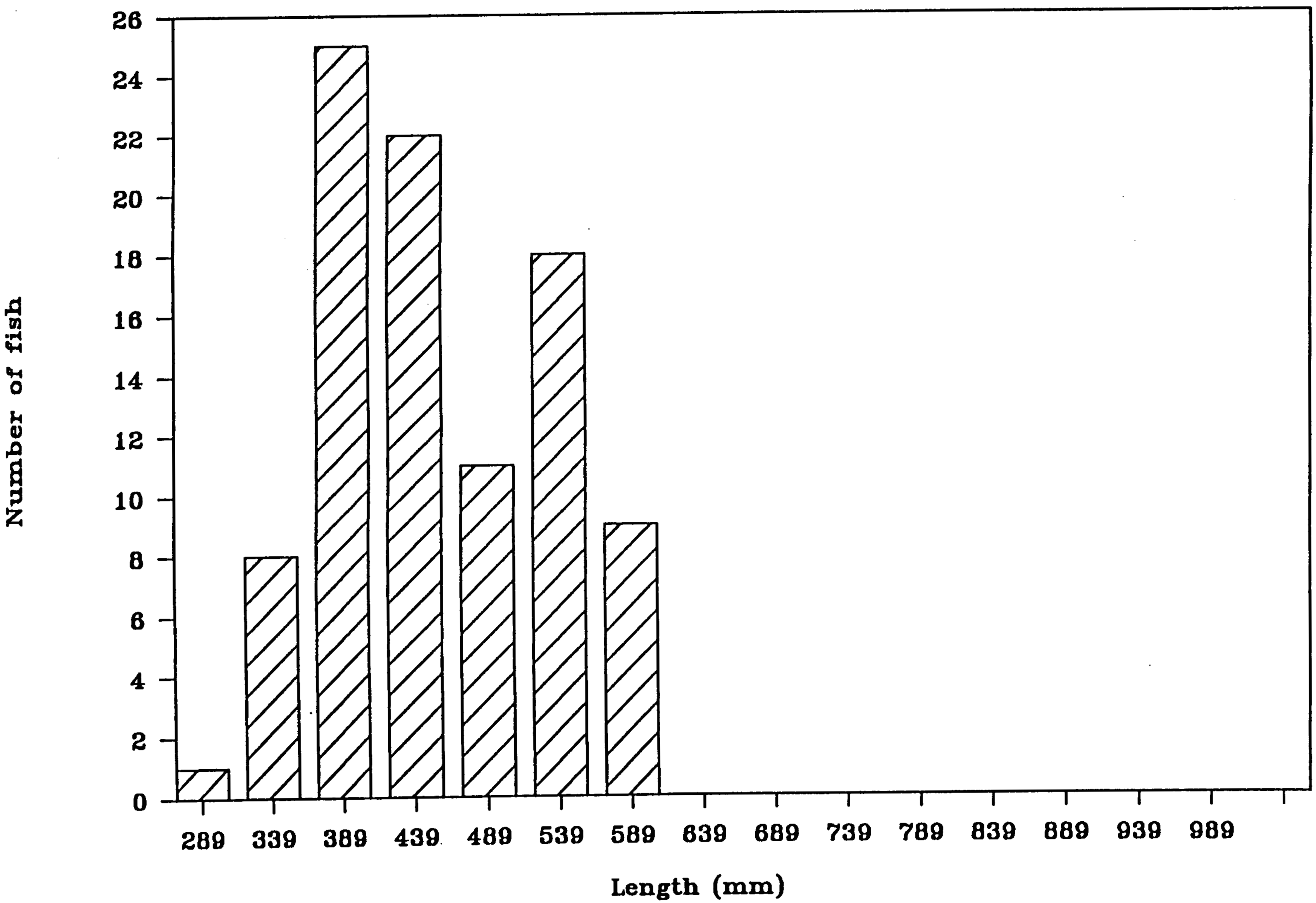
Appendix C.--Continued. *Paracaesio stonei.*



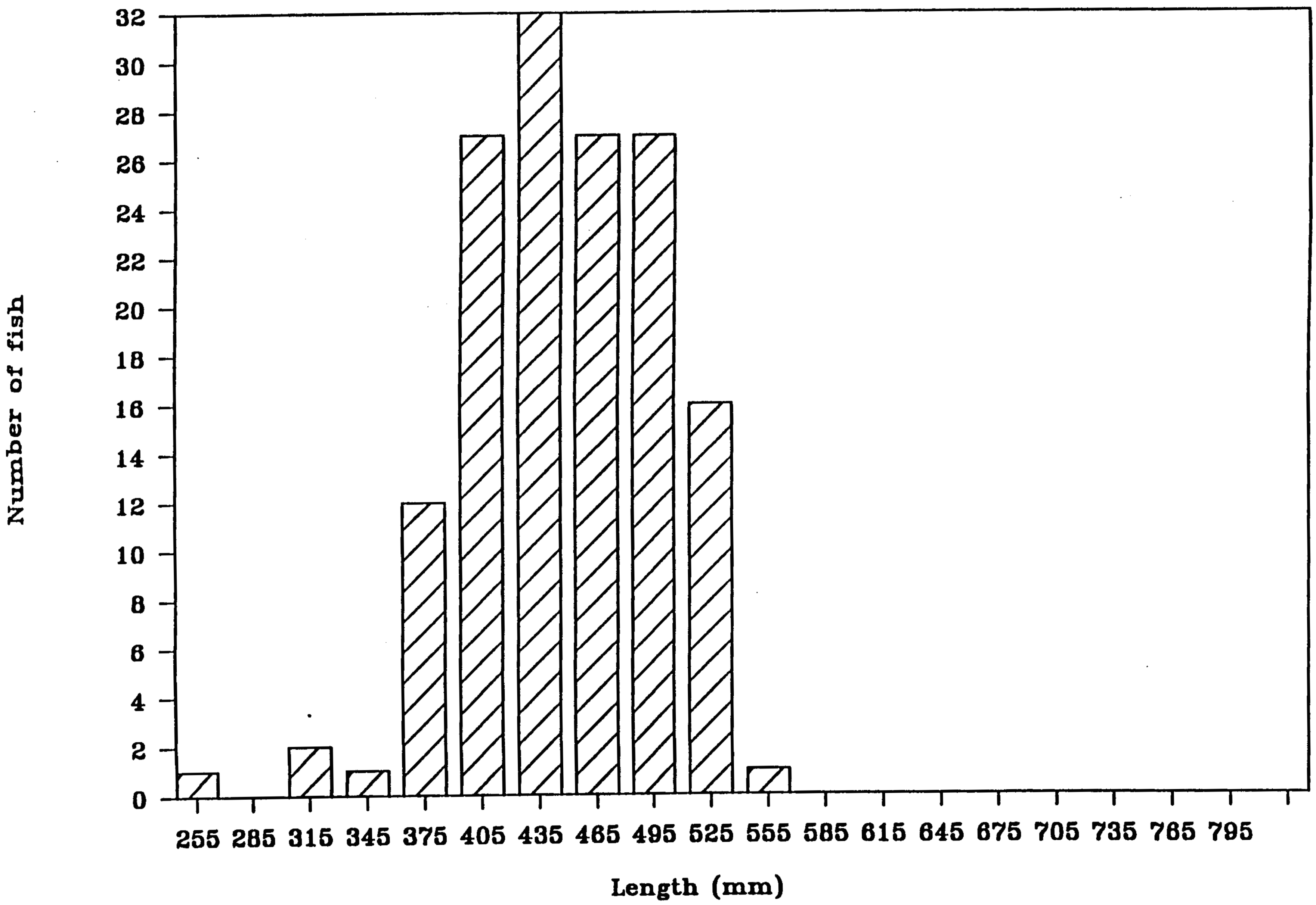
Appendix C.--Continued. *Pristipomoides filamentosus.*



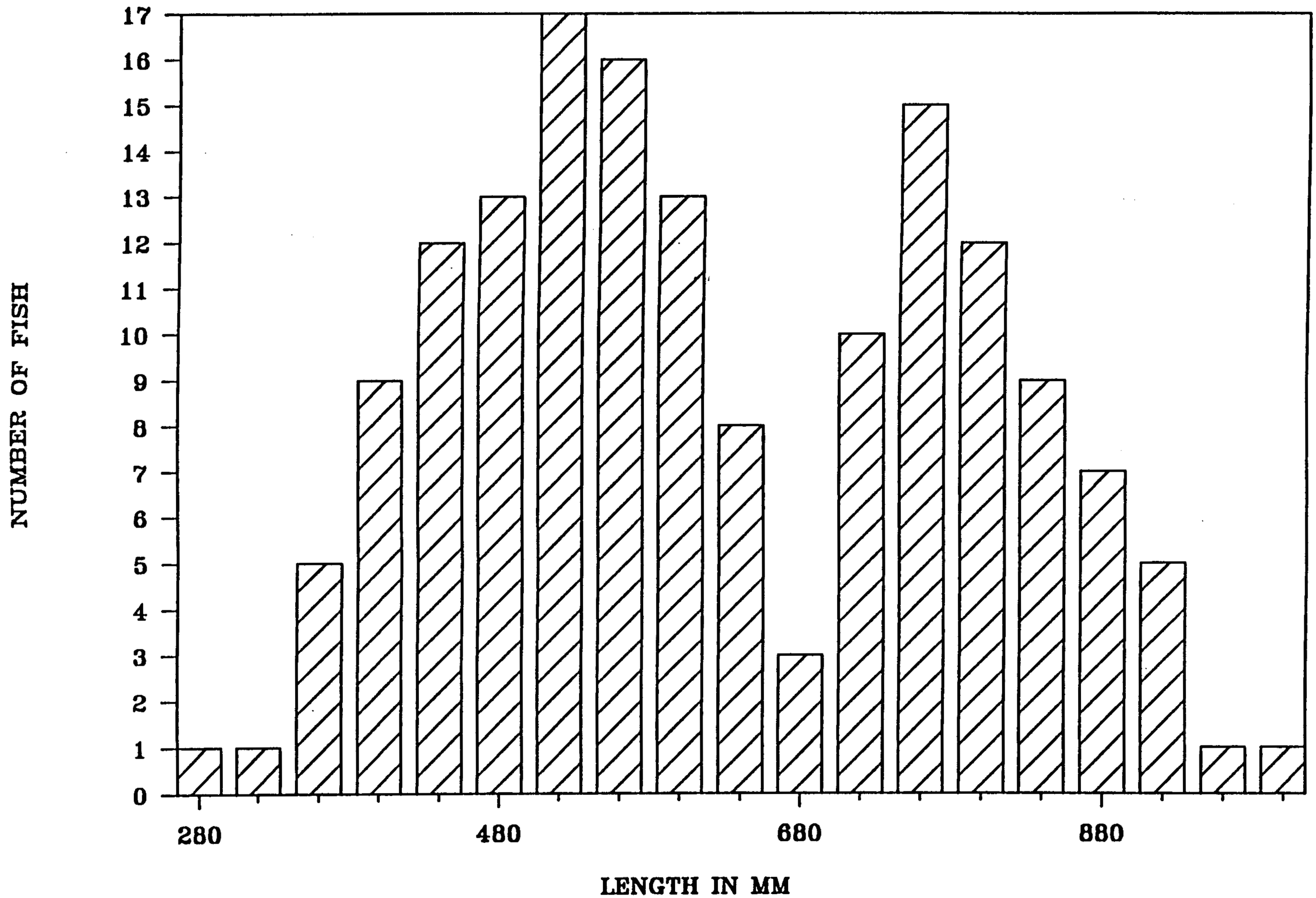
Appendix C.--Continued. *Pristipomoides multidens.*



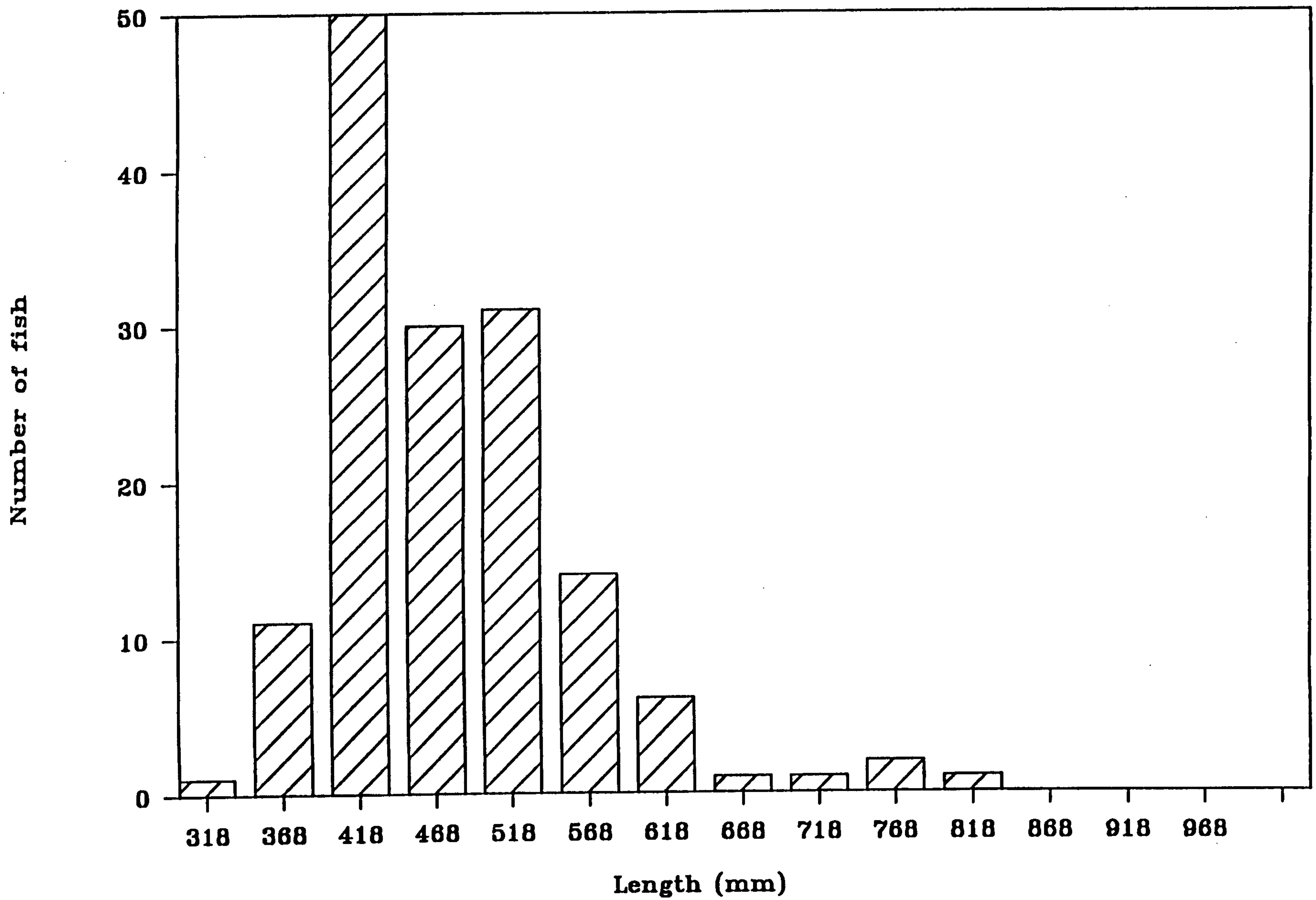
Appendix D.--Length-frequency from Schouten Islands. *Pristipomoides filamentosus*.



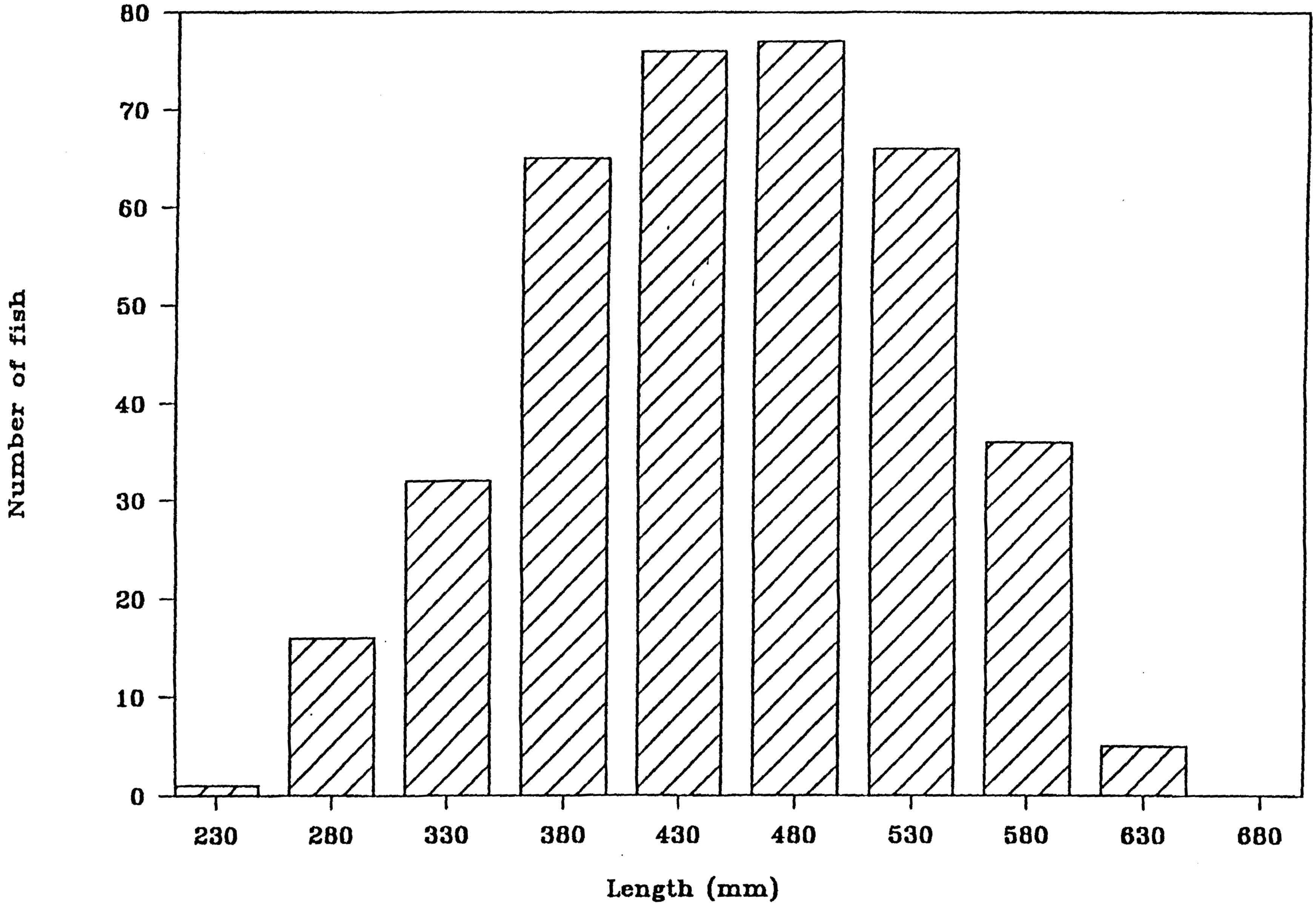
Appendix D.--Continued. *Lutjanus malabaricus*.



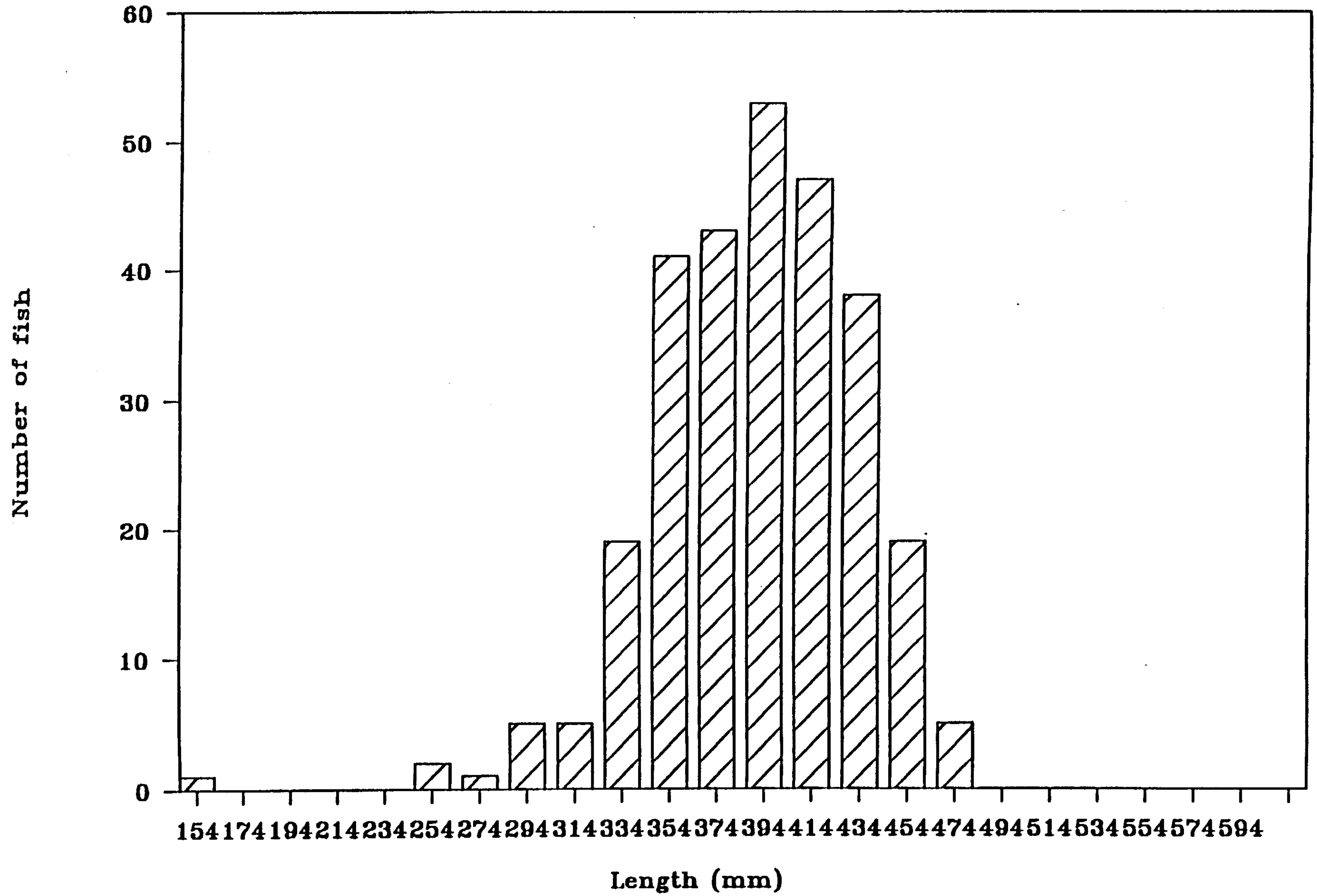
Appendix D.--Continued. *Etelis carbunculus*.



Appendix D.--Continued. *Paracaesio stonei.*



Appendix D.--Continued. *Pristipomoides multidens.*



Appendix D.--Continued. *Wattsia mossambicus*.

ESTIMATED MAXIMUM SUSTAINABLE YIELD FOR THE DEEP BOTTOMFISH FISHERY IN TONGA

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ABSTRACT

Depletion studies using the Allen model were conducted on four seamounts in the Kingdom of Tonga during 1987-88 to obtain estimates of initial biomass. These estimates were then used to calculate a preliminary range of maximum sustainable yield (MSY) equaling 64-198 metric tons per year. However, estimated fishing effort exceeded the level that achieves MSY by about 50%. It is recommended that current effort levels be decreased to reduce the risk of overfishing.

INTRODUCTION

The commercial development of the bottomfish fishery in the Kingdom of Tonga began in 1980 after successful exploratory trial fishing was conducted by a deepwater fishing project of the South Pacific Commission in 1978 and 1979. The two target species of this new fishery were deepwater snappers and groupers. The Foundation for the People of the South Pacific also implemented the development of this fishery by establishing a demonstration boat project. With the demonstration boat and Western Samoan-designed hand reels, fishermen were trained in the techniques required to fish the extensive seamounts (Mead 1979). Bottomfish fishing currently occurs in Tonga at depths of 50-450 m. In addition to bottomfish fishing, many boats troll for pelagic species while traveling to and from the fishing grounds, and some boats cease bottomfish fishing entirely during the fishing season for skipjack tuna, *Katsuwonus pelamis*.

Since 1983, the United Nations Capital Development Fund program has built 45 wooden, inboard, diesel fishing vessels. These vessels, about 28 feet in length, were constructed at the boatyard of the Tongan Fisheries Division of the Ministry of Agriculture, Forestry, and Fisheries.

In 1986, the Fisheries Division of Tonga decided to implement a stock assessment program on the bottomfish fishery of Tonga. Because the existing data were inadequate for the proposed program, a new system was designed by the Fisheries Division (Langi 1988). In August 1987, the sampling methodology was reviewed, and a preliminary analysis of the data was conducted; a more detailed analysis of the data was done in 1988 and covered a 2-year period (J. Polovina, Southwest Fisheries Science Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, 2570 Dole

St., Honolulu, HI 96822-2396). The present paper presents the results of an analysis of the catch and effort data collected from November 1986 to June 1989.

MATERIALS AND METHODS

The data used in this study were collected from seamounts in Tonga; excluded were data from the shallower banks, which have different species composition. Catch and effort data were recorded for about 45% of the fishing trips completed each year. The total number of fish, by species, was calculated on a trip-by-trip basis. Fishermen also reported the geographic locations fished, according to the grid locations shown in Figure 1. Fish were weighed individually during the first year of the study; thereafter, the weight of the catch was estimated from the established length-weight relationships. Fishing effort was recorded in line-hours. Collection of length-frequency data was conducted on a quarterly basis, and a sufficient sample size system was established for the less abundant species. Only length-frequency data collected from species (N = 7) landed during all four quarterly sampling periods were used in this analysis (Table 1).

Table 1.--The seven major deepwater species as a percent of the bottomfish landings (in numbers) in Tonga, 1986-89.

Species	Percentage of total
All others	37.0
Epinephelus morrhua	2.4
E. septem fasciatus	1.3
Etelis carbunculus	2.8
E. coruscans	10.8
Lethrinus chrysostomus	17.5
Pristipomoides flavipinnis	8.7
P. filamentosus	18.4

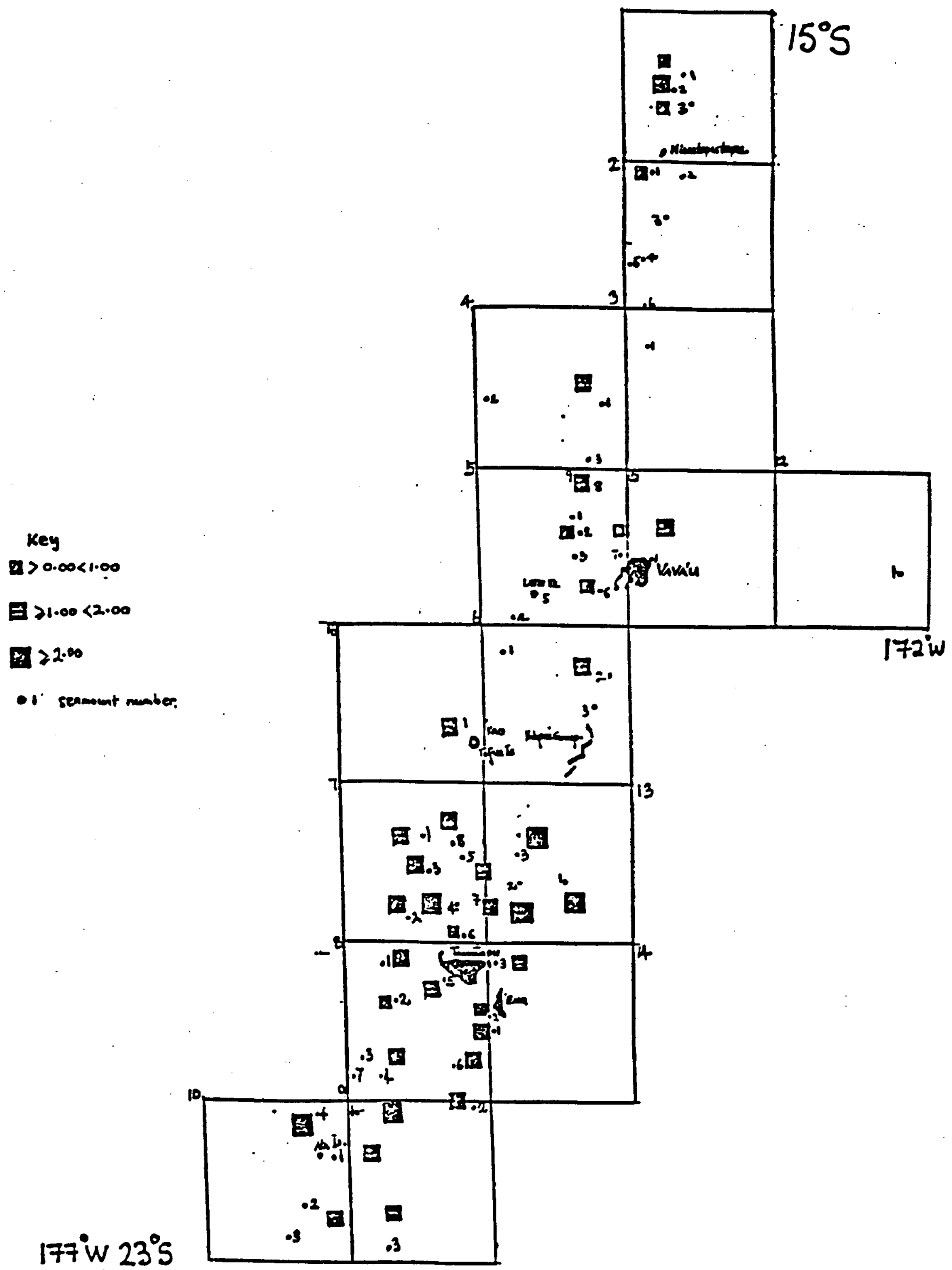

Figure 1.--Map of Tonga showing seamount locations.

Since summaries of the length-weight and size-frequency data were already presented by Langi and Langi (1987), the present study was directed toward obtaining estimates of initial biomass. The analysis from previous years (Langi et al. unpubl. manuscr.) enabled a yield estimate to be calculated from three seemingly depleted seamounts. We had intended to examine the data from the same three seamounts, plus any other suitable seamounts, to confirm or refine the previous estimates. However, one of the seamounts (10-01) proved not to be depleted at all and was rejected from the analysis, so two other depleted seamounts (9-03 and 8-01) were added. The four seamounts from which data were collected for the depletion studies were 8-01, 9-01, 9-03, and 10-04. The first number refers to grid location (cf. Fig. 1); the second set of numbers refers to the number assigned to each seamount within a grid. Depletion studies were based on the Allen (1966) model to allow for a longer period in which reproduction and recruitment would occur. Catch and effort data for January 1987 through June 1989 and estimates of natural mortality for resources in the Mariana Islands (Polovina and Ralston 1986) were used to estimate initial biomass, recruitment, and fishing mortality as determined by the Allen (1966) method and modified by Sainsbury (1984).

Fishing mortality (F) was estimated from catchability (q), which was estimated from the depletion analysis of the four seamounts. The value of q from each depletion analysis was multiplied by the length of 200 m isobath to obtain a standardized q. The mean of all standardized q values from the four seamounts was multiplied by the total fishing effort divided by the length of 200 m isobath to give an estimate of annual F, which can be interpreted: When F equals M, then the fishing effort is optimal to produce maximum sustainable yield (MSY); when F exceeds M, then fishing effort is excessive.

The estimate of biomass per nautical mile of the 200 m isobath was calculated by dividing the initial biomass by the number of nautical miles estimated at this depth for each of the four seamounts. The estimate of biomass per nautical mile was then multiplied by the total length of the 200 m isobath calculated for the Tongan seamounts. The MSY was calculated for a proportion of this total biomass by two methods: Pauly (1983) and Beverton and Holt (1986).

RESULTS

Table 2 summarizes the total landings and total unit of fishing effort for the Tongan seamount fishery in 1986-89. The total catch for 1989 was estimated on the basis of the monthly catch during the first 6 months of the year. Effort increased markedly during the first full year of the fishery, and landings reached a maximum during 1987. Although effort increased in 1988, the catch dropped. Since that time, the fishery has harvested a steady 450-500 metric tons (t) per year.

Table 2.--Summary of the yearly estimated landings, effort (line-hours), and fishing mortality (*F*) of the bottomfish fishery in Tonga, November 1986-June 1989.

Year	Catch (No.)	Effort (100s)	Average-weight (kg)	Landing sampled	Percentage of total sampled	Total landings (t)	*F*[a]
1986[b]	16,986	86.73	4.40	74.74	55	135.89	0.2
1987	30,889	232.12	4.40	135.91	24	566.30	1.4
1988	61,281	275.03	4.40	269.64	55	490.25	0.7
1989[c]	48,576	254.74	3.80	184.59	41	450.22	0.9

[a]*F* was computed as effort divided by the fraction sampled, then multiplied by catchability and divided by the length of 200 m isobath for the archipelago.

[b]Annual catch was estimated by multiplying the November-December 1986 actual catch by six.

[c]Annual catch was estimated by doubling the January-June 1989 actual catch.

The results of the depletion studies, based on the Allen model, are in Table 3, as are the estimates of recruitment, catchability, and total number of fish per nautical mile. Additionally, the coefficients of correlation for the fit of the Allen model to the data are included (Table 3). Figures 2-6 show the fit of this model for each of the four seamounts.

Table 4 summarizes the estimates of the number of fish per nautical mile for two values of natural mortality ($M = 0.25$ vs. $M = 0.50$). These estimates were converted to fish biomass by using the established length-weight relationships. The resulting biomass estimate per nautical mile also is included (Table 4).

The median 2.4 t/nmi (Table 4) was used to estimate the total unexploited biomass for the estimated 294 nmi of the 200 m isobath of the Tongan seamounts. On the basis of this study, the total biomass of deepwater bottomfish in the Tongan seamounts is estimated at 706 t. A reasonable range of the biomass available to the fishery in Tonga can be

Table 3.--Estimated catchability (q) and recruitment (r) per nautical mile with two different values of natural mortality (M), for the bottomfish fishery in Tonga, using the Allen model. CPUE = catch per unit effort; nmi-200 = nautical miles of 200 m isobath.

Area	a	q	CPUE	R^2	No.	nmi-200	No./nmi	q*nmi	r/nmi	r/nmi/year
						M = 0.04				
0801	3.66	0.0010	2.77	0.95	2,770.00	5.00	554.00	0.00500	28.70	344.43
0901	2.04	0.0007	1.67	0.84	2,385.71	6.80	350.84	0.00476	16.80	201.65
0903	3.55	0.0002	3.83	0.96	21,277.78	35.00	607.94	0.00630	22.09	265.14
1004	4.86	0.0025	3.70	0.93	1,480.00	1.20	1,233.33	0.00300	63.52	762.25
					Average q/nmi	0.0048		Average r/nmi/year		393.368
						M = 0.04				
0801	3.73	0.0009	2.77	0.96	3,077.78	5.00	615.56	0.00450	16.41	196.96
0901	1.57	0.0004	1.67	0.78	4,175.00	6.80	613.97	0.00272	11.43	137.15
0903	3.49	0.0002	3.83	0.96	19,150.00	35.00	547.14	0.00700	9.87	118.47
1004	3.98	0.0016	3.70	0.87	2,312.50	1.20	1,927.08	0.00192	41.05	492.56
					Average q/nmi	0.0039		Average r/nmi/year		249.393

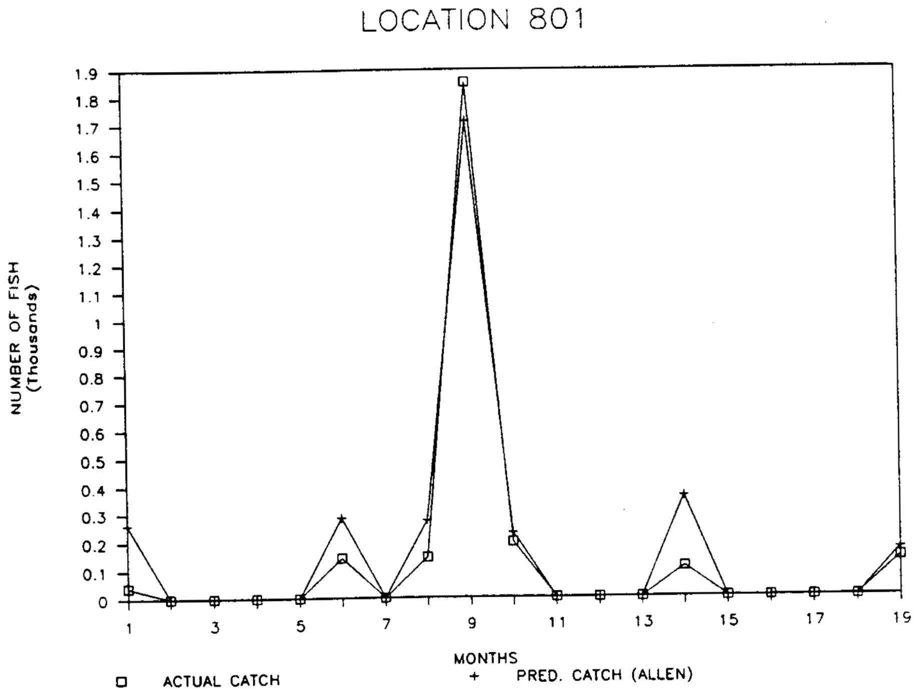

Figure 2.--Plot of actual catch and catch predicted from fit of Allen's model by month for the deepwater snapper and grouper fishery during a period of stock depletion at seamount No. 801.

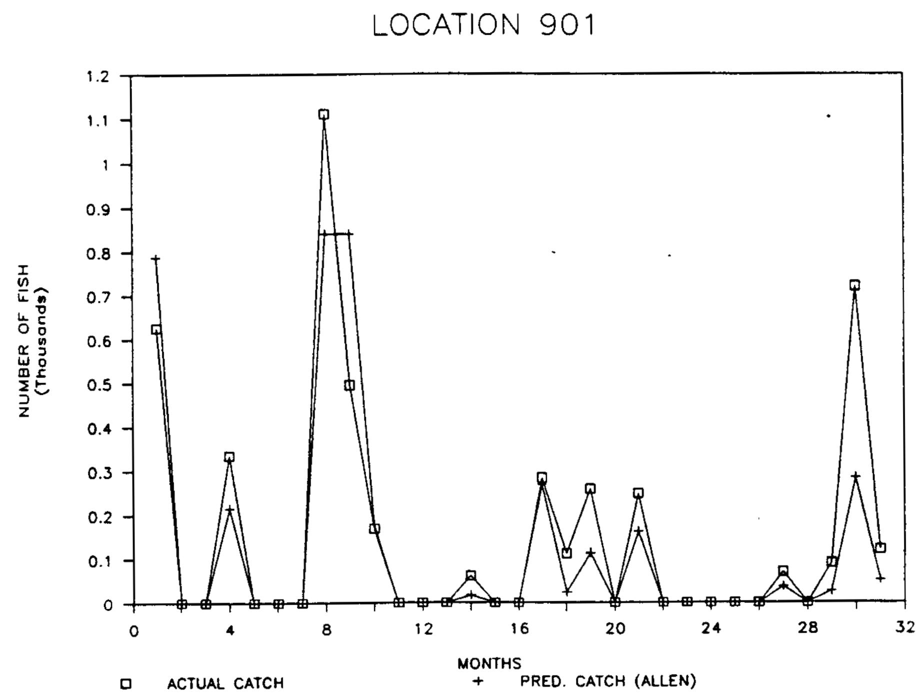

Figure 3.--Plot of actual catch and catch predicted from fit of Allen's model by month for the deepwater snapper and grouper fishery during a period of stock depletion at seamount No. 901.

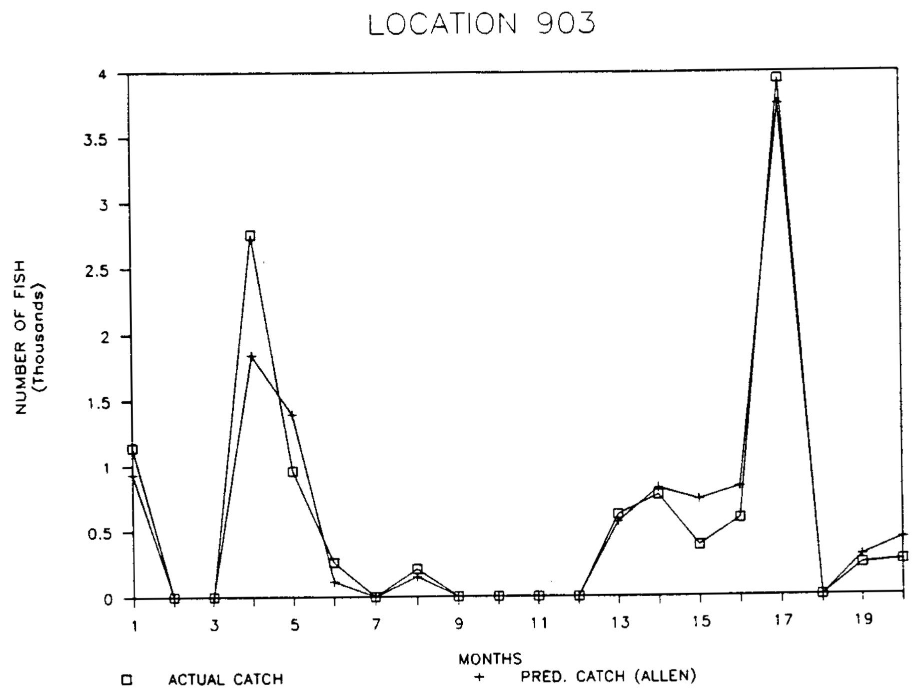

Figure 4.--Plot of actual catch and catch predicted from fit of Allen's model by month for the deepwater snapper and grouper fishery during a period of stock depletion at seamount No. 903.

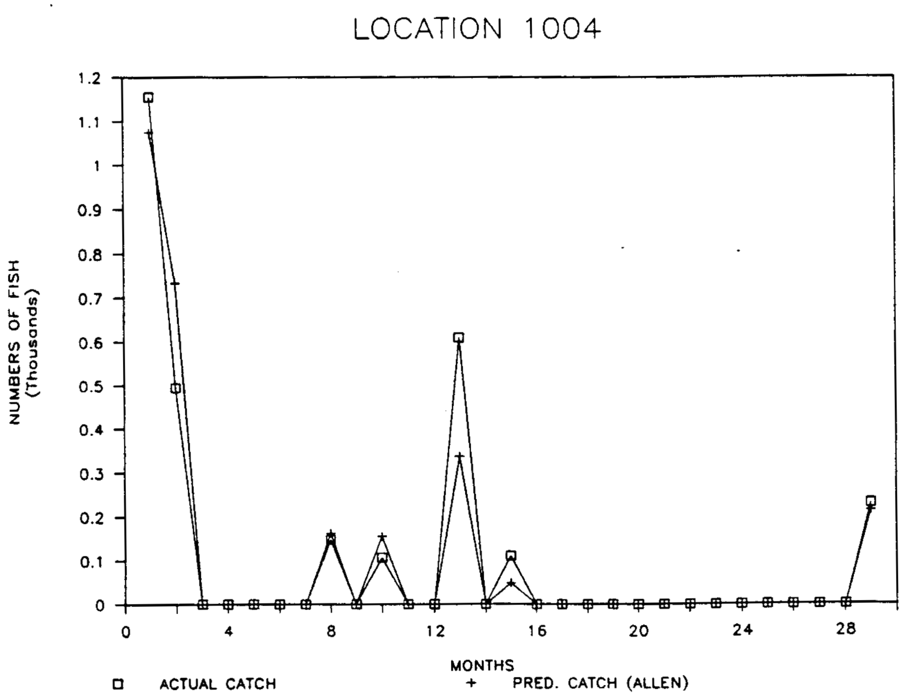

Figure 5.--Plot of actual catch and catch predicted from fit of Allen's model by month for the deepwater snapper and grouper fishery during a period of stock depletion at seamount No. 1004.

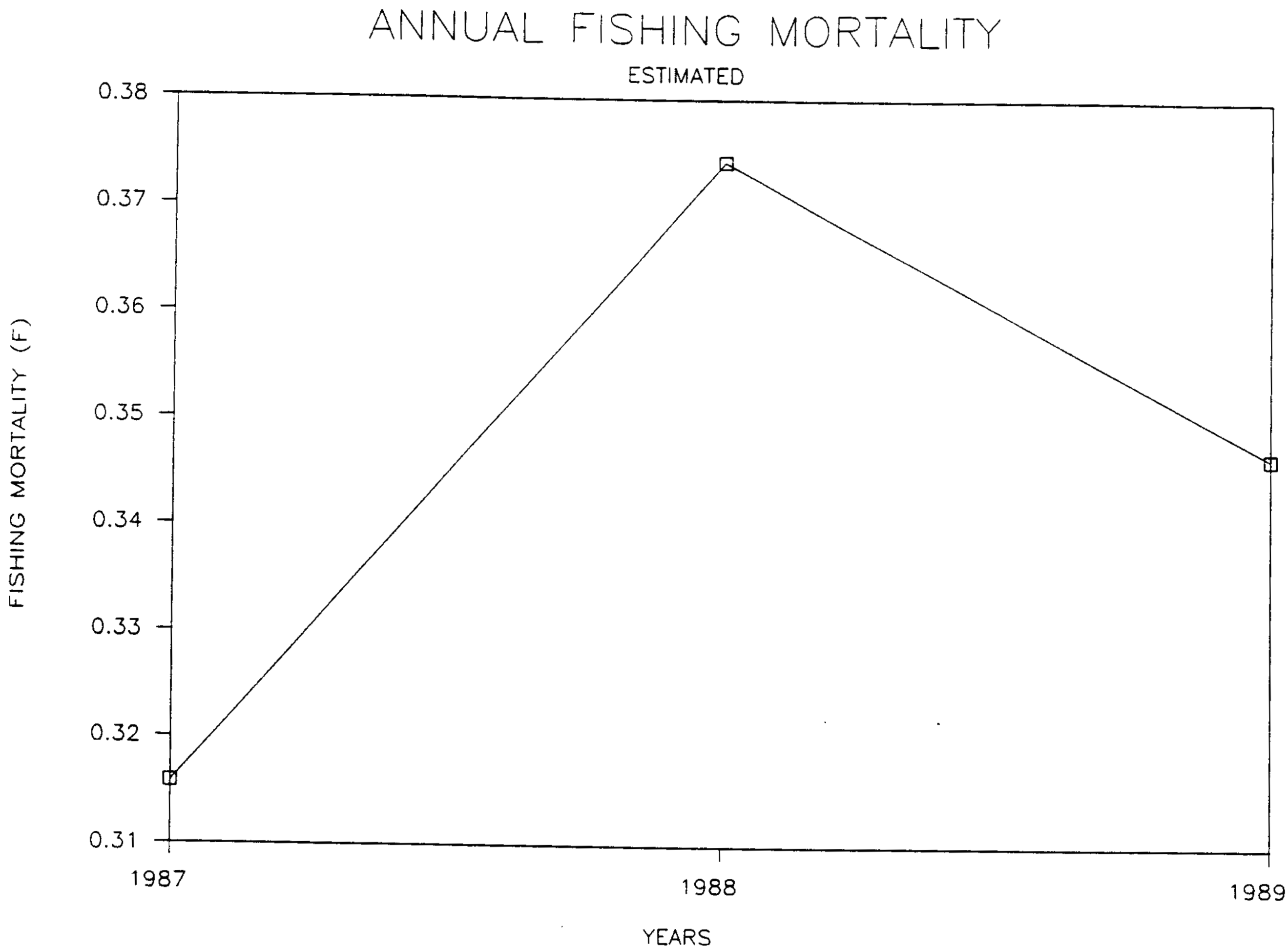

Figure 6.--Estimated annual instantaneous fishing mortality for the archipelago, 1987-88.

Table 4.--Estimated number of fish per nautical mile, and the estimated unexploited biomass, based on two values of natural mortality (*M*). The median biomass per nautical mile used to calculate standing biomass was 2.4 t.

Seamount	No. of fish/nmi (M=0.25)	No. of fish/nmi (M=0.50)	Length of 200 m isobath (nmi)	Mean fish weight (kg)[a]	Biomass (t/nmi) (M=0.25)	Biomass (t/nmi) (M=0.5)
8-01	616	554	5.00	3.9	2.4	2.2
9-01	614	351	6.80	3.9	2.4	1.4
9.03	547	608	35.00	3.9	2.1	2.4
10.04	1,927	1,233	1.20	3.9	7.5	4.8

[a]Average weight of fish in 1987-89 from Table 1.

obtained by using the MSY estimate from the Beverton and Holt (1986) method as a conservative lower limit and the MSY estimate obtained from the Pauly (1983) method as an upper limit. Accordingly, the range of MSY for Tonga would be 64-198 t/year.

DISCUSSION

The estimated MSY of 64-198 t/year is equivalent to 215-673 kg • nmi^{-1} • year. The surplus production from last year's analysis is 737 kg per nmi (Langi and Langi 1987); therefore, the estimate gained from our analysis seems close to last year's estimate. Current fishing mortality (*F*) is an estimated 0.9 (Table 1) compared with an *F* of 0.7 for last year. The level of *F* is 2-3 times the natural mortality (0.25-0.5), which suggests that fishing effort exceeds the level that achieves MSY. It would be prudent to decrease fishing mortality by 50% to reduce the risk of overfishing. This would be achieved if fishing effort were decreased by 50%. Although a number of assumptions are necessary to estimate the actual biomass, the estimates arrived at separately for several seamounts generally agree with each other. This agreement and the excellent fit of the data to the Allen model indicate that these estimates are reasonable and are probably quite representative of the actual biomass on the fishing grounds. Most importantly, careful monitoring of the fishery should be continued so that management decisions can be made in a timely manner if a significant decrease in the catch is noted. Since the export market is essentially unlimited, it is up to the Tongan Government to set limits that allow the continued availability of a resource that will provide protein and employment for future generations.

We also believe that it may be unwise to allow the exploitation of this fishery by foreign vessels; the Tongan fleet is already harvesting more than the recommended amount for a sustained fishery. This supports the established exclusive economic zone around the Kingdom of Tonga; the zone ensures that this valuable resource will continue to support a viable fishery for years to come.

ACKNOWLEDGMENTS

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Our sincere thanks to Semisi Fakahau, the principal fisheries officer for allowing us to participate in this workshop, to V. A. and S. A. Langi of the Research Unit, and to the research team for all of the effort on this project.

CITATIONS

Allen, K. R.
1966. Some methods for estimating exploited populations. J. Fish. Res. Board Can. 23:1553-1574.

Beverton, R. J. H., and S. J. Holt.
1986. Manual of methods for fish stock assessment part 2. Table of yield functions. FAO Fish. Tech. Pap. 38 (Rev. 1).

Langi, S.
1988. Past and present data collection systems of the bottom fishery in Tonga: a comparison. Background paper 39, Workshop on Inshore Fishery Resources, South Pacific Commission, Noumea, New Caledonia, 18 p.

Langi, V. A., and S. A. Langi.
1987. A stock assessment programme on the bottom fishes of the seamounts, Kingdom of Tonga: The first 9 months. Fishbyte 5(3), Dec. 1987, ICLARM.

Langi, V. A., S. A. Langi, and J. J. Polovina.
Unpubl. manuscr. Estimation of deep water snapper yield from Tongan seamounts. Ministry of Agriculture, Forestry, and Fisheries, Fisheries Division, Kingdom of Tonga.

Mead, P. D.
1979. Report of the South Pacific Commission deep sea fisheries development project in the Kingdom of Tonga, 3 June-20 September 1978. South Pacific Commission, Noumea, New Caledonia.

Pauly, D.
1983. Some simple methods for the assessment of tropical fish stocks. FAO Fish. Tech. Pap. 234:1-52.

Polovina, J. J., and S. Ralston.
1986. An approach to yield assessment for unexploited resources with application to the deep slope fishes of the Marianas. Fish. Bull., U.S. 84:759-770.

Sainsbury, K. J.
1984. Optimal mesh size for tropical multispecies trawl fisheries. J. Cons. int. Explor. Mer 41:129-139.

YIELD ASSESSMENT OF THE DEEP BOTTOMFISH FISHERY IN VANUATU

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ABSTRACT

After 7 years of exploitation, Vanuatu's deep bottomfish fishery remains at a low level of fishing effort. It is apparent that catch per unit effort is exponentially correlated to the size of the fishing area (Pauly 1984). As shown by depletion estimates with the Allen model (Sainsbury 1984), Paama and Ambae yields seem to be affected by fishing effort. The yearly unexploited exploitable biomass varies from 57 to 32 metric tons (t) in Paama and from 36 to 21 t in Ambae based on natural mortality of 0.25 to 0.50, respectively. With an age at recruitment of 3 years and a natural mortality of 0.25, ranges of maximum sustainable yield (MSY) are between 3.4 and 18.3 t in Paama and between 2.2 and 11.5 t in Ambae. As annual recorded catches are actually higher, this suggests that equilibrium has yet to be achieved. Extrapolation to Vanuatu as a whole suggests that the MSY objectives should be 113.2-603.5 t/year, which would allow a full-time fleet of 20-100 boats, each fishing 120-150 days/year.

INTRODUCTION

In the last 15 years, fisheries development in many South Pacific island states has concentrated on the exploitation of the demersal fish species of the outer reef slope. As part of that effort, the South Pacific Commission master fishermen visited the Cook Islands, Fiji, the Federated States of Micronesia, Papua New Guinea, and Vanuatu to improve fishing gear and to evaluate the potential of these resources (Dalzell 1990). In 1982 the Fisheries Department of Vanuatu established a Village Fisheries Development Program (VFDP), through which more than 100 fishing associations were created throughout the Vanuatu archipelago. The main objective of this program was to develop a commercial fishery based upon the exploitation of demersal species living on the outer reef slope between depths of 100 and 400 m. A data collection system based on general trip and catch information was set up by the VFDP, and a more detailed data collection system was established by the Office de la Recherche

Scientifique et Technique Outre-Mer (ORSTOM), which recorded the species composition and length-frequency data for 11 of the most important commercial species in the fishery.

Three studies on stock assessment have been carried out since 1983. The first (Brouard and Grandperrin 1984) looked at the biology and the dynamics of the deep bottomfish population and provided the first estimates of maximum sustainable yield (MSY) for the area. The second (Schaan et al. 1987) presented the status of the fisheries established by the VFDP. The third (Carlot and Nguyen 1989) reevaluated some parameters of growth and mortality for four species by using data collected by the village fishing projects.

Using data collected by the village fishing projects, this paper has the following objectives:

(1) evaluate the unexploited biomass, fishing mortality, and MSY from the annual catch and effort recorded on 11 islands;

(2) present the results of a depletion estimate, by island;

(3) compare the first estimate of MSY made in Vanuatu by Brouard and Grandperrin (1984); and

(4) compare our ranges of biomass with the mean estimation obtained for Fiji, the Cook Islands, Papua New Guinea, Solomon Islands, the Kingdom of Tonga, and Western Samoa.

METHODS

The Vanuatu archipelago consists of about 80 islands, most of which are of volcanic origin. The deep bottomfish fishing area (i.e., between 100 and 400 m depth contour) covers about 735,800 ha, and the 100 m depth contour is 1,358 nmi (Brouard and Grandperrin 1984). Apart from a narrow coastal fringing reef, there are no lagoons, and the continental shelf is minimal (Fig. 1). The outer reef slope drops sharply and has an average slope of 1.0 in 10.0. The slope can vary considerably between islands [e.g., with 1.0 in 2.5 around Pentecost and 1.0 in 5.0 north of Efate (Brouard and Grandperrin 1984)].

Most of the fishing vessels in Vanuatu are 5-8 m long, propelled by 25 hp outboard motors, and equipped with two to four Samoan-type hand reels. Fishing is normally carried out from an anchored vessel.

Fisheries data were collected from 1982 to the present (1989). The statistical data form currently in use is shown in Appendix A. Total catch (in kilograms); number of trip hours, fishing hours, and reels; fishing area; and average depth of fishing were usually recorded for each trip. The fishermen were also required to measure the fork length (FL) of individual fish from etelines (six species), epinephelines (three species), *Lutjanus malabaricus*, and *Aphareus rutilans*. To help in this data

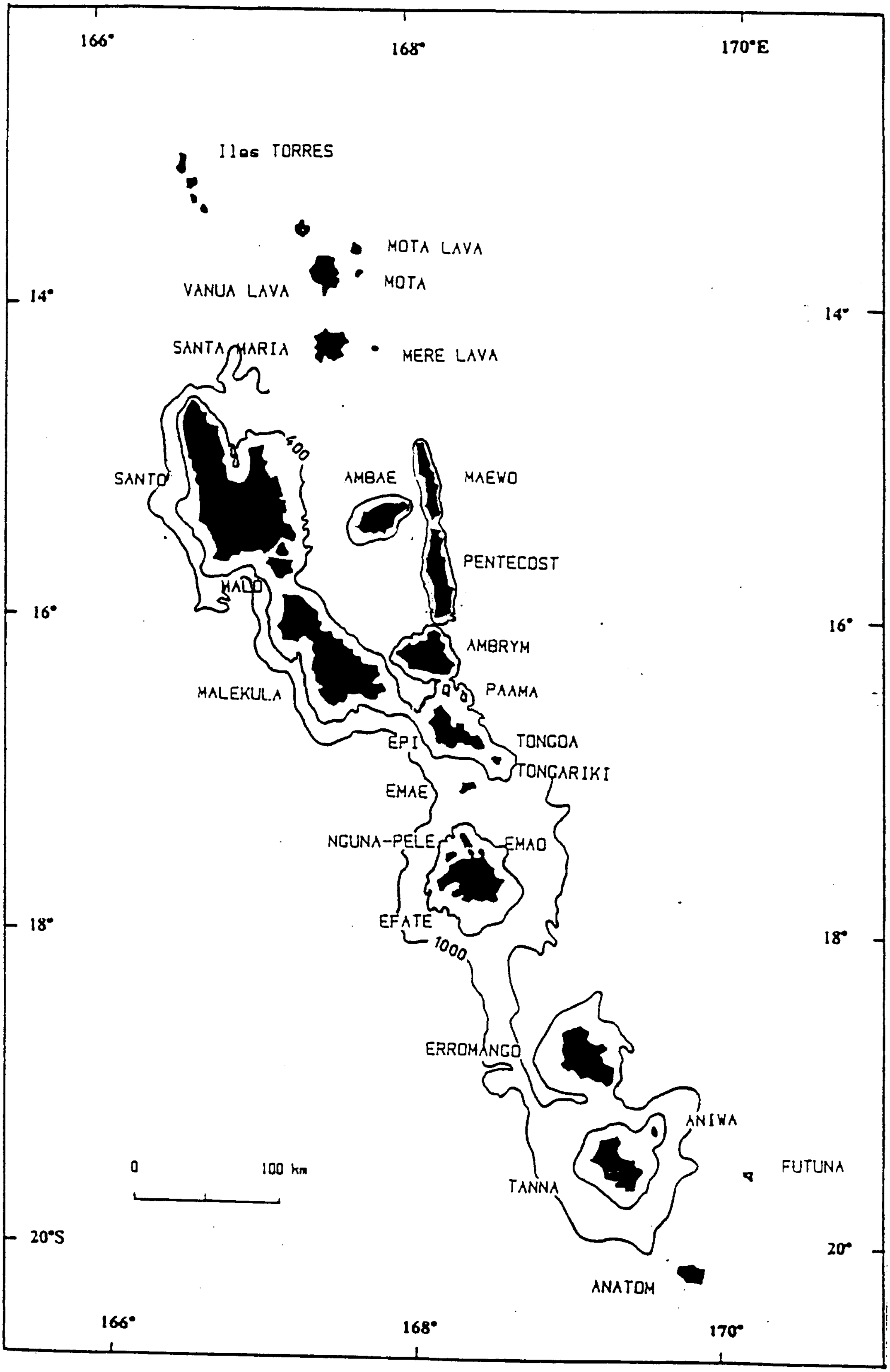

Figure 1.--The Vanuatu archipelago.

collection, ORSTOM provided each fishing association with a booklet with a map of fishing areas around each island and pictures with the characteristics of species that should be measured. The fishermen also were provided a measuring board.

Vanuatu has had problems in data collection, which in turn could lead to an underestimation of the total and localized production figures. Experience has shown that some VFDP associations do not complete forms and some do not provide the information regularly. Part of this is due to an uncontrolled, private, opportunistic deep bottomfish fishery, which is mostly concentrated near the urban areas and sells its catches directly to hotels and restaurants.

Based on the fishery data collected in 1982-89, the relationship between the annual total catches (in kilograms) and the number of trips recorded for the islands (Appendix B) is examined. Length frequencies also were used to determine the length at recruitment and the average fish length of the adult population.

DATA ANALYSIS

Application of a global production model on mean annual catch and effort recorded for Vanuatu did not show much curvature (Carlot and Nguyen 1989). This may mean that the level of exploitation is still low, because a linear relationship between catch and fishing effort may represent the beginning of the production curve. For situations in which the ranges of fishing effort are very limited, the application of a production model may not be totally applicable (Polovina 1989). In such situations, Polovina (1989) suggested that both catch and effort data should be adjusted by a measure of habitat area.

Assuming also that possible differences in topography and habitat size between Vanuatu's islands could induce variations in abundance, catch (in kilograms) per hectare was plotted against the number of trips per hectare for each of the 11 islands. The evolution of the slopes of these curves [which actually represent catch per unit effort (CPUE)] was examined with the correspondent size of the fishing area.

The Allen model (Sainsbury 1984) also was applied to each island by using long-term time series of annual catch and effort, given a constant rate of natural mortality. An equation to express the relationship is as follows (Sainsbury 1984):

$$C_i = qf_iR/(1-e^{-m})-qf_i(\sum_{j=1}^{j=i-1} C_j e^{-m(i-j)} + C_i/2);$$

where C is the catch (in kilograms) for the year i, q is the catchability coefficient, f_i is fishing effort in trips for the year i, R is recruited biomass, and m is natural mortality.

The above provides a determination of a catchability coefficient and the biomass recruited. In the first year of exploitation, catches are equal to

$$C = qfN \ ;$$

where q is catchability, f is fishing effort, and N is virgin biomass. The unexploited exploitable biomass is then determined by dividing the CPUE (C/S) observed in the first year of the fishery by the catchability coefficient estimated with the Allen model.

Fishing mortality also has been calculated for each island by multiplying the catchability coefficient by the average fishing effort applied during the time of exploitation. Fishing mortality for the total surface fishing area of the Vanuatu archipelago is estimated based on the average catchability coefficient calculated for each island.

The MSY is determined as a proportion of the unexploited exploitable biomass. Lower ranges of the MSY are calculated from the tables of Beverton and Holt (Beddington and Cooke 1983) by using different rates of natural mortality, M; a mean age of recruitment, t_r; and the growth constant, K, determined from the global $M/K = 2.0$ estimates for deepwater snappers (Ralston 1985). From a mean length at recruitment, age at recruitment is given by the von Bertalanffy relationship (Pauly 1983). Length for which 99% of the catches are recorded is taken as the asymptotic length. An average annual growth rate of 0.1 has been assumed.

Higher ranges of MSY are estimated from the Pauly (1983) relation

$$MSY = 2.3\ Wt^{\ (-0.26)} B_{\infty} \ ,$$

where Wt is the mean weight of the adult population, and B_{∞} is the unexploited exploitable biomass estimate from the Allen model. Based on the length at sexual maturity of seven species (Brouard and Grandperrin 1984), the mean weight of adult fish is calculated; therefore, an average weight of the adult population could be estimated.

RESULTS

During the 7 years of commercial, small-scale, deep bottomfish fishing, the VFDP associations reported 11,323 trips and a total catch of 35 t for all of Vanuatu. An annual average of 5.8 t taken during 1,900 trips was recorded. For the 87 associations in operation in 1988, a mean of 22 trips per association per year was recorded. For the whole of Vanuatu, the average CPUE was about 31 kg per trip.

Length-frequency distributions for seven species are presented in Figure 2. As these species represent 60% of the total weight of catches (Schaan et al. 1987), their average length at recruitment and length of adult fish in the population should be representative of the whole population. The average length at recruitment is 25 cm FL. The average asymptotic length is 84 cm, indicating a mean age at recruitment of close

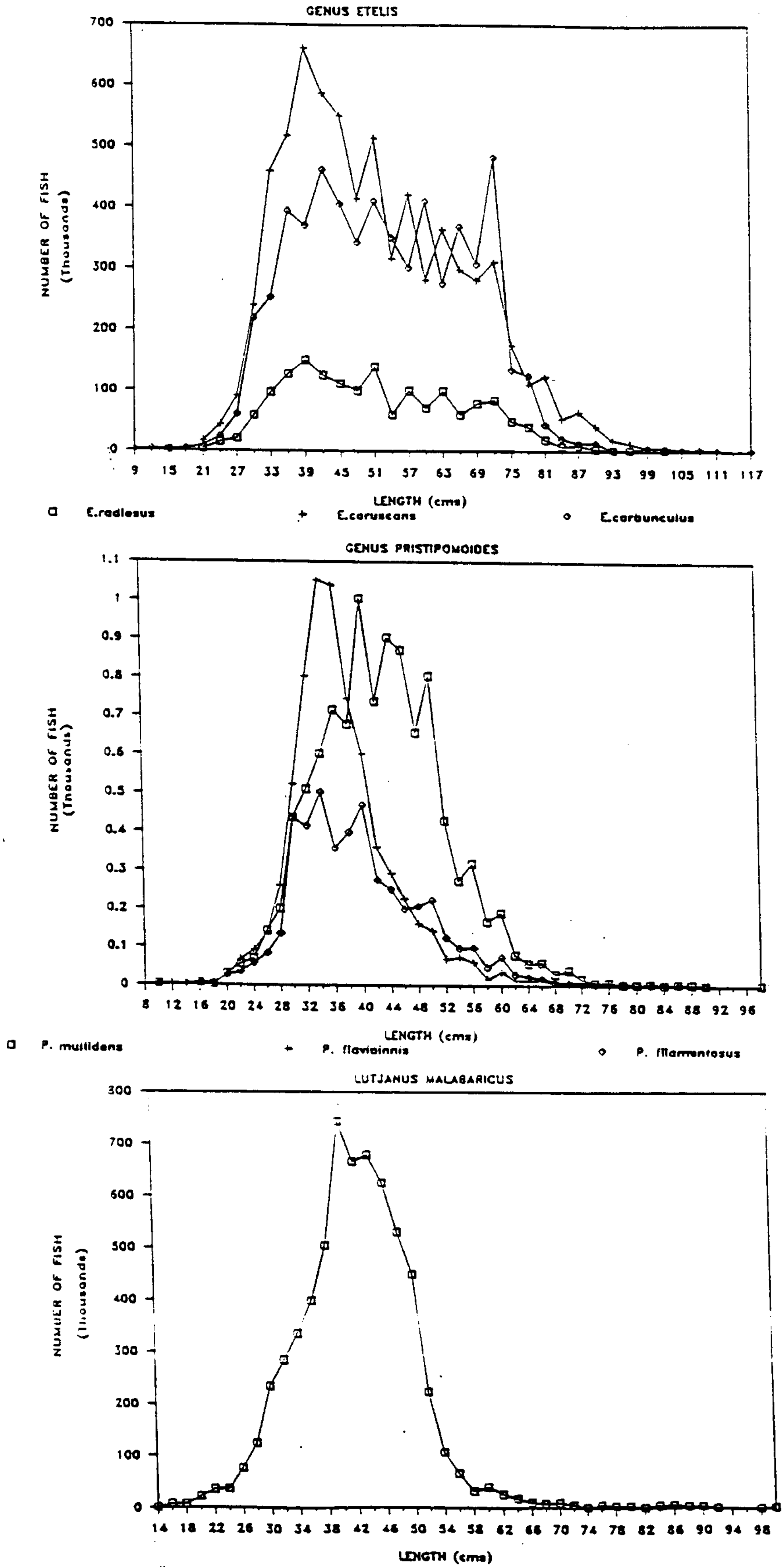

Figure 2.--Length-frequency distributions recorded between January 1987 and February 1989 in Vanuatu for the *Etelis* spp., *Pristipomoides* spp., and *Lutjanus malabaricus*.

to 3 years. Average weight of the adult population is therefore estimated at 2.2 kg per fish.

The global relationship between weight of fish and number of trips is better fitted to a linear correlation ($Y = 28.058X + 503.986$, $R^2 = 0.895$, d.f. = 61) than to the Schaefer model (Pauly 1983; $Y = 35.39X - 0.0132X^2$, $R^2 = 0.041$, d.f. = 61; Fig. 3A). The relationship between the density of catches and the concentration of fishing effort is also linear for each island (Appendix C). However, CPUE related to the correspondent size of fishing areas shows a curvature resembling an exponential relation (in Pauly 1984; $Y = X \exp(-2.797) \exp(-0.157X)$, $R^2 = 0.968$, d.f. = 5; Fig. 3B). An optimum CPUE of 40 kg per trip is observed for a fishing area of 70,000 ha.

Only the time series of annual catch and fishing effort recorded in Paama and Ambae fit the Allen model (Appendix D). For ranges of natural mortality between 0.24 and 0.48, the predicted CPUEs are closely correlated with those recorded in 1983-87. Depletion is apparent for the same time period in the two islands (Fig. 4). An increase in CPUE and differences between predicted and actual data are apparent for 1988, especially in Paama with a natural mortality of 0.48.

For the two natural mortalities values (0.24 and 0.48), ranges of unexploited exploitable biomass are between 32 and 57 t in Paama and between 21 and 36 t in Ambae. Average recruited biomass is estimated at about 9.5 t/year for Paama and 7.5 t/year for Ambae. At the two islands, rates of fishing mortality are close to those of natural mortality (Table 1). However, extrapolating these values to Vanuatu as a whole gives a fishing mortality equal to 0.08.

Table 1.--Fitting to the Allen model for the catch and effort recorded in Paama and in Ambae, 1982-88.

Surface area (ha)	Length of isobath	M	K	Q	B_∞	R	F	R/nmi	B_∞/ha	B_∞/nmi
					Paama					
25,384	28	0.18	0.1	-0.00104	66,635	8,028	0.17	287	2.63	238
		0.24	0.1	-0.00121	57,084	9,248	0.21	330	2.25	2,039
		0.48	0.2	-0.00217	31,920	101,287	0.37	367	1.26	1,140
					Ambae					
11,843	62	0.18	0.1	-0.00068	41,980	6,411	0.15	103	3.54	714
		0.24	0.1	-0.00079	35,957	7,279	0.12	117	3.04	582
		0.48	0.2	-0.00142	21,257	7,996	0.31	129	1.79	344

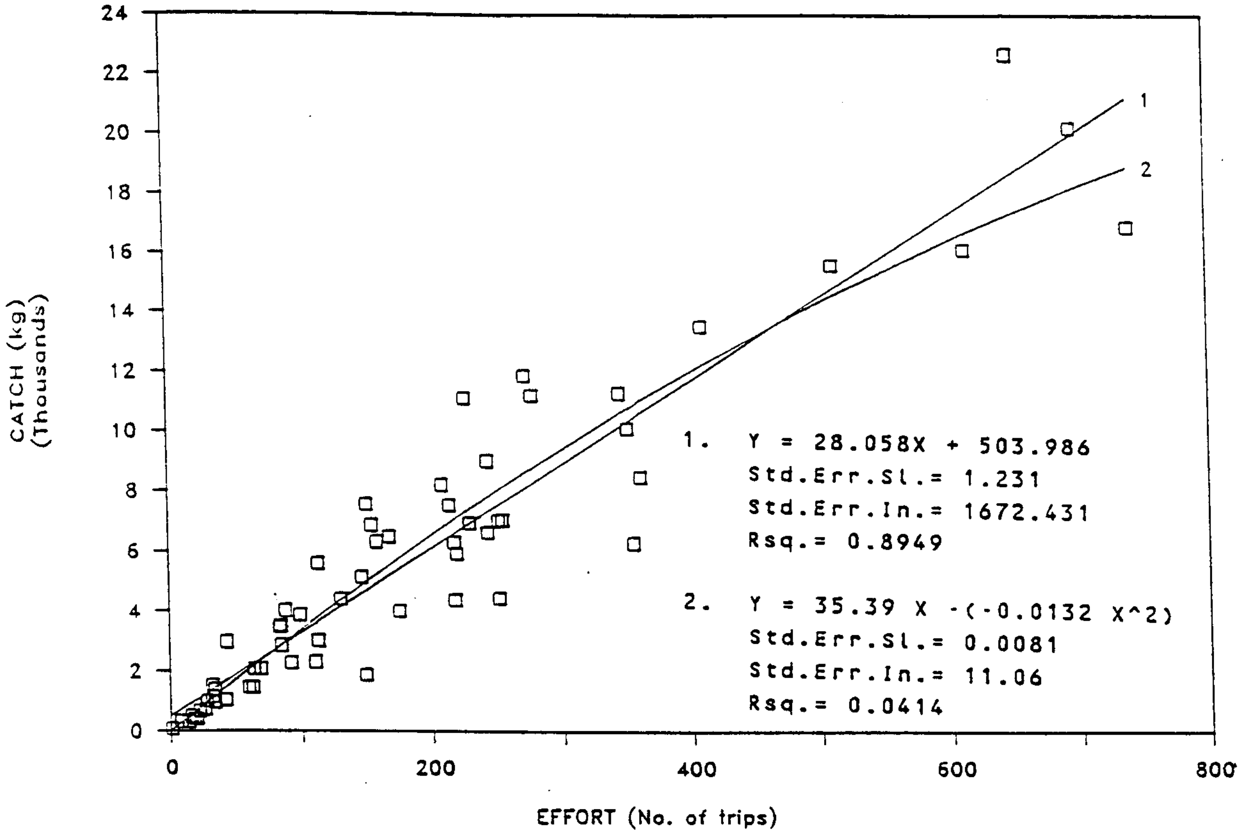

Figure 3A.--Correlation between annual catch and fishing effort fitted to (1) a linear regression and (2) the Schaefer model (in Pauly 1983).

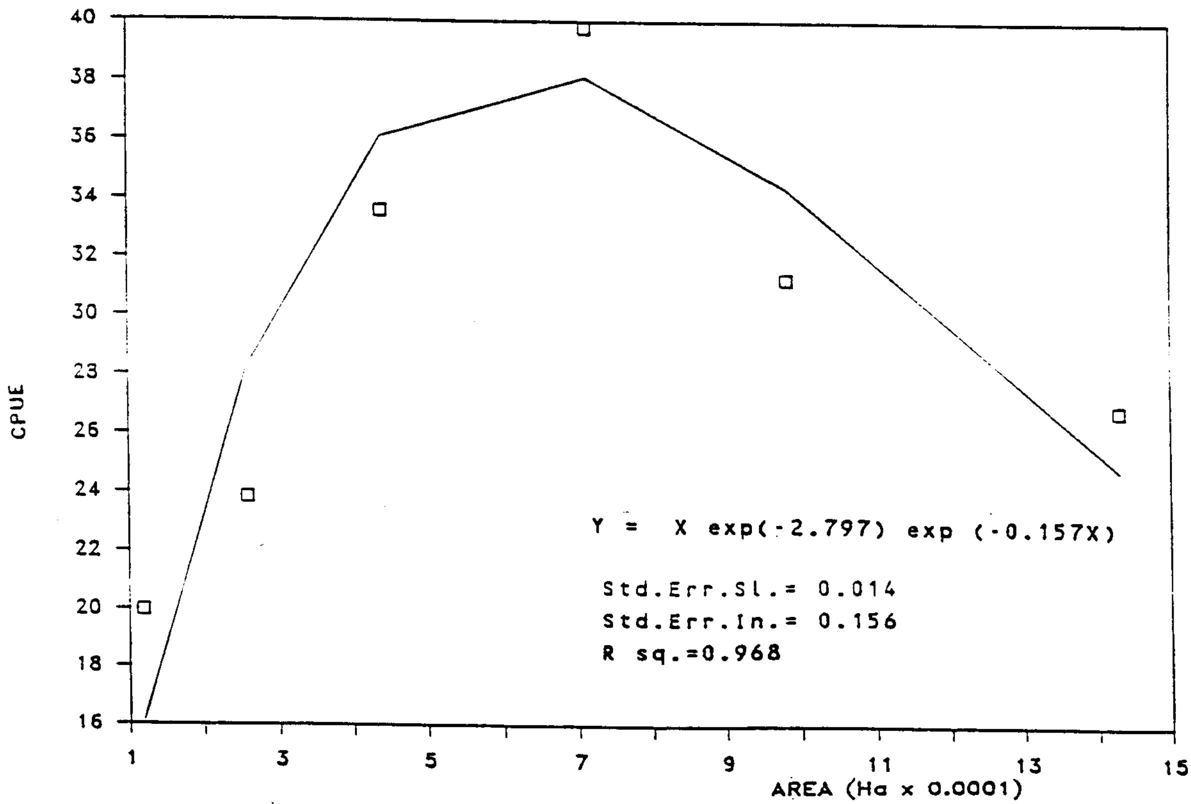

Figure 3B.--Catch per unit effort (CPUE; kilograms per trip) versus size of the fishing area (hectares) for different fishing grounds in Vanuatu fitted to an exponential relation (in Pauly 1984).

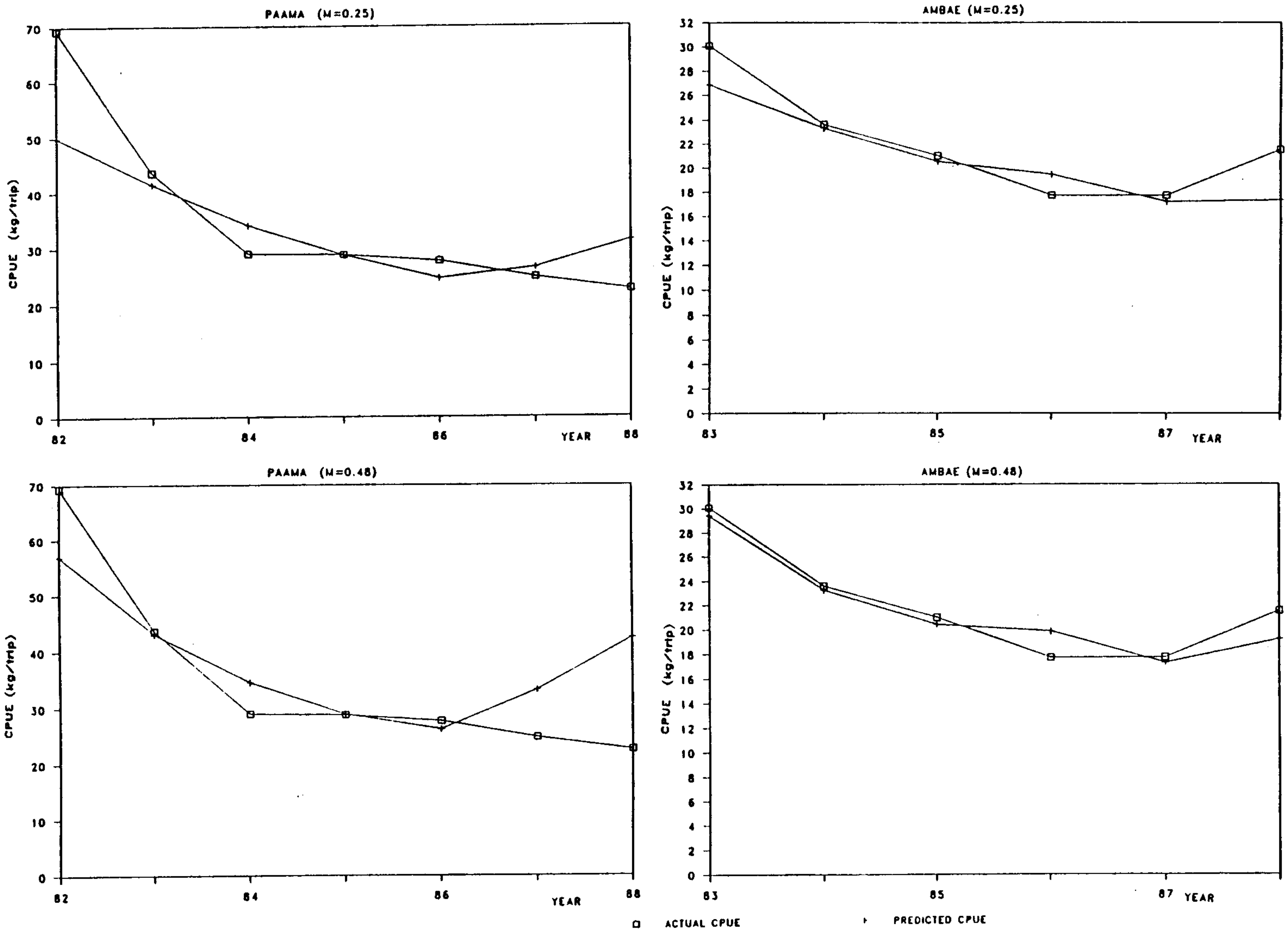

Figure 4.--Depletion estimates for time series of catch per unit effort (CPUE) recorded in Paama in 1982-88 and in Ambae in 1984-88.

Table 2.--Maximum sustainable yield (MSY) estimates using the Beverton and Holt tables (age at recruitment, 3 years) and Pauly relation.

	M = 0.25				M = 0.5			
Method	MSY/B_∞	MSY (kg)	MSY/ha	MSY/nmi	MSY/B_∞	MSY (kg)	MSY/ha	MSY/nmi
				Paama				
Beverton-Holt	0.06	3,425	0.13	122.0	0.18	5,618	0.22	200.6
Pauly	0.28	15,983	0.63	571.0				
				Ambae				
Beverton-Holt	0.06	2,157	0.18	34.8	0.18	3,741	0.32	60.3
Pauly	0.32	11,506	0.97	186.0				

Annual MSY has been estimated with Beverton and Holt tables for an age at recruitment of 3 years and for natural mortality (M) between 0.24 and 0.48. This calculation suggests an MSY of between 3.4 and 5.6 t for Paama and between 2.1 and 3.7 t for Ambae. With the Pauly method, the MSY estimate is equal to 32% of the unexploited exploitable biomass. For a natural mortality equal to 0.24, annual MSY is about 18.2 t in Paama and 11.5 t in Ambae (Table 2).

For this value of M (0.24), an exploitable unexploited biomass of 1,886.2 t is estimated for Vanuatu. Estimations of annual MSY for the Vanuatu archipelago indicates a figure of 113.2 t with Beverton and Holt tables and 603.5 t with the Pauly method.

DISCUSSION AND CONCLUSION

Considering the low levels of fishing activity recorded per association, linear correlation between catch and effort and the low value of fishing mortality estimated for the whole of Vanuatu, the deep bottomfish populations are, in general, still underexploited. Fishing effort seems limited by market demand rather than by the size of the fish population.

However, depletion studies with the Allen model and values of fishing mortality indicate that the yields in Paama and Ambae seem to be affected by several years of fishing effort, except in 1988 when fishing effort in Paama was particularly low. As these islands have small fishing areas, it is suspected that the density of the fish (probably correlated with the size of fishing area) could influence the yields. The relationship between CPUE and size of fishing area might confirm this hypothesis. A comparable phenomenon has also been observed for the etelines (*Etelis* spp. and *Pristipomoides* spp.), where CPUE seems to increase with the size of the island (Dalzell 1990). Influences of different habitats therefore seem to be taken into account in dynamics evaluations (Polovina 1989).

For the entire Vanuatu archipelago, Brouard and Grandperrin (1984) calculated the range of annual MSY at 300-700 t. Our range of MSY is narrower but overlaps with theirs. Under the same fishing conditions (three reels, 4-5 hours of fishing, 150 trips/year, and CPUE close to 3 kg per hour per reel), our range of MSY for the entire archipelago indicates that 20-100 vessels could operate in the fishery. This fleet exists but its level of activity is probably lower than specified above.

Biomass per nautical mile in Paama is close the mean value of 2.7 t/nmi recorded for the seamounts in the Pacific. With one of the shortest lengths of 200 m depth contour recorded in the Pacific, Paama's topography could relate closer to the seamount figure than to an island. Similarly, the biomass per nautical mile in Ambae is closer to an island's mean estimate of 0.7 t/nmi (Polovina et al. 1990) than to a seamount's.

Annual catches recorded for Ambae and Paama are higher than the upper range of our estimations, possibly suggesting that equilibrium has yet to be achieved. However, to be precise, it would be necessary to determine more accurately the natural mortality rate.

With more accurate fishing effort data (e.g., the number of trip hours per reel, fishing depth, area of capture), the application of dynamic models could be improved. However, before applying further dynamic evaluations, it would also be necessary to evaluate what is the proportion of the real production declared by the statistics to total catches. Depletion studies may also require short surveys of intensive fishing in fixed places if the level of fishing effort remains similar to those recorded.

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Reichenfeld, as well as the VFDP and the fishermen without whom this study would not have been possible.

CITATIONS

Beddington, J. R., and J. G. Cooke.
1983. The potential yields of fish stocks. FAO Fish. Tech. Pap. 242, 47 p.

Brouard, F., and R. Grandperrin.
1984. Deep bottom fishes of the outer reef slope in Vanuatu. Notes et document d'Oceanographie de la mission ORSTOM de Port Vila, 11, 131 p.

Carlot, A., and F. Nguyen.
1989. Preliminary study on populations of Vanuatu deep bottom fish after seven years of exploitation. Presented at the U.S. Agency for International Development and National Marine Fisheries Service Workshop on Tropical Fish Stock Assessment, 5-26 July 1989, Honolulu, Hawaii.

Dalzell, P.
1990. Deepwater dropline fishing surveys in the South Pacific in 1975-88: A preliminary analysis of the data collected by the South Pacific Commission Master Fishermen's Program. (In this volume.)

Pauly, D.
1983. Some simple methods for the assessment of tropical fish stocks. FAO Fish. Tech. Pap. 234, 52 p.

1984. Fish population dynamics in tropical waters: a manual for use with programmable calculators. ICLARM Studies and Reviews 8, 325 p.

Polovina, J. J.
1989. A system of simultaneous dynamic production and forecast models for multispecies or multiarea. Can. J. Fish. Aquat. Sci. 46:961-963.

Polovina, J. J. R. A. Benco, A. H. Carlot, E. Cillaurren, P. Dalzell, N. Howard, D. Kobayashi, T. F. Latu, P. Lokani, G. Nath, H. Pitiale, A. Sesewa, R. Shomura, T. Sua, G. Tiroba, and S. Tulua.
1990. Introduction and summary of methods and results from the Tropical Stock Assessment Workshop. (In this volume.)

Ralston, S.
1985. Mortality rates of snappers and groupers. Pages 375-404 *in* J. J. Polovina and S. Ralston (editors), Tropical snappers and groupers: biology and fisheries management. Westview Press, Boulder.

Sainsbury, K. J.
1984. Optimal mesh size for tropical multispecies trawl fisheries. J. Cons. Cons. int. Explor. Mer 41:129-139.

Schaan, O., A. Carlot, and F. Nguyen.
1987. Exploitation of deep sea fish resources by the village fisheries in Vanuatu. Notes et documents d'Oceanographie de la mission ORSTOM de Port Vila 16, 145 p.

Appendix A.--Statistical data filled out by the associations of the Fisheries Department of Vanuatu's Village Fisheries Development Program.

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REMARKS

Appendix B.--Annual catches (in kilograms) and fishing effort (number of trips) recorded for 11 islands in Vanuatu, 1982-88 (from Carlot and Nguyen 1989).

ISLAND		1982	1983	1984	1985	1986	1987	1988
	NO. TRIPS	32	32	85	99	409	83	34
TANNA	CATCH (kg)	1540	1165	2867	3883	13547	3474	955
	CPUE	48.1	36.4	33.7	39.2	33.1	41.9	28.1
	CUM CATCH	1540	2705	5572	9455	23002	26476	27431
	NO. TRIPS			88	278	113	150	227
EFATE	CATCH (kg)			4021	11212	5593	7579	11113
	CPUE			45.7	40.3	49.5	50.5	49.0
	CUM. CATCH			4021	15233	20826	28405	39518
	NO. TRIPS			154	158	28		
TONGOA	CATCH (kg)			6874	6323	1010		
	CPUE			44.6	40.0	36.1		
	CUM.CATCH			6874	13197	14207		
	NO. TRIPS	130	168	209	64	69	92	26
EPI	CATCH (kg)	4412	6481	8219	2082	2093	2276	743
	CPUE	33.9	38.6	39.3	32.5	30.3	24.7	28.6
	CUM.CATCH	4412	10893	19112	21194	23287	25563	26306
	NO. TRIPS			84	252	218	34	16
AMBRYM	CATCH (kg)			3515	7033	4383	1396	503
	CPUE			41.8	27.9	20.1	41.1	31.4
	CUM.CATCH			3515	10548	14931	16327	16830
	NO. TRIPS	43	273	218	351	255	42	14
PAAMA	CATCH (kg)	2981	11895	6314	10118	7059	1040	317
	CPUE	69.3	43.6	29.0	28.8	27.7	24.8	22.6
	CUM CATCH	2981	14876	21190	31308	38367	39407	39724
	NO. TRIPS	18	146	16	244	511	244	345
MALEKULA	CATCH (kg)	416	5154	502	6648	15646	9015	11295
	CPUE	23.1	35.3	31.4	27.2	30.6	36.9	32.7
	CUM.CATCH	416	5570	6072	12720	28366	37381	48676
	NO. TRIPS	20	739	220	648	613	214	696
SANTO	CATCH (kg)	399	16936	5935	22716	16154	7544	20283
	CPUE	20.0	22.9	27.0	35.1	26.4	35.3	29.1
	CUM.CATCH	399	17335	23270	45986	62140	69684	89967
	NO. TRIPS		149	112	230	110	113	175
PENTECOST	CATCH (kg)		1883	3040	6950	2315	3018	4011
	CPUE		12.6	27.1	30.2	21.0	26.7	22.9
	CUM.CATCH		1883	4923	11873	14188	17206	21217
	NO. TRIPS			22	361	110	252	355
AMBAE	CATCH (kg)			663	8508	2315	4449	6298
	CPUE			30.1	23.6	21.0	17.7	17.7
	CUM.CATCH			663	9171	11486	15935	22233
	NO. TRIPS				8	60	1	63
BANKS/TORRES	CATCH (kg)				328	1469	75	1466
	CPUE				41.0	24.5	75.0	23.3
	CUM.CATCH				328	1797	1872	3338
	NO. TRIPS	243	1507	1208	2693	2496	1225	1951
VANUATU	CATCH (kg)	9748	43514	41950	85801	71584	39866	56984
	CPUE	40.1	28.9	34.7	31.9	28.7	32.5	29.2

Appendix C.--Linear correlations between kilograms/hectare and number of trips/hectare for fishing areas in the South Pacific.

Location	Surface area (ha)	Slope	SE slope	Intercept	SE intercept	R^2
Ambae	11,843	19.986	3.146	0.0037	0.0798	0.9307
Pentecost	25,000	32.838	4.165	0.0080	0.0393	0.7845
Ambrym	26,650	--	--	--	--	--
Tanna	42,438	33.593	1.731	0.0092	0.0139	0.9792
Tongoa	45,354	--	--	--	--	--
Banks/Tor.	66,422	39.781	4.136	0.0080	0.0110	0.9113
EPI+Paama	76,152	--	--	--	--	--
Efate	95,330	31.289	3.548	0.0012	0.0162	0.8861
Malekula	101,344	--	--	--	--	--
Santo	142,970	28.848	3.982	0.0058	0.0199	0.9000

Appendix D.--The Allen model fit to the times series of catch and effort in Ambae and Paama.

M	Slope	SE slope	Intercept	SE Intercept	*P>T* slope	*P>T* intercept	R^2
				Ambae			
0.24	-0.00079	0.00015	27.077	1.400	0.013	0.0003	0.992
0.48	-0.00146	0.00032	29.770	2.222	0.021	0.0009	0.994
				Paama			
0.24	-0.00121	0.00026	52.161	4.457	0.006	0.0001	0.998
0.48	-0.00217	0.00038	59.415	4.899	0.002	0.0001	0.998

ASSESSMENT OF THE BOTTOMFISH RESOURCE OF WESTERN SAMOA: AN INTERIM REPORT

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INTRODUCTION

Western Samoa (Fig. 1) consists of two large islands (Upolu and Savaii) and two small islands (Manono and Apolima); the total land mass of the four islands is 1,100 square miles. The present population of 168,000 inhabitants is highly dependent upon locally caught fish and fishery products to meet its protein needs. However, in recent years, fresh fish has been slowly replaced by canned fish and mutton flaps; part of this substitution is due to increases in the prices of locally caught fish. These price increases and the recent development of overseas markets have attracted local and external investors in commercial fishing in Western Samoa.

The Fisheries Division of the Government of Western Samoa has recognized the importance of properly managing its fishery resources; thus, the Government recently requested assistance from the United States Agency for International Development in assessing the deep-sea bottomfish resources of Western Samoa. This project began in January 1989. Data to evaluate the resources were collected from the Government's 47-foot research vessel *Tautai Matapalapala*.

Included among the many other objectives of this project on the resource assessment of bottomfish in Western Samoa are the vital objectives of obtaining estimates of the standing stock and the maximum sustainable yield (MSY). This interim report presents an analysis of data collected during the first 6 months of operation.

MATERIALS AND METHODS

Fishing data were collected from the *Tautai Matapalapala* in predetermined areas (zones), which were divided to give an even amount of fishable habitat around the two major islands (Fig. 1). Zones 18 and 19 (the 17 Fathom and Pasco Banks, respectively) are the two prominent banks of Western Samoa. Data collected at sea included fishing depth, effort (line-hours), time of capture, station type, and zone number. Data collected onshore included species identification, length and weight measurements, and sexing of the catch.

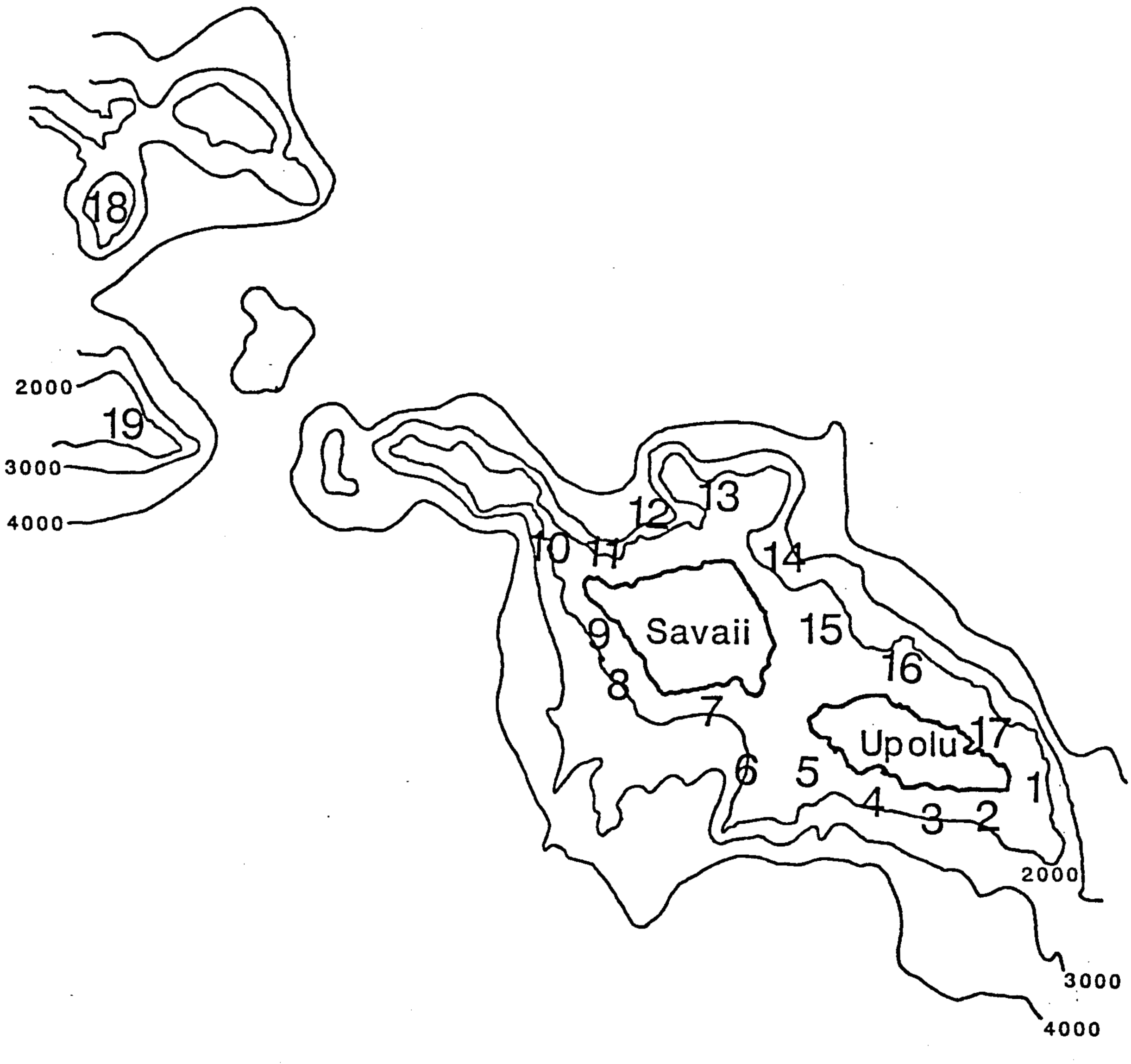

Figure 1.--Fishing zones around Western Samoa.

A depletion experiment was conducted in zone 18. During each trip, the fishing activities (stations) involved fishing by drifting or with the vessel anchored. The decision whether to anchor or drift was usually based on weather conditions, ocean currents, and bottom substrate.

Analytical Methods

The approach to estimating MSY involved two steps (Polovina and Ralston 1986). First, unexploited exploitable biomass (*B*) was determined from depletion analysis based on the Leslie model (Ricker 1975). Catch per unit effort (CPUE) was regressed on cumulative catch to estimate catchability (q) and the number of exploitable fish at the beginning of the depletion (N), then B was estimated by multiplying N by the mean fish weight. Subsequently, MSY was estimated as a fraction of B. Since the data were limited, a range was established for MSY: the Beverton-Holt method (in Beddington and Cooke 1983) was used to set a conservative lower MSY limit; the Pauly (1983) method was used to establish an upper MSY figure. Using the Beverton-Holt method to estimate MSY requires information on recruitment, growth, and natural mortality.

The Pauly method is based on a presumed physiological relationship of size of fish, maturity, and biomass. This relationship is expressed as

$$MSY = 2.3W^{-0.26}B ,$$

where W is the mean weight after sexual maturity and the asymptotic weight expressed in grams for the seven major bottomfish species in the Western Samoan fishery and B is the unexploited exploitable biomass.

RESULTS

The summary of total catch is presented in Appendix A, which shows the percentage of species composition in descending order. *Etelis* spp. were the most abundant of the 45 bottomfish species identified. Appendix B is a summary of catch at different zones by the two types of fishing (anchored and drift), the number of fish, fish weight, effort (in line-hours), and mean CPUE. Appendix C lists the species in order of decreasing abundance within 20-fathom depth intervals.

Length-Weight Relationship

The length-weight relationship for the seven major snapper species (*E. carbunculus*, *E. coruscans*, *Pristipomoides flavipinnis*, *P. filamentosus*, *P. typus*, *P. zonatus*, and *Aphareus rutilans*), which constituted about 60% of the total catch, are presented in Appendix D and Table 1. All of the length-weight plots show good fits and are statistically significant with high R^2 values.

Table 1.--Summary of length-weight relationships for seven major snapper species in Western Samoa for the equation weight = $A(\text{length})^B$.

Species	N	$A(\times 10^{-5})$	B	R
Aphareus rutilans	77	6.10	2.7	0.94
Etelis carbunculus	158	3.76	2.9	0.99
E. coruscans	149	5.50	2.7	0.99
Pristipomoides filamentosus	63	0.51	2.1	0.87
P. flavipinnis	121	0.16	2.5	0.87
P. typus	89	7.15	2.7	0.86
P. zonatus	140	0.14	2.5	0.77

Length Frequencies

The length frequencies for the seven major species are in Appendix E. For most of the species, the modal sizes of the males and females do not coincide. The available data were inadequate to examine possible causative factors. Possible reasons for the differences include sampling problems, size-related differences in behavior between sexes, differential growth, and mortality.

CPUE

The CPUE was calculated from the number of fish per line-hour and the weight (kg) per line-hour. The mean catch rate for each zone shows that zone 18 had the highest catch rate (Appendix F). It should be noted, however, that six of the zones have not yet been fished. With respect to depth, the mean CPUE decreases with depth (Appendix G); however, the availability of bottomfish appeared to increase between 80 and 180 fathoms as indicated by the cluster of high CPUE. A plot of CPUE and time (Appendix H) indicates that the best time for fishing is between 0600 and 1200 and between 1400 and 1800.

The comparison of mean CPUE for drift and anchored fishing suggests that drift fishing produced higher catch rates (Appendix I). This trend was not statistically significant because of the large variation in CPUE.

Depletion Experiment

The Leslie model was fit to the catch and effort data from zone 18 (17 Fathom Bank). The CPUE regressed on cumulative catch did not show a declining trend as would be expected if fishing effort had an impact on the available biomass. The best fit appeared to be a straight line (Appendix J). The results suggest that there is no sign of depletion as yet. The plot of the CPUE of the major snapper species against cumulative catch showed some signs of depletion (Appendix J); however, the regression was not statistically significant. Results indicate this was due primarily to the fact that the standing stock was larger than originally estimated.

MSY Estimates

Table 2 presents the total habitat area for each zone (based on the 200 m isobath) and the estimated MSY, which is calculated as a function of B. Since the results of our depletion study were not statistically significant, a B value for Western Samoa was estimated from data obtained from several depletion studies carried out in the Pacific islands in recent years (Polovina et al. 1990). Based on the pooled data, the estimated biomass for the length of the 200 m isobath is 0.7 t/nmi around the islands and 2.6 t/nmi around seamounts.

The lower bound of MSY using the Beverton-Holt method was computed to be 17 t/year, taking the values of natural mortality (M) of 0.25, age at recruitment of 4 years, and M/K of 2.0 from the literature (Ralston 1987). The upper bound for MSY using the Pauly method was computed to be 50 t/year. Based on this preliminary study, the estimated MSY for the bottomfish resources of Western Samoa ranges from 17 to 50 t/year.

DISCUSSION AND CONCLUSIONS

The estimated MSY for the bottomfish resources of Western Samoa is 17-50 t/year. While the current estimated landings of 25 t/year fall within this range, there should be no immediate concern of overfishing: The fishery is still in the early stages of development, and bottomfish apparently are still being fished down to equilibrium levels. The fishery should be monitored carefully over the coming years to obtain better estimates of MSY and to avoid overfishing of these valuable resources.

Table 2.--Total habitat area for each zone defined by 200 m isobath and estimated maximum sustainable yield (MSY) using the Pauly (1983) method. Seamount zone 18 is listed separately at bottom of table.

Zone No.	Habitat area (nmi^2)	*B*	MSY (t/year)
1	12.0	8.40	0.7560-2.2680
2	9.0	6.30	0.5670-1.7010
3	11.5	8.05	0.7245-2.1735
4	12.0	8.40	0.7560-2.2680
5	13.0	9.10	0.8190-2.4570
6	24.5	17.15	1.5435-4.6305
7	14.0	9.80	0.8820-2.6460
8	15.5	10.85	0.9760-2.9295
9	9.0	6.30	0.5670-1.7001
10	8.5	5.95	0.5355-1.6065
11	9.0	6.30	0.5670-1.7010
12	11.5	8.05	0.7245-2.1735
13	6.0	4.20	0.3780-1.1340
14	19.0	13.30	1.1970-3.5910
15	25.0	17.50	1.5750-4.7220
16	24.0	16.80	1.5120-4.5360
17	9.5	6.65	0.5985-1.7955
Total	233.0		14.6790-44.0370
18	7.9	20.54	1.8486-5.5458

Since the depletion experiment at zone 18 (17 Fathom Bank) did not result in declining catch rates, a reevaluation of this experiment should be undertaken immediately. It appears that the fishing effort imposed by the research vessel on this bank is inadequate to make a noticeable reduction in the fishable biomass. Alternatives are to increase fishing effort in zone 18 over the next 6 months.

ACKNOWLEDGMENTS

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CITATIONS

Beddington, J. R., and J. G. Cooke.
1983. The potential yield of fish stocks. FAO Fish. Tech. Pap. 242:1-47.

Pauly, D.
1983. Some simple methods for the assessment of tropical fish stocks. FAO Fish. Tech. Pap. 234, 52 p.

Polovina, J. J., R. A. Benco, A. H. Carlot, E. Cillaurren, P. Dalzell, N. Howard, D. Kobayashi, T. F. Latu, P. Lokani, G. Nath, H. Pitiale, A. Sesewa, R. Shomura, T. Sua, G. Tiroba, and S. Tulua.
1990. Introduction and summary of methods and results from the Tropical Stock Assessment Workshop. (In this volume.)

Polovina, J. J., and S. Ralston.
1986. An approach to yield assessment for unexploited resources with application to the deep slope fishes of the Marianas. Fish. Bull., U.S. 84:759-770.

Ralston, S.
1987. Mortality rates of snappers and groupers. Pages 375-404 *in* J. J. Polovina, and S. Ralston (editors.), Tropical snappers and groupers: biology and fishery management. Westview Press, Boulder.

Ricker, W. E.
1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191:1-382.

Appendix A.--Species listing (by number caught) and percent species composition in descending order of occurrence. Sampling was conducted off Western Samoa in January-June 1989.

Rank	Species abbreviation	No.	Percentage
1	Etelis carbunc	160	10.8622
2	Etelis corusca	152	10.3191
3	Pristipo zonatus	140	9.5044
4	Paracaes kusakar	122	8.2824
5	Pristipo flavipi	122	8.2824
6	Pristipo typus	93	6.3136
7	Lutjanus bohar	91	6.1779
8	Aphareus rutilan	78	5.2953
9	Wattsia mossamb	75	5.0916
10	Pristipo filamen	65	4.4128
11	Paracaes stonei	42	2.8513
12	Caranx sp	33	2.2403
13	Promethi prometh	30	2.0367
14	Epinephe morrhua	28	1.9009
15	Lutjanus timoren	27	1.8330
16	Epinephe sp	23	1.5614
17	Pristipo auricil	21	1.4257
18	Gymnosar unicolo	16	1.0862
19	Lethrinu sp	14	0.9504
20	Seriola dumeril	14	0.9504
21	Unidentified spp	13	--
22	Pristipo multide	11	0.7468
23	Aprion viresce	8	0.5431
24	Lethrinu elongat	8	0.5431
25	Pristipo amoenus	8	0.5431
26	Ruvettus pretios	8	0.5431
27	Lethrinu amboine	7	0.4752
28	Taractic steinda	7	0.4752
29	Cephalop sonnera	5	0.3394
30	Cephalop sp	5	0.3394
31	Epinephe sp2	5	0.3394
32	Anomalop sp	3	0.2037
33	Caranx sexfasc	3	0.2037
34	Cephalop igarash	3	0.2037
35	Epinephe spl	3	0.2037
36	Lutjanus caerule	3	0.2037
37	Lutjanus kasmira	3	0.2037
38	Promethi sp	3	0.2037
39	Travelly sp	3	0.2037
40	Elagatis bipinnu	2	0.1358
41	Eumegist sp	2	0.1358

Appendix A.--Continued.

Rank	Species abbreviation	No.	Percentage
42	Lutjanus argenti	2	0.1358
43	Seriola sp	2	0.1358
44	Yellowfi sp	2	0.1358
45	Ariomma everman	1	0.0679
46	Carangoi orthogr	1	0.0679
47	Caranx rngbris	1	0.0679
48	Cephalop obutusa	1	0.0679
49	Cephalop sexmacu	1	0.0679
50	Cookeolu boops	1	0.0679
51	Epinephe cometae	1	0.0679
52	Epinephe salmono	1	0.0679
53	Epinephe sp3	1	0.0679
54	Gempylid sp	1	0.0679
55	Gymnocra rivulat	1	0.0679
56	Lethrinu kallopt	1	0.0679
57	Lutjanus gibbus	1	0.0679
58	Neoscomb pacific	1	0.0679
59	Ostichth japonic	1	0.0679
60	Pristile oligole	1	0.0679
61	Pufferfi sp	1	0.0679
62	Serranid sp	1	0.0679
63	Sphyraen sp	1	0.0679
64	Thyrsito marleyi	1	0.0679
65	Variola louti	1	0.0679

Appendix B.--Summary of catch by two types of fishing at different zones in Western Samoa (A = anchored fishing stations; D = drift fishing stations).

Zone No.	No. of stations	Type of fishing	No. of fish	Fish weight (kg)	Line-hours	Mean CPUE
1	6	A	13	31.08	56.24	0.28
	2	D	7	9.25	3.35	1.79
2	11	A	45	223.85	81.87	0.66
	5	D	3	4.10	4.99	0.66
3	0	A	-	-	-	-
	0	D	-	-	-	-
4	0	A	-	-	-	-
	0	D	-	-	-	-
5	2	A	10	32.75	14.28	0.65
	0	D	-	-	-	-
6	9	A	59	159.35	71.51	0.91
	8	D	14	38.66	14.30	0.90
7	10	A	43	118.00	75.18	0.47
	4	D	7	6.60	4.75	2.10
8	6	A	23	66.70	34.15	0.58
	13	D	31	74.75	42.72	0.71
9	0	A	-	-	-	-
	0	D	-	-	-	-
10	8	A	206	464.01	119.10	1.87
	9	D	24	23.50	14.18	0.84
11	0	A	-	-	-	-
	1	D	0	0	0.67	0
12	0	A	-	-	-	-
	6	D	7	5.60	8.71	0.61
13	0	A	-	-	-	-
	10	D	11	12.25	14.74	0.66
14	6	A	86	300.05	64.28	0.85
	18	D	28	78.40	24.39	1.53
15	4	A	9	7.55	14.48	0.83
	1	D	0	0	0.22	0
16	0	A	-	-	-	-
	0	D	-	-	-	-
17	0	A	-	-	-	-
	0	D	-	-	-	-
18	40	A	497	1409.21	295.94	1.96
	69	D	205	434.15	63.50	3.92
19	5	A	108	301.35	66.99	1.24
	6	D	16	32.30	6.99	1.70
	Total		1,452	3833.46	1097.53	

Appendix C.--Species listing in order of decreasing abundance within 20-fathom depth intervals. All stations and zones combined.

Depth range (fathoms)	Species abbreviation	No. of fish	Percentage of total
0-20	Aprion viresce	1	50.0000
	Pristipo typus	1	50.0000
20-40	Lutjanus bohar	12	70.5882
	Pristipo flavipi	2	11.7647
	Lethrinu sp	1	5.8824
	Lutjanus gibbus	1	5.8824
	Variola louti	1	5.8824
40-60	Lutjanus bohar	33	39.2857
	Caranx sp	5	5.9524
	Etelis carbunc	5	5.9524
	Pristipo filamen	5	5.9524
	Pristipo typus	4	4.7619
	Aphareus rutilan	3	3.5714
	Gymnosar unicolo	3	3.5714
	Pristipo flavipi	3	3.5714
	Aprion viresce	2	2.3810
	Epinephe sp	2	2.3810
	Paracaes kusakar	2	2.3810
	Pristipo auricil	2	2.3810
	Pristipo zonatus	2	2.3810
	Seriola dumeril	2	2.3810
	Cephalop sexmacu	1	1.1905
	Etelis corusca	1	1.1905
	Lethrinu amboine	1	1.1905
	Lethrinu elongat	1	1.1905
	Lethrinu kallopt	1	1.1905
	Lutjanus caerule	1	1.1905
	Pristipo multide	1	1.1905
	Promethi prometh	1	1.1905
	Sphyraen sp	1	1.1905
	Travelly sp	1	1.1905
	Wattsia mossamb	1	1.1905
60-80	Etelis carbunc	30	9.0634
	Aphareus rutilan	28	8.4592
	Pristipo flavipi	28	8.4592
	Lutjanus bohar	24	7.2508
	Pristipo zonatus	24	7.2508
	Pristipo typus	22	6.6465
	Etelis corusca	20	6.0423
	Wattsia mossamb	20	6.0423

Appendix C.--Continued.

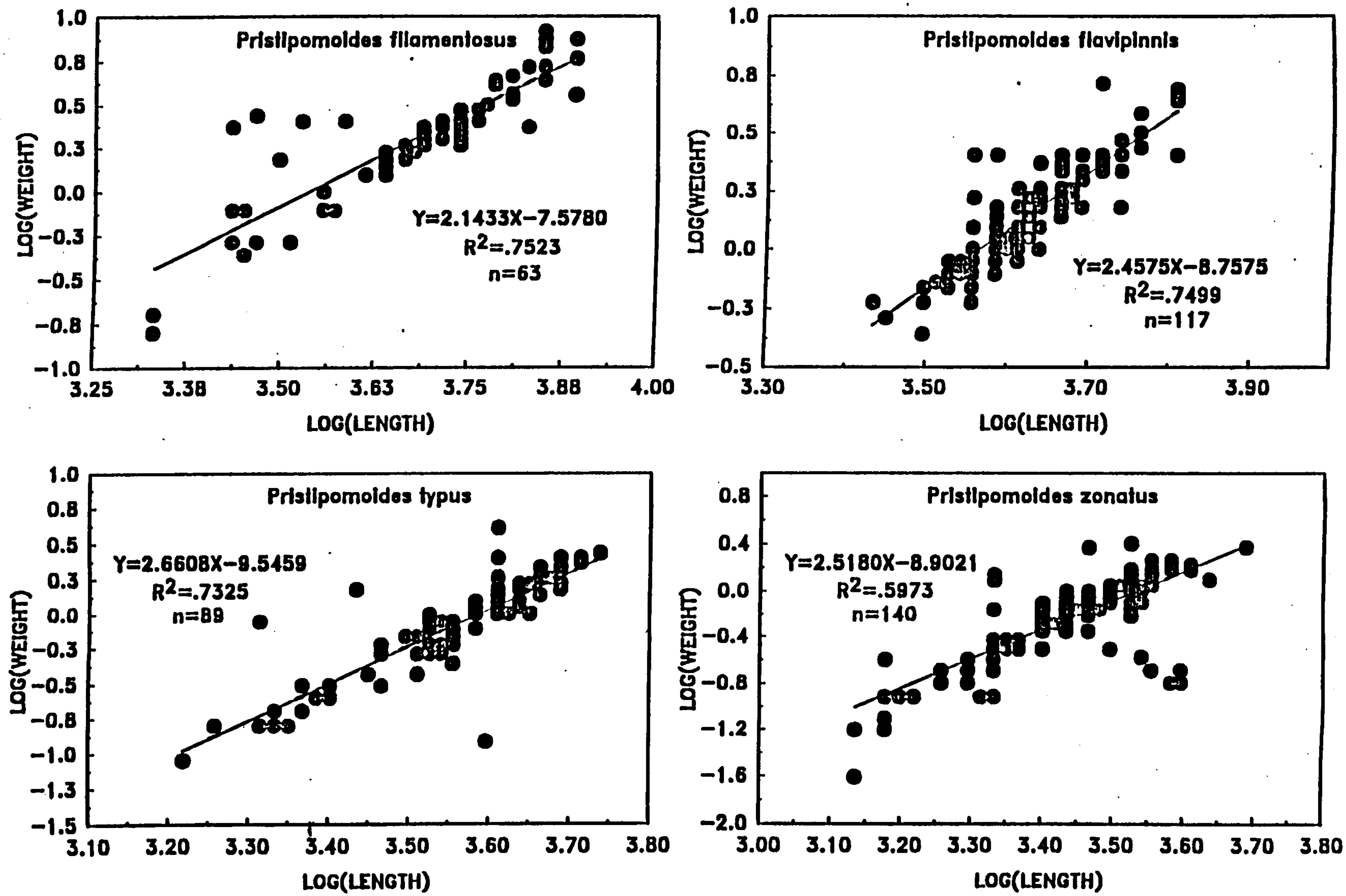
Depth range (fathoms)	Species abbreviation	No. of fish	Percentage of total
	Paracaes kusakar	19	5.7402
	Caranx sp	18	5.4381
	Pristipo filamen	14	4.2296
	Promethi prometh	13	3.9275
	Lutjanus timoren	11	3.3233
	Epinephe sp	9	2.7190
	Lethrinu elongat	7	2.1148
	Cephalop sonnera	4	1.2085
	Epinephe sp2	4	1.2085
	Seriola dumeril	4	1.2085
	Miscellaneous spp	33	9.9693
80-100	Paracaes kusakar	34	11.4478
	Etelis carbunc	33	11.1111
	Pristipo flavipi	33	11.1111
	Pristipo zonatus	28	9.4276
	Wattsia mossamb	25	8.4175
	Pristipo typus	24	8.0808
	Aphareus rutilan	22	7.4074
	Paracaes stonei	14	4.7138
	Pristipo filamen	11	3.7037
	Etelis corusca	10	3.3670
	Lutjanus bohar	10	3.3670
	Lutjanus timoren	8	2.6936
	Epinephe morrhua	7	2.3569
	Caranx sp	5	1.6835
	Epinephe sp	5	1.6835
	Promethi prometh	5	1.6835
	Caranx sexfasc	3	1.0101
	Miscellaneous spp	20	7.7340
100-120	Etelis corusca	44	13.4557
	Etelis carbunc	41	12.5382
	Pristipo zonatus	37	11.3150
	Pristipo flavipi	32	9.7859
	Paracaes kusakar	30	9.1743
	Pristipo typus	27	8.2569
	Pristipo filamen	22	6.7278
	Wattsia mossamb	16	4.8930
	Epinephe morrhua	13	3.9755
	Aphareus rutilan	12	3.6697
	Paracaes stonei	7	2.1407
	Lutjanus timoren	5	1.5291
	Promethi prometh	5	1.5291
	Epinephe sp	4	1.2232

Appendix C.--Continued.

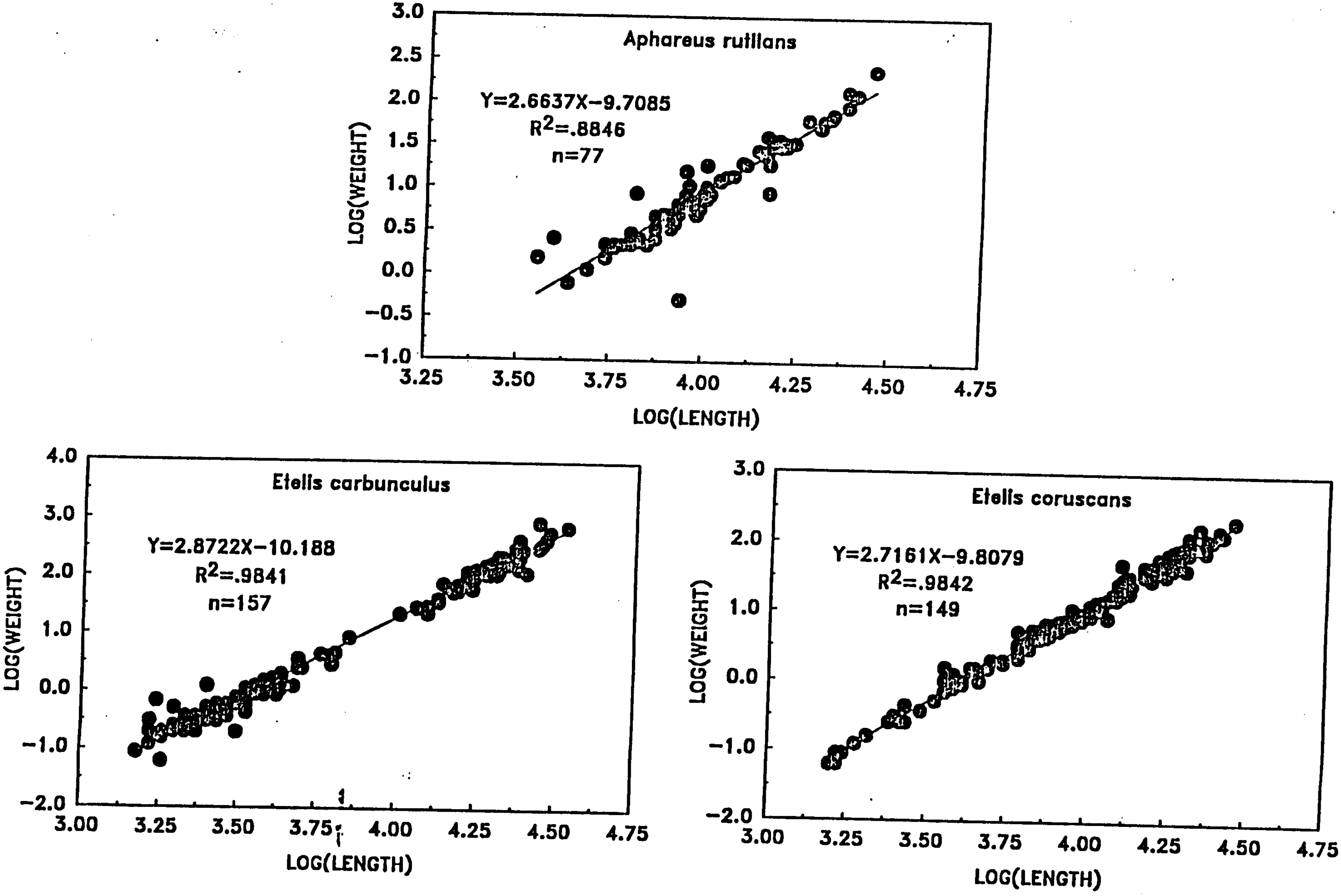
Depth range (fathoms)	Species abbreviation	No. of fish	Percentage of total
	Lutjanus bohar	4	1.2232
	Pristipo auricil	4	1.2232
	Miscellaneous spp	25	7.6450
120-140	Etelis corusca	33	21.5686
	Pristipo zonatus	20	13.0719
	Paracaes kusakar	17	11.1111
	Etelis carbunc	16	10.4575
	Paracaes stonei	10	6.5359
	Pristipo flavipi	10	6.5359
	Wattsia mossamb	9	5.8824
	Pristipo typus	5	3.2680
	Pristipo auricil	4	2.6144
	Promethi prometh	4	2.6144
	Caranx sp	3	1.9608
	Taractic steinda	3	1.9608
	Epinephe morrhua	2	1.3072
	Gymnosar unicolo	2	1.3072
	Lutjanus bohar	2	1.3072
	Pristipo amoenus	2	1.3072
	Pristipo filamen	2	1.3072
	Pristipo multide	2	1.3072
	Seriola dumeril	2	1.3072
	Miscellaneous spp	7	3.2680
140-160	Etelis corusca	21	23.5955
	Etelis carbunc	17	19.1011
	Pristipo zonatus	15	16.8539
	Paracaes stonei	4	4.4944
	Pristipo filamen	4	4.4944
	Pristipo typus	4	4.4944
	Aphareus rutilan	3	3.3708
	Pristipo auricil	3	3.3708
	Pristipo multide	3	3.3708
	Ruvettus pretios	3	3.3708
	Paracaes kusakar	2	2.2472
	Pristipo amoenus	2	2.2472
	Pristipo flavipi	2	2.2472
	Promethi prometh	2	2.2472
	Ariomma everman	1	1.1236
	Epinephe spl	1	1.1236
	Gymnosar unicolo	1	1.1236
	Lutjanus argenti	1	1.1236

Appendix C.--Continued.

Depth range (fathoms)	Species abbreviation	No. of fish	Percentage of total
>160	Etelis corusca	13	48.1481
	Etelis carbunc	5	18.5185
	Paracaes kusakar	2	7.4074
	Epinephe cometae	1	3.7037
	Paracaes stonei	1	3.7037
	Pristipo auricil	1	3.7037
	Pristipo flavipi	1	3.7037
	Pristipo zonatus	1	3.7037
	Seriola dumeril	1	3.7037
	Taractic steinda	1	3.7037



Appendix D.--Natural log length and natural log weight data and regressions for seven main species.



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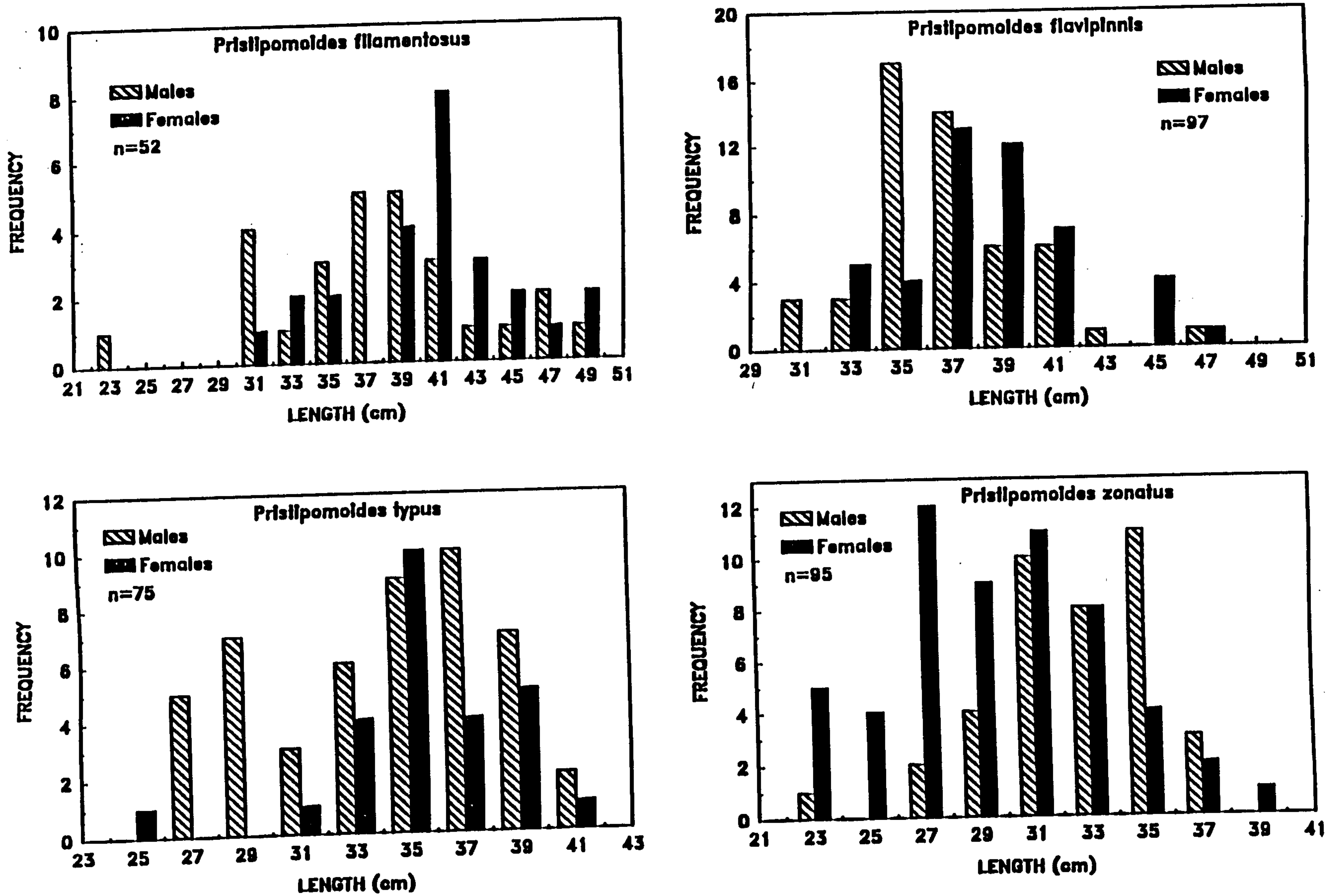
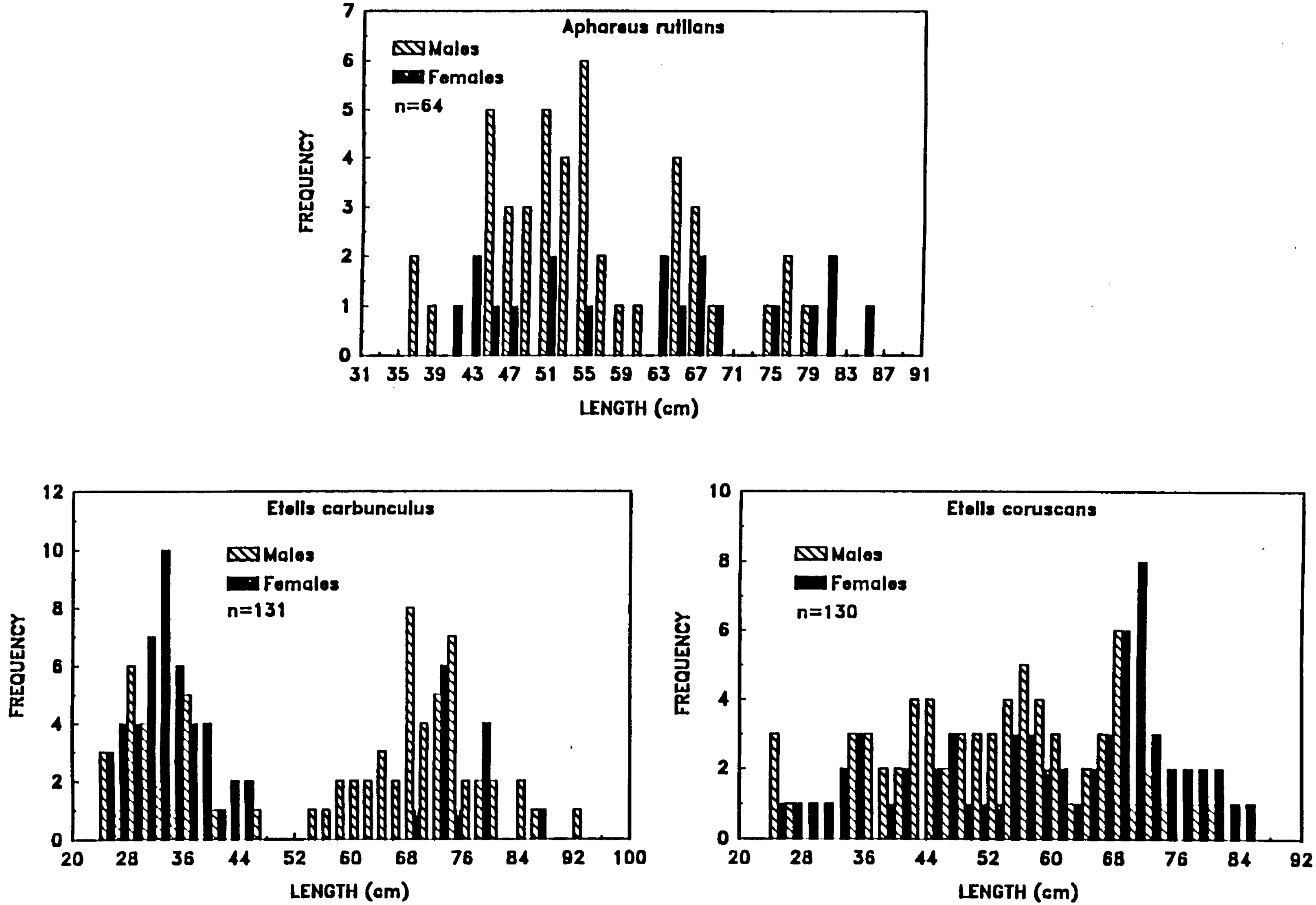
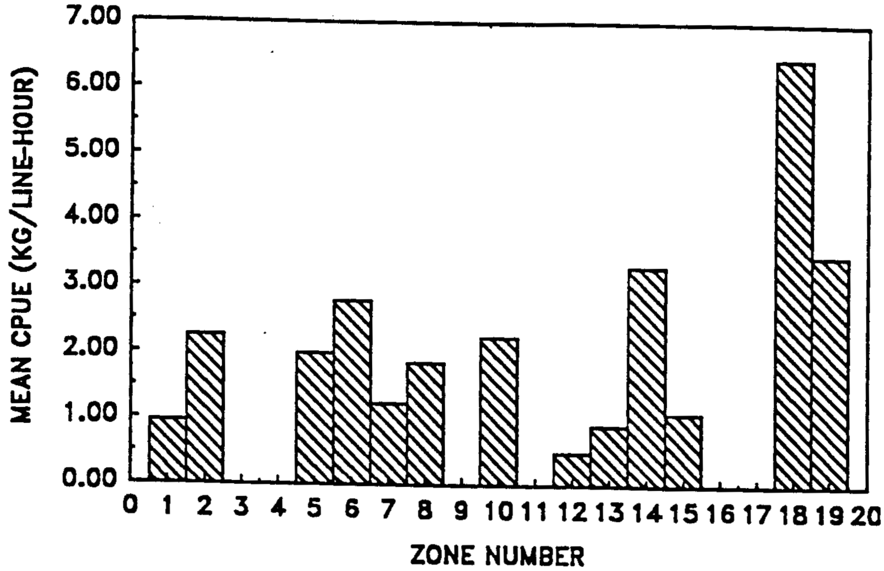
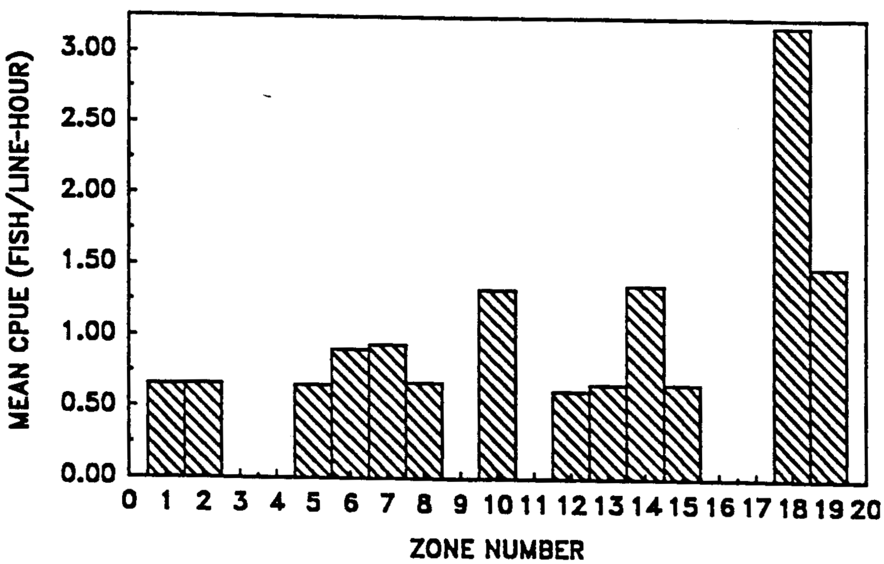


Appendix E.--Length-frequency data for seven main species.

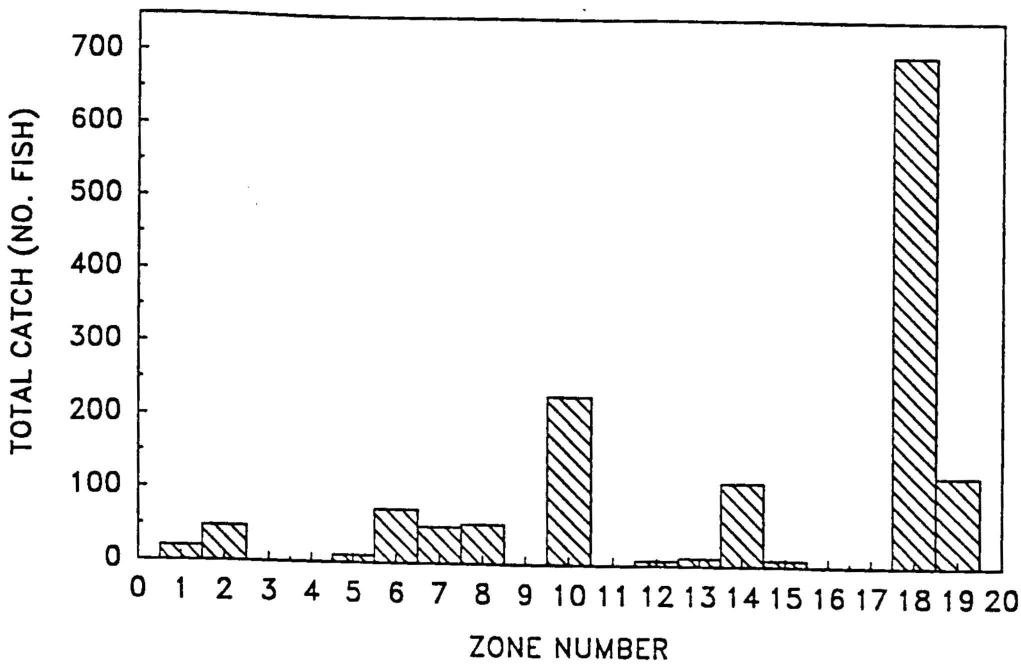


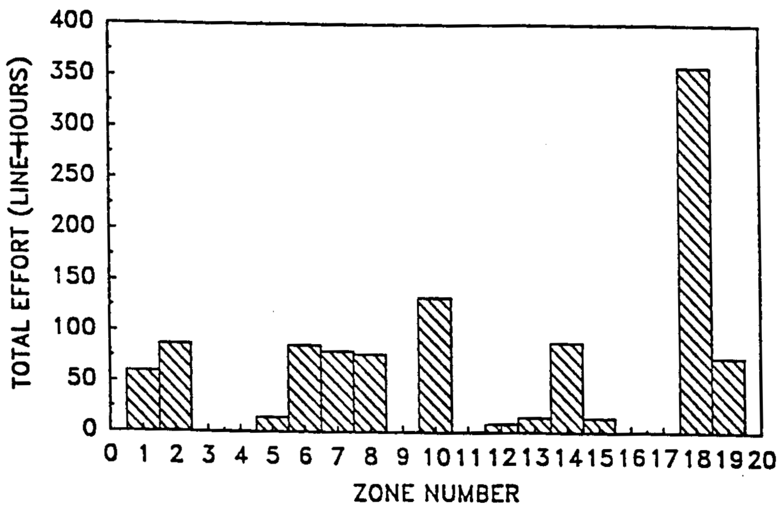
Appendix E.--Continued.



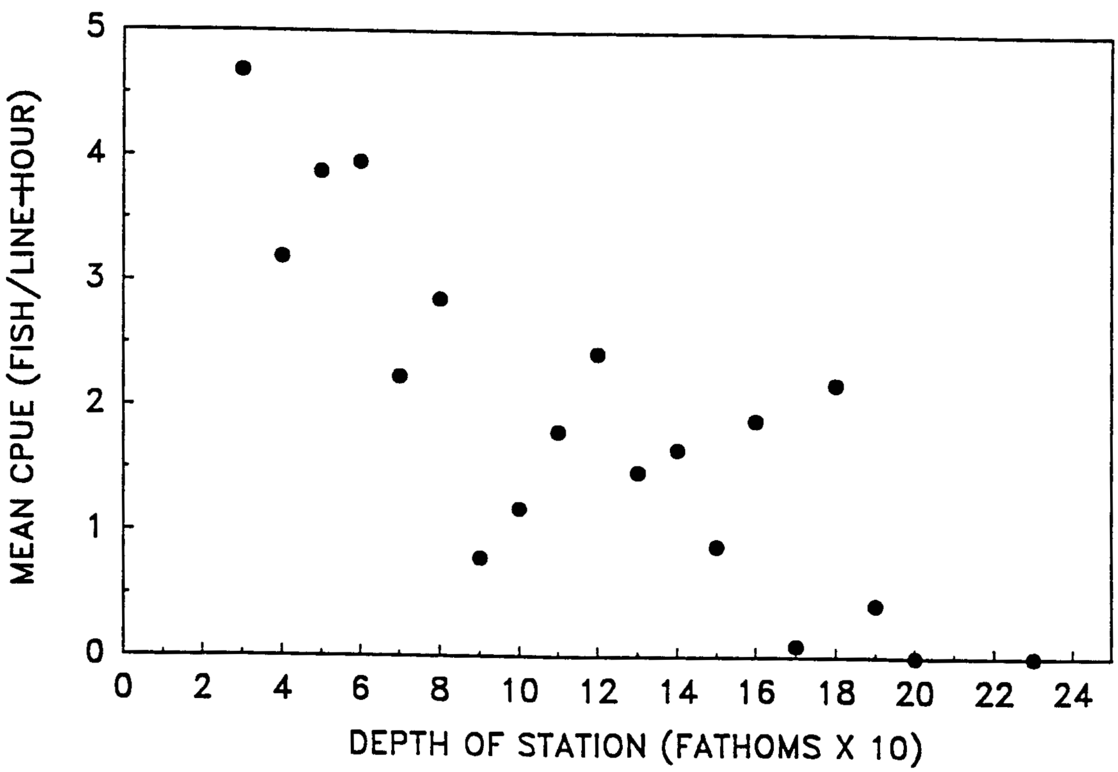


Appendix F.--Catch per unit effort (CPUE; by weight and by number) and fishing effort for the 20 fishing zones.

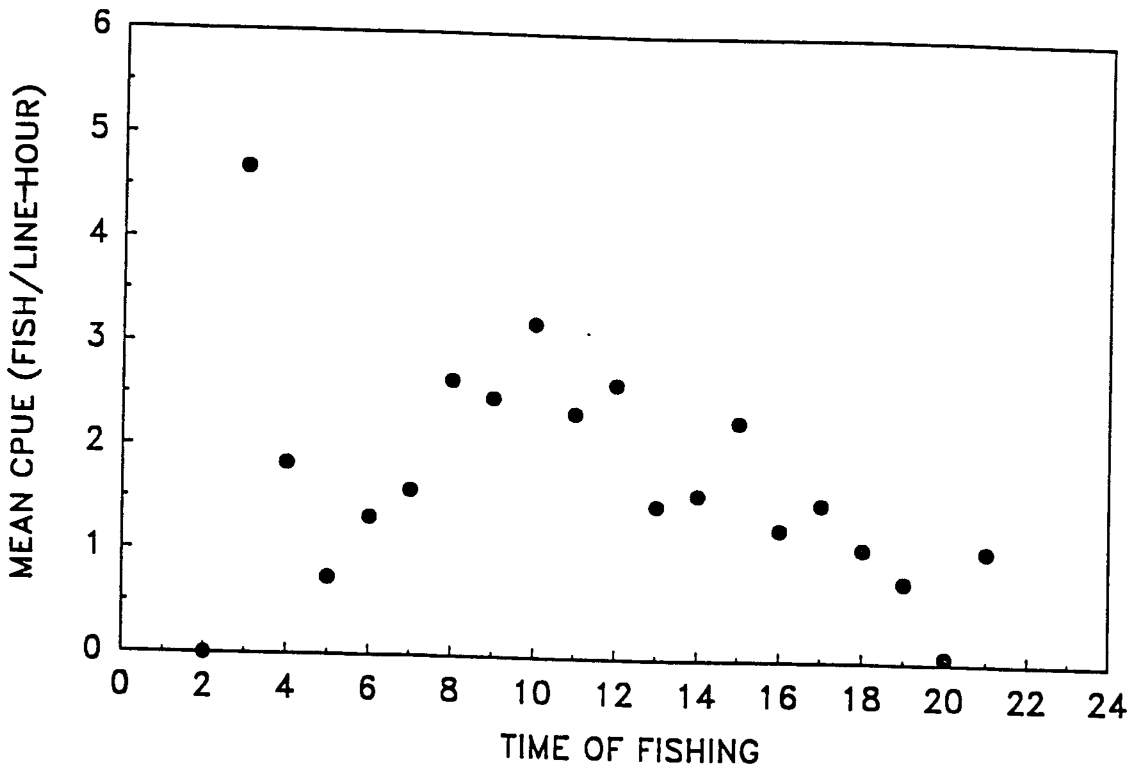




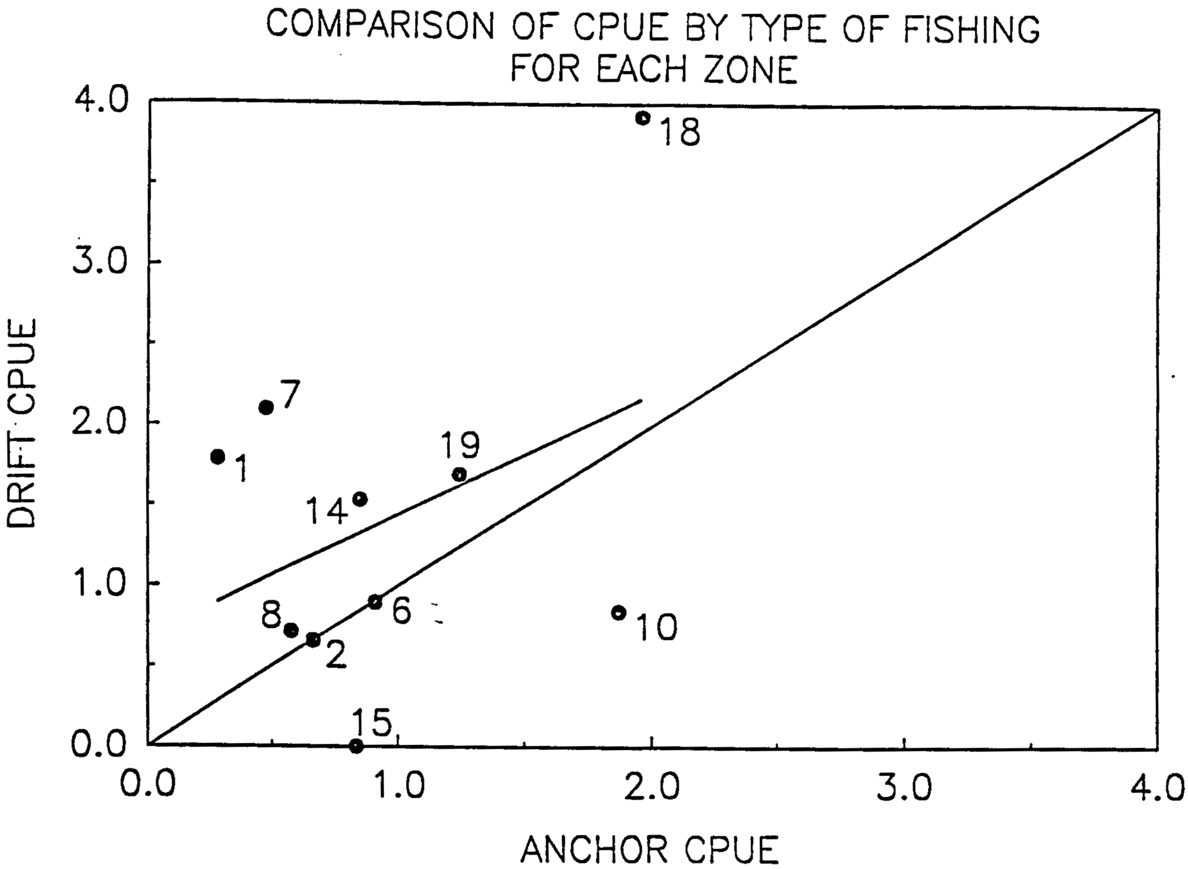
Appendix F.--Continued.



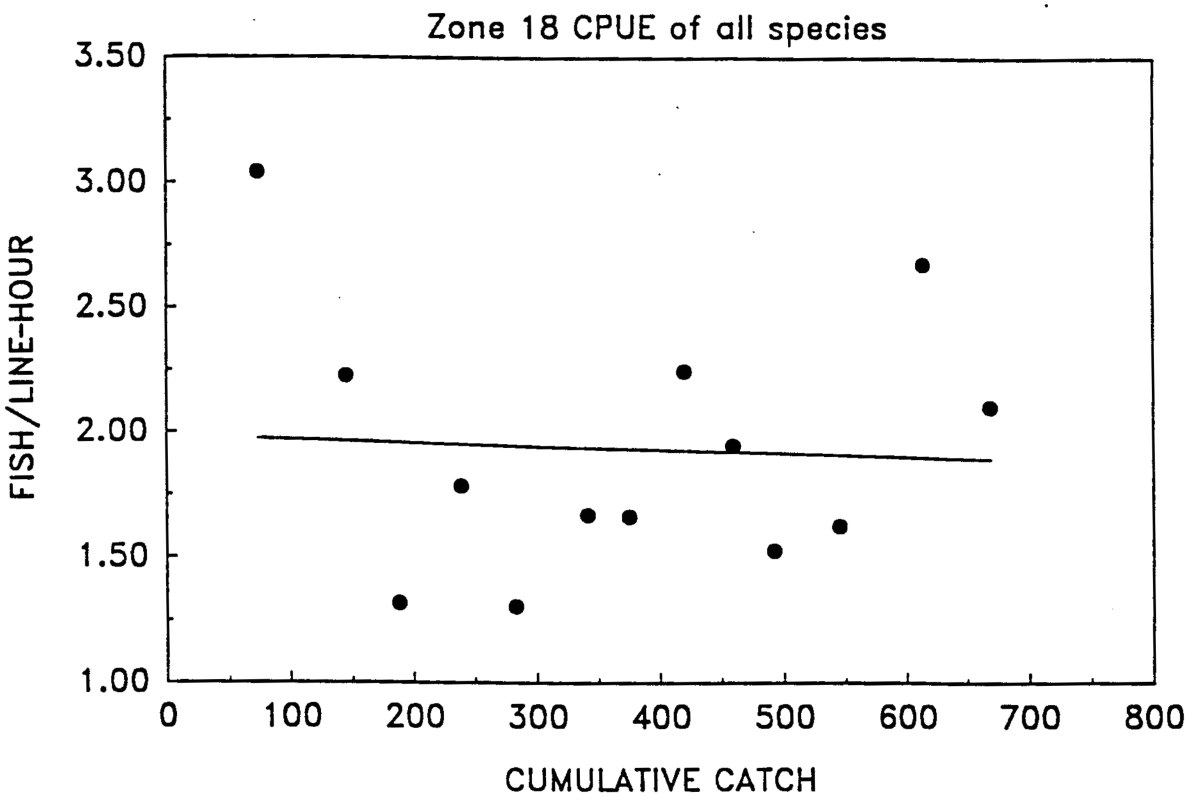
Appendix G.--Catch per unit effort (CPUE) by depth.

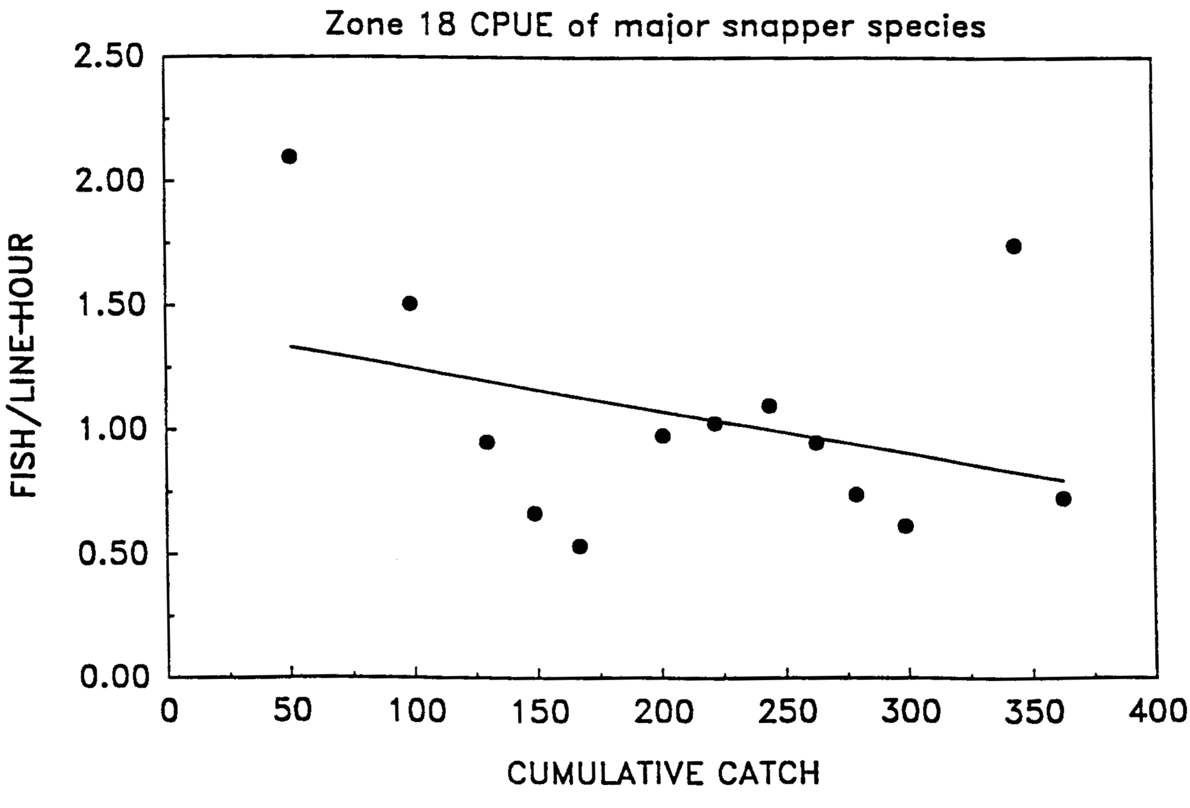


Appendix H.----Catch per unit effort (CPUE) by time of fishing.



Appendix I.--Catch per unit effort (CPUE) by type of fishing for each zone.





Appendix J.--Catch per unit effort (CPUE) versus cumulative catch for all species and major snappers at zone 18.

DEEPWATER DROPLINE FISHING SURVEYS IN THE SOUTH PACIFIC IN 1974-88: A PRELIMINARY ANALYSIS OF DATA COLLECTED BY THE SOUTH PACIFIC COMMISSION MASTER FISHERMEN'S PROGRAM

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ABSTRACT

A preliminary analysis is presented of data collected by handline on deep reef fish stocks in the South Pacific in 1974-88. The dominant species captured belonged to the snapper family (Lutjanidae), of which about 70% were from the two subfamilies Etelinae and Apsilinae. Other important catch components were the groupers (Serranidae) and the emperors (Lethrinidae). Catch composition was markedly different between low-lying atolls and high islands. The atoll catches contained proportionately fewer eteline and apsiline species than did the high island catches.

Total catch and catch rates of teleosts did not significantly differ between atolls and high islands. Catch rates at the atolls, however, were far more variable than at the high islands. Catch rates of eteline and apsiline species appeared to increase with increasing island land mass, while those of jacks and tunas (Carangidae and Scombridae) and oil fish and snake mackerels (Gempylidae) suggested the opposite. Mean catch rates increased with depth to about 250 m, then declined markedly. An investigation of the interactions between depth and time of day on catch rates revealed that peak catch rates in shallow water occurred from midday to midnight, whereas catches beyond 50 m distinctly peaked at each 50 m depth interval during the early morning. Two other peaks in catch rates were evident around midday and late evening for fishing at ¢200 m depths.

A decline in the number of species caught by dropline fishing east of the Republic of Belau was evident; this result is consistent with the biogeographic trends in other fishes and invertebrate groups within the region. The biogeography of the common dropline species is also discussed. Attempts were made to estimate possible catch rates at the optimum level of fishing effort, since the survey results presented here pertain mainly to virgin stocks.

INTRODUCTION

Demersal fishing in the South Pacific islands is usually confined to shallow ($\leq$30 m) coral reefs and lagoons, whereas fishing in deeper waters usually takes the form of trolling for pelagic species such as tunas and mackerels. Thus, demersal fish stocks inhabiting the deep slopes beyond the coral reefs generally have been unexploited or only lightly exploited throughout most of the South Pacific. Exceptions are the limited artisanal fisheries for deepwater snappers, Etelinae, and oil fish, *Ruvettus pretiosus*, in some Polynesian atolls (Wankowski 1979). By contrast, the fish stocks of the deep reef slopes of the Hawaiian Islands have been continuously exploited for over 50 years, and detailed catch statistics on the fishery are available from the late 1950s to the present (Ralston and Polovina 1982; Polovina 1987).

Survey fishing on deep reef stocks by the South Pacific Commission (SPC) commenced during the mid 1970s. Fishing activities were undertaken at the request of a South Pacific government interested in obtaining more information about its inshore fish resources. A master fisherman was usually sent to the state for 3-12 months, during which time he surveyed different fishing areas, trained local people in fishing techniques, and evaluated gear and vessel performance. As part of the duties, the master fisherman was expected to keep meticulous records of fishing activities, including catch, catch composition, fishing effort, boats, crew, and type of bait used. These fishing records extend from 1977 to the present (1988) and encompass most states and territories in the South Pacific region. In this paper, a preliminary summary and analysis of these records are presented to give a regional perspective of deepwater dropline fishing as an adjunct to the detailed case studies presented in this volume.

History of SPC Deepwater Handline Fishing Activities

The initial activities of the SPC master fishermen's program were part of the Outer Reef Artisanal Fisheries Project (ORAFP). Under the auspices of this project, five visits were made to Vanuatu (Hume 1975), Western Samoa (Hume et al. 1976), Cook Islands (Hume 1976), Tuvalu (Egington and Mead 1978), and the Solomon Islands (Egington et al. 1979). Equipment and vessels used during these visits consisted of electric reels, freezers, and ice makers run by gasoline-powered generators, and high speed "jet" boats. When the ORAFP was superseded by the Deep Sea Fisheries Development Project (DSFDP), greater emphasis was placed on lower technology, artisanal boats, and gear.

The electric fishing reels initially used by the master fishermen were replaced by a wooden hand reel originally developed in Western Samoa by the Food and Agricultural Organization of the United Nations (Gulbrandsen 1977). This reel design (Fig. 1), familiar now to most fisheries workers in the South Pacific, has been used at all locations visited by the DSFDP. A summary of these visits by the ORAFP and the DSFDP is in Table 1. Although the vessels used by the DSFDP varied between the locations,

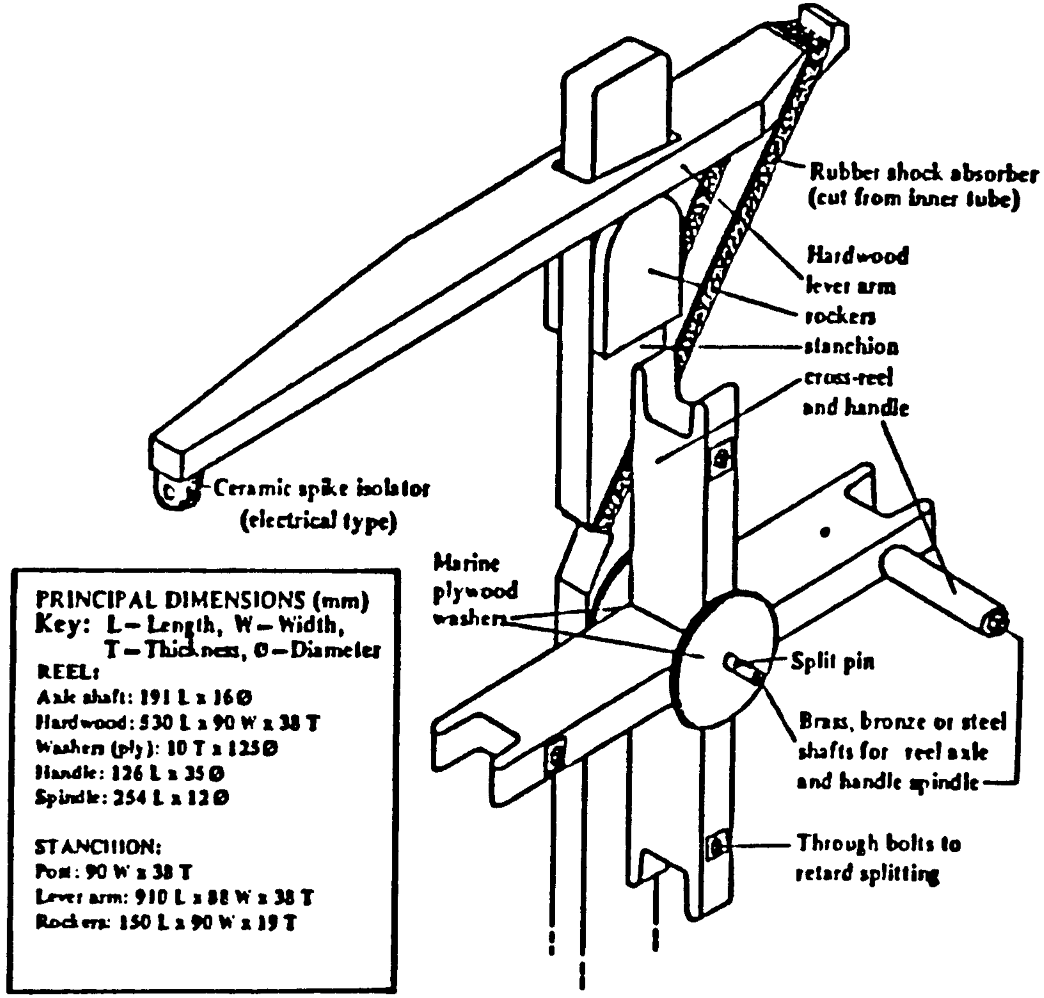


Figure 1.--The Western Samoan hand reel used by the South Pacific Commission master fishermen.

Table 1.--Summary of visits to different countries and territories by South Pacific Commission master fishermen.

Country or territory	No. of visits
American Samoa (AS)	2
Commonwealth of the Northern Mariana Islands (NMI)	1
Cook Islands (CI)	5
Federated States of Micronesia (FSM)	4
Fiji (FJ)	4
French Polynesia (FP)	1
Guam (GM)	0
Kingdom of Tonga (TO)	4
Kiribati (KI)	2
Marshall Islands (MI)	1
Nauru (NU)	0
New Caledonia (NC)	3
Niue (NI)	3
Papua New Guinea (PNG)	4
Pitcairn Island (PI)	0
Republic of Belau (BU)	2
Solomon Islands (SI)	1
Tokelau (TK)	3
Tuvalu (TU)	4
Vanuatu (VA)	4
Wallis and Futuna Islands (WF)	2
Western Samoa (WS)	2
Total	51

emphasis was placed on small-scale designs, often constructed locally. As oil and gasoline prices increased, greater interest was shown in sail-powered and sail-assisted vessels. Later project activities extended to other types of gear (e.g., vertical and bottom longlining) and, in one instance, fish trapping.

The activities of the SPC master fishermen have led to the establishment of local dropline fisheries in the Kingdom of Tonga, Fiji, Vanuatu, and, to a lesser extent, the Federated States of Micronesia and Papua New Guinea (PNG).

METHODS

Most of the fishing carried out by the DSFDP used small (4-16 m) vessels (mean, 8.5 m) with two to six hand reels (mean, three reels). The arrangement of hooks and sinkers for the droplines is shown in Figure 2. Suitable fishing areas near a given island or reef were located with an echo sounder, target depths usually being 100-200 m. Where possible, an anchor was dropped in depths shallower than those of the selected fishing site, so that prevailing winds would carry the boat back over the deeper areas as the anchor line was released.

The preferred bait for dropline fishing was skipjack tuna, *Katsuwonus pelamis*, but over 100 different types of bait were used by the master fishermen in the course of the project. These ranged from different species of tunas, reef fishes, small scads, and commercial longline bait to octopi, squids, and even salted chicken guts. Fishing trip length was highly variable (range, 2-190 hours; mean, 17 hours). The typical crew consisted of a master fisherman and a number of trainees, either island fishermen or fisheries officers.

The fishing records for each trip were summarized on the Catch Data Record form shown in Figure 3. Weight (in kilograms), number of fish caught, effort, and depth of fishing were recorded during each hour of a trip. The composition of the total catch also was recorded but could not be partitioned into catch composition on an hourly basis. Thus, hourly catch rates could not be broken down into species except when fishing depth remained unchanged during the course of a trip.

Fishing trips using other fishing methods also were included on the form. On some occasions, bottomfish fishing was carried out with handlines but was recorded separately from the hand reel catches. The other fishing activity normally associated with dropline fishing was trolling, often for bait.

Data Processing

The catch, effort, and species composition data from each survey were summarized in tabular form prior to being written up in a technical report. These summaries are available both in published and unpublished forms, and the data therein can be conveniently extracted. Specific software was created to allow the data for each trip to be entered from the record forms into a computer. Included in this software were sorting routines to summarize the catch and effort data by depth and time of day.

Data Limitations and Sources of Error

The ORAFP and DSFDP were not intended to be research projects, and the primary objectives in each instance were to establish whether deep dropline fishing was viable at a given location and to train island personnel in the

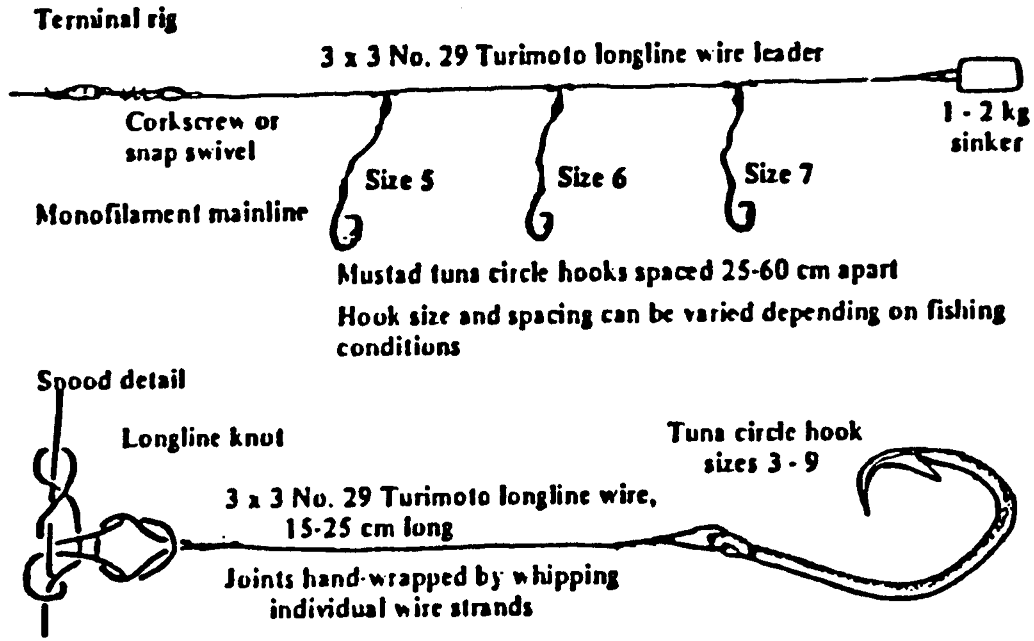


Figure 2.--Typical terminal gear for bottomfish fishing with the Western Samoan hand reel.

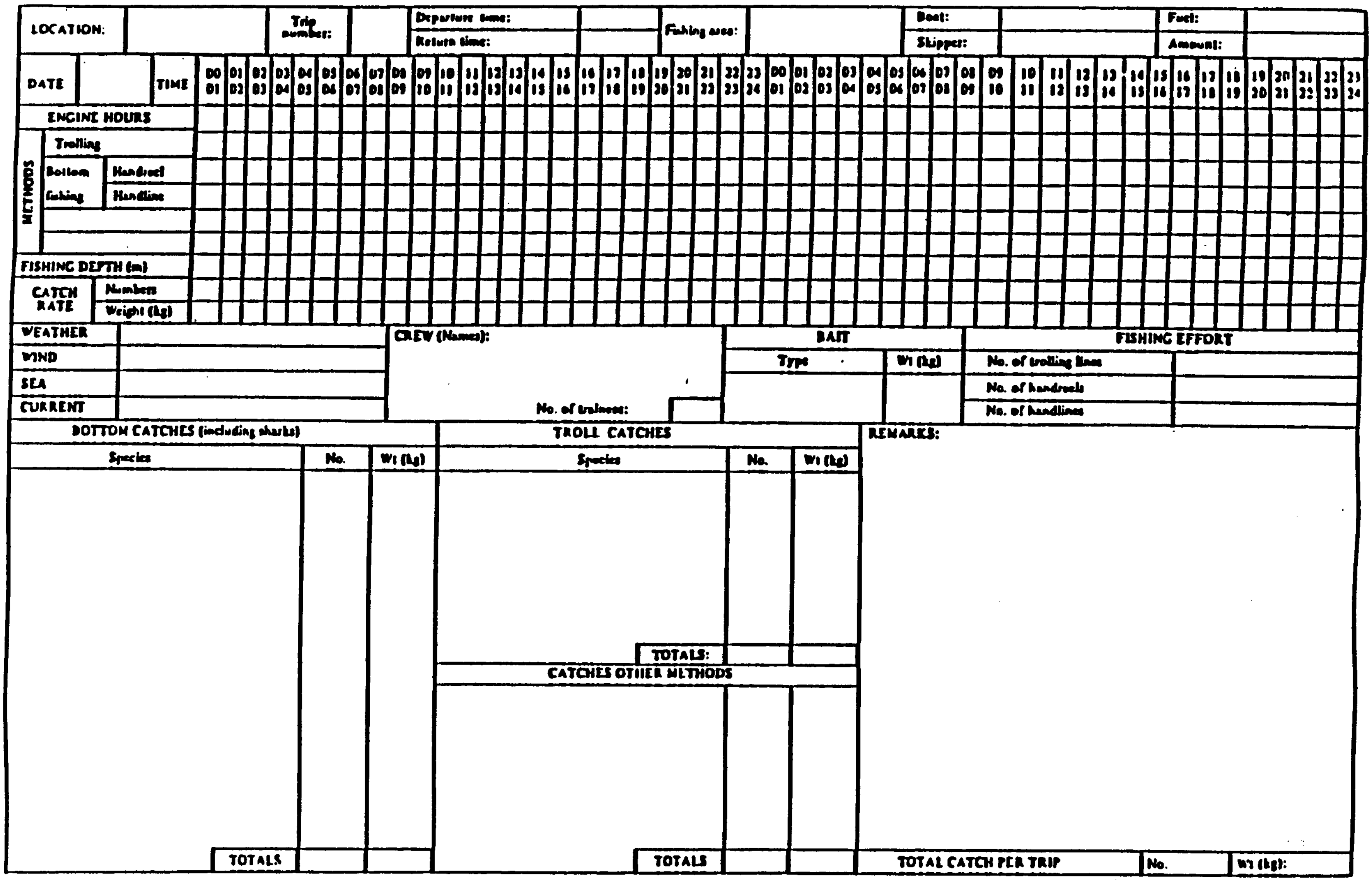


Figure 3.--The Catch Data Record form employed by the South Pacific Commission master fishermen.

fishing techniques. As a result, a wide variety baits were used in the course of this work. Variations in bait and its attractiveness will introduce variation in the feeding response of the fish. For this reason, experimental dropline fishing in northern PNG by Richards and Sundberg (1984) used only kawakawa, *Euthynnus affinis*, for bait.

Unlike Richards and Sundberg (1984), who also employed the same vessel throughout their study and kept crew personnel changes to a minimum, the SPC program had six different master fishermen during the course of the study. These fishermen were responsible for the collection of the data and used a wide variety of vessels and crews. In most instances, the crews were mostly trainees, initially unfamiliar with the fishing operation.

Another source of error in the data, particularly with earlier records, is the rejection of sharks and some teleosts as undesirable and, hence, their exclusion from the catch data. Later records included shark weight but, in some instances, gave the dressed (trunk only) rather than whole weight. This was due to the need to drain the blood from shark flesh to prevent the breakdown of metabolites into ammonia and uric acid. Dressed shark weight was simply doubled to convert it back to whole weight. In some survey fishing, the red snapper *Lutjanus bohar* was rejected and discarded because of its reputation as a commonly ciguatoxic fish. In these instances, only rough estimates of the number and weight of this species were given. Such actions, as described above, will necessarily introduce bias into the reporting of catch rates.

The master fishermen's visits to a given location ranged from 1 to 12 months (mean, 5 months). Records of catches and catch rates for most of the visits thus pertain to only part of the year for specific locations, and in some instances, only a few fishing trips were made to a fishing ground. Thus, the seasonality of the catch rates cannot be determined. Ralston (1978) detected seasonality in the catch rates of several deep reef species in Hawaii but thought they might be artifacts due to variations in effort. Brouard and Grandperrin (1985), however, reported that fishermen in Vanuatu temporarily stopped fishing in a given area because of declines in catch per unit effort (CPUE) and that some seasonal fluctuations in abundance were probably associated with behavioral responses to biological phases (e.g., spawning).

Another source of data error is the unfamiliarity with the taxonomy of the species captured by dropline. Many of the species recorded from the deep reef have only recently been identified and described. Indeed, the expansion of dropline fishing in the South Pacific provided an impetus to improve the classification of such common families as the Lutjanidae (snappers), Serranidae (groupers), Lethrinidae (emperors), and trevallies or jacks (Carangidae). The skills of the various master fishermen in recognizing species differed. Further, there was a learning effect: The master fishermen became more skilled at recognizing different species as familiarity increased.

RESULTS

Between August 1974 and December 1988, the SPC master fishermen undertook survey fishing at 19 of the 22 member countries of the SPC, the exceptions being Guam, Nauru, and Pitcairn Island (Table 1). The master fishermen conducted dropline fishing at nearly 60 different locations and made 1,370 individual fishing trips, 83% of the trips involving hand reel fishing. A total of 140.8 metric tons of fish were captured with 21,563 line-hours of fishing effort; catches consisted of fish from 42 different families, 93 genera, and at least 208 species.

Catch Composition

The percent composition of the dropline catches, by weight and number for each of the countries and territories surveyed by the SPC master fishermen, is in Tables 2 and 3. The family Lutjanidae (snappers) is divided here into two groups, the subfamilies Etelinae and Apsilinae (deepwater snappers), and is distinguished from the other common suborder Lutjaninae (or shallow-water snappers). For convenience, the deepwater snappers are referred to collectively as the etelines. Eteline species (the main target species of dropline fishing) usually were captured below 50 m, and the Lutjaninae, in the catches from shallow lagoons and deep reef slopes. As a general rule, certain species (e.g., *Lutjanus bohar* and *L. argentimaculatus*) migrate down the reef slope to deeper water as they increase in size (Wright et al. 1986).

The major component of the dropline catches as a whole was the Lutjanidae, which constituted 44.8 and 54.4% by weight and number, respectively. The etelines were the largest major taxonomic group present in the catches and made up about 70% of the snappers caught. Other important catch components were the emperors or Lethrinidae and the groupers or Serranidae. Together, the snappers, emperors, and groupers comprised between 60 and 80% of the catches by number and weight, respectively.

The South Pacific is composed of a variety of different island forms ranging from small coral atolls to large archipelagic island groups such as PNG and the Solomon Islands. The different geomorphologies of these islands may influence such environmental variables as rainfall and, hence, run-off with concomitant effects on sediments and production. Ogden (1982) has suggested that fishery productivity from coralline areas may be related to island height, amount of rainfall and run-off, and complexity of the coastline. Ogden (1982) postulated that fishery production increases from atolls to small, high islands to large, high islands. Although the stocks considered here are found beyond the reef, the physical characteristics of a particular island will still influence species composition and catch rates.

The species composition data were grouped according to island size and geomorphology. Islands were classified as atolls; small, high islands; and

Table 2.--Percentage catch composition (by weight) of dropline catches by family and subfamily for countries and territories (see Table 1 for definitions of abbreviations) in the South Pacific.

Location	Etelinae/ Apsilinae	Lutjaninae	Lethrinidae	Serranidae	Carangidae/ Scombridae	Gempylidae	Sphyraenidae	Other teleosts	Sharks
PNG	49.2	16.1	3.8	7.2	7.0	0.5	0.9	0.4	15.3
SI	61.0	14.3	0.4	10.8	1.9	0.03	7.8	3.8	0.0
VA	45.5	10.6	2.1	19.1	3.9	4.6	0.2	1.3	12.9
NC	24.4	9.6	19.4	11.4	5.6	0.0	2.8	0.2	25.3
FJ	24.6	11.9	5.4	8.1	15.1	2.7	5.2	1.5	25.6
WS	45.9	7.1	1.2	5.6	5.0	25.0	0.0	3.8	6.5
AS	42.4	18.1	14.9	2.1	12.4	0.7	8.9	0.8	0.0
TO	49.0	3.9	20.2	13.8	5.5	0.8	1.1	0.5	5.0
NU	10.1	27.2	11.2	13.5	9.2	3.9	1.2	15.3	3.3
FSM	21.7	18.6	4.4	7.4	18.5	2.4	1.0	4.9	21.2
WF	56.8	4.6	5.8	12.2	11.6	0.0	0.1	0.3	8.8
CI	50.7	2.0	1.2	9.4	9.9	4.7	0.1	6.7	15.2
FP	28.7	2.5	0.2	30.2	19.7	14.1	0.1	1.6	3.0
BU	36.0	11.8	4.1	12.4	15.2	7.0	1.7	3.5	5.2
NMI	60.3	0.0	0.1	0.5	34.4	0.0	0.0	0.0	0.0
TU	17.1	10.2	0.9	10.1	12.6	32.8	0.7	0.5	15.2
KI	13.5	32.8	3.4	21.6	5.5	5.4	0.4	0.7	17.1
TK	21.8	2.9	6.1	6.9	27.9	5.5	1.5	2.3	25.4
MI	8.5	14.3	6.5	10.1	8.1	1.1	0.3	2.3	48.9
Mean	32.7	12.1	6.1	12.0	11.7	6.8	1.7	2.1	15.1

Table 3.--Percent catch composition (by number) of dropline catches by family and subfamily for countries and territories (see Table 1 for definitions of abbreviations) in the South Pacific.

Location	Etelinae/ Apsilinae	Lutjaninae	Lethrinidae	Serranidae	Carangidae/ Scombridae	Gempylidae	Sphyraenidae	Other teleosts	Sharks
PNG	58.7	18.8	6.4	7.0	4.3	0.03	0.6	0.7	3.5
SI	65.2	19.2	0.3	4.5	0.8	0.03	5.3	4.6	0.0
VA	49.5	23.6	3.5	13.0	2.1	1.6	0.1	2.5	4.0
NC	27.2	10.4	28.7	13.9	3.6	0.0	1.4	0.9	13.8
FJ	40.8	18.6	10.0	12.6	7.9	1.3	5.2	0.6	3.1
WS	32.6	1.3	0.2	1.8	4.2	36.4	0.0	2.9	20.5
AS	18.6	33.5	28.1	2.8	5.7	0.6	9.3	1.5	0.0
TO	46.3	3.2	29.4	12.1	1.9	0.7	0.7	2.6	3.2
NI	19.5	19.3	12.7	18.1	9.7	2.7	0.7	16.8	0.5
FSM	23.9	19.4	9.3	12.2	18.9	1.5	0.3	6.1	8.6
WF	63.9	7.8	6.7	13.3	6.8	0.0	0.5	0.2	0.7
CI	67.1	1.8	1.5	15.4	4.8	0.7	0.05	6.9	2.0
FP	39.3	1.2	0.2	37.2	11.8	5.8	3.8	0.4	0.3
BU	32.4	20.4	7.1	15.2	13.8	4.7	0.8	6.1	0.8
NMI	80.8	0.0	0.0	0.6	12.8	0.0	0.0	0.0	5.8
TU	30.8	14.2	3.0	12.1	17.0	17.8	1.3	3.1	1.1
KI	22.1	33.4	5.0	26.8	5.9	2.5	0.8	1.8	2.1
TK	28.5	14.1	8.6	18.3	20.8	1.5	1.6	5.1	1.8
MI	9.6	28.7	14.1	25.9	7.5	2.8	0.7	2.6	8.1
Mean	38.7	15.7	9.9	14.3	9.2	3.3	1.5	3.6	3.8

large, high islands. Atolls were easily defined since they are distinct geological structures with limited land areas, generally <30 km^2. The exception is Kiritimati (formerly Christmas Island), which is in the northern Line Islands and is the largest (363 km^2) atoll island in the world. Large, high islands also were relatively easy to define, with land areas of >10,000 km^2. This category essentially comprised the Melanesian Islands of PNG, Solomon Islands, Vanuatu, Fiji, and New Caledonia. The remaining islands were included in the small, high island category with land areas of <10,000 km^2; this category contained small, mountainous islands (e.g., the Society Islands) and upraised atolls (e.g., Niue).

The mean catch compositions for the three island types are in Tables 4 and 5 and Figures 4 and 5. Although the catch compositions distinctly differed among the three groups, differences were greatest between the high islands and the atolls. Nearly half of the catches from high islands consisted of etelines, with the Lutjanidae comprising 53 and 66% of the catches by weight and number, respectively. In contrast, etelines from the atoll locations contributed only 15 to 24% by weight and number, respectively. Overall, Lutjanidae comprised 34 and 47% of the atoll catches by weight and number, respectively. The atoll catches had a greater of serranids, shallow-water lutjanids, gempylids, sharks, carangids, and scombrids. As might be expected, catch composition significantly differed between the high islands and atolls and between the small, high islands and the large, high islands in both weight and number (chi-square, $P < 0.05$, d.f. = 8).

Catch Rates

The most precise index of fishing effort for dropline fishing is the number of line-hours (i.e., the number of lines multiplied by the time spent fishing), with CPUE expressed as catch per line-hour. A cruder index of effort that may be applied in place of line-hours is the number of trips, where CPUE is expressed as catch per trip. Trip length was, however, highly variable (see above), making comparisons between different locations rather tenuous. The catch per trip for the entire data set ranged from 25 to 380 kg, with a mean of 114.8 kg.

The CPUEs, expressed in line-hours for individual locations, ranged from 0.4 kg/line-hour at Tamana Atoll in Kiribati to 32.9 kg/line-hour in the Lau islands of Fiji; the overall mean was 6.8 kg/line-hour. As stated earlier, estimates of total catch may be biased because of discarded fish, particularly sharks. Catch rates of teleosts only ranged from 0.3 to 14.9 kg/line-hour, with a mean of 5.8 kg/line-hour. The frequency distributions of CPUEs for the total catch, as well as the teleosts alone, are in Figure 6. Both data sets suggest that the CPUEs are log normally distributed, particularly in the case of the total catch.

The catch rates were subdivided by the same categories used for the species composition data: Atolls; small, high islands; and large, high

Table 4.--Percent catch composition (by number) for dropline catches at large, high islands (LHI); small, high islands (SHI); and atolls (AT) in the South Pacific.

Family/subfamily	LHI	SHI	AT
Etelinae/Apsilinae	48.3	44.0	23.9
Lutjaninae	18.1	10.8	23.0
Lethrinidae	9.8	9.2	6.8
Serranidae	10.2	13.0	18.3
Carangidae/Scombridae	3.7	9.9	14.0
Gempylidae	0.6	4.0	3.6
Sphyraenidae	2.5	1.2	0.7
Other teleosts	1.9	5.3	2.0

Table 5.--Percent composition (by weight) for dropline catches at large, high islands (LHI); small, high islands (SHI); and atolls (AT) in the South Pacific.

Family/subfamily	LHI	SHI	AT
Etelinae/Apsilinae	40.9	41.9	14.8
Lutjanidae	12.5	9.8	18.7
Lethrinidae	6.2	6.3	3.6
Serranidae	11.3	11.4	10.3
Carangidae/Scombridae	6.7	14.8	14.3
Gempylidae	1.6	3.1	7.2
Sphyraenidae	3.4	1.2	0.7
Other teleosts	1.4	4.6	0.9
Sharks	15.8	6.6	29.7

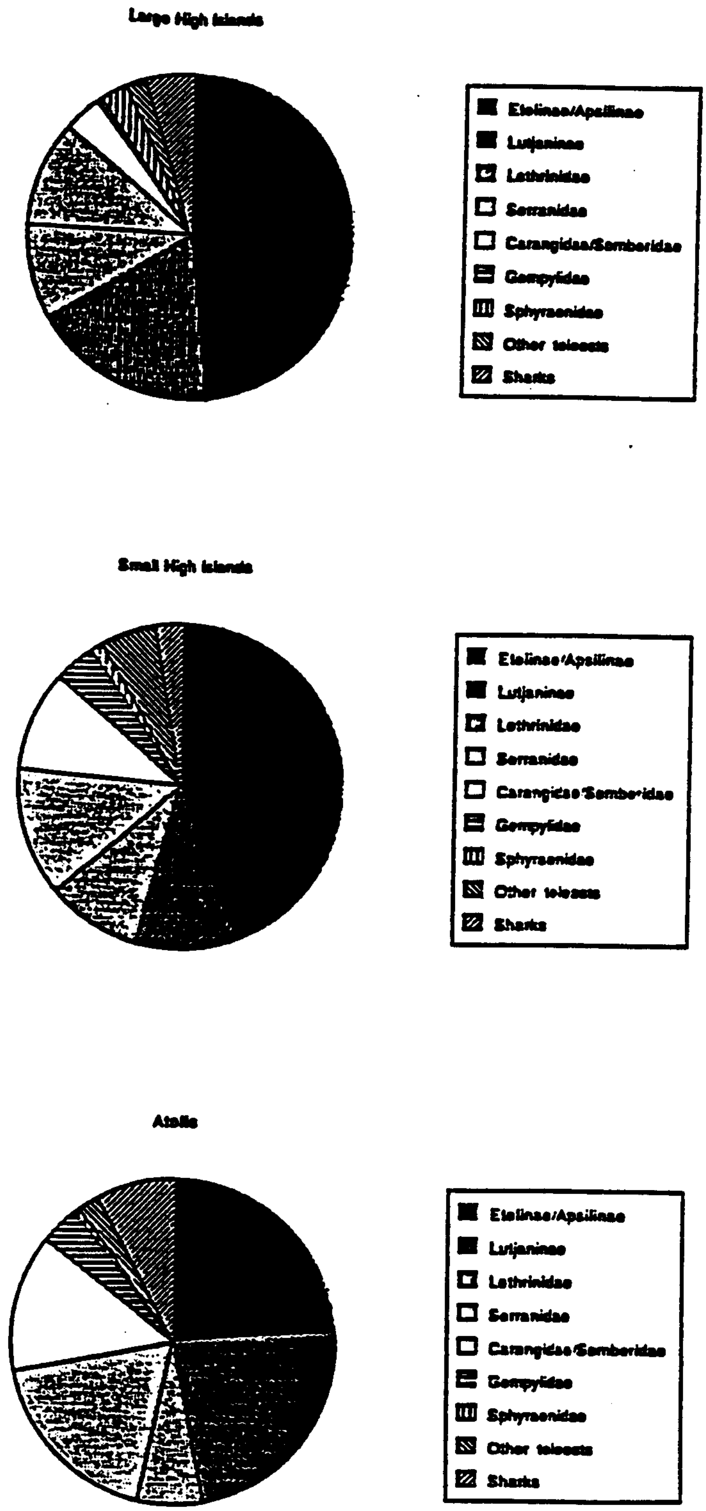


Figure 4.--Percent catch composition (by number) of fishes caught by handline around large, high islands; small, high islands; and atolls in the South Pacific region.

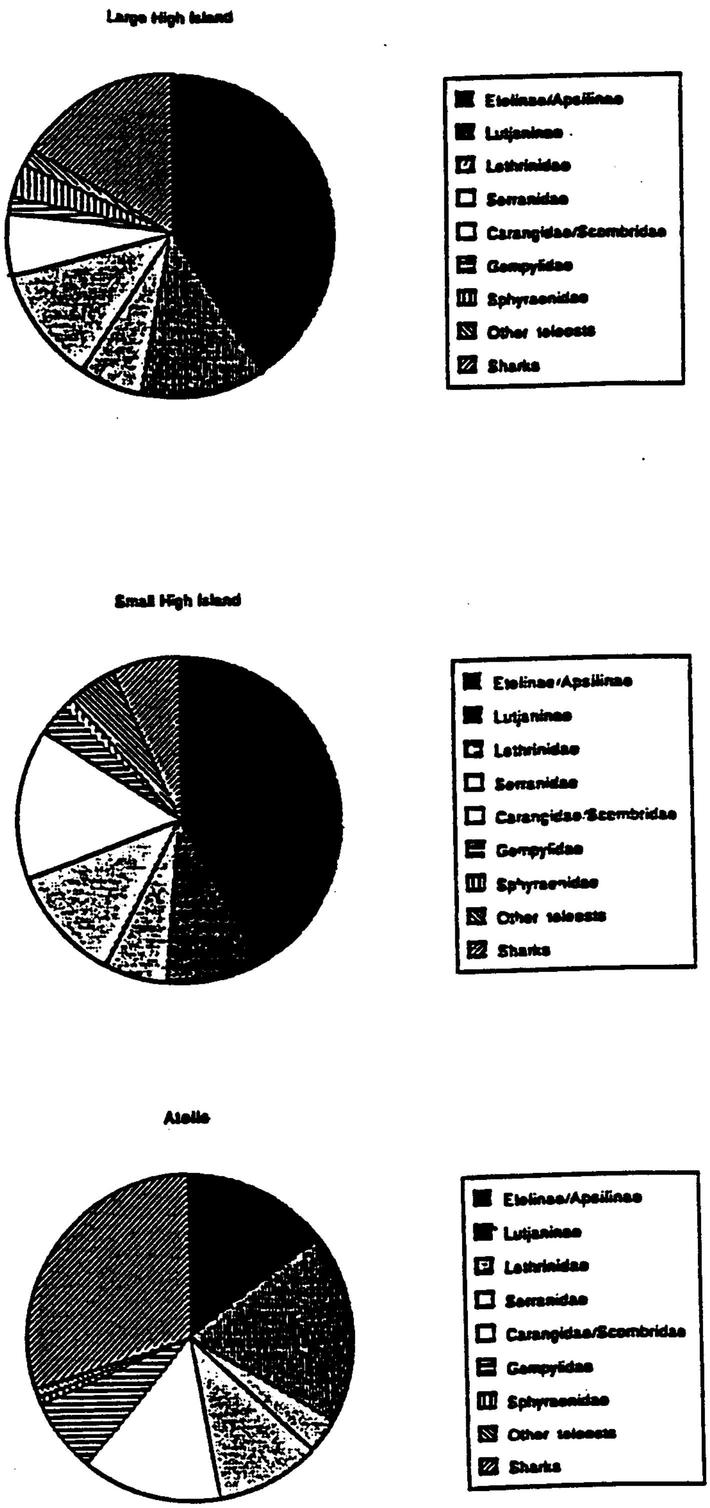


Figure 5--Percent catch composition (by weight) of fishes caught by handline around large, high islands; small, high islands; and atolls in the South Pacific region.

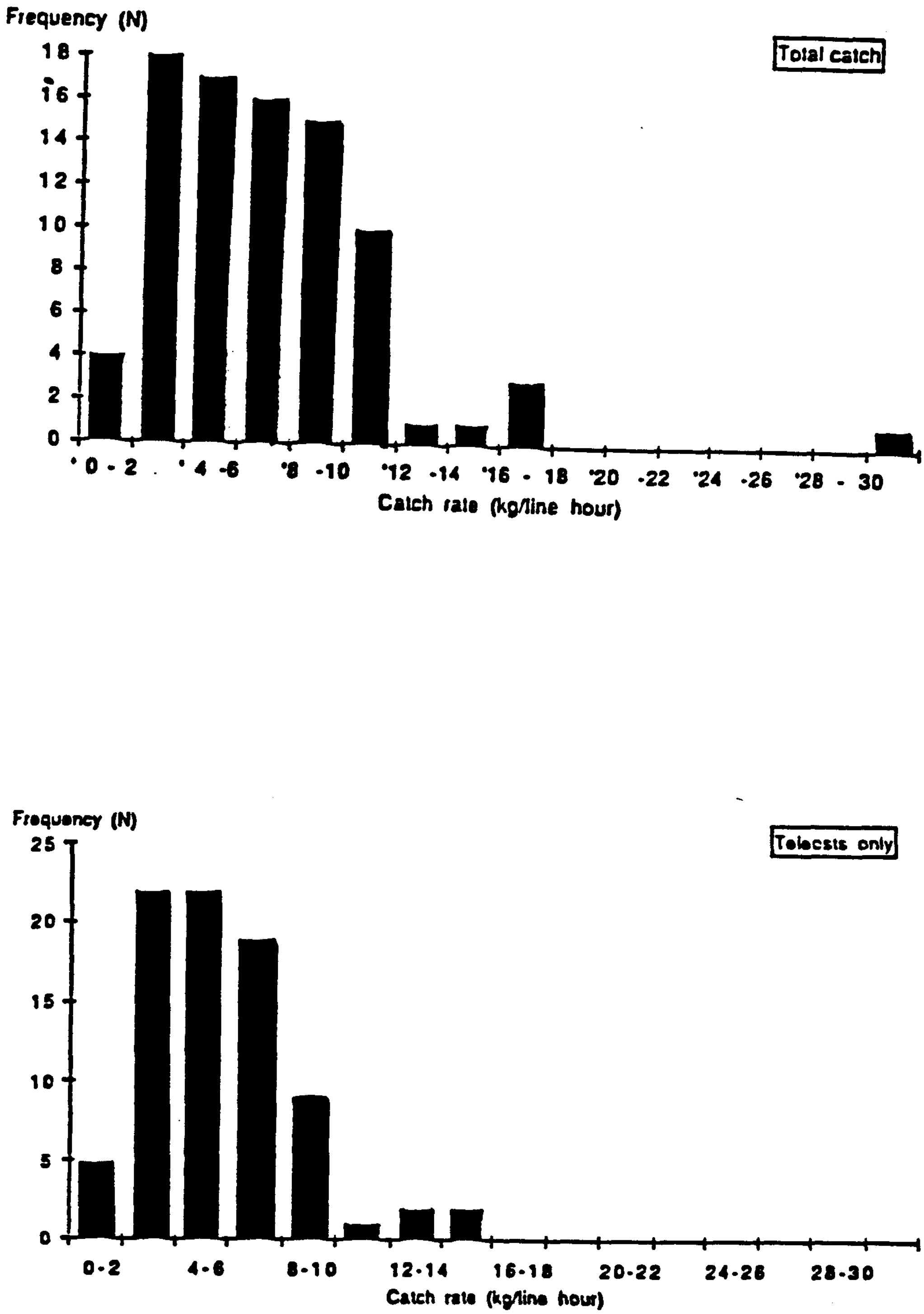


Figure 6.--Frequency distributions of total catch rates and teleost catch rates from handlining in different locations throughout the South Pacific.

islands. The different island groupings with individual island areas and respective catch rates are in Table 6. A simple comparison was first made of high versus low islands in terms of total catch rates. The small, high islands and the large, high islands were combined for this comparison since there were few high islands. Total catch rates and teleost catch rates appeared to be almost normally distributed (Fig. 7) for the high islands, and means were 5.9 and 5.3 kg/line-hour, respectively. By comparison, catch rates at atolls were not normally distributed (Fig. 8). Mean CPUEs at atolls for total and teleost catches equaled 7.7 and 6.8 kg/line-hour, respectively. Means of high and low island catch rates did not significantly differ for total catches (t = 1.601, $P > 0.1$, d.f. = 42) nor teleost catches (Student's t-test, $P > 0.1$, d.f. = 42).

The catch rates for the different islands are plotted against the natural logarithm of the respective land area in Figure 9. The log of land area was used since this spans seven orders of magnitude for the islands in the data set. The data show that the three classifications of islands with respect to land area are probably reasonable. Further, the scatters of points show that the atoll data have the greater variation in CPUEs. This can also be expressed as the coefficient of variation (CV; i.e., mean divided by standard deviation multiplied by 100), which for the atoll data set was 61.6% compared with 40.5% for the high island sites.

There was no obvious trend between CPUE and island size. A regression of CPUE versus $\log_e$ area had a negative slope but was not significant. Similar plots were made using the teleost CPUE data and the CPUE for individual catch components. Only one group of fishes, the etelines, had a significant relationship between catch rate and island size ($y = 1.171 + 0.151x$, $r = 0.391$, $P < 0.01$, d.f. = 42).

Given the variation inherent in the data, however, such trends probably would not be readily apparent from simple statistical treatments. To elucidate possible trends in the CPUE data with respect to island type, the mean catch rates from each island class for total catch, teleosts, and individual catch components were plotted against the median island size (Fig. 10). Median island size was used to minimize the influence of extreme island land masses (e.g., PNG) on small data sets. This treatment revealed no obvious trends in the data between the CPUEs of the total catch, teleosts, lutjanines, serranids, and sharks versus island size. Apparently, however, a positive association existed between the catch rates of etelines, lethrinids, and sphyraenids versus island size, while the data for lutjanines, gempylids, carangids, and scombrids suggested declining CPUEs associated with increasing land area.

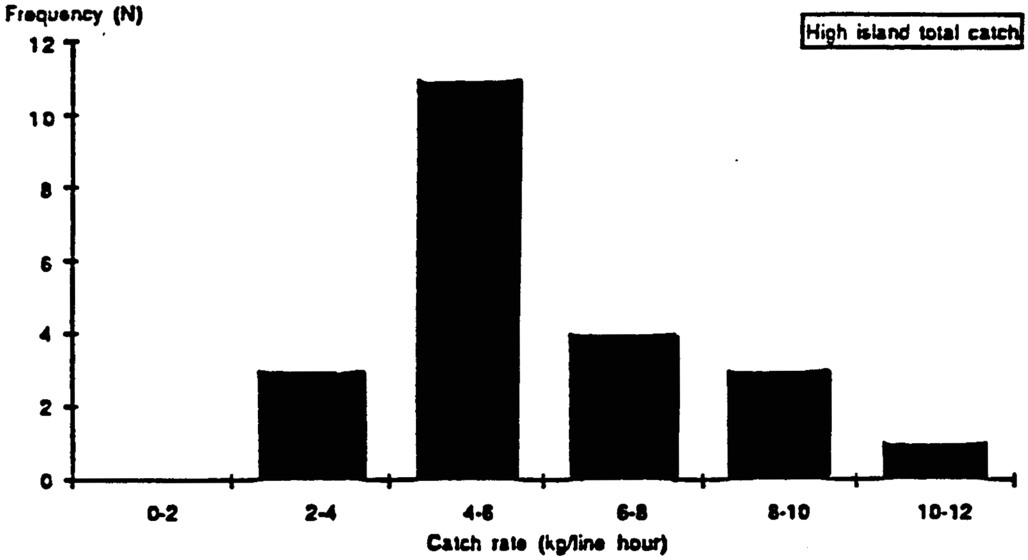
Other factors affecting the CPUE of dropline fishing were the interactions between water depth and time of day when fishing took place. Individual, hourly catch rates were aggregated by 50 m depth intervals (0-49 m, 50-99 m, and so on) over the entire data set and averaged for each depth interval and for each hour. A plot of the mean catch rate versus the midpoint of each 50 m depth interval is in Figure 11. Catch rates increased markedly with depth over the first three depth ranges, from 5.3

Table 6.--Land areas and catch per unit effort (CPUE) for large, high islands (LHI); small, high islands (SHI); and atolls (AT) in the South Pacific.

Location	Land area (km^2)	CPUE (kg/line-hour)
	LHI	
Papua New Guinea	462,243.0	5.5
Solomon Islands	27,556.0	5.7
New Caledonia	19,103.0	9.7
Fiji	18,272.0	11.6
Vanuatu	11,880.0	7.2
	SHI	
Western Samoa	2482.0	4.1
Kingdom of Tonga	646.0	9.5
Belau	460.0	4.9
Pohnpei	334.2	4.5
Niue	259.0	5.8
American Samoa	200.0	5.7
Wallis	150.0	8.0
Saipan	122.9	2.2
Futuna	115.0	7.2
Kosrae	109.6	6.9
Yap Proper	100.2	5.0
Truk Lagoon	99.9	5.5
Ua Pou	79.0	6.7
Rarotonga	64.0	2.2
Mehetia	50.0	4.7
Tubai	45.0	4.7
Rurutu	32.0	2.3
	AT	
Kiritimati	363.4	16.5
Abemania	27.8	8.5
Tarawa	21.9	10.3
Abaiang	16.0	4.5
Maina	15.9	8.2
Arno/Majuro	13.8	11.0
Kuria	12.3	8.0
Arorae	9.5	0.9
Tamana	4.8	0.4
Ulithi	4.7	14.4
Nukunonu	4.7	2.5
Fakaofo	4.0	3.0

Table 6.--Continued.

Location	Land area (km^2)	CPUE (kg/line-hour)
	AT	
Atafu	3.5	1.9
Ruo	3.2	7.0
Ant	1.9	5.5
Pakin	1.1	3.9
Penrhyn	1.0	11.2
Vaitupu	0.5	8.2
Ngulu	0.4	13.2
Nukufetau	0.3	6.1
Funafuti	0.3	7.6
Nukulaelae	0.2	16.3



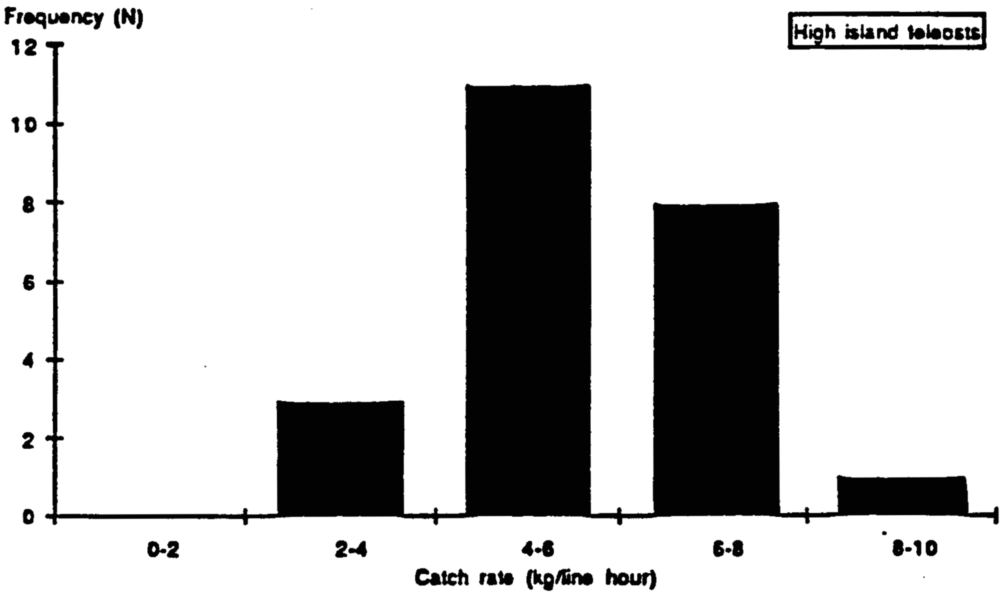
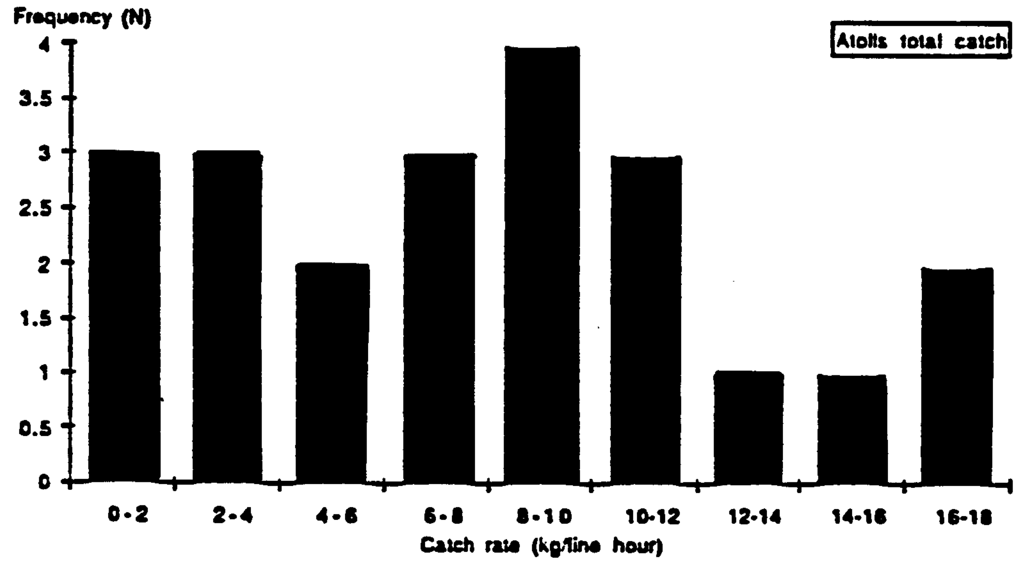


Figure 7.--Frequency distributions for total catch and teleost catch rates from handlining in South Pacific high islands.



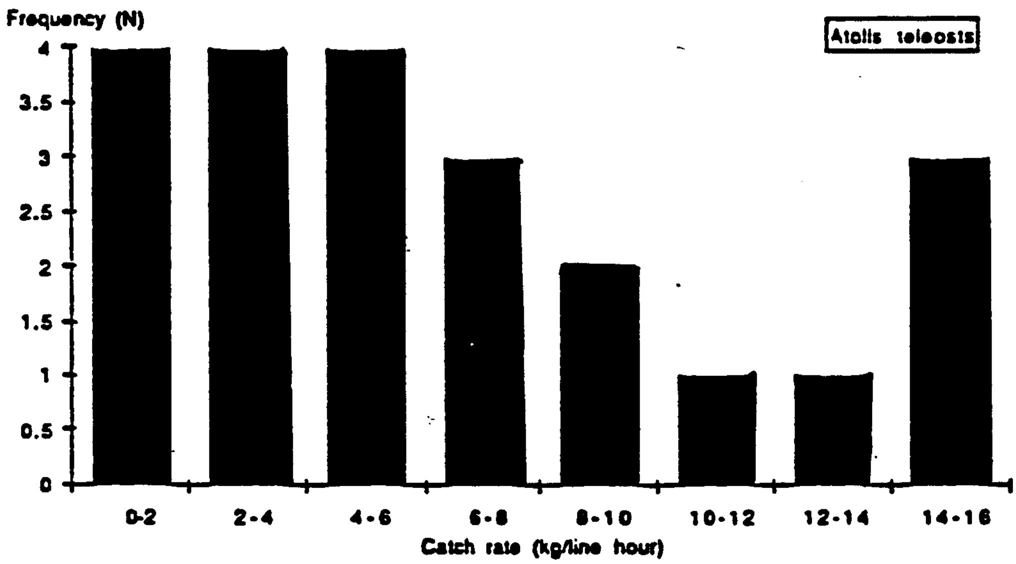


Figure 8.--Frequency distributions for total catch and teleost catch rates from handlining at South Pacific atolls.

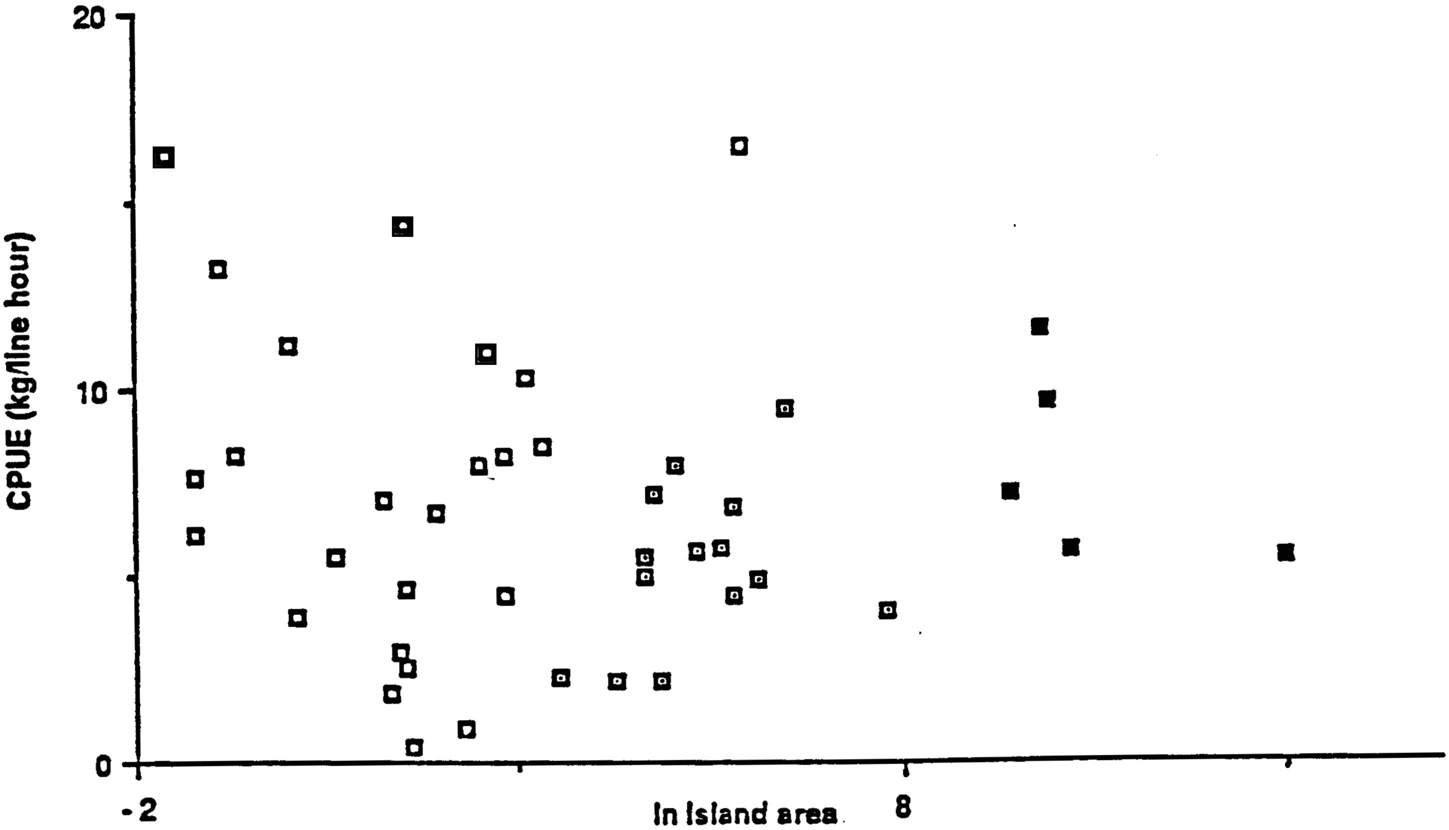


Figure 9.--Catch rates from handlining in the South Pacific: (■) large, high islands; (▣) small, high islands; (□) and atolls versus respective land area.

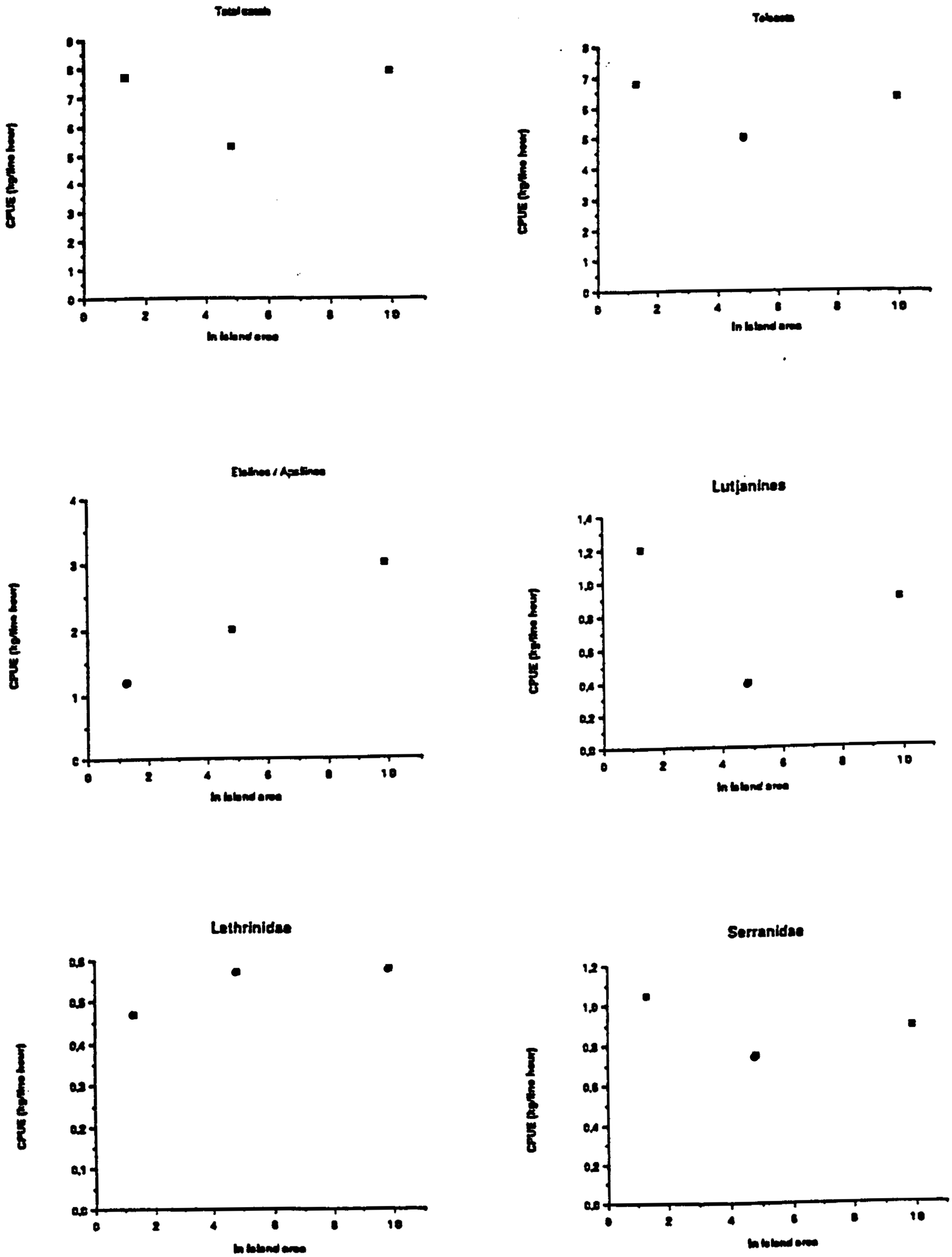


Figure 10.--Mean dropline catch rates for total catch, teleosts only, and catch components in the South Pacific: large, high islands; small, high islands; and atolls versus the land area of median islands.

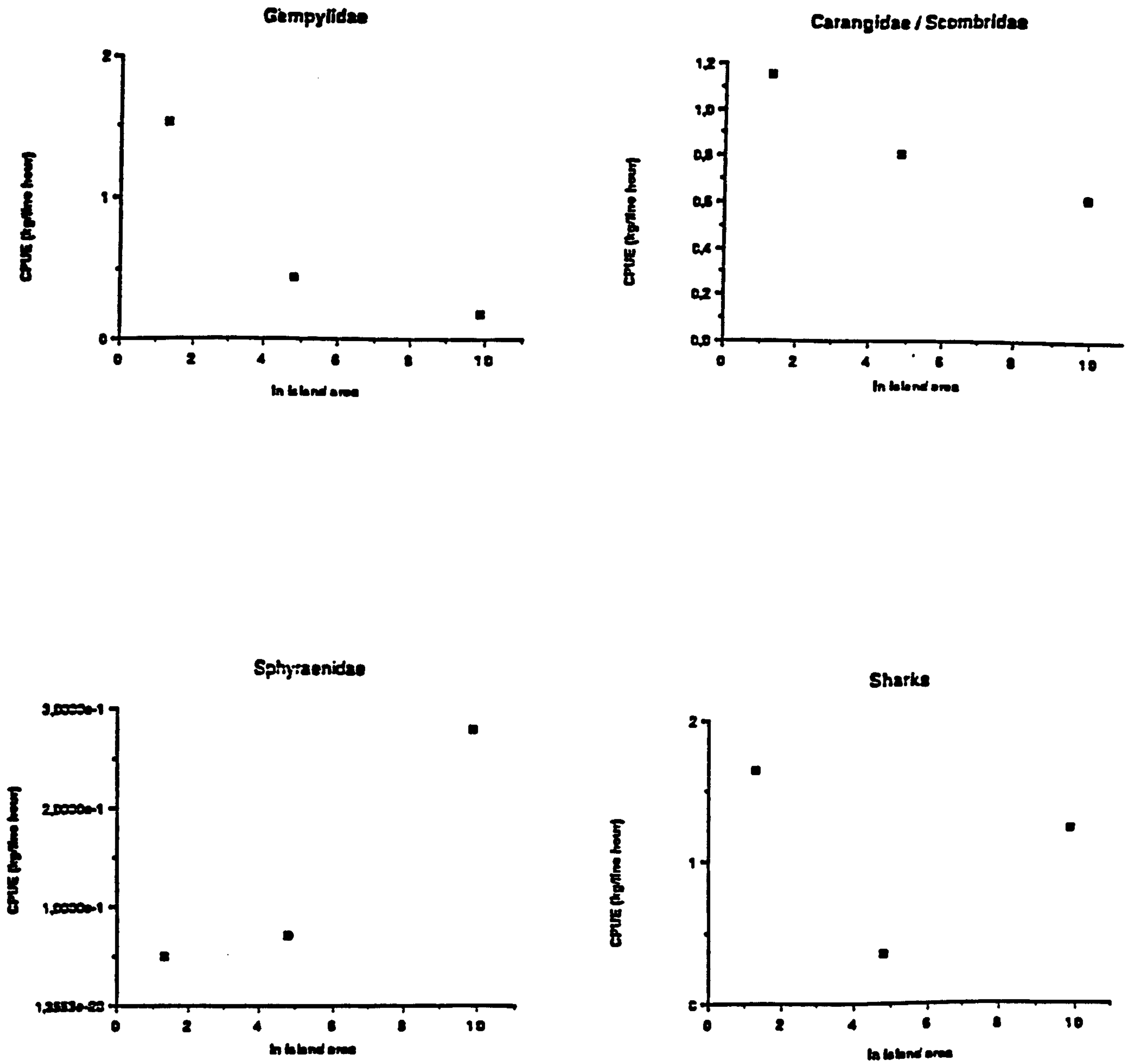


Figure 10.--Continued.

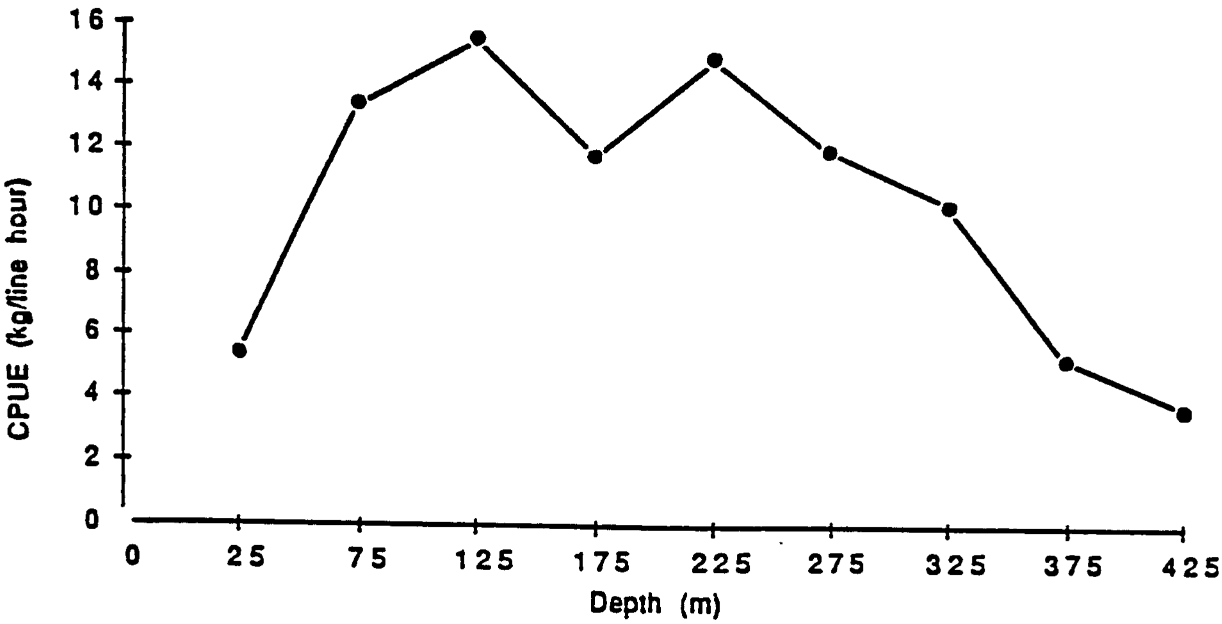


Figure 11.--Mean dropline catch rate versus depth in the South Pacific.

to 15.5 kg/line-hour. Although the mean catch rate at the 150-199 m depth interval declined somewhat, catch rates appeared to be relatively stable between the 50-99 m and 250-299 m depth intervals. Catch rates declined markedly at depths greater than 300 m. No observations were recorded for the 450-499 m depths, and only a few catches were at 500-550 m.

The mean hourly catch rates for each depth interval are in Figure 12. Although the catch rates varied markedly between depth intervals, the pattern of CPUE changes over a 24-hour period was well defined, particularly at the deeper depths. In the shallowest depth zone, 0-49 m, catch rates were lowest during early morning, reaching a minimum at around 0500. Thereafter, catch rates increased gradually until about midday, leveled off until midnight, then again declined. All depths beyond 50 m had a pronounced peak in hourly CPUE in the early morning, usually between midnight and 0500. Between 50 and 200 m, the hourly CPUE patterns did not have any clear similarities after 0600. At 200 m and deeper, however, there was a strong indication of pronounced peaks in CPUE around midday and between 2000 and 2200.

Depletion Effects

Intensive fishing at a given location may lead to a rapid decline in CPUE and possibly a change in species composition, particularly if the stock is in a virgin state. This is evident when the fishable area is small and the recruitment effects are limited. Polovina (1986) reported on the results of a depletion experiment by dropline fishing on a seamount in the Northern Mariana Islands. Catch rates of the dominant species, the deepwater snappers *Pristipomoides zonatus* and *Etelis carbunculus*, declined markedly with cumulative catch, while the CPUE of a subdominant species, *P. auricilla*, increased in the same proportion over the same period.

The SPC catch data from atolls were examined to see whether any depletion effects were evident. Plots of cumulative catch against cumulative effort either showed no evidence of curvature (i.e., were linear) or showed an exponential increase in cumulative catch. The former trend indicates that no obvious depletion due to fishing occurred, while the latter suggests a learning effect as vessel crews became more familiar with the fishing techniques. Examples of both types of curves are shown in Figure 13.

Biogeography of Deep Reef Species

The South Pacific region lies on the Pacific Plate, the Earth's largest lithospheric plate. The biogeography of the Pacific Plate is characterized by a sharp decrease in number of taxa eastwards from the western plate margin and by a high degree of endemism on the plate (Springer 1982). This refers not only to shore fishes but also to molluscs, arthropods, and certain mammals.

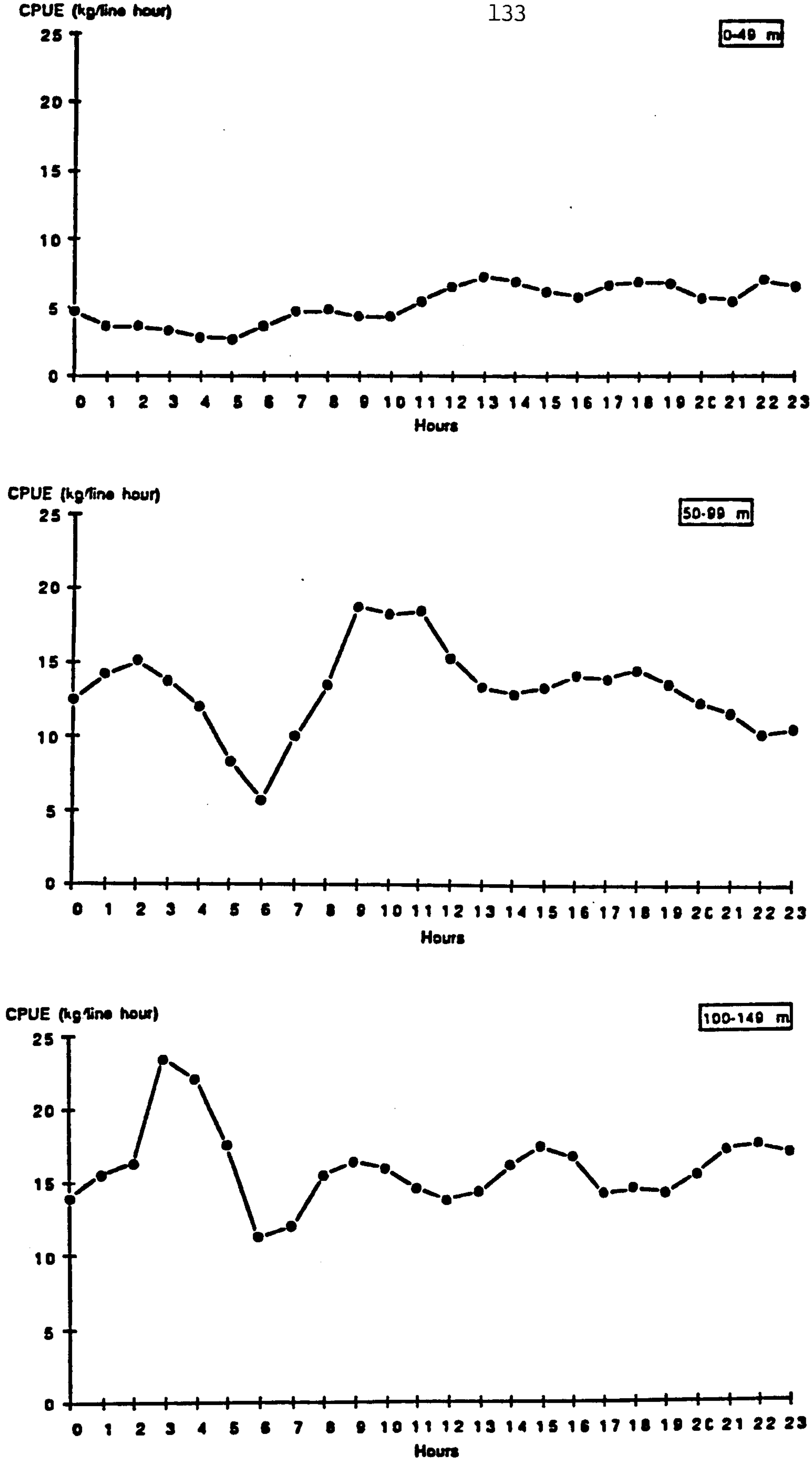
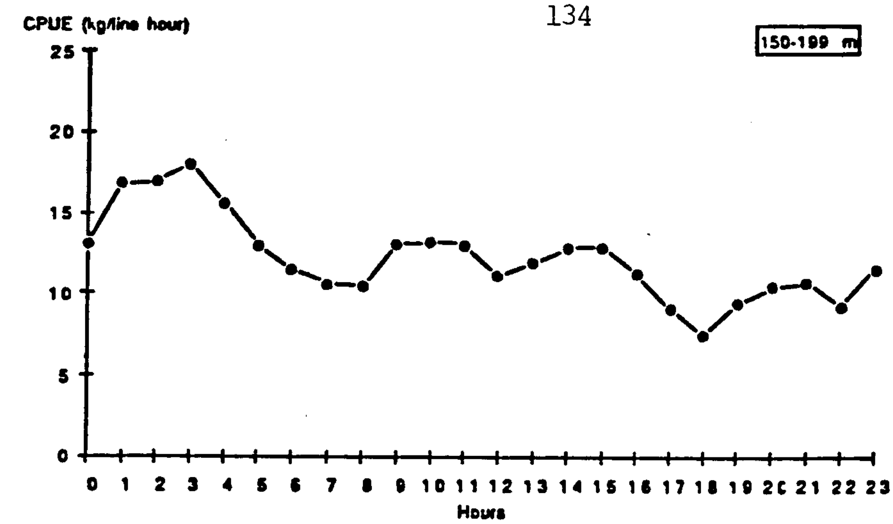


Figure 12.--Mean hourly catch rates for handlining in the South Pacific at 50 m depth intervals.



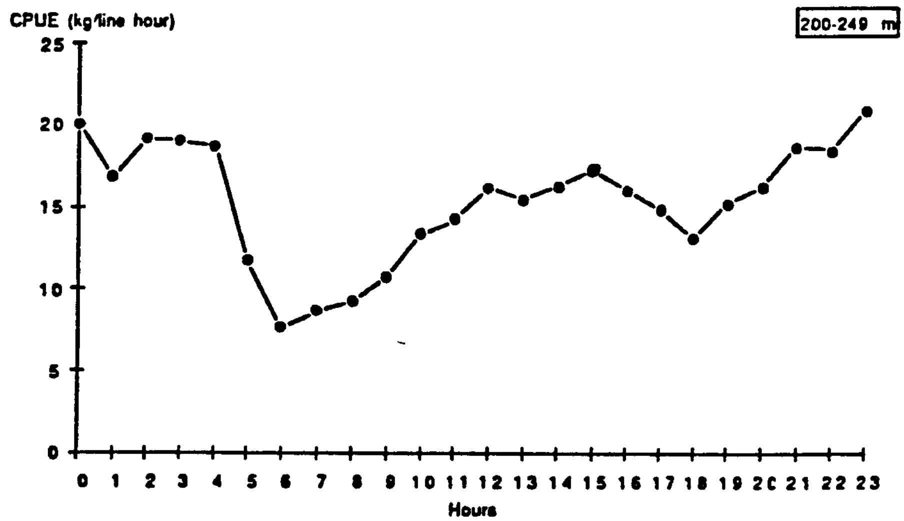
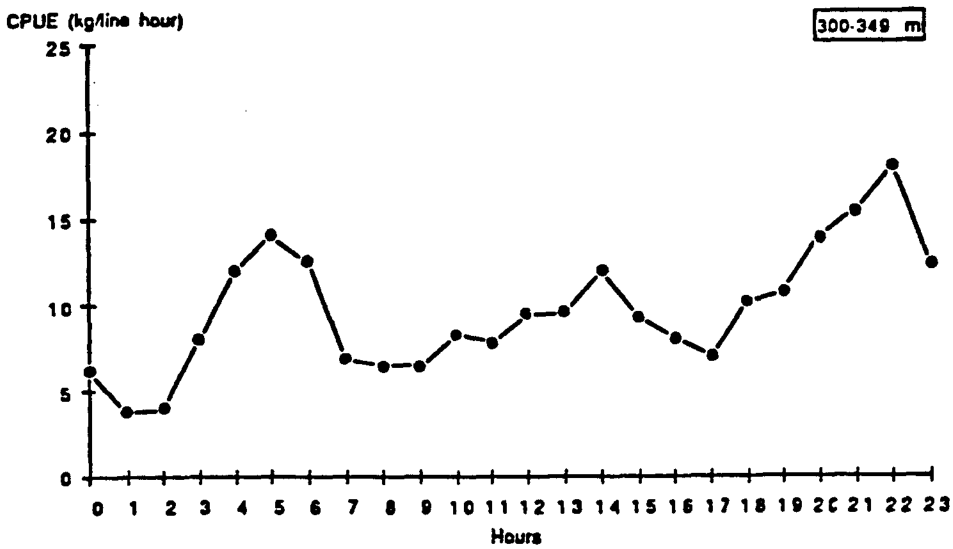
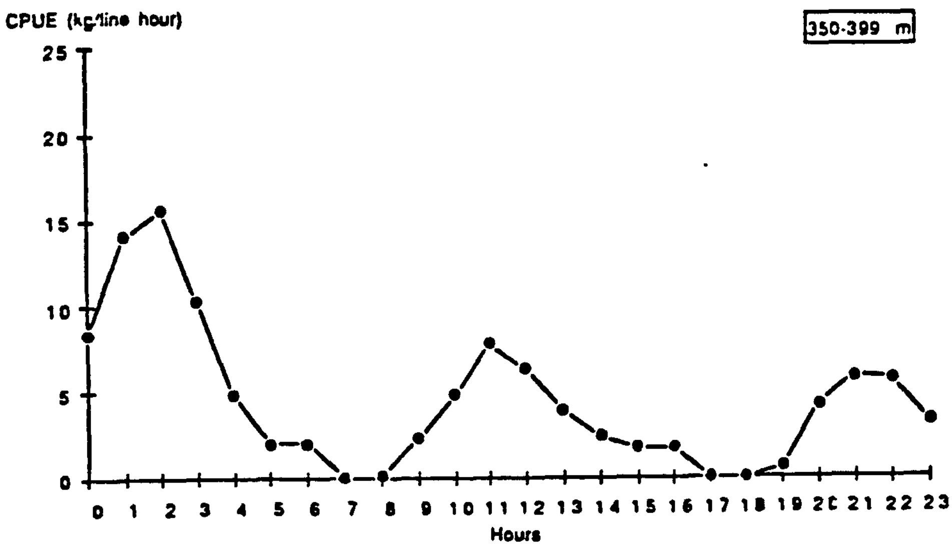


Figure 12.--Continued.





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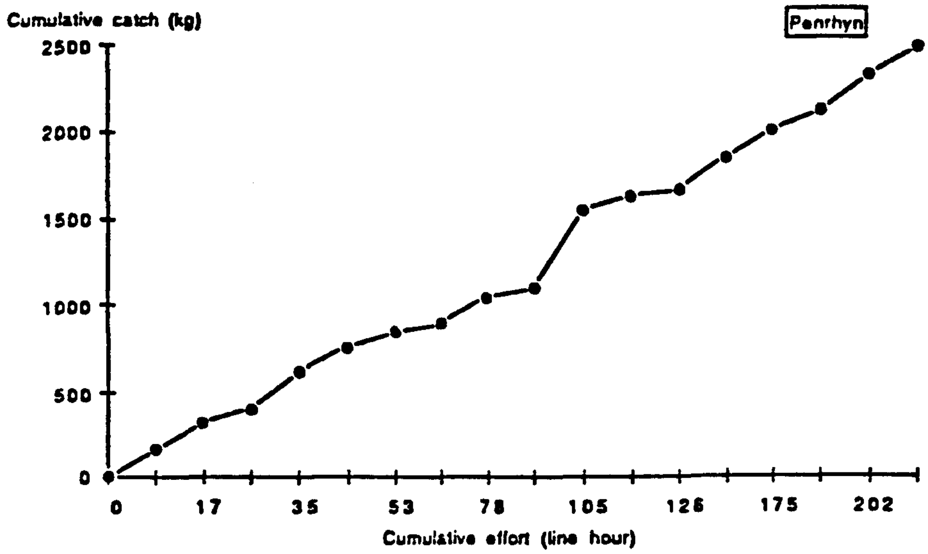

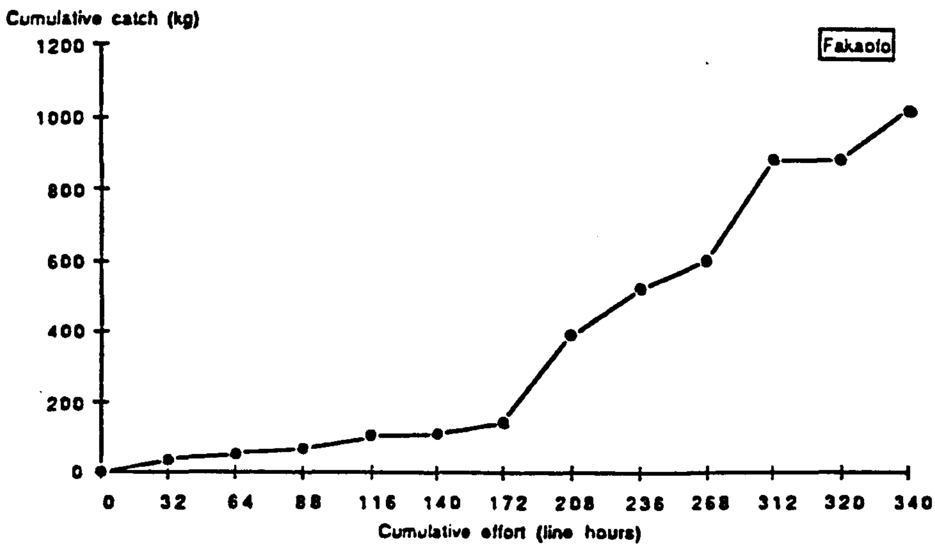

Figure 13.--Cumulative catch versus cumulative effort for handline catches at Penrhyn Atoll (Northern Cook Islands) and Fakaofo Atoll (Tokelau).

From the dropline catches, the number of species was totaled, excluding any obvious shallow-water fishes. Inclusion of shallow-water species occurred when other fishing activities (e.g., handlining and fish trapping) were undertaken in shallow lagoons. The westernmost island group visited by the SPC master fishermen was the Republic of Belau. This formed a convenient western boundary from which the straight-line distance could be measured for all other fishing locations. These distances are in Table 7, together with the total number of species at each location. A plot of these distances (Fig. 14) demonstrates the decline in species number in the dropline catches as the distance east of Belau increased.

The line is fitted to the data, except for the Solomon Islands and Fiji. The low number of species (23) at the Solomon Islands is unrealistic given the western location of this archipelago and its proximity to the species-rich PNG. The single visit to the Solomon Islands was conducted under the auspices of the ORAFP when less emphasis was given to meticulously identifying all species in the catches. As such, 175 fishes were simply classified as "mixed species." By contrast, particular emphasis was given to identifying all species in the catches during visits to Fiji, because of the taxonomic expertise of resident staff in Fiji's Fisheries Division (A. D. Lewis, South Pacific Commission, Noumea, New Caledonia, pers. commun.).

Springer (1982) showed that the greatest species diversity on the Pacific Plate is found at the plate margin. Thus, in addition to an east-west species gradient, there is also a marginal-nonmarginal effect associated with species diversity on the plate. This is most evident in the southern islands of the South Pacific where the Melanesian Islands joins the Polynesian Islands. The plate margin is defined by the islands from PNG to Tonga and American Samoa, while the southern Cook Islands and French Polynesia are nonmarginal sites. Several species widespread in the rest of the region are absent from the Cook Islands, French Polynesia, or both. Good examples of these are *Epinephelus chlorostigma*, *E. hoedti*, *E. miliaris*, *Lethrinus kallopterus*, *L. variegatus*, *Lutjanus argentimaculatus*, *Pristipomoides flavipinnis*, *P. multidens*, *Seriola purarescens*, and *Wattsia mossambica*.

Examples of species found widely throughout the region and in the central and eastern Polynesian Islands include *Aphareus furcatus*, *A. rutilans*, *Aprion virescens*, *Caranx lugubris*, *Etelis carbunculus*, *E. coruscans*, *E. morrhua*, *E. septemfasciatus*, *E. retouti*, *Gymnosarda unicolor*, *Lethrinus miniatus*, *Lutjanus bohar*, *L. kasmira*, *Pristipomoides auricalla*, *P. filamentosus*, *P. zonatus*, *Ruvettus pretiosus*, *S. rivoliana*, and *Variola louti*.

Certain deep reef species also appear to have limited distributions. For example, from the catch records the deepwater snapper *Etelis radiosus* appears to be confined to the high islands of Melanesia and the small, high island of Wallis. A single specimen was recorded from the atoll of Nukulaelae in Tuvalu and may simply be a misidentification or a straggler. The emperor *Lethrinus chrysostomus* is confined to the southern Melanesian

Table 7.--Number of deep reef species recorded for dropline catches from different locations in the South Pacific. For each location, the distance east of the Republic of Belau is given.

Location	Distance east of Belau (km)	No. of species
Republic of Belau	0	102
Yap	500	69
Truk	2,000	88
Papua New Guinea	2,250	94
Kosrae	3,250	63
Solomon Is.[a]	3,375	23
Marshall Is.	4,000	44
Kiribati	4,500	78
Vanuatu	4,500	51
New Caledonia	4,750	65
Tuvalu[b]	5,250	51
Fiji[c]	5,625	107
Wallis and Futuna Islands	5,875	61
Tokelau	6,250	49
Western Samoa	6,250	45
Tonga[d]	6,375	68
American Samoa	6,500	41
Niue	6,750	42
Kiritimati	7,655	26
Penrhyn	7,900	37
Rarotonga	8,170	29
French Polynesia	9,655	47

[a]Specimens unidentified equaled 175.
[b]Original totals included shallow-water species.
[c]Emphasis given to correct identification of species.

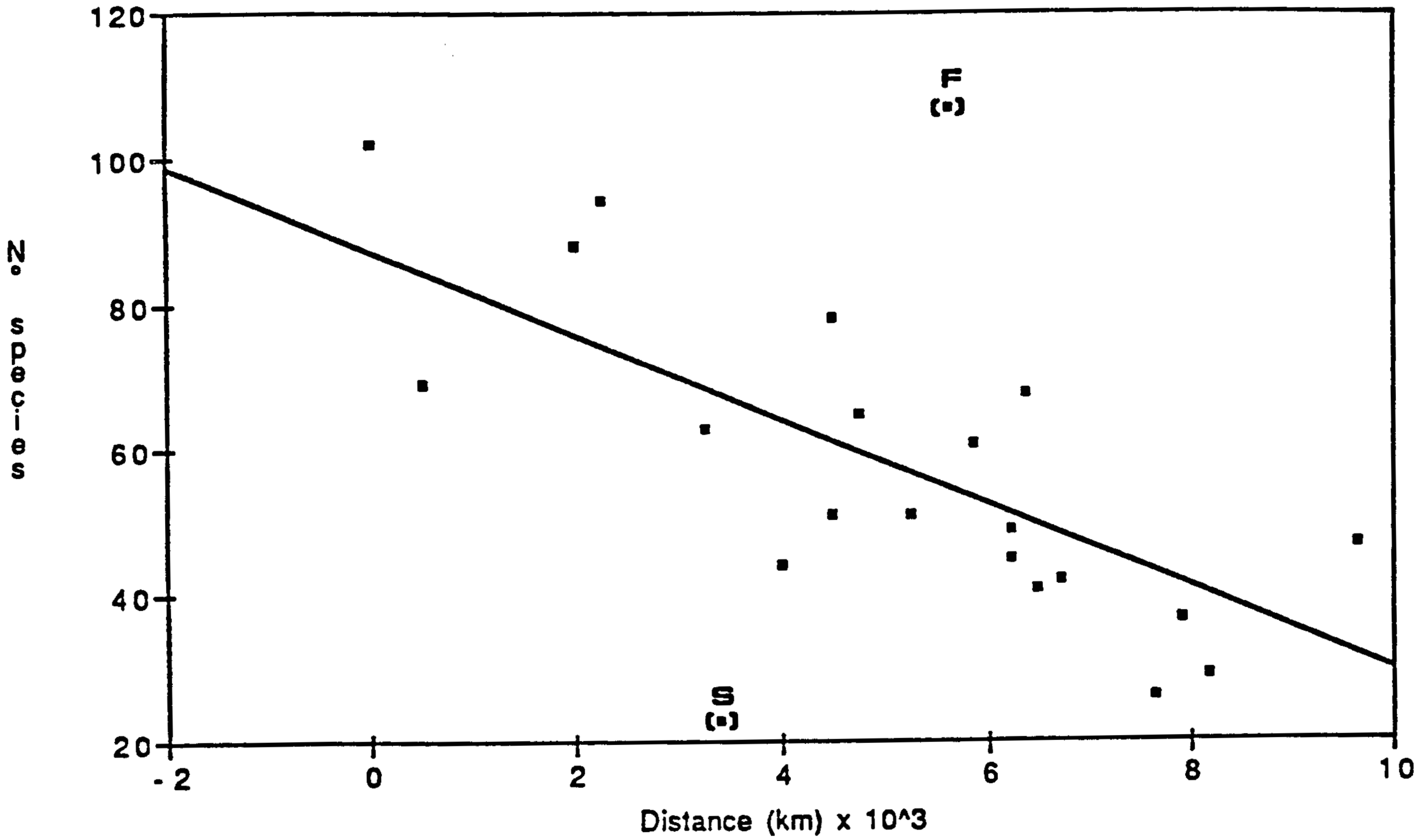

Figure 14.--Total number of deep reef species captured by handline from different locations in the South Pacific versus the distance east of Belau. The points for Fiji (F) and the Solomon Islands (S) were excluded from the regression, which takes the form $y = 91.04 - 0.0066x$, $r = 0.8$, $P < 0.001$.

Islands of New Caledonia, Vanuatu, and Fiji and to the Kingdom of Tonga. This species is essentially a South Pacific subtropical species. One record of *L. chrysostomus* from Kosrae is likely to represent a misidentification of the closely related congener *Lethrinus amamianus*. Other species found in the dropline catches at restricted locations included *Epinephelus aureolatus*, *E. cometae*, *E. magniscuttis*, and *Gymnocranius japonicus* and were similar in distribution to *L. chrysostomus*.

DISCUSSION

The survey fishing carried out by the SPC master fishermen's program were almost exclusively on unfished virgin populations. As such, the catch rates from these data must be treated circumspectly from a fishery development standpoint. The catch rates at the maximum sustainable yield (MSY) for most of these stocks may be reduced by about 50% from the initial CPUE (Gulland 1983). Further, unchecked expansion of fishing effort may lead to severe declines of deep reef fish stocks, particularly on submerged pinnacles and seamounts.

Sustained fishing, even by a single individual, may be sufficient to rapidly reduce deep reef fish populations on such structures. This appears to be the case with the Haputo Pinnacle near Guam; this site was fished persistently for 15 months by a single fisherman during 1967-68 (Ikehara et al. 1970). The catch rate on this seamount was initially about 13.8 kg/line-hour but was reduced to 1.3 kg/line-hour by the end of the 15-month period. Fishing occurred at depths around 180 m, and the dominant species in the catches were *Aphareus rutilans*, *Etelis coruscans*, *E. carbunculus*, and *Epinephelus* spp. As far as can be ascertained, catch rates on the Haputo Pinnacle have not recovered to former levels. Similarly, the Tongan deepwater dropline fishery is based largely around ocean seamounts. Data presented by Langi et al. (1989) suggest that CPUE also declines rapidly with sustained fishing effort in these locations.

Catch rates around high islands appear to be far less variable than around coral atolls, and it is realistic to suggest that the mean CPUE of virgin stocks around such locations generally will be about 6.0 kg/line-hour for all fish and about 5.0 kg/line-hour if sharks are not included (i.e., only teleosts are included). Assuming that effort is permitted to increase slowly to the level of fishing effort generating MSY (f_{opt}), then a CPUE of 2.5-3.0 kg/line-hour is likely to be experienced when the fishery is in equilibrium.

The catch rates for dropline fishing around atolls are far more variable than around high islands. Interestingly, an analysis of pelagic baitfish catches from high islands and atolls of western and central Micronesia by the SPC tuna program (SPC 1984) also demonstrated greater variability at atolls than at high islands. Further, the data strongly suggest that the atoll catches contains significantly lower proportions of eteline species and larger amounts of low value species such as sharks and gempylids. Following the simple model for catch rates at MSY, then initial catch rates of 7.0-8.0 kg/line-hour for the virgin stock would be reduced to 3.5-4.0 kg/line-hour at f_{opt} and be much more variable, and the catches would have a lower value than those from high islands.

The differences in catch composition between high islands and atolls are also evident in the CPUE data for separate catch components. As eteline species comprise substantially less of the atoll catches, it is not surprising that the CPUE for these species should be less than at the high islands. Further, this initial exploration of the SPC dropline data suggests a positive correlation between eteline CPUE and island size. However, this result, while interesting, must be interpreted with caution, given earlier comments about the variance in these data. This caveat similarly applies to the interpretation of apparent inverse relationships between island size and the CPUEs of gempylids, carangids, and scombrids.

The data on CPUE versus depth suggest that catch rates will be maximized by fishing between depths of 100 and 250 m. This does not take into account, however, the effects of time of day on catch rates. Catch rates in shallow (<50 m) waters are at a maximum between midday and midnight. Conversely, there is a pronounced peak in catch rates during early morning at all depths beyond 50 m, and at >200 m depths, there are three distinct peaks. Unfortunately, the hourly catch data do not specify species; thus, the changes in species composition that may be associated with the variations in CPUE with time of day are unknown. Also unknown is whether the peaks in CPUE reflect diel changes in abundance, feeding behavior of different species, or both.

Richards and Sundberg (1984) investigated the interactions of dropline CPUE with depth and time of day for virgin deep reef stocks in northern PNG. They found that hourly CPUE peaked at about midday at the deepest (275 m) depth but that this peak occurred progressively later in the day in the shallower depth ranges. The main peak in the shallowest (95 m) depth fished by Richards and Sundberg (1984) was around 1800. Brouard and Grandperrin (1985) found that, in Vanuatu, day and night mean CPUEs were very similar with averages of 3.25 and 3.38 kg/line-hour, respectively. When broken down by 40 m depth intervals, however, they concluded that catch rates were greatest in shallow water at nighttime, similar to the SPC data.

The studies by Richards and Sundberg (1984) and Brouard and Grandperrin (1985) were made on stocks in relatively restricted locations. The analysis of CPUE versus depth and time of day performed here is for a data set encompassing most of the islands of the tropical South Pacific. Analysis of the interactions between depth and time of day in more restricted locations (e.g., the Melanesian Islands) may be more appropriate. Further studies on the dropline data collected by the SPC master fishermen will look at this aspect and others such as species distribution and associations by location and depth.

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CITATIONS

Brouard, F., and R. Grandperrin.
1985. Deep-bottom fishes of the outer reef slope in Vanuatu. South Pacific Commission Regional Technical Meeting on Fisheries, Work. Pap. 12, 127 p.

Egington, R., R. H. James, and J. Crossland.
1979. Report on the South Pacific Commission outer reef artisanal fisheries project in the Solomon Islands. South Pacific Commission, Noumea, New Caledonia.

Egington, R. E., and P. Mead.
1978. Report on the South Pacific Commission outer reef fisheries project in Funafuti (Tuvalu). South Pacific Commission, Noumea, New Caledonia, 19 p.

Gulbrandsen, O.
1977. Outer reef fishery in Western Samoa. South Pacific Commission Ninth Regional Technical Meeting on Fisheries, Noumea, New Caledonia, Work. Pap. 25, 9 p.

Gulland, J. A.
1983. Fish stock assessment: a manual of basic methods. John Wiley and Sons, New York, 223 p.

Hume, H.
1975. Report on the South Pacific Commission outer reef fisheries project in the New Hebrides. South Pacific Commission, Noumea, New Caledonia, 13 p.

1976. Report on the South Pacific Commission outer reef assessment project in the Cook Islands. South Pacific Commission, Noumea, New Caledonia, 21 p.

Hume, H., R. E. Egington, and R. H. Baird.
1976. Report on the South Pacific Commission outer reef fisheries project in Western Samoa. South Pacific Commission, Noumea, New Caledonia, 19 p.

Ikehara, I. I., H. T. Kami, and R. K. Sakamoto.
1970. Exploratory fishing survey of the inshore fisheries resources of Guam. Pages 425-437 *in* Proceedings of the 2nd CSK Symposium, Tokyo.

Langi, V. A., S. A. Langi, and J. J. Polovina.
1989. Annual yield for Tongan seamounts. Unpubl. manuscr., var. pag.

Ogden, J. C.
1982. Fisheries management and the structure of coral reef fish communities. Pages 147-159 *in* G. R. Huntsman, W. R. Nicholson, and W. W. Fox (editors), The biological bases for reef fishery management. NOAA. Tech. Memo. NMFS-SEFC-80.

Polovina, J. J.
1986. A variable catchability version of the Leslie model with application to an intensive fishing experiment on a multispecies stock. Fish. Bull., U.S. 84:423-428.

1987. Assessment and management of deepwater bottom fishes in Hawaii and the Marianas. Pages 505-532 *in* J. J. Polovina and S. Ralston (editors), Tropical snappers and groupers: biology and fisheries management. Westview Press, Boulder.

Ralston, S.
1978. A description of the bottomfish fisheries of Hawaii, American Samoa, Guam, and the Northern Marianas. A report submitted to the Western Pacific Regional Fisheries Management Council, Honolulu, Hawaii, 102 p.

Ralston, S. R., and Polovina, J. J.
1982. A multispecies analysis of the commercial deep sea handline fishery in Hawaii. Fish. Bull., U.S. 80:435-448.

Richards, A., and P. Sundberg.
1984. Variation in dropline catch rates and average fish weights of deep water demersal reef fish in Papua New Guinea, as a function of time and depth. Res. Rep. 84-16, Fisheries Research and Surveys Branch, Department of Primary Industry, Port Moresby, 22 p.

South Pacific Commission.
1984. An assessment of the skipjack and baitfish resources of Northern Mariana Islands, Guam, Palau, Federated States of Micronesia and Marshall Islands. Skipjack Survey and Assessment Programme Final Country Report No 18, South Pacific Commission, Noumea, New Caledonia, 111 p.

Springer, V. G.
1982. Pacific Plate biogeography, with special reference to shorefishes. Smithsonian Contributions to Zoology, No. 367, 182 p.

Wankowski, J. W. J.
1979. Subsistence fishing methods on Nuguria, Nukumanu, and Takuu Atolls. Harvest 5(3):1-11.

Wright, A., P. J. Dalzell, and A. H. Richards.
1986. Some aspects of the biology of the red bass, *Lutjanus bohar* (Forsskal), from the Tigak Islands, Papua New Guinea. J. Fish Biol. 28:533-544.

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