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**OPTIMISATION OF YIELD OF *PRISTIPOMOIDES FILAMENTOSUS* FROM THE
TONGAN SEAMOUNT FISHERY BY CHANGING SIZE AT FIRST CAPTURE**

by

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Background Paper

Optimisation of Yield of *Pristipomoides Filamentosus* From the Tongan Seamount Fishery by Changing Size at First Capture

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Introduction

The Kingdom of Tonga has developed a fishery for its deep slope reef fishery resources based principally on 6 key species of eteline snappers and epinepheline groupers. Fishing began in the early 1980's following exploration of the resource through the South Pacific Commission masterfisherman programme (Dalzell and Preston, 1992). Fishing occurs from boats constructed under an FAO / UNDP programme on the drop off of the banks and numerous seamounts located within Tongan waters, although today a number of more efficient vessels have entered the fishery. Samoan hand reels containing monofilament line terminating in wire trace with three baited tuna circle hooks of sizes between 3 and 9 (Mead, 1979), however, are exclusively used by all vessels. A data collection programme to provide monitoring and information for management began in 1986 (Langi 1987). Catch effort, and length frequency data were collected and analysed for key species in the catch (Latu and Tulua, 1992).

A number of management strategies for this fishery have been considered (Anon, 1994.) This paper examines only one specific question related to the potential for optimising benefit from the fishery by controlling the size at which fish are caught. It considers one species, *Pristipomoides filamentosus* and one sea mount located south of Tongatapu at 175° 46' E and 22° 54' S (seamount 09 03 in the Tongan Fisheries nomenclature). Data for the period 1987-1991 were analysed to provide parameters for this assessment.

Methodology.

In order to investigate the effects of changing size at first capture, a simulation model called Multi-species Interactive Dynamic Age-structured Simulation, or MIDAS, was used. This model largely follows the mathematical structure of the dynamics of exploited fish populations as formulated by Beverton and Holt (1957). The algorithms are described in detail in Kirkwood *et al* (1994). It is a fully age-structured model incorporating density dependence in the form of any one of a number of stock-recruitment relationships. The key biological parameters are the

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natural mortality rate, the Von Bertalanffy growth parameters and the size at which sexual maturity is reached. The primary management controls are the size at which exploitation begins and the level of fishing effort that is applied.

The model is capable of two categories of calculation: equilibrium and non-equilibrium (transient). In the former case, equilibrium states at various effort levels can be calculated and, for example, equilibrium yield-effort curves can be produced. For the latter type, the way in which stock states (eg yield, biomass) will change over time in response to a varying effort pattern can be determined.

Firstly, transient calculations were used to estimate an initial biomass for the stock which would give rise to the sort of yields recorded given observed effort levels. Then, since fishing mortality could be estimated, a value for the catchability in each year could be determined. Note that the estimates of initial biomass and catchability are used for scaling only, and do not affect the shape of these curves. This information could then be used to derive the equilibrium yield-effort curves discussed below.

For the simulation, two assumptions had to be made about values of parameters which are not known for the Tongan stocks. No maturity data was recorded, so length at maturity was assumed to be equal to that of the Seychelles *P. filamentosus* stock. Next, no estimate of a stock recruitment relationship for this species is available. However, comparison with species having similar lifespans and for which this relationship is known (MRAG, 1994), suggested that a Beverton-Holt type stock recruitment relationship with parameter $d=0.8$ would be reasonable. The parameter d indicates the degree of density dependence and is described more fully in Kirkwood *et al* (1994) and MRAG (1994).

Data used to Parameterise the model

Catch and effort data for seamount 09 03 indicated that the catch was predominantly mono-specific (Table 1; Fig 1). Species composition was a function of depth (Mees, 1994) and a generalised linear interactive model (GLIM, Francis *et al*, 1993) was used to standardise catch rate data for *P. filamentosus* with respect to depth (seasonal variation was not significant, $p=0.41$, whilst depth was highly significant, $p<0.0001$). The Fox biomass dynamic production model was used with catch and standardised effort data (CEDA, MRAG, 1992a) to derive the unexploited biomass for this sea mount (Biomass = 76,742 kg with the following confidence intervals : 2.5%, 65,269 kg; 97.5%, 329,246 kg). The estimated sustainable yield was 11,752 kg. This biomass estimate was used to scale the Y axis for model outputs.

Fishing mortality was derived through length converted catch curve analysis applied to annual length frequency data for fish caught at sea mount 09 03 (Table 1). The catchability constant, q , was derived from fishing mortality and standardised effort ($F=qE$). Catchability would not be expected to vary

significantly over time if the fishing method remained the same, as it did. Two values of q were used : an average value over all years, and the one derived for 1988 which is the year with the most data for catch curve analysis).

These parameters were used to scale the axes of the yield-effort curves in order that output generated could be related to fishing effort and catches at this sea mount. It should be understood, however, that a certain amount of uncertainty remains. In particular, the raised catch and effort are based on total sampling frequencies reported by Latu and Tulua (1992), and for seamount 09 03 they may not apply. Without scaling, the axes would represent relative yield and relative effort and the shape of the outputs, that is the relationship between yield and effort, would not have changed. The parameters used to determine the relationship between yield and effort were natural mortality and growth, the length weight relationship, reproductive parameters and gear selectivity (Table 2).

The length weight relationship was derived by Latu and Tulua (1992). Growth parameters were derived from stratified length frequency data for months where all Tongan locations were sampled (to avoid spatial effects; insufficient data was available to examine growth at sea mount 09 03 only). The ELEFAN routine of Pauly and David (1981) was applied using the analytical software LFDA (MRAG, 1992b). Although there are problems applying this method to long lived slow growing species such as *P. filamentosus* (see also Langi, 1990) the parameters are within the ranges reported for this species from other parts of the world (K 0.146, L_{∞} 78 cm, Hawaii, to K 0.31 L_{∞} 97.1, Hawaii FISHBASE Ref 4560). The instantaneous coefficient of natural mortality was estimated empirically (Pauly, 1980) at a water temperature of 18°C relevant to the depth band in which *P. filamentosus* was caught (Tawara *et al.*, 1987; 1989).

As indicated above, no assessment of reproductive parameters has been made for *P. filamentosus* from Tonga. Length at first maturity (L_m) is estimated to be 50% of maximum length for island lutjanid species (Grimes, 1987), and Langi and Langi (1987) estimated this parameter from $0.5L_{\infty}$ (38.6 cm). Length at maturity has been established for this species in Seychelles (Mees, 1993; and for an extended data set, Mees, 1995, Table 2). It would appear from this data and that from other parts of the world (eg Papua New Guinea, minimum length at maturity, 34 cm, FISHBASE, Ref 5724) that the rule, $0.5L_{max}$, equates to the minimum length at first maturity. Thus the relative proportions of $L_{m_{50}}:L_{\infty}$ and $L_{m_{75}}:L_{\infty}$ (lengths at which 50% and 75% of fish reach maturity) observed in Seychelles were used to establish the maturity ogive for the model. Owing to the uncertainty of this parameter in the Tongan case however, sensitivity of model outputs to its variation was tested by applying values set at $L_{m_{50}} = 50\%L_{\infty}$ also.

Gear selectivity for hooks and lines was determined using length frequency data aggregated over all depths and locations during the study period. No data on hook size was collected and so selectivity to changes could not be determined. L_c , the first fully exploited length class was selected as the cut off point in length

converted catch curve analysis. Probability of capture at length was derived from catch curve analysis and a moving average (ELEFAN II, Gayanillio et al, 1988; Table 2). The ogive defined by the lengths $L_{C_{50}}$ and $L_{C_{75}}$ (length at which 50% and 75% of all fish at that length will be caught by that gear) was used to establish the current relationship of yield to effort. In order to investigate the effect of changing length at first capture the parameter $L_{C_{50}}$ was varied. For these simulations knife edge selection was assumed since data was lacking on the potential change in shape of any gear selection ogive that may result from changing hook size.

Results : Effect of changing size at first capture

Gear selectivity was established using aggregated data. The length at which fish were caught on seamount 09 03 was similar each year (Fig. 2) and was high ($L_{C_{50}} = 77.8\%$ of L_{∞} , Table 3). For annual data aggregated over all Tongan locations length at capture varied ($L_{C_{50}} = 53.0\% - 76.5\%$ of L_{∞} , Table 3) and in particular was lower in 1988 and 1990 (Fig. 3). The length frequency distribution and mean length did not change significantly with depth, but there was a significant difference by location within Tonga being greater for fish caught south of Tongatapu (mean FL 58.1 cm) than in the central region of Ha'apai (48.3 cm) or north around Vava'u (47.0 cm). There was no significant difference in mean length or length distribution between the northerly locations (Mees, 1994). During 1988 and 1990 more fish were sampled from the northerly locations.

Simulations to test the effect of changing size at first capture were performed around the sizes observed (Table 3), from $L_{C_{50}} = 30\%$ of L_{∞} to $L_{C_{50}} = 70\%$ of L_{∞} using catchability derived in 1988 and a maturity ogive corresponding to that in Seychelles (Fig. 4). The effect of changing the estimate of catchability was investigated (Fig. 5). The parameter q was used to scale the x axis. A low catchability would suggest that the yield achieved at the maximum effort expended (6,180 reel hours, 1989) was below the maximum for the current gear selectivity (Fig. 5), whilst assuming the higher q value would imply that the maximum yield had almost been achieved (Fig. 4). Sensitivity to length at maturity was tested assuming fish matured earlier, at $L_{m_{50}} = 50\%$ L_{∞} (Fig. 6). In the first case at current selectivity, fish are caught below the length at maturity ($L_{C_{50}} < L_{m_{50}}$, Table 2). In the latter case the reverse is true ($L_{C_{50}} > L_{m_{50}}$). Again comparing current selectivity values, it may be seen that if maturity occurs at smaller lengths than observed in Seychelles then maximum yield is achieved at greater effort, and that increasing effort beyond that which achieves maximum yield has a less detrimental effect. This is even more pronounced at smaller lengths at first capture.

In subsequent discussion only the more conservative simulations will be examined (Fig 4, $q = 1988$ value, $L_{m_{50}} = 62\%L_{\infty}$). As length at first capture increases, the maximum yield increases and is attained at greater effort. At the greatest length examined, however, maximum yield was not achieved within the scale of the

simulation (theoretically it is at infinite effort), and for a given effort, yield is initially less than that obtained with smaller lengths at first capture. In this case only large fish are caught and there are fewer of them. Where length at first capture is below length at maturity, increasing effort beyond that which achieves maximum yield results in recruitment overfishing. Yield decreases and excessive effort can result in eradication of the stock. Yield is optimised where length at first capture is the same as length at maturity, and yield remains constant with increasing effort above that giving the maximum.

At seamount 09 03 fish are being caught above 70% of L_{∞} . This is inefficient. However, recruitment overfishing will not occur and effort could safely be increased. Decreasing the length at first capture would result in increased yields from this seamount at current effort levels. For the whole Tongan fishery directed at *P. filamentosus*, Fig. 4 may be interpreted to represent relative fishing effort and relative yield, although the present level of effort cannot be determined. In this case, fish from the north of the region (1988, 1990) are caught at lengths corresponding to gear selection parameters (L_{cur}), slightly below length at maturity, whilst those from the south are caught at lengths above maturity. In neither case will increasing effort result in dramatic loss of yield.

Discussion

Yield of *P. filamentosus* can be optimised through regulation of size at first capture and the level of fishing effort. The optimum is achieved when length at first capture (L_{c50}) is equal to length at maturity. However, the level of effort to achieve maximum yield is more than twice that required when L_{c50} is slightly below length at maturity ($L_{c50\%}$). The gain in yield is negligible and economically it would prove more profitable to exploit the resource just below maturity. Effort applied in excess of the optimum would not have a significantly detrimental effect and providing that length at first capture was not allowed to fall below 50% of L_{∞} this strategy may safely be recommended. In Tonga, fishing for *P. filamentosus* is well within these limits and indeed in the south yield could be increased by decreasing length at capture. It is not recommended that length at first capture in the north of Tonga falls below that at present.

There are a number of implications of these findings. Firstly, it is not appropriate to return 'undersized' fish from a deep bottom fishery. Most fish will already be dead once landed on the vessel and mortality of any returned could be expected to be high. Size limitation can thus only be achieved through gear restrictions. Hooks are relatively unselective to large fish and Ralston (1982) found that small hooks were nearly as efficient at catching large snappers from the Hawaiian deep bottom fishery as larger hooks. For the ascending left hand selection ogive he found a sigmoid curve. This is where selection is important in relation to fish size and hook size. However, small differences in size at capture occur with relatively large changes in hook size. For longline fisheries modification of fish size is achieved within a range of 67-217% increase in hook size (cited in Ralston, 1982).

Thus it would in theory be possible to regulate size at capture through hook size, but this may not be practical. Thus in order to optimise yield regulation of effort may be the only practical solution. This is much more difficult to achieve, not least because there are no reliable estimates of the total yield available from this fishery. However, the indications are that above optimum effort will not be greatly detrimental to the resource of *P. filamentosus* subject to the limitations in parameter estimates discussed.

Next, the lack of information on hook size in relation to size of fish caught in Tonga is a shortcoming in the data collection programme which should be addressed in order to provide additional information upon which to base management decisions. Are the differences observed in length at capture from north to south environmentally related or do they result from the use of different hook sizes or techniques by fishermen in the south? Also lacking is data on maturity. If differences in size are environmentally related do fish mature at different lengths with varying latitude in Tonga and thus are fish being exploited within safe limits of effort as suggested? If length at maturity has been underestimated there is a greater danger that recommending a decrease in length at first capture in the south of Tonga will lead to recruitment overfishing. Thus to facilitate management decisions, data to enable estimation of this parameter should be collected.

Should additional information indicate that control of length at first capture was possible through regulation of hook size then choice of size may have multispecies implications. Although the catch from seamount 09 03 was predominantly mono specific, it is in fact a multi species fishery. Different hook sizes may be implicated for each species, ie. the optimum yield of each species may be achieved with a different hook size. This may be feasible through targeting by depth band, but enforcement would be difficult and it would be more practical to indicate a single minimum hook size. Optimisation of yield would then need to be based on a multi-species approach selecting for the optimum economic yield from the species mix. MIDAS is capable of such assessments, but data is lacking on the effect of hook size on length at first capture for any species. It would not be sufficient to compare species simulations at fixed proportions of L_{∞} since a hook size resulting in gear selection $L_{c_{50}}$ equivalent to 60% of L_{∞} for *P. filamentosus*, say, may be 30% for *E. septemfasciatus*, for example. However, comparison of the relationship of yield at effort for the current level of selectivity for a number of species would be sensible, and could indicate optimum yield at effort.

Finally, it should not be forgotten that the Tongan fishery is predominantly based on sea mounts. The principle of optimising yield by regulating size at first capture for an individual mount applies equally to all aggregated locations. However, the dramatic decline in yield indicated for very small lengths with increasing effort may not in fact occur if seamounts are not self recruiting and are replenished by larval recruitment from adjacent banks. This scenario would suggest other management strategies beyond the scope of this paper. Again, however, it highlights the lack of

information (relating to larval dispersal and recruitment at seamounts) and the requirement for detailed biological information in order to derive sound management policies.

Acknowledgements

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TABLE 1 : Catch, effort, standardised catch rate and effort, fishing mortality and catchability for *P. filamentosus* at seamount 09 03 between 1987 and 1991.

Year	Sampling frequency	Total Effort		Standardised		Catch (kg)		F (P. fil) all depths	catchability q
		Trips	Reel hrs	kg/rl.hr	effort	Total	<i>P. filamentosus</i>		
87	23.85%	17	1438	7.64	1437	14729	10981	NA	NA
88	54.35%	44	3674	6.11	2933	29568	17923	0.38	0.00012955
89	40.45%	72	6947	4.46	6180	40217	27564	0.24	0.00003883
90	45.00%	4	613	NA	NA	3922	3029	0.22	NA
91	40.00%	58	7488	4.11	3657	39080	15029	0.26	0.00007110

TABLE 2 : Parameter estimates for *P. filamentosus* from Tonga, and reproductive parameters from Seychelles used in MIDAS, and the corresponding fork length (cm) to the proportion $L_{50}:L_{\infty}$ used in simulations to test the effect of changing length at first capture.

Details	Parameter	Tonga		Seychelles	
		<i>P. filamentosus</i>	% L_{∞}	<i>P. filamentosus</i>	% L_{∞}
Length-weight relationship	a	0.0000712			
	b	2.67			
Growth Parameters	L_{∞}	77.6		81.7	
	K	0.22		0.288	
	to	-0.44			
Natural mortality	M	0.41			
Reproductive parameters	$L_m(0.5.linf)$	38.8	50.0%	40.9	50.0%
	$L_m.min$			36.6	44.8%
	L_m25			45.0	55.1%
	L_m50			51.0	62.4%
	L_m75			59.0	72.2%
Gear Selectivity (FL, cm)	L_c	45.0	58.0%		
	L_c25	38.3	49.4%		
	L_c50	42.2	54.4%		
	L_c75	44.6	57.5%		
Simulations:	Lc50 varied : FL (cm) at	L_c50	23.3	30.0%	
	different ratios of L_c50	L_c50	31.0	40.0%	
	to L_{∞}	L_c50	38.8	50.0%	
		L_c50	46.6	60.0%	
		L_c50	54.3	70.0%	

TABLE3 : Length at capture estimates for *P. filamentosus* caught over the whole of Tonga from 1986 to 1991, and annual estimates, and for fish caught only at seamount 09 03 between 1988 and 1991.

Details		All data	1986	1987	1988	1989	1990	1991	SM 0903
Length at capture (FL, cm)	Lc	45.0	61.0	63.0	45.0	49.0	49.0	59.0	63.0
	Lc50	42.2	59.4	61.2	41.1	46.2	42.5	50.6	60.4
	Lc75	44.6	61.3	63.2	43.4	48.8	48.1	58.0	62.5
Lc50 as % of Loo		54.4%	76.5%	78.9%	53.0%	59.5%	54.8%	65.2%	77.8%

Fig. 1: Observed catch rates at seamount 09 03 for the principle species caught on Tongan seamounts (*P. filamentosus*, *P. flavipinnis*, *Etelis coruscans*, *E. carbunculus*, *Epinephelus morhua* and *E. septemfasciatus*) and GLIM standardised catch rates for *P. filamentosus* (Pf.Std). Catch rates were standardised with respect to depth. The mean annual fishing depth is indicated.

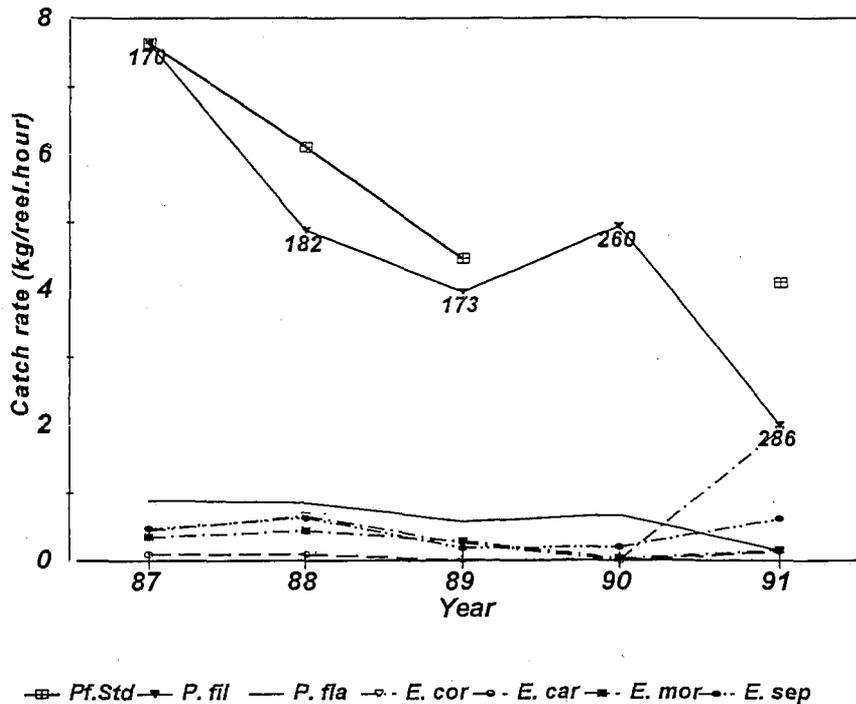


Fig. 2 : Sampled length frequency distributions for *P. filamentosus* at semount 09 03 in 1988, 1989, 1990 and 1991 respectively.

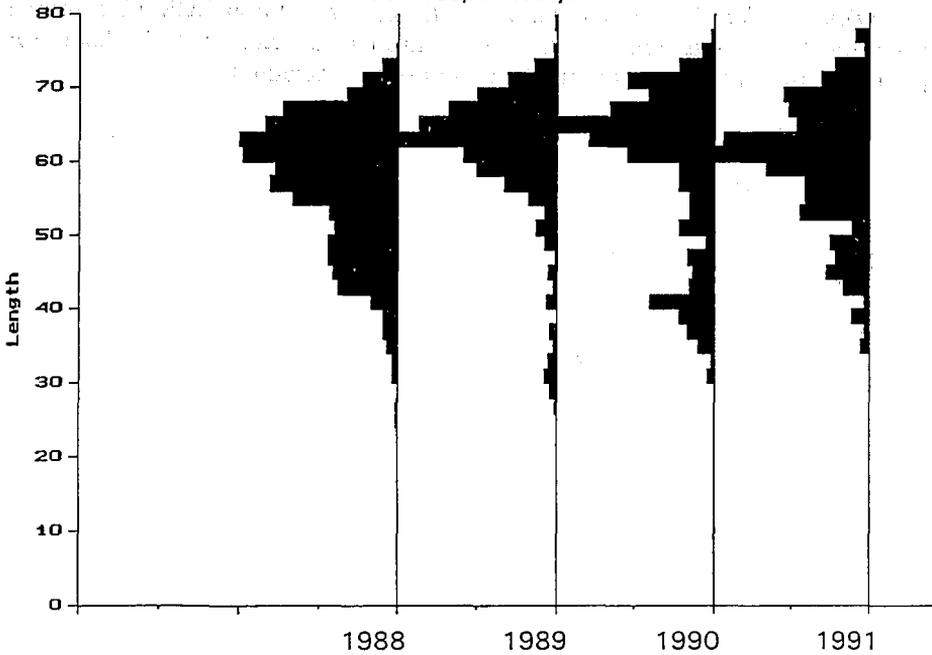


Fig. 3 : Sampled length frequency distributions for *P. filamentosus* caught over the whole of Tonga, firstly aggregated data for 1986-91, and then respectively data for each of '86 (n = 353 from south, 0 from north); 87(1125 S, 959 N); 88 (1546 S, 2329 N); 89 (1984 S, 1233 N); 90 (498 S, 1000 N) and 91 (331 S, 484 N).

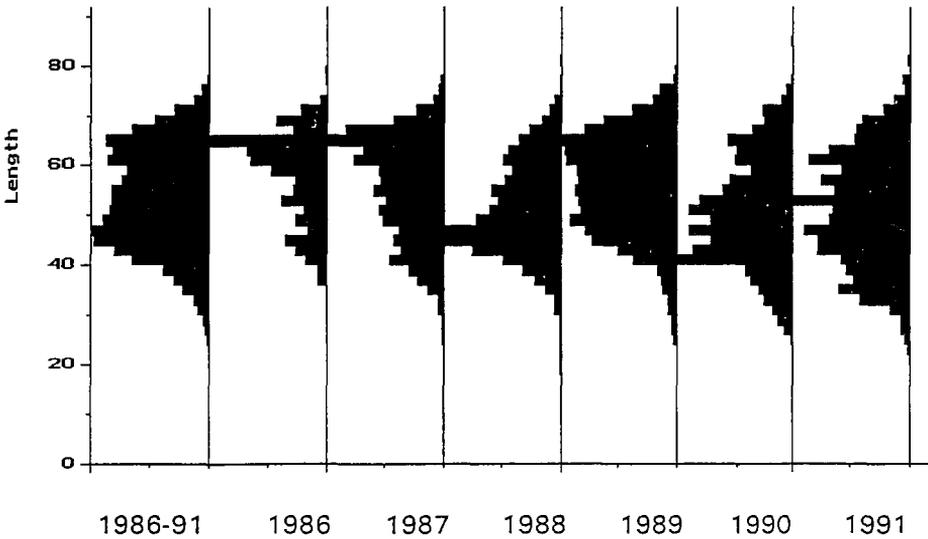


Fig. 4 : Simulations of equilibrium yield against effort for *P. filamentosus*, calibrated to represent the resource on seamount 09 03, indicating the effect of varying length at first capture (L_{c50}) as a proportion of L_{∞} . Calibration of the x axis was achieved using the catchability derived for 1988. The maturity ogive was set with values equivalent to those observed in Seychelles ($L_{m50} = 62\% L_{\infty}$). Standardised effort levels for the most recent data (1991) and for the year in which the greatest effort was directed at the resource (1989) are indicated. L_{ccur} represents the current gear selectivity observed for fish taken at all locations within Tonga.

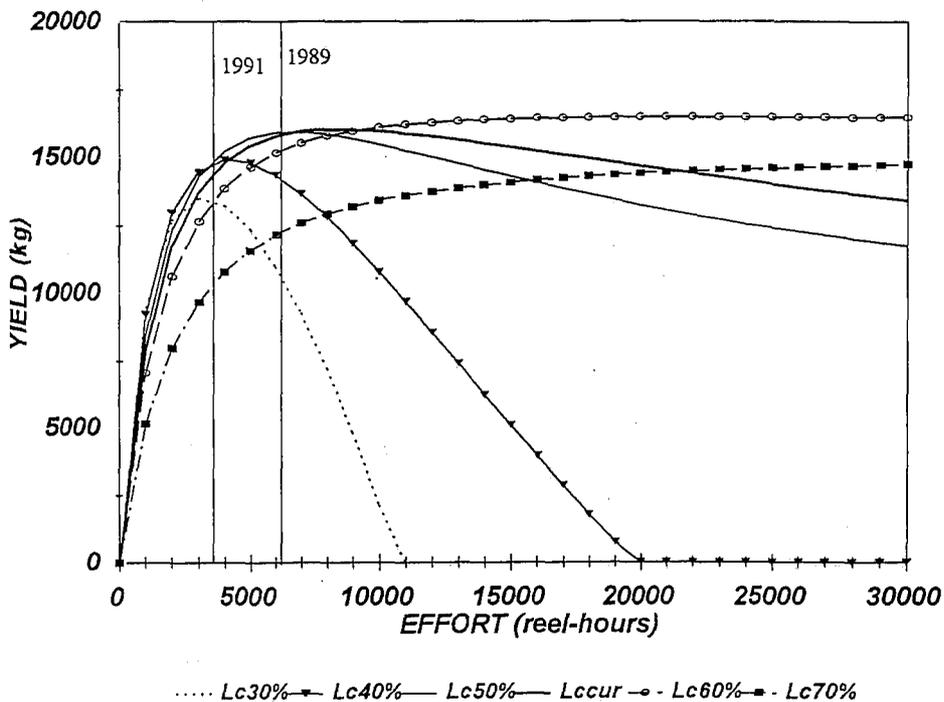


Fig. 5 : Simulations of equilibrium yield against effort for *P. filamentosus*, calibrated to represent the resource on seamount 09 03, indicating the effect of varying length at first capture (L_{c50}) as a proportion of L_{∞} . Calibration of the x axis was achieved using average catchability for 1988, 1989 and 1991. The maturity ogive was set with values equivalent to those observed in Seychelles ($L_{m50} = 62\% L_{\infty}$).

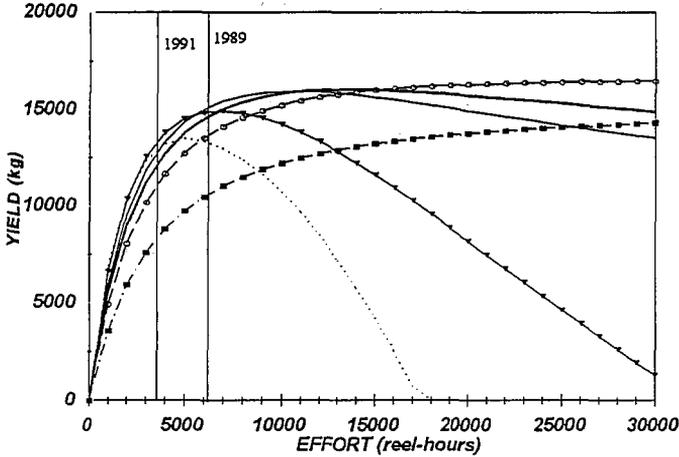


Fig. 6 : Simulations of equilibrium yield against effort for *P. filamentosus*, calibrated to represent the resource on seamount 09 03, indicating the effect of varying length at first capture (L_{c50}) as a proportion of L_{∞} . Calibration of the x axis was achieved using the catchability derived for 1988. The maturity ogive was set with values equivalent to $L_{m50} = 50\% L_{\infty}$.

