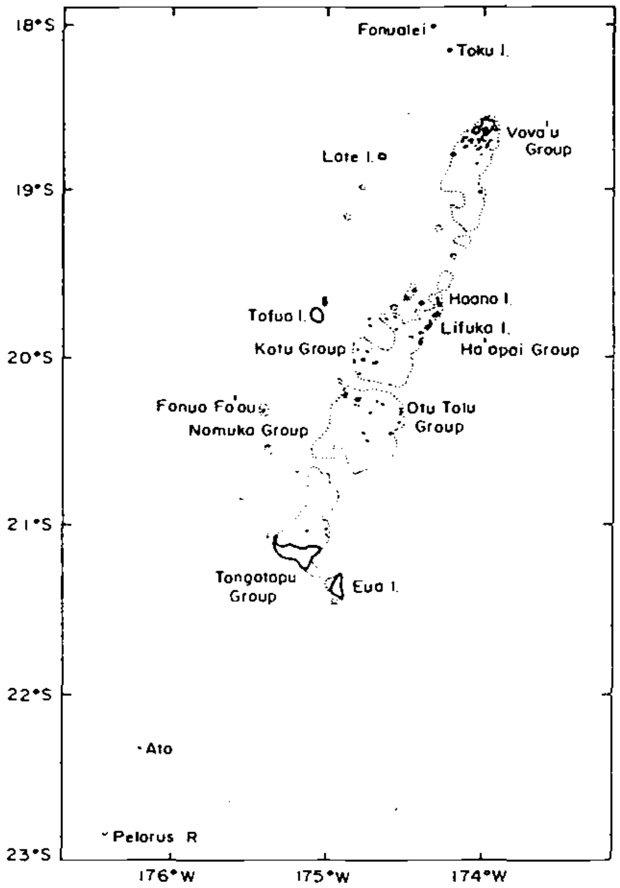
THE TONGAN DEEP REEF-SLOPE FISHERY

AN ANALYSIS OF DATA FROM 1987-1991 :



INTERIM REPORT TO GOVERNMENT OF TONGA , MINISTRY OF FISHERIES

FOR

THE MANAGEMENT OF TROPICAL MULTI-SPECIES FISHERIES PROJECT

MRAG LTD 1994

Addendum:

Since the original completion of this report (1994), a number of additional analyses relating to the Tongan fishery have been performed. These included :

- Application of Generalised Linear Interactive Modelling techniques to examine variability in the data due to factors such as changing season, depth and location. This was employed to establish whether significant changes in catch composition occurred over time, or whether apparent changes could be attributed to such variability. These analyses are reported in a project Final Report and in Mees (in press: Multispecies responses to fishing at Indian Ocean and Tongan offshore reefs. *In* Proceedings of the eighth International Coral Reef Symposium, Panama, 23-29 June 1996).

- Single species management based on controls on effort and length at capture were investigated and reported in a project Final Report and, for one species, in Mees and Rossouw (1995: Optimisation of yield of *Pristipomoides filamentosus* from the Tongan seamount fishery by changing size at first capture. *In* Dalzell, P. and T.J.H. Adams (compilers) South Pacific Commission and Forum Fisheries Agency Workshop on the Management of South Pacific Inshore Fisheries, Noumea). Manuscript collection of country statements and background papers, Volume I, SPC/Insh. Fish. Mgmt/BP7 pp 291-306

- An insufficient time series of data from 1993 to the present was available at the time of analysis for inclusion in a project Final Report. Summary analyses indicating analytical procedures for deriving accurate catch assessments by boat and individual seamount were performed (Mees and Lotoahea, 1995 : An analysis of catch and effort data from the Tongan deep reef slope fishery from November 1993 to June 1995) The analyses include catch and effort assessment, summary length frequency details, and a graphical representation of catch and effort for seamounts subject to different levels of fishing pressure. Depletion effects due to increasing fishing pressure were not detected and this analysis was taken no further. This is an internal report (MRAG/Tonga Ministry of Fisheries), and is available on request.

- The original 1994 report refered to the potential for sequential fishing of seamounts. An additional annex (5) to this report indicates annual catches by location for the six principle seamount fishery species and for banks species. The pattern of fishing over time is clearly illustrated.

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Definitions

Length

FL - fork length
Lmin - minimum length observed in catch
Lmax - maximum length observed in catch

Length-Weight relationship $W = aL^b$

W - weight
L - length (fork length unless otherwise specified)
a - condition factor
b - constant

Von Bertalanffy growth parameters :

K - growth coefficient
$L\infty$ - asymptotic length
T_0 - initial condition parameter

Mortality

M - natural mortality
F - fishing mortality
Z - total mortality

Reproduction

Lmmin - minimum length at which a mature fish was observed
Lm - length at onset of maturity
Lm50% - length at which 50% of population are mature

Recruitment and gear selectivity

Lfg - length at which fish recruit to the fishing grounds - may be < Lmin
Lc - smallest length fully represented in the catch
$L_{50\%}$ - length at which 50% of fish are retained by gear and 50% escape
$L_{75\%}$ - length at which 75% of fish are retained by gear and 25% escape
R - recruitment (number of recruits, also N(Tr))

Catch and effort

C - catch
f - fishing effort
cpue - catch per unit effort
q - catchability coefficient

SUMMARY

1. Detailed analyses of the Tongan deep reef-slope fishery (1987-1991) for snappers and groupers are presented stratified by depth and location. Previous analyses are reviewed. The principal species exploited were : *Pristipomoides filamentosus*, *P. flavipinnis*, *Etelis coruscans*, *E. Carbunculus*, *Epinephelis morhua*, *E. septemfasciatus*. Fishing occurred on banks and seamounts.

2. Analyses are subject to potential bias due to inadequate sample design : sampling frequency was not recorded by location and a single overall figure is given. Trips sampled are biased in relation to place of origin of vessel and landing site, with 80% of records relating to the south whilst at the start of the survey more boats were located in the north.

Catch and effort :

3. Fishing effort (reel-hours) per trip increased over the study period. Possible explanations are : less efficient vessels left the fishery; longer trips were required over time to maintain catches (catch rates per trip were constant over time but decreased per reel-hour : see Figs 24, 25) Reel-hours were the unit of effort employed.

4. Fishing effort and catch rates (all species combined) decreased over the study period at all locations (Vava'u and North, Ha'apai; Ha'apai south & Tongatapu north; Tongatapu south). However, effort at depths greater than 200 m increased.

5. Species composition differed according to depth fished : Lethrinidae, 0-150 m ; *Pristipomoides* spp., 100-200 m; *Etelis* spp., 200-400 m; *E. morhua*, 150-300 m; *E.septemfasciatus*, 200-400 m. Fishing depth at Ha'apai south & Tongatapu north was less than elsewhere. Fishing at this location was predominantly on the banks and species composition differed.

6. Individual species catch rates showed an increase for *E. coruscans* over time and decrease for *P. filamentosus*. This was not considered a result of species interactions or depletion, but a function of depth and target species changes. For data stratified by depth and location frequently a decrease in catch rate was observed for *E. septemfasciatus* matched by an increase in that for *E. coruscans*. This may be due to interaction or targeting : *E. septemfasciatus* is the largest species exploited; Large specimens will not be replaced rapidly (mean length for this species decreased with time); fishermen report removing this species in order to increase catches of *Etelis* spp (although this observation may relate to the time period of single trips).

7. In addition to increasing depth over time, there was a shift of effort from bank locations to seamount locations from 1989. Mean fishing depth was 270 m on seamounts and 126 m on banks. 87% of the catch from seamounts was the 6 main species, 37% on banks. However, depth was a better indicator of species composition than 'mount' or 'bank'.

8. From seamount data alone stratified by depth there was no strong indication of depletion for any individual species and this may be a result of sequential fishing.

9. To compare with other authors, biomass dynamic production models were applied to annual catch and effort data stratified by depth and location to eliminate 'noise' from targeting, depth or location switching. They indicated that in most cases there was insufficient contrast in cpue data (ie. no depletion) to achieve viable results. The best fitting data to model related to seamounts only at depths greater than 300 m for a guild of the six main species. Generally the guild fitted better than individual species (interactions masked?; lack of detail on effort targeted directly at certain species). A potential yield of 588 tonnes (445-1,193) was derived for all seamounts at all depths, but due to the poor fitting data and small number of data points (5 years) these figures should be used cautiously in any management decisions. Furthermore, the applicability of such models to aggregated seamount data is questioned -such models assume a closed population with full mixing, which is not the case for seamounts. Yield assessments based on individual seamounts may be more appropriate.

10. A modification of Allen's (1966) model was applied to monthly catch and effort data for individual seamounts. Of 18 examined two indicated depletion and reasonably good estimates of biomass were derived. For seamount 1403 a yield of 186-274 kg km^{-2} was estimated for a guild of the six main species and 141-282 kg km^{-2} for *P. filamentosus* alone assuming a census of all trips to that location. Errors in recording sampling frequency to each mount significantly affect the estimate of yield which increases to 504-766 kg km^{-2} if the reported overall sampling frequencies are applied. Raising these estimates to all seamounts yield is estimated to be in the range 55-768 t. Due to uncertainties relating to sampling frequency these figures should be used cautiously in any management decisions.

Length frequency data :

11. Examination of length frequency data for the 6 main species indicated :

- A significant difference in mean length and frequency distribution for Tongatapu south compared to all northern locations suggesting different populations or parts of the same population are exploited in the north and south;

- With time the range of lengths observed was significantly different for all species, but there was no significant change in mean length. For *E. septemfasciatus* this result was considered surprising : the mean length in 1987 was considerably less than in 1991;

- The trend was for length to increase with depth, but not significantly, and there was no significant change in mean length with depth. The length frequency distribution was significantly altered (compressed) at depth;

- Bimodal distributions were observed for *E. carbunculus* and *E. septemfasciatus*.

12. The following population demographic parameters were derived : the von Bertalanffy growth parameters, K (growth coefficient), $L\infty$ (the asymptotic length), t_0 (nominal time at which length of fish is 0); total mortality, Z, the instantaneous rate of natural mortality, M, and fishing mortality, F; L_c the first fully exploited length class and gear selectivity ogive parameters $L_{50\%}$ and $L_{75\%}$; L_{min}, L_{max} and L_{mean} for each data set, and L_m the length at sexual maturity. For estimation of certain parameters (eg growth) information was stratified by depth and location, otherwise aggregated data was used.

- length frequency data for these long lived slow growing species indicated little modal progression, and were poor or inadequate for estimation of growth parameters. Nevertheless, the best estimate derived is indicated.

- Mortality estimates were highly sensitive to the values of K, $L\infty$ used. Thus errors in estimating growth parameters affect these estimates also. In employing these parameter estimates in management models these shortcomings should be appreciated.

Effects of fishing pressure :

13. The effects of fishing may be summarised :

- Total catch rates decreased with time, but for individual species no consistent trend was observed with data stratified by depth and location. For the Tongan fishery sequential fishing from seamount to mount may mask catch rate decreases. Thus any decrease in abundance due to fishing is also masked, and considerable care must be exercised in managing such a fishery.

- The species exploited are all long lived slow growing predators with similar population demographic characteristics. Obvious species composition changes arising from fishing pressure which could not be related to changing fishing practices were not observed. There was some evidence that fishing pressure was causing a reduction in *E. septemfasciatus* and associated increase in *E. coruscans* indicating possible interaction between these species or at least competition for baited hooks. Similarly decreases were observed for *E. carbunculus* but the situation was further complicated by the bi-modal population structure and predominance of different modes in different years.

- Fishing altered the population structure of each species, causing a narrowing of the distribution of lengths caught. Mean length however did not change significantly and was not a good indicator of fishing pressure.

- It was not possible to examine changes in population demographic variables over time since the data was inadequate for accurate determination using length based techniques.

- The effect of fishing on reproductive status or sex ratio of the stocks was not determined due to lack of data

- In addition to the effects of fishing reported, the fact that this fishery specifically removes top predators could have un-recorded ecological side effects on species composition of non-target species and upon the environment itself.

14. In relation to the management of tropical multi-species fisheries project of which this analysis represents a case study, the following should be noted:

    - For the species exploited changes in species composition due to fishing are negligible and interactions not easy to detect.

    - Changes arising from other factors (depth, location change, target switching) need to be modelled, or such variability eliminated by examining only stratified data sets.

    - Certain of the parameters required for modelling may be determined with confidence (length-weight relationship, species composition, population structure, fishery parameters). For others only crude estimates may be derived using the information available from the Tongan fishery (ie. growth, mortality from length based methods, length at maturity). Certain parameters cannot be derived at all due to lack of information (sex ratio, reproductive strategy, age/length at recruitment onto fishing grounds, stock recruitment relationship). Sensitivity analyses are required to determine the importance of the unavailable and crudely estimated parameters and to thus indicate the value of finding alternative means to estimate them.

1. INTRODUCTION

An analysis of a 5 year data set (November 1986 - December 1991) relating to Tonga's sea mount and deep slope fishery for deep water snappers and groupers is presented. MRAG's involvement began in 1993 when Tonga Ministry of Fisheries agreed to collaboration on the Overseas Development Administration (ODA) Fish Management Science Programme (FMSP) project : 'Management of Tropical Multi-species Fisheries'. The data set, and its continuation (data collection resumed in November 1993), form a case study for the multi-species project. The current analyses examine the data in more detail than has previously been the case (See Annex 1) and present interim findings in advance of the new data becoming available. Figures and tables are used extensively to present the results and text is kept to a minimum.

1.1. Tonga - General Description

The Kingdom of Tonga consists of a widely scattered group of 171 islands (land area, 699 km^2) lying between 15°00'-23°30' S and 173°00'-179°00' W in the Pacific Ocean. The 200 nmi exclusive economic zone (EEZ) encompasses 700,000 km^2 of ocean. There are three major island groups : the low coral islands of the Tongatapu and Eua Group in the south, and of most of the central Ha'apai Group, and the raised coral islands comprising most of the Vava'u Group in the North. Some islands are volcanic. The capital, Nuku'alofa, is situated on Tongatapu. The total population was estimated to be 104,000 in 1984 (UNEP/IUCN, 1988).

The climate is mild : average temperatures range from 23°C in the south to 26°C in the north. The south-east trade winds prevail but during the warm period (October - March) tropical cyclones may occur. Average rainfall in Nuku'alofa is 1733 mm (UNEP/IUCN, 1988).

A chain of volcanic seamounts occur on the Tonga Ridge running parallel to the Tonga Trench in a NNE-SSW line. The extent of the 200 m isobath (as an index of the fishable habitat for deep slope species) was estimated to be 960 nmi for all banks and seamounts (Langi and Langi, 1987), and 294 nmi for sea mounts alone (Langi *et al.* 1988). These are considered to be underestimates since many areas are poorly charted and new mounts are still being discovered. Certain sea mounts have been charted in detail (Tawara et al. 1987; 1989). Water temperatures recorded during December by Tawara et al. (1987; 1989) were similar for any given depth for the seamounts examined : sea surface, 26°C; 50 m, 23°C; 100 m, 22°C; 150 m, 20°C; 200 m, 19°C; 250 m, 18°C; 300 m, 16-17°C; 400 m 12-14°C; 500 m, 10°C; 1000 m, 5°C.

1.2. The Deep Slope Fishery

Tonga was a net importer of fish at the end of the 1970's (UNEP/IUCN, 1988). Resources of coastal reefs and lagoons were considered to be under pressure. Following exploratory fishing by the South Pacific Commission Fisheries

Programme (Mead, 1979; 1987; Dalzell and Preston, 1992) Government of Tonga began to promote exploitation of deep slope resources of snapper and grouper. Commercial exploitation began in 1980.

To provide suitable fishing vessels at reasonable terms to fishermen a boat building programme was established under the United Nations Capital Development Fund. FAO / UNDP provided technical assistance. This programme aimed to provide a fleet of 40 vessels designed for bottom fishing using FAO Samoan hand reels containing monofilament line terminating in wire trace with three baited tuna circle hooks (for a description of the fishing method see Mead, 1979). Earlier vessels were 20 feet in length, equipped with 2 reels and fished banks close to the main islands. Subsequently 28' and 32' wide and narrow bodied vessels fitted with 4 reels were constructed which fished further offshore. The 40 vessels were completed by 1988 and the addition of privately built boats brought the total fleet size to 44 that year. For a number of reasons the fleet had declined to 19 vessels by 1992. Certain export companies began to introduce larger vessels of different designs in 1992 and 1993 against which the 28' vessels compete poorly due to limited range and ice-hold capacity. This trend looks set to continue. Thus the structure and fishing power of the fleet will change significantly.

Fishing activity is directed at shallow banks surrounding the islands and deep sea mounts. Initially intended to relieve fishing pressure on inshore reefs the fishery soon became export oriented with a demand for deep slope snappers and groupers. Since 1980 the nature of the fishery has thus changed, shifting more towards deep water and the sea-mount fishery, and away from the shallow banks fishery. The two may be considered separate fisheries although some overlap of species occurs. Geographical distinctions may also be made in the fishery : that based at Tongatapu is highly export oriented, whilst boats on Vava'u target fish mainly for the local market. Ha'apai boats may be considered intermediate, often landing catches in Tongatapu.

2. SAMPLING AND ANALYTICAL METHODS

Data collection began in 1986 (Langi, 1987) and continued to the end of 1991. Catch (number by species[1]) and effort (trips, men, lines, hooks, hours) was recorded at landing sites in Tongatapu and Vava'u from UNCD boats on a weekly basis. Other details included depth and fishing location, recorded by grid square (Fig. 1). Private boats and those landing within Ha'apai were not sampled. Sampling frequency was recorded and used to raise sample values to total estimated catch and effort. Each quarter, fork length (to 1 cm) was recorded for the dominant species in the catch. Individual length-weight data was recorded during 1987 only. Limited data collection occurred during the early part of 1992,

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[1] The six major species represented in the catch : *Pristipomoides filamentosus, P. flavipinnis, Etelis coruscans, E. carbunculus, Epinehelis morhua* and *E. septemfasciatus* are considered deep water species. *Lethrinus chrysostomus* is the major component of the shallow water catch. Data was also collected on *L. rubriopeculatus, Gymnocranius japonicus,* a grouper spp. and 'others'.

mostly on Vava'u. Data collection resumed in November 1993 following the same procedures but with greater detail recorded (weight and number by species, climatic conditions).

Catch weight : For the 1986-91 data set early analyses converted catch number to weight using a mean weight per fish regardless of species. Subsequently mean annual length per species was equated and converted to mean annual weight through length-weight relationships. This value was applied to catch number. For other species a value of 1.5 kg per fish was used (Latu and Tulua, 1992). In the present analysis since length frequency data relates to specific trips, weight at length per species was estimated for all length frequency data. The mean weight of individuals caught per species per trip was multiplied by the numbers per trip to estimate catch per species per trip. For trips with no length frequency data the mean annual weight per individual was applied. For other species 1.5 kg was used as the mean weight. This is considered to be more accurate, based on individual trips.

Fishing effort is reported as reel hours, hook hours and trips. Latu and Tulua (1992) base their analyses on trips stating that as fishermen do not have watches reel hours are inaccurate. King (1992) uses reel-hours but points out that commonly 13 fishing hours per day were recorded whilst actual fishing hours are more like 7 hours per day. Thus recorded reel-hours overestimates the true effort. An examination of reel hours fished indicated a range of 0 to 800. Thus, in the present analysis zero and obviously incorrect high values were excluded. Some trips were apparently only hours long - however, the cpue for these trips did not suggest that reel hours was necessarily entered incorrectly (see Figs 2 & 3), and Langi (pers. comm.) has indicated that very short trips are correct - they relate to mechanical problems etc.. Reel-hours per trip have increased with time and if correct this invalidates the use of the trip as a measure of effort. Reel-hours are used in the present analysis.

Sampling Frequency : Latu and Tulua (1992) indicate the overall sampling frequency. No stratification is presented to indicate the sampling frequency by landing site or fishing location. In this report, a correction was applied to the sampling frequency to account for the omission of dubious records and those with zero catch (total fish or total weight) or effort (reel-hours) from the analysis (hence any slight differences from the values reported in Latu and Tulua (1992)). Raised estimates of effort (trips) are the same as reported elsewhere, but raised catches differ slightly due to the different methods of converting numbers to weight. The following should also be noted as a potential source of error in analyses stratified by depth or location : total sampling frequency only is known. For individual locations and depths it is assumed that the same sampling frequency applies (due to random sampling). However, this may not be the case : Langi *et al* (1992) refer to locations with complete coverage - in these cases raised estimates of catch and effort will be overestimates. Furthermore, it is evident that there is a bias towards sampling boats from Nuku'alofa and nearby localities which land at Nuku'alofa (Table 1). Since these boats target export species to a greater extent than elsewhere, raised catches (in this and previous analyses) employing the quoted overall sampling frequencies may tend to overestimate the landings of export species, and underestimate others.

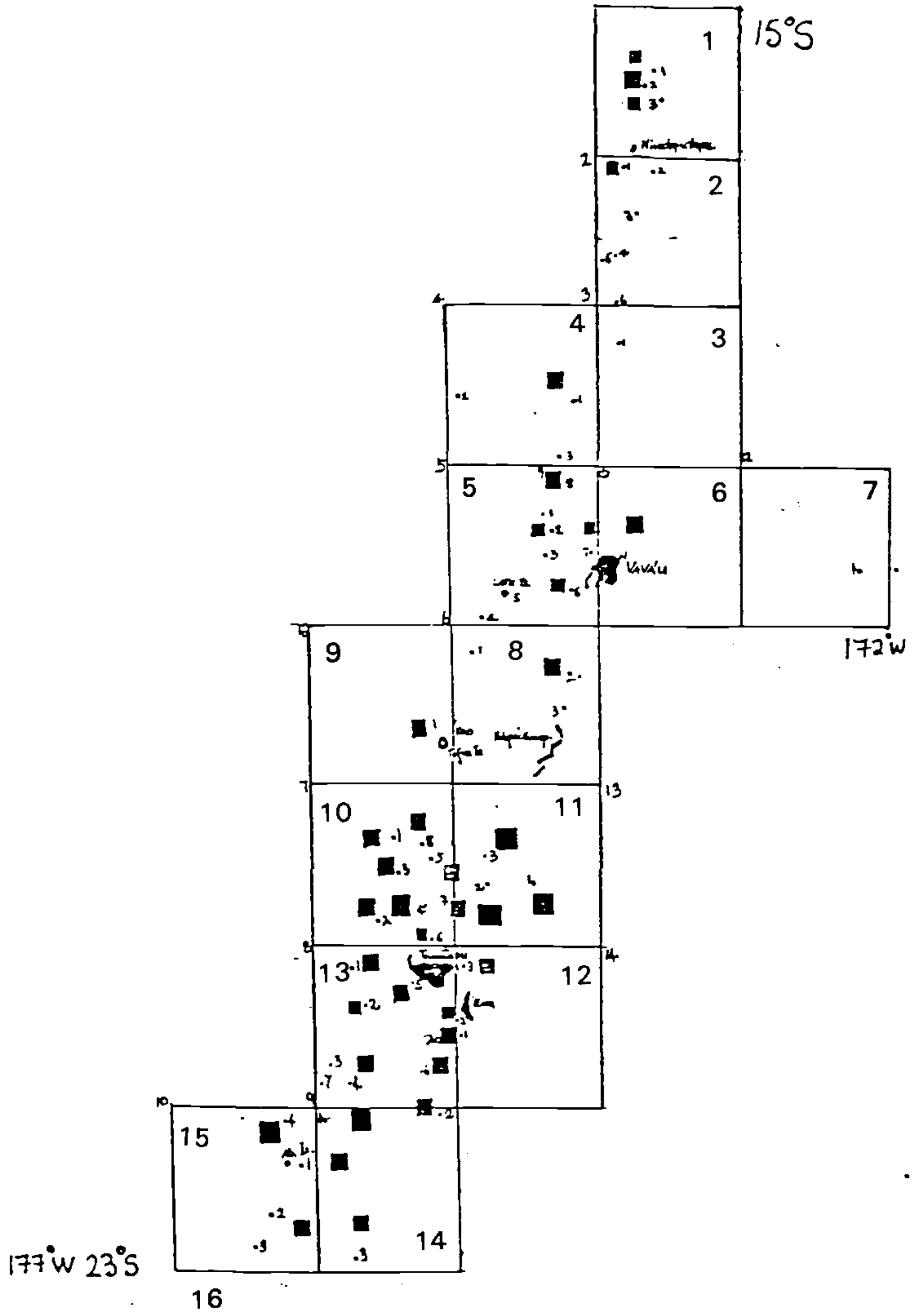
Table 1 : The number of trips sampled per year by place of origin of vessel.

LOCN \ YEAR	86	87	88	89	90	91	total
FONOI	0	2	19	16	3	4	44
NOMUKA	1	45	54	28	18	13	159
NUKU'ALOFA	2	148	277	225	154	194	1000
TUNGUA	1	12	25	4	5	3	50
VAVA'U	1	62	131	52	17	19	282
UNKNOWN	5	69	94	35	24	10	237
(Total)	10	338	600	360	221	243	1772

Fishing location was recorded as coded grid squares (corresponding to 1° squares) and numbered mounts or banks. Map 1 of Latu and Tulua (1990a) indicates these locations. However, it is not clear whether all numbered locations are sea mounts or only those marked as solid squares (Map title is ambiguous). Latu (pers comm) was unable to clarify the situation and stated that for purposes of analysis all catches of the six major species were considered to arise from sea mounts. Langi (pers comm.) provided an incomplete list of mounts and banks. In the present report grid squares have been re-coded to facilitate analysis (see Table 2). Each location occurring on the database (Table 3) was assessed as mount, bank or otherwise as indicated in Tables 2 and 3 (column 'Mees'). Those locations not marked on Latu and Tulua (1990a) for which an approximate position could not be determined on Admiralty chart 2421 were coded ?.

Previous analyses have considered the database as a whole or have distinguished between sea mount and bank locations. In the present report, those locations marked 'M' in the column 'Mees' of Table 3 are sea mounts. Locations for which the identity is uncertain (Mv, ?) have been excluded from analyses relating to sea mounts only. However, in order to estimate the total catch arising from mounts or banks it was necessary to 'guesstimate' the identity of the uncertain locations (based on mean depth and proportion of main species in catch by weight, column 'Probable identity', Table 3) and apportion effort between banks and mounts. Analyses were thus performed only on sample data from locations for which the identity was reasonably certain. This will give accurate estimates of catch rates, species composition etc. directly from the sampled data. Raised estimates of total catch and effort, however, have been adjusted according to the values in Table 4.

Fig. 1 : Map of the Tongan Archipelago showing locations of seamounts, marked as numbers and solid squares from Latu and Tulua 1990, and new grid square codes



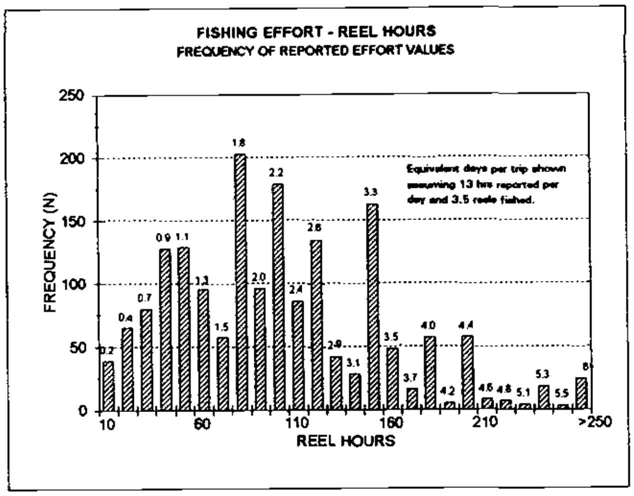


Fig. 2 The number of fishing trips made at different levels of fishing effort

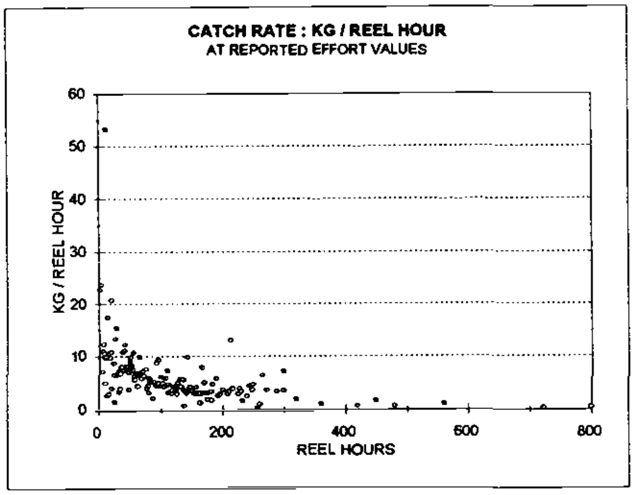


Fig. 3 Catch rates observed at different levels of fishing effort

Table 2 : A description of grid square locations, including the revised coding used in the present report.

Latu & Tulua grid code	New code	Analytical sub-locations	Assessment of mount or bank - based on Fig. 1 in Latu and Tulua (1991) and Admiralty chart 2421
-45	0	Unknown	
-80	0		
0	0		
1	1	Vava'u and north	Probably all mounts, deep water
2	2		Probably all mounts, deep water
3	3		Probably all mounts, deep water
4	4		Probably all mounts, deep water
5	5		Grid encloses part of archipelago around Vava'u (shallow), and some volcani islands (4,5,8,9 on Latu's map ?) - depth fished? Langi correct?
15	6		Includes Vava'u. Deep water north of Vava'u - probably all mounts.
6	8	Ha'apai group	Grid encloses Ha'apai Group (banks) and some deep water. 1 is probably Metis shoal, rest on shallow banks
16	9		Include Tofua and Kao islands. Probably mounts - deep water.
7	10	Ha'apai south & Tongatapu north	Grid encloses shallow bank north of Tongatapu (4,5,6,7), islands or volcanos (1,3), and deep water (2,8). 2 appears to be mount of volcanic activity. 1,3 may be mounts (depth?)
13	11		Encloses Nomuka Group - mostly shallow banks (2,3). 1 may be in area of deep water (mount)?
14	12	Tongatapu and south	Encloses Eua - probably all mounts (deep water).
8	13		Includes island of Tongatapu. South of this is deep water. Probably all mounts except 5 which may be on reef which extends 4 miles off southern coast of Tongatapu
9	14		Probably all mounts, deep water except shallow bank in south
10	15		Probably all mounts, deep water
11	16		Probably all mounts, deep water

Table 3 : Assessment of locations as sea-mounts or banks, based on details in Table 2 and upon information relating to the mean depth fished and proportion of the catch consisting of the main species (B = Bank, M = sea mount, Mv = volcano, possibly a mount, ? uncertain)

New grid	Analytical sub-locations	mount	mean depth	% main species	Langi	Latu & Tulua	Mees	Probable identity
0	Unknown	0	210	81%			?	M
0		4	320	100%			M	
0		9	360	100%			M	
1	Vava'u and north	0	203	60%			M	
1		1			M	M	M	
1		2			M	M	M	
1		3	290	98%	M	M	M	
1		4	222	78%			M	
2		1	193	58%	M	M	M	
2		2			M	?	M	
2		3			M	?	M	
2		4			M	?	M	
2		5			M	?	M	
2		6			M	?	M	
3		1			M	?	M	
3		2			B		M	
3		3	100	20%			M	
4		1	130	92%		M	M	
4		2			M	?	M	
4		3	258	84%		?	M	
4		4	360	100%			M	
4		9	280	93%			M	
5		12			B		?	B
5		6	182	62%	B	M	B	
5		0	300	100%			M	
5		1	184	74%	M	M	M	
5		2	206	77%	M	M	M	
5		3	252	69%	M	?	M	
5		7	270	105%	B	M	M	
5		10	360	91%	B		M	
5		11	300	99%	B		M	
5		4	213	70%	B	?	Mv	M
5		5	187	57%	B	?	Mv	B
5		8	229	82%	B	M	Mv	M
5		9	245	89%	B	M	Mv	M
6		2	184	57%	B?	M	?	B
6		1	300	77%	B?	?	M	
7		1			M	?	M	
8	Ha'apai group	0	140	70%			?	B
8		4	215	69%	B		?	B
8		5	332	92%			?	M
8		6	183	55%			?	B
8		7	170	53%			?	B
8		8	273	82%			?	M
8		9	283	86%			?	M
8		10	283	61%			?	M
8		11	200	84%			?	M
8		12	270	90%			?	M
8		2	166	61%	B	M	B	
8		3	210	73%	B	?	B	
8		1	313	92%	B	?	M	
9		0	190	56%	M?		M	
9		1	218	74%	M?	M	M	
9		2	330	85%	M?		M	
9		4	165	61%	M?		M	

Table 3 Continued :

New grid	Analytical sub-locations	mount	mean depth	% main species	Langi	Latu & Tulua	Mees	Probable identity
10	Ha'apai south & Tongatapu north	0	200	92%			?	M
10		9	273	72%			?	M
10		10	202	41%			?	B
10		30	150	1%			?	B
10		4	85	27%	B	M	B	
10		5	106	31%	B	M	B	
10		6	112	31%	B	M	B	
10		7	110	45%	B	M	B	
10		2	185	67%	M	M	M	
10		8	122	44%	M	M	M	
10		1	173	50%	B	M	Mv	B
10		3	136	39%	B	M	Mv	B
11		4	231	67%	B?		?	B
11		5	280	72%	B?		?	M
11		6	210	47%	B?		?	B
11		7	234	71%	B?		?	B
11		9	246	62%	B?		?	B
11		10	324	80%	B?		?	M
11		11	360	100%	B?		?	M
11		12	185	68%	B?		?	B
11		0	186	53%	B?		B	
11		1	186	53%	B?	M	B	
11		2	122	43%	B?	M	B	
11		3	112	23%	B?	M	B	
11		8	158	49%	B?		B	
11		13	70	14%	B?		B	
11		14	135	35%	B?		B	
12	Tongatapu and south	4	220	31%			?	B
12		1	270	97%	B	M	M	
12		2	250	81%	B	M	M	
12		3	202	66%			M	
12		5	260	93%			M	
13		21	120	82%			?	B
13		3	160	33%	M	?	B	
13		5	165	66%	B	M	B	
13		19	105	2%			B	
13		0	217	74%			M	
13		1	226	74%	M	M	M	
13		2	231	79%	M	M	M	
13		4	264	89%	M	M	M	
13		6	350	91%	M	M	M	
13		7	278	93%	M	?	M	
13		8	195	82%			M	
13		9	302	94%			M	
13		10	268	91%			M	
13		11	308	91%			M	
13		12	236	80%			M	
13		13	230	70%			M	
13		14	330	94%			M	
13		16	236	79%			M	
13		17	240	100%			M	
13		18	267	89%			M	
13		20	391	97%			M	
14		0	187	81%			M	
14		1	280	91%	M	M	M	
14		2	215	94%	M	M	M	
14		3	212	93%	M	M	M	
14		4	323	97%		M	M	
14		5	196	94%			M	
14		6	228	91%			M	
15		0	220	68%	M?		M	
15		1	217	83%	M?	?	M	
15		2	218	86%	M?	M	M	
15		3	305	93%	M?	?	M	
15		4	248	87%	M?	M	M	
15		5	291	92%	M?		M	
15		6	330	97%	M?		M	
16		1	178	78%	M?		M	

Table 4 : Number of trips sampled by depth and location and estimation of raising factors

A : for Sea mounts (M) and Banks (B)

Location	1		2		3		4		Total	
Depth	M	B	M	B	M	B	M	B	M	B
<100	5	5	3	5	11	223	25	1	44	234
101-200	19	16	6	20	20	114	207	7	252	157
201-300	20	6	18	7	9	22	224	0	271	35
>300	9	3	22	3	0	13	239	0	270	19
Total	53	30	49	35	40	372	695	8	859	445

B : for probable mounts and banks

Location	1		2		3		4		Total	
Depth	M	B	M	B	M	B	M	B	M	B
<100	3	0	4	2	2	79	0	0	9	81
101-200	45	7	7	6	10	95	0	2	62	110
201-300	18	2	13	3	19	47	0	0	50	52
>300	26	0	14	2	25	33	0	1	65	36
Total	92	9	38	13	56	254	0	3	188	280

C :Raising factor for mounts and banks

Location	1		2		3		4		Total	
Depth	M	B	M	B	M	B	M	B	M	B
<100	1.6	1.0	2.3	1.4	1.2	1.4	1.0	1.0	1.2	1.3
101-200	3.4	1.4	2.2	1.3	1.5	1.8	1.0	1.3	1.2	1.7
201-300	1.9	1.3	1.7	1.4	3.1	3.1	1.0	-	1.2	2.5
>300	3.9	1.0	1.6	1.7	-	3.5	1.0	-	1.2	2.9
Total	2.7	1.3	1.8	1.4	2.4	1.7	1.0	1.4	1.2	1.6

3. PRESENT ANALYSES OF THE 1986 -1991 DATA SET

3.1. Catch and Effort Data

Catch and effort data for all locations and depths pooled is summarised in Table 5 and Figures 4-9. This equates to the analysis presented in Latu and Tulua (1990a; 1992).

In the present report further analyses are stratified by depth and location. Previous authors (see Annex 1) have pooled information from all locations and all depths. Even where sea mount data alone has been examined, all depths were pooled. Since all vessels are fitted with echo sounders it would seem reasonable to assume that the reported depth indicates the true depth range fished. A certain amount of inaccuracy will occur since only one depth was reported for a trip of several days (similarly for location - sea mount may change within a trip - this has been addressed in the data collection programme since November 1993). Nevertheless, analysis by reported depth (all locations and 1986 - 1991 pooled) was consistent with expectation : the number of trips and species caught per trip decreased with increasing depth (Fig. 10); species depth ranges were consistent with the literature - *Pristipomoides* spp. (100 - 200 m, Fig. 11), Etelis spp. (200 - 400 m, Fig. 12), *Epinephelis morhua* (150 - 300 m), *E. septemfas*ciatus (200 - 400 m, Fig. 13), and others, mostly Lethrinidae (< 150 m, Fig. 14).

3.1.1. Analysis by location :

Four locations were identified : Vava'u and north (grid square locations 1 - 7, Fig 1); Ha'apai (grid 8 - 9); southern Ha'apai (Nomuka group) and north of Tongatapu (grid 10 -11); and Tongatapu and south (grid 12 - 16). Sampled data (Table 6) indicates that approximately 80% of sampling effort was directed at boats landing at southern locations. This was the case each year (Fig 15). However, in 1987 more boats were located in the north (Niuatpatapu, 1, Vava'u, 16, Ha'apai, 6) than the south (Tongatapu 11, Eua, 3, Langi et al., 1992). By 1993 similar numbers existed in the north (14) and south (16) although the southern boats were considered more commercially active. It has already been shown (Table 1) that a bias towards sampling boats from the south occurred and it would seem that fishing location is subject to similar bias with northern locations under-represented. Raised values of catch and effort are thus unreliable, whilst catch rates and species composition data by location are accurate (Table 5). Similarly the pattern displayed in Fig 15 may be assumed correct : alternation of effort between Ha'apai-south and Tongatapu and Vava'u and Ha'apai.

Greater catch rates were achieved in the south than the north, although the lowest occurred in southern Ha'apai / Tonga north (Fig. 16). Mean fishing depth was less at this location than elsewhere, but in all locations it increased with time (Table 5). At all locations there was a tendency for cpue to decrease with time. Species catch rates showed no consistent trend with time north of Vava'u , but it is apparent that *E. coruscans* became increasingly more important (Fig. 17), similarly for Ha'apai (Fig 18). In southern Ha'apai / Tonga north 'other' species were predominant, consistent with the lower fishing depth Fig. 19), whilst at Tongatapu south decreasing catch rates of certain species (*P. filamentosus*) were matched by increases for *E. coruscans* (Fig. 20). Together with knowledge of increasing depth with time this is consistent with a change of target species rather than depletion.

3.1.2. Analysis by depth :

Total fishing effort decreased from 1987 - 1991 (Table 5), but whilst effort particularly decreased at depths less than 200 m, it increased at depths greater than 300 m (Table 7 and Figs. 21 & 22). Total catch landed followed the same trend (Fig 23). Catch rates expressed per trip showed no change with time at any depth range (Fig 24), but decreased per reel-hour (Fig. 25). Fishing effort (reel-hours) per trip increased with time (Fig. 26). Explanations could be that less efficient vessels dropped out of the fishery with time, or that longer trips were required to maintain total catches. This would suggest that the trip should not be used as a measure of effort in assessing yield (see Latu and Tulua, 1992). Reel-hours are used in the remainder of this report.

Species composition is significantly affected by depth (Table 7). 'Others', principally lethrinids, predominate in the range 1-100 m, and catch rate decreases over the period 1988 - 1991 (Fig 27). In the depth range 101 - 200 m *Pristipomoides filamentosus* and others are predominant. Catch rate fluctuates but decreases in *P. filamentosus* are matched by increases in *Etelis coruscans* suggesting targeting rather than depletion was the cause (Fig 28).

E. coruscans predominates in the ranges 201-300 and 301-400 and >400. *P. filamentosus* is still important between 201 - 300 m and catch rates of *E. coruscans* are less than those achieved at greater depths. *E. carbunculus* and *E. septemfasciatus* show decreasing catch rates with time whilst the other species do not (Fig 29). At depths greater than 300 m *P. filamentosus* is no longer important, and the same species catch rate trends are observed (Figs 30 & 31). All depths greater than 200 m could thus be treated as one analytical stratum (Fig. 32) as King (1992), although, because of the significant reduction of *P. filamentosus* below 300 m there is a case for taking the cut-off point as 300 m.

In subsequent analyses of catch and effort data, sub stratification by both depth and location was considered inappropriate for Vava'u and Ha'apai due to small sample size at these fishing locations.

3.1.3. Analysis by sea-mount / bank.

Data from all sea mounts and banks collected over the period of the study indicate that the mean fishing depth was 270 m and 126 m respectively, and the mean proportion of the total catch by weight consisting of the six major species was 87% and 35%. Over time, depth and species composition have changed, depth increasing each year at both sea mount and bank locations, and correspondingly the proportion of *Etelis coruscans* (Table 8). Between individual sea mount or bank locations the depth fished or proportion of the major species in the catch can vary considerably (Table 3) indicating that species composition alone is not a good indicator of the identity of a location. Frequently the depth fished on the banks has been > 200 m, presumably at the edge of the bank, and the proportion of the major species high. Certain locations around small volcanoes / islands (marked Mv in Table 3) shelve steeply and cannot strictly be defined as sea mounts or banks. Species composition varies according to depth fished at these locations.

The patterns of catch, effort and species composition occurring at the banks and sea mounts are described in Table 8 and Figures 33 - 40[2]. The general pattern observed for all data occurred for both mounts and banks : decreasing effort and total catches over time (Figs 33 & 34), but in particular the effort applied to the banks fishery decreased; steady catch rates per trip (Fig 35), but declining catch rates measured per reel-hour (Fig. 36) due to increasing reel-hours effort per trip (Fig 37); increasing depth with time. The species composition of the sea mounts was predominantly of the 6 main export species, whilst that of the banks was 'others', principally Lethrinids, although as depth increased the proportion of 'others' decreased (Table 8). Catch rates by species also show this trend (Figs 39 & 40).

Sub stratification of the sea mount fishery by depth is indicated in Table 9 and Figs. 41-48, and of the banks fishery in Table 10 and Figs. 49 - 56. Fishing effort decreased for the shallow depth ranges and increased only at depths greater than 300 m This was true for both sea mounts (Fig 41) and banks (Fig 49) with the result that by 1991 very little effort was applied on the banks. Individual species catch rates for the sea mount fishery indicated some decrease with time (eg. *E. septemfasciatus*, 200 - 299 m, Fig 47; *E. carbunculus*, > =300 m, Fig 48), but this may have been a result of target switching or interaction between species and generally there was not strong evidence of depletion. This might be expected from a sea mount fishery where sequential fishing of different mounts would maintain catch rates despite local depletion. For the banks fishery a decreasing catch rate was only observed for 'other' species in the 1-100 m depth band (Fig 54).

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[2] Note : This author was unable to generate the same effort values for sea mount locations as those published in Latu and Tulua (1992) using either their definition of locations (see Table 3) or those employed in this report. Catch rates per trip were not observed to fall (Fig 35) over time at sea mounts. Furthermore, it is clearly not the case that all export species derive solely from sea mounts. Consequently the subsequent analysis by Latu and Tulua (1992) in which yield was derived using production models should be viewed with considerable caution.

ALL LOCATIONS AND DEPTHS POOLED

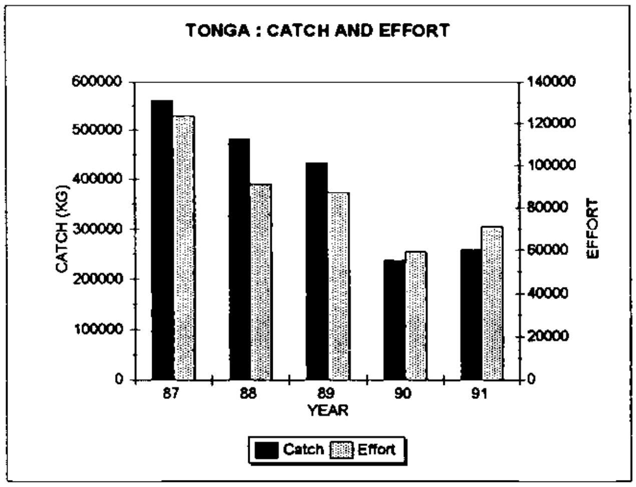


Fig. 4 : Catch (Kg) and effort (Rlhrs) per annum

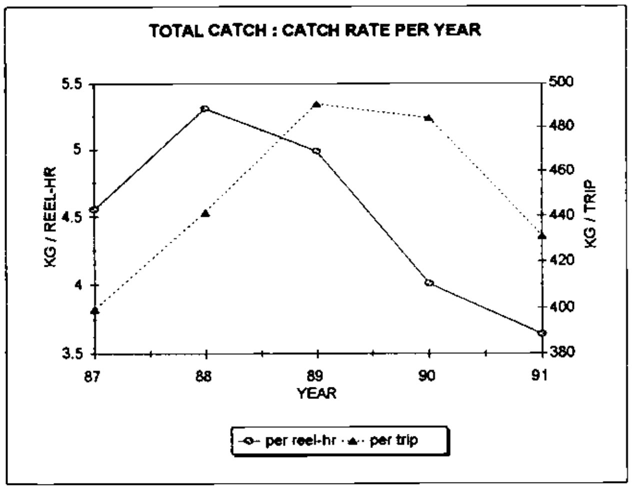


Fig. 5 : Catch rates per annum by trip and reel-hour

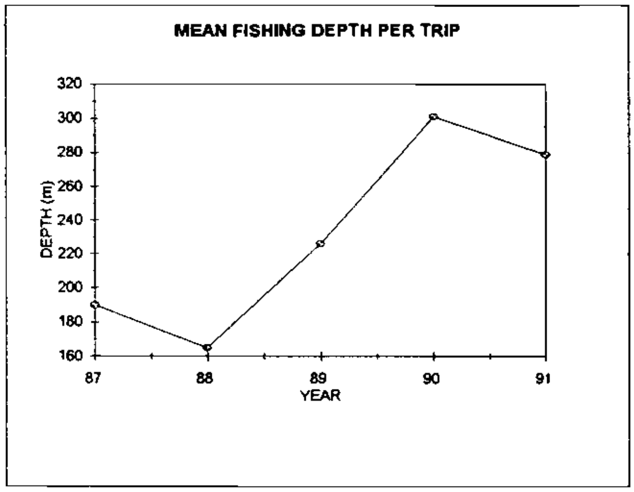


Fig. 6 : The mean fishing depth per annum

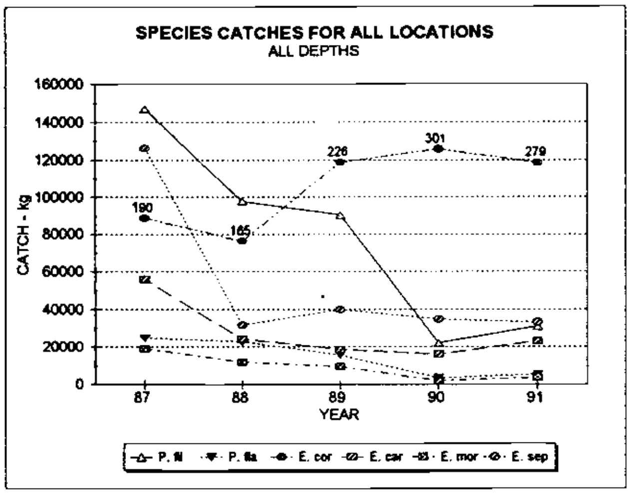


Fig. 7 : Fig. 7 : Species catches per annum

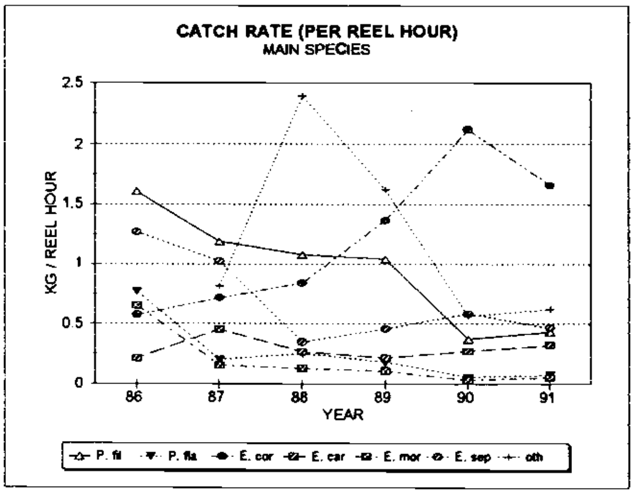


Fig. 8 : Species catch rates per annum

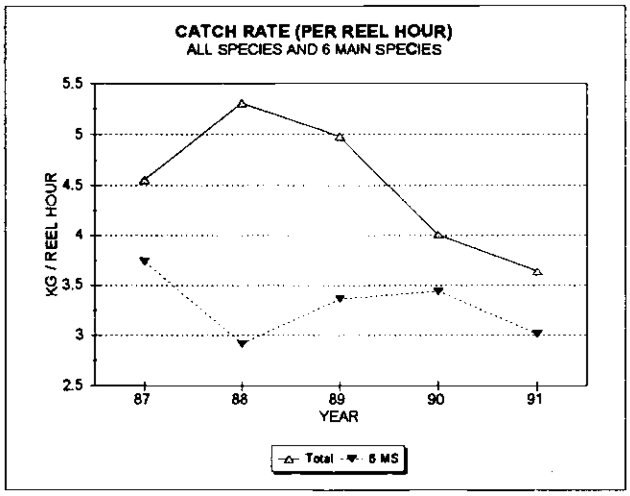
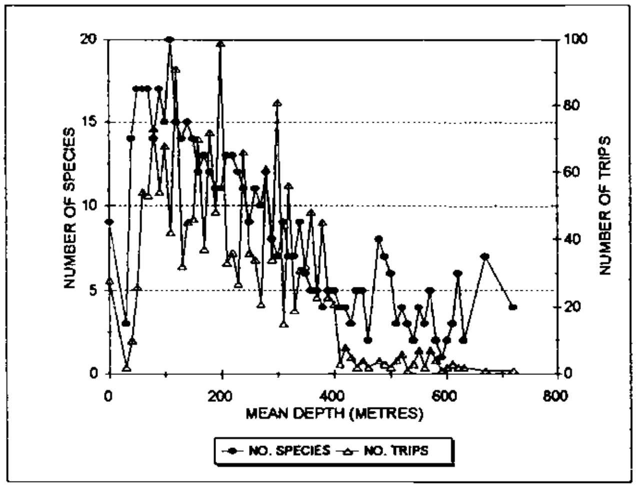


Fig. 9 : Catch rates for guilds of all species and the 6 main export species

ALL LOCATIONS AND DEPTHS POOLED



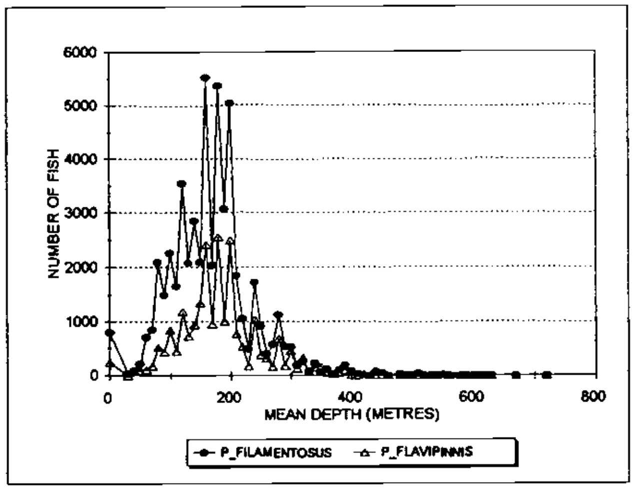
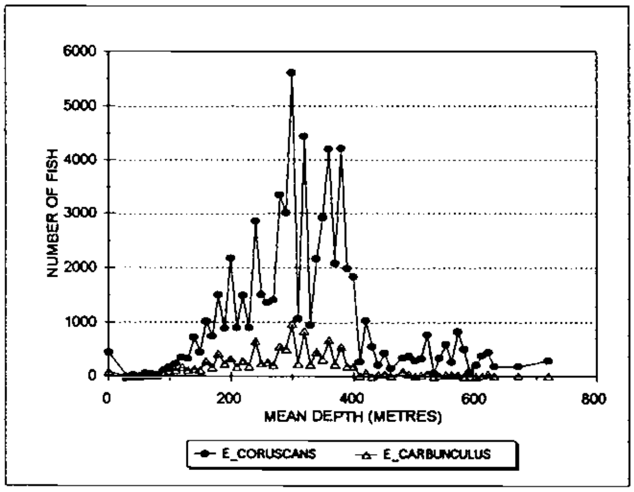


Fig. 10 : To show the number of fishing trips sampled and number of species caught by depth

Fig. 11 : Number of Pristipomoides sampled at dept



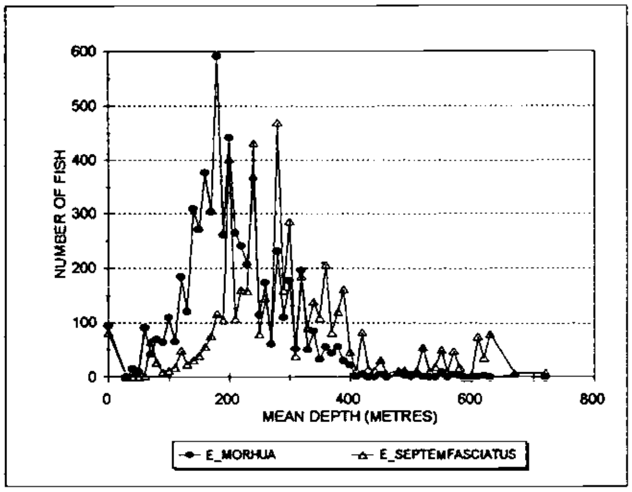


Fig. 12 : Number of Etelis sampled by depth

Fig. 13 : Number of Serranidae sampled at depth

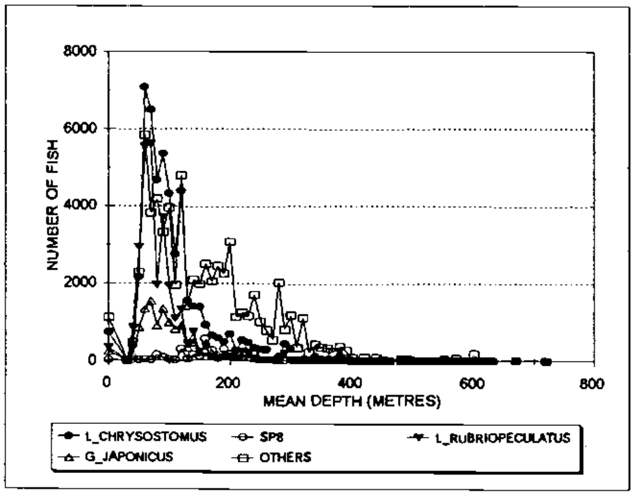


Fig. 14 : Other species sampled at depth

DATA STRATIFIED BY GEOGRAPHIC LOCATION, ALL DEPTHS POOLED

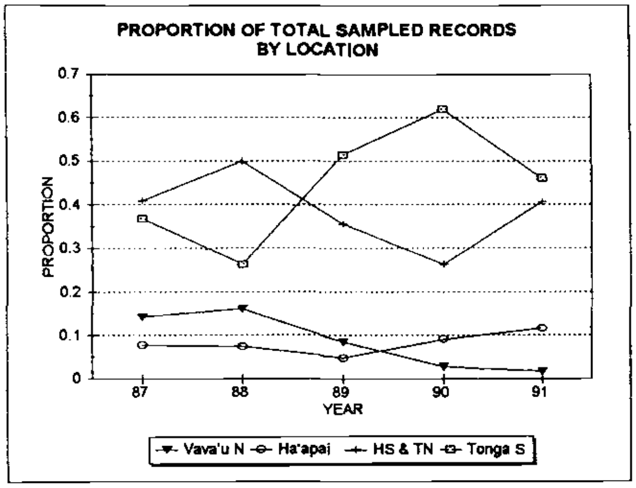


Fig. 15 : Proportion of total records on database (ie. trips sampled) by fishing location

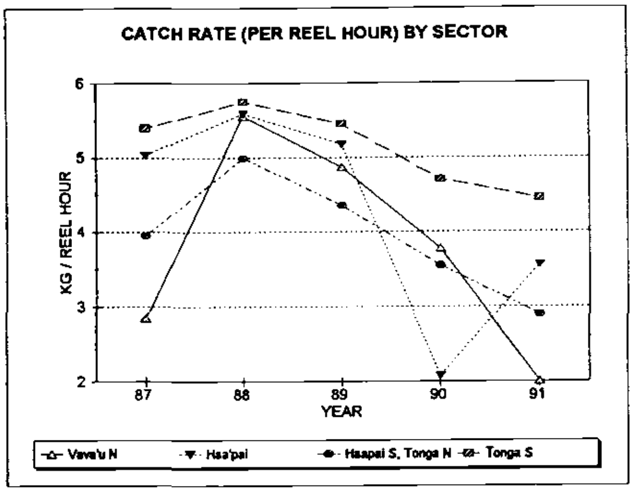


Fig. 16 : Catch rates by location

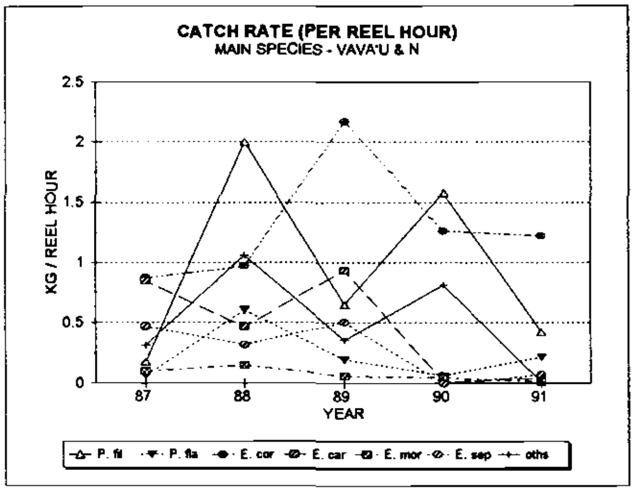


Fig. 17 : Species catch rates , Vava'u and North

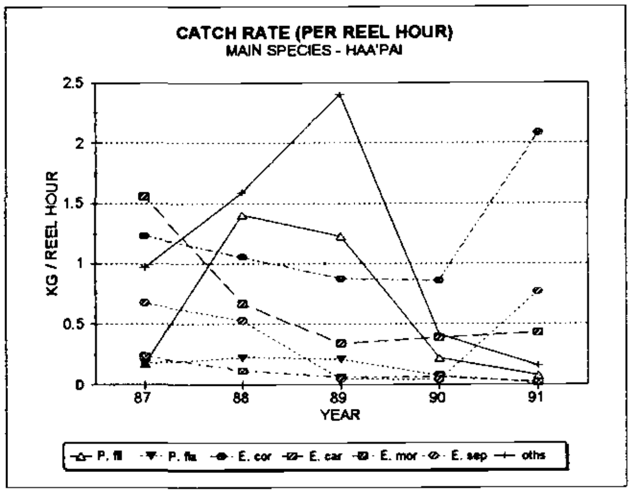


Fig. 18 : Species catch rates, Ha'apai

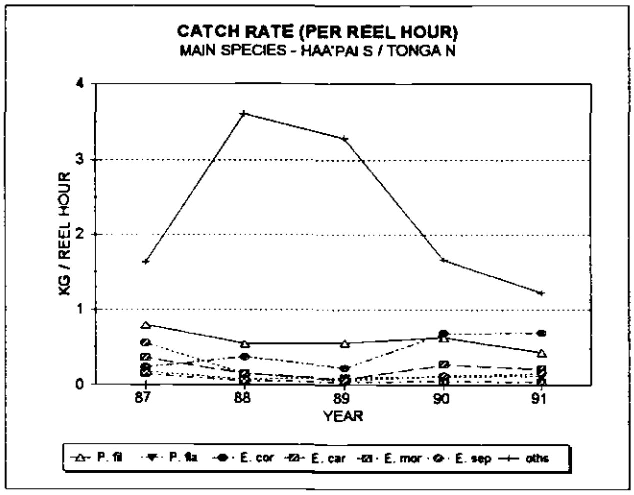


Fig. 19 : Species catch rates, Ha'apai south and Tongatapu north

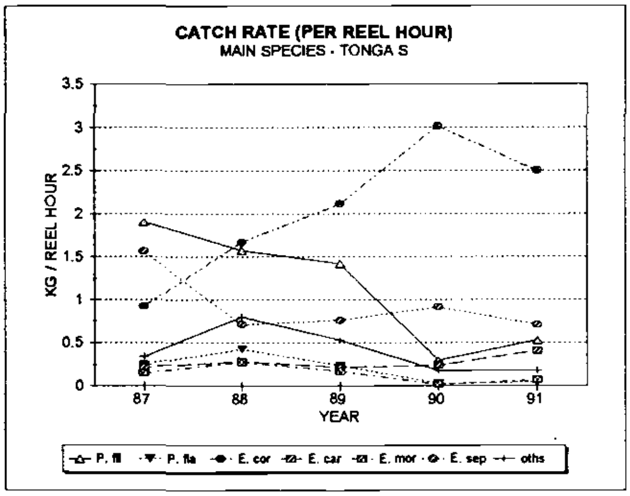


Fig. 20 : Species catch rates - Tongatapu south

DATA STRATIFIED BY DEPTH, ALL LOCATIONS POOLED

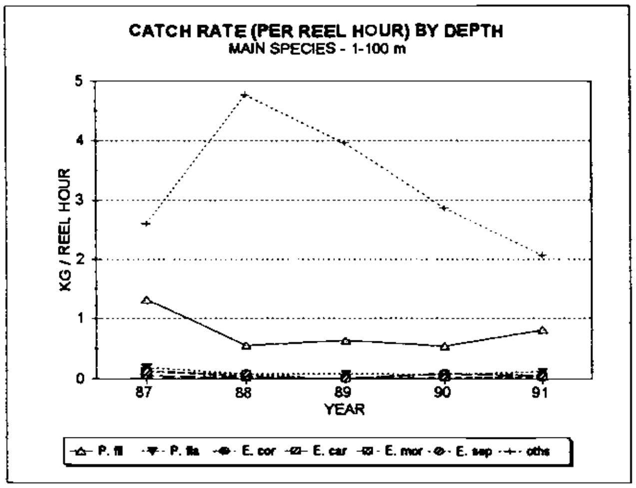


Fig. 27 : Species catch rates - 1-100m depth band

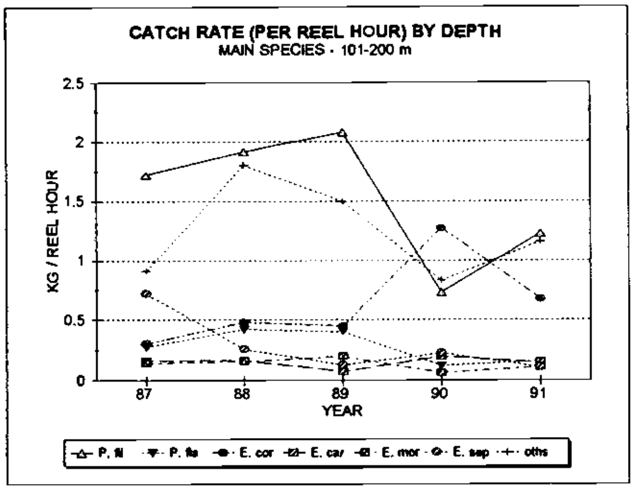


Fig. 28 : Species catch rates - 101 - 200m depth ban

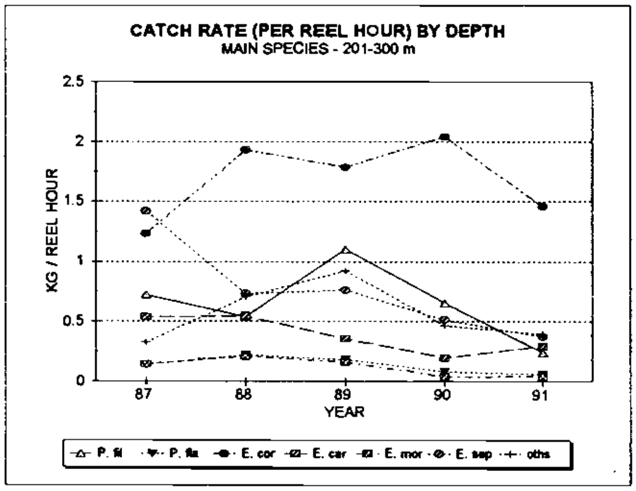


Fig. 29 : Species catch rates - 201-300m depth band

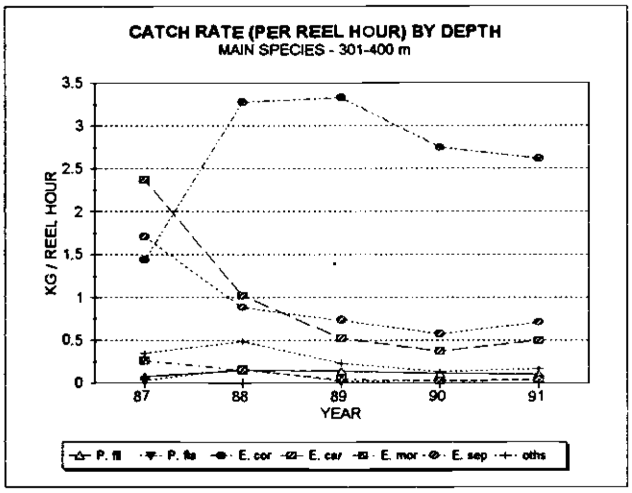


Fig. 30 : species catch rates - 301-400m depth band

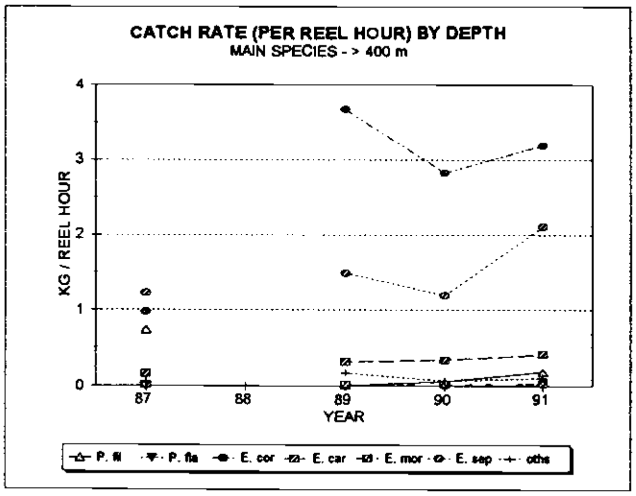


Fig. 31 : Species catch rates at depths > 400m

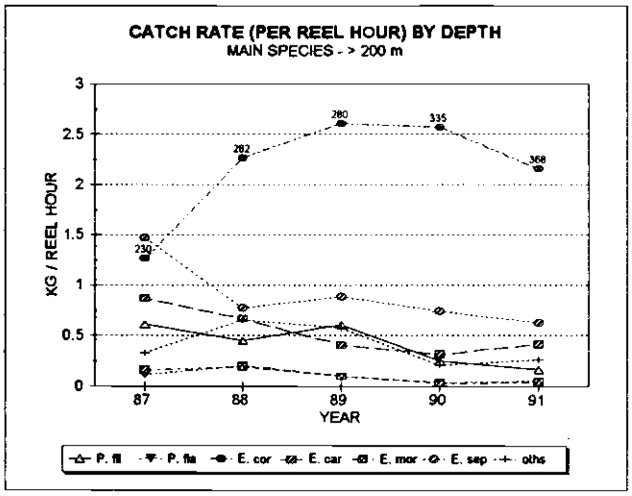


Fig. 32 : Species catch rates at depths > 200m

DATA STRATIFIED BY DEPTH, ALL LOCATIONS POOLED

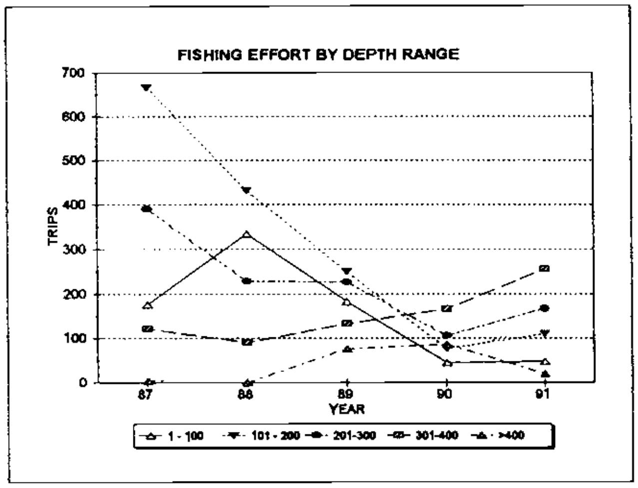


Fig. 21 : Fishing effort (trips) by depth range

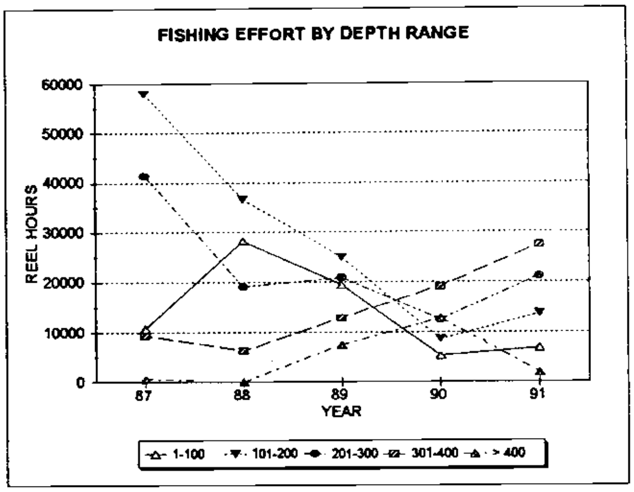


Fig. 22 : Fishing Effort (reel-hours) by depth range

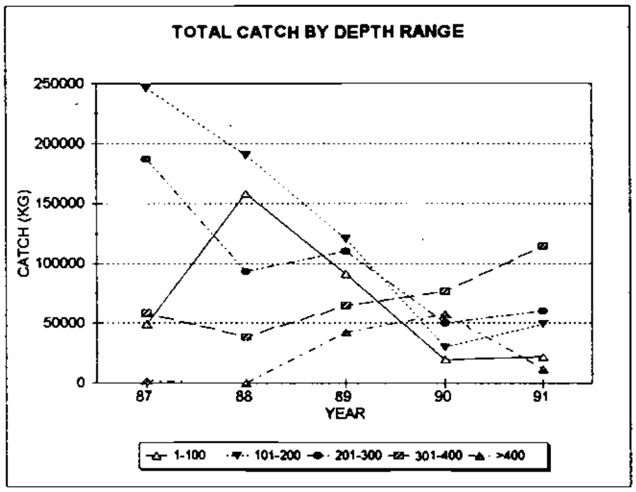


Fig. 23 : Total catch by depth range

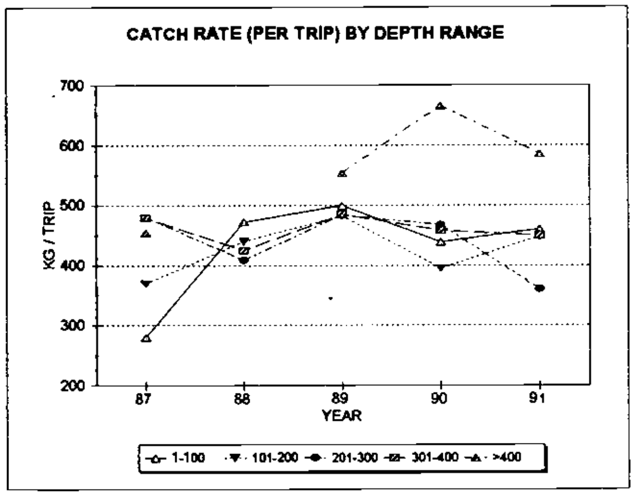


Fig. 24 : Catch rate per trip at depth

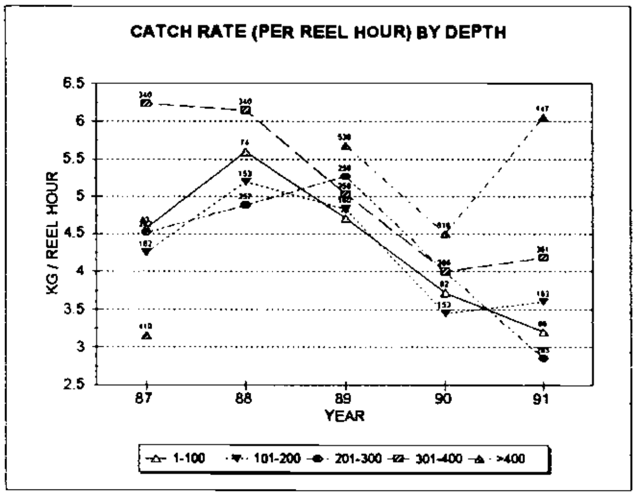


Fig. 25 : Catch rate per reel-hour at depth

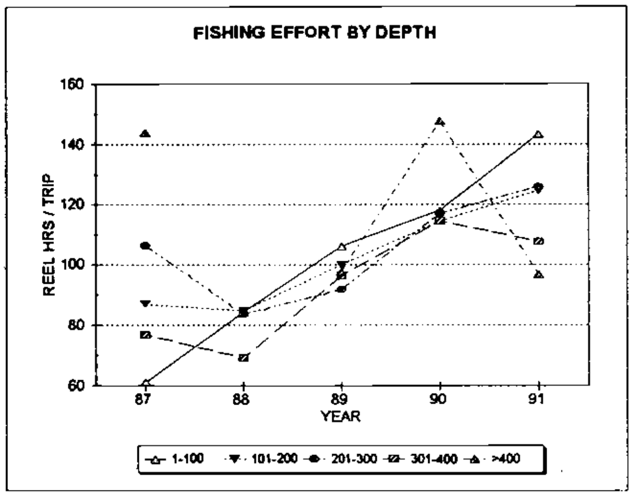


Fig. 26 : Fishing effort (reel-hours) per trip with time

DATA STRATIFIED BY LOCATION : MOUNTS / BANKS FOR ALL TONGA. ALL DEPTHS POOLED

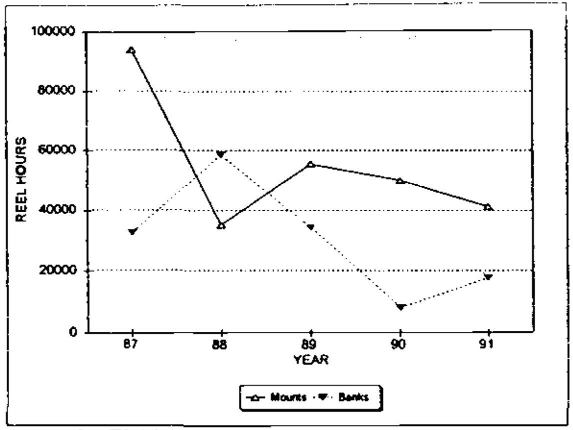


Fig. 33 : Fishing effort pa at mounts and banks

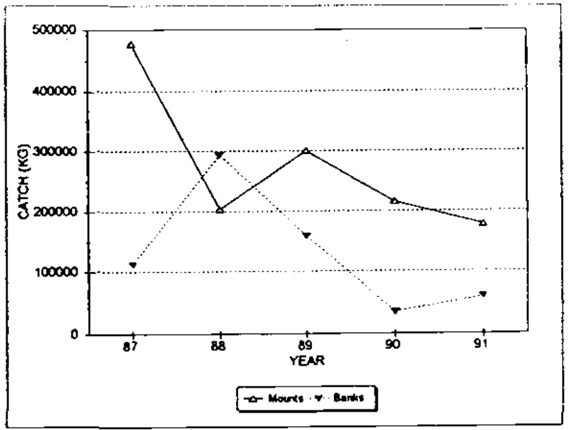


Fig. 34 : Total landed catch from mounts and banks

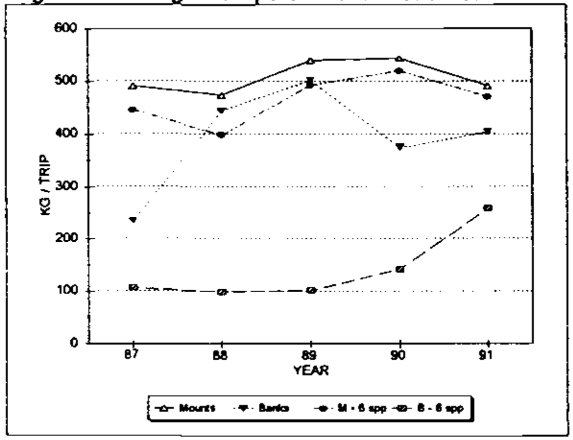


Fig. 35 : Catch rates per trip

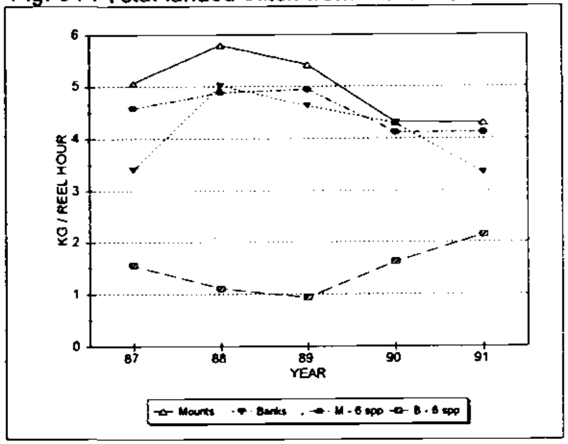


Fig. 36 : Catch rates per reel hour

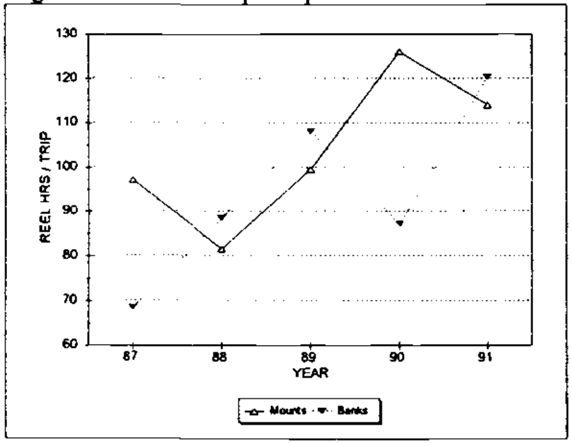


Fig. 37 : Fishing effort (reel-hours) per trip

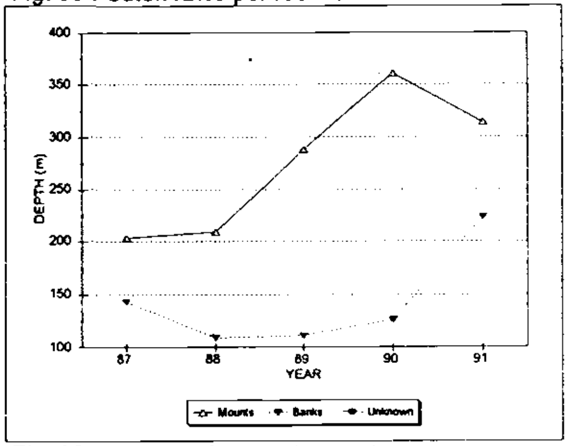


Fig. 38 : Mean fishing depth per trip

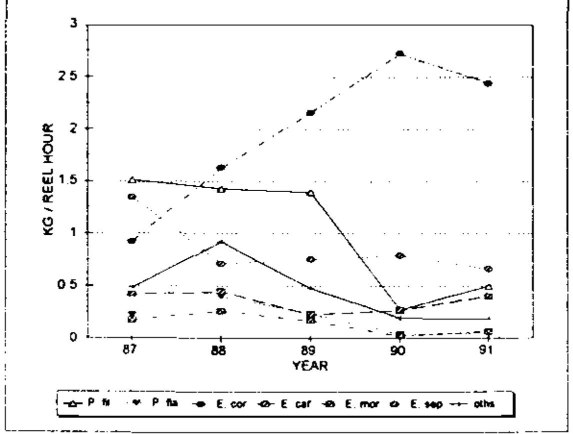


Fig. 39 : Species catch rates on sea mounts

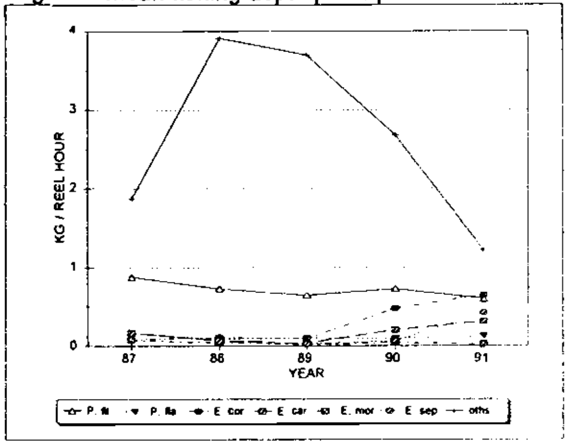


Fig. 40 : Species catch rates on banks

DATA STRATIFIED BY LOCATION AND DEPTH : SEA MOUNTS, ALL TONGA

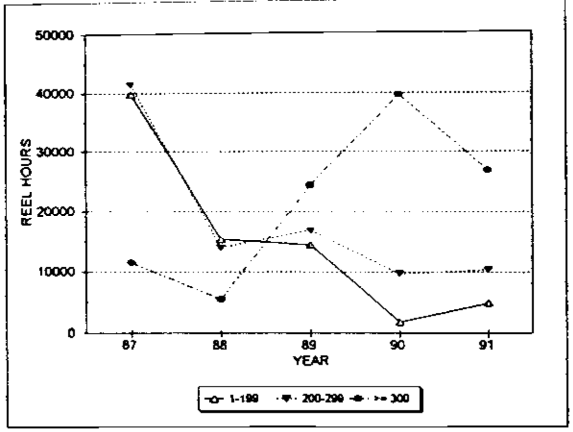


Fig. 41 : Total fishing effort (reel hours) by depth

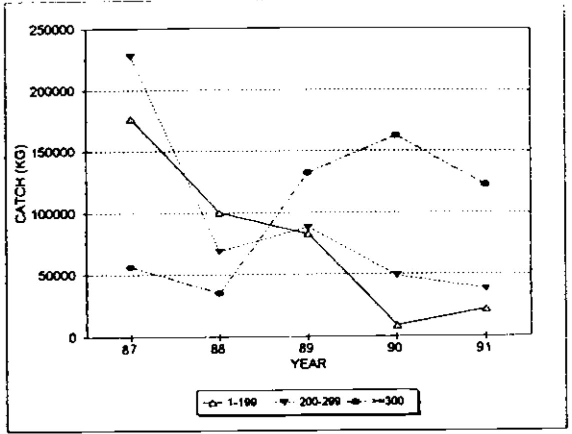


Fig. 42 : Total catch by depth band

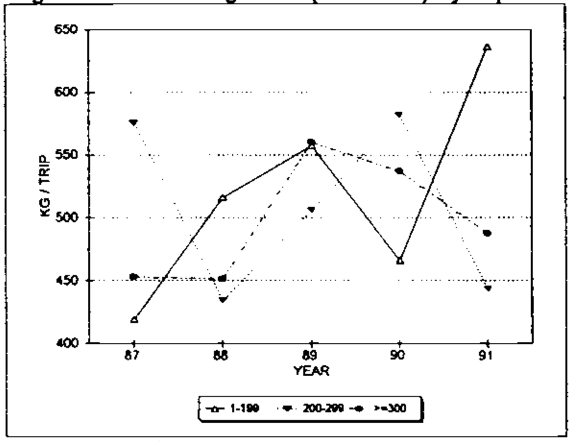


Fig. 43 : Total catch rate per trip by depth

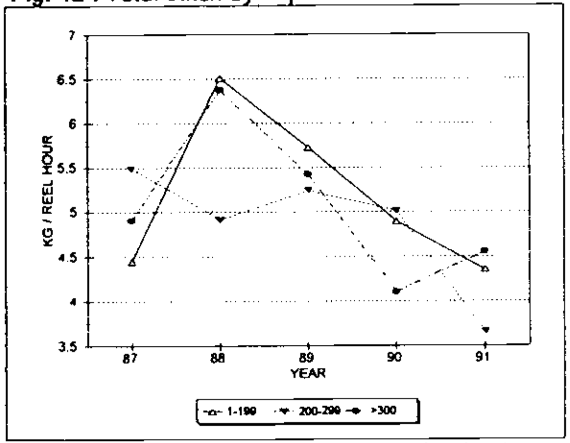


Fig. 44 : Total catch rate per reel-hour by depth

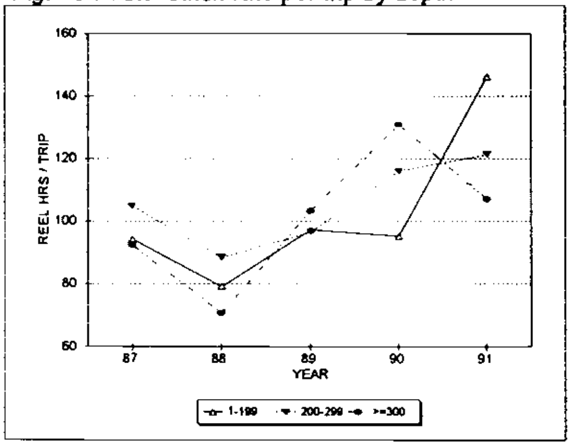


Fig. 45 : Fishing effort (reel-hours) per trip by depth

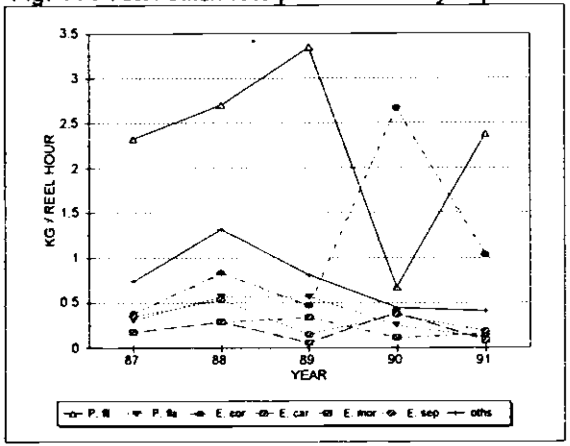


Fig. 46 : Species catch rates in 1-199m depth band

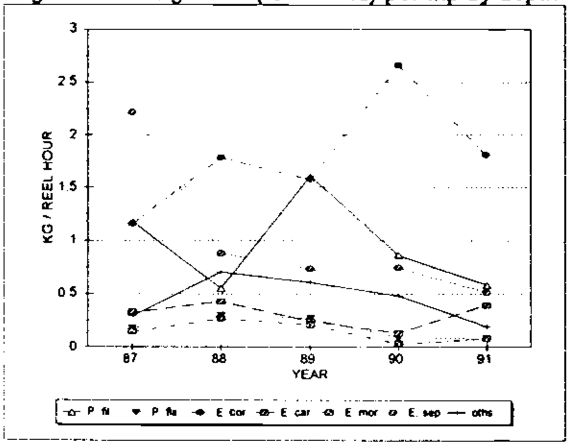


Fig. 47 : Species catch rates, 200-299m depth band

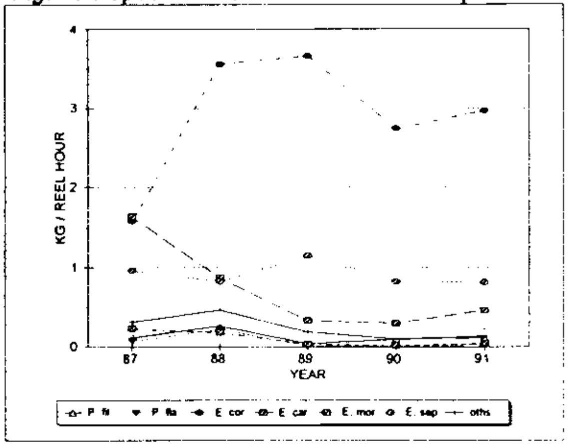


Fig. 48 : Species catch rates, >=300m depth band

DATA STRATIFIED BY LOCATION AND DEPTH : BANKS, ALL TONGA

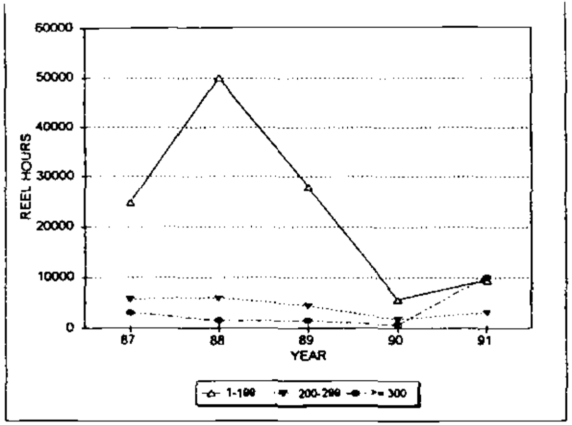


Fig. 49 : Total fishing effort (reel-hours) by depth

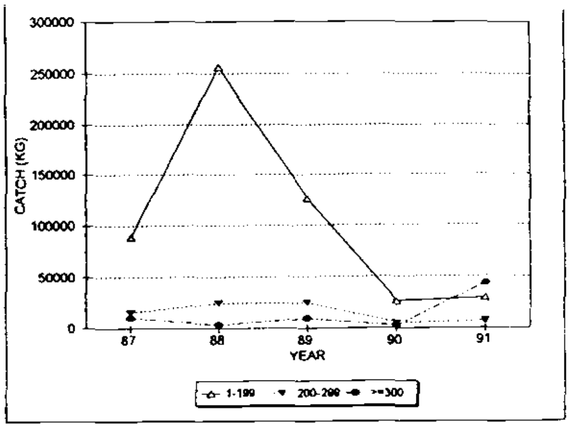


Fig. 50 : Total catch by depth

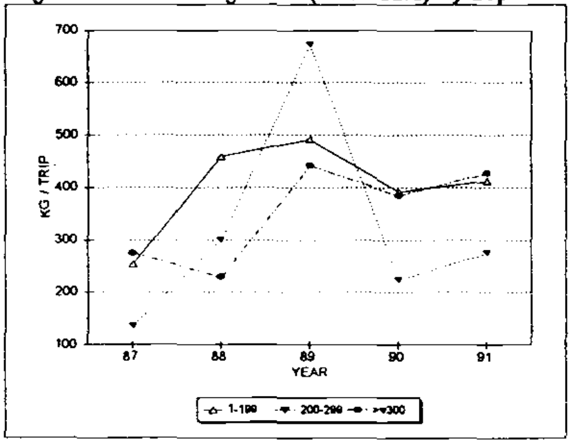


Fig. 51 : Total catch rate per trip by depth

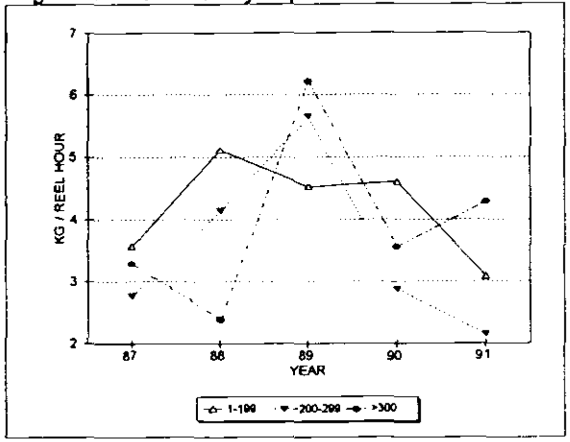


Fig. 52 : Total catch rate per reel-hour by depth

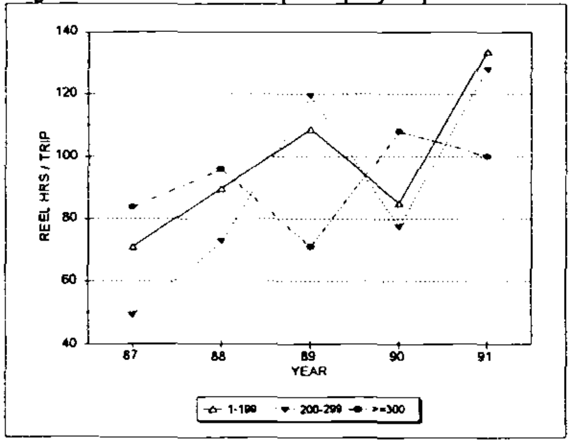


Fig. 53 : Fishing effort (reel-hours) per trip

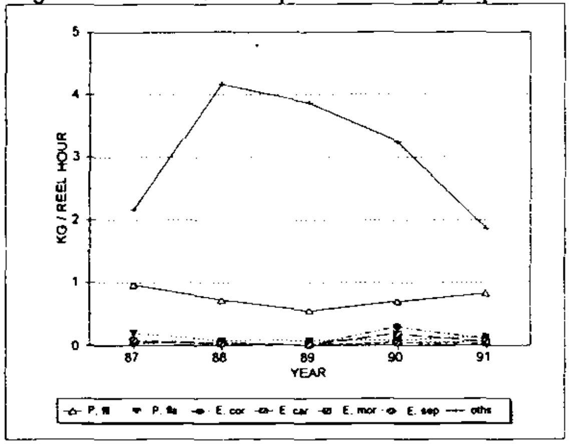


Fig. 54 : Species catch rates, 1-199m depth band

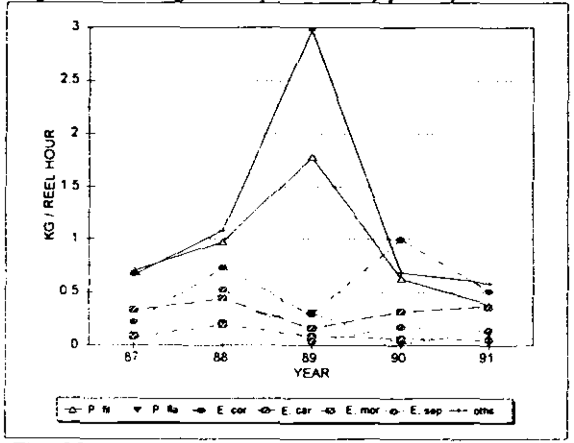


Fig. 55 : Species catch rates, 200-299m depth band

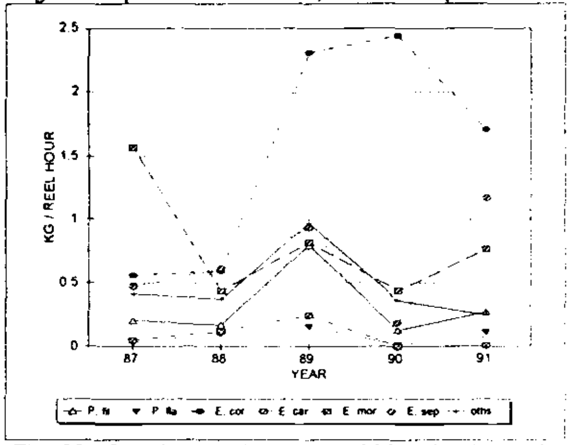


Fig. 56 : Species catch rates, >=300m depth band

TABLE 5 : Summary of annual fishing details for all locations and depths pooled and for individual locations (depths pooled).

DETAILS	1987	1988	1989	1990	1991
	ALL LOCATIONS				
Catch (tonnes)	562.66	482.17	434.24	237.76	259.69
Effort - trips	1409	1091	885	491	603
- reel-hours	123547	90778	87103	59340	71365
cpue (kg / reel-hour)	4.55	5.31	4.99	4.01	3.64
Species Composition	%	%	%	%	%
P. filamentosus	26.1%	20.3%	20.8%	9.3%	11.9%
P. flavipinnis	4.4%	4.8%	3.6%	1.5%	2.1%
E. coruscans	15.8%	15.8%	27.4%	52.9%	45.6%
E. carbunculus	9.9%	5.0%	4.3%	6.8%	8.9%
E. morhua	3.4%	2.4%	2.2%	0.8%	1.5%
E. septemfasciatus	22.4%	6.6%	9.2%	14.6%	12.8%
L. chrysostomus	6.2%	14.5%	9.0%	4.3%	5.4%
Sp 8	0.5%	0.8%	0.7%	0.1%	0.3%
L. rub	0.4%	8.7%	7.6%	2.6%	2.3%
G. jap	46.4%	2.8%	3.3%	1.2%	1.8%
oths	10.2%	18.3%	11.9%	6.0%	7.5%
Mean depth (m)	190	165	226	301	279
Mean no. species	10	14	12	9	7
Sampling frequency %	23.85	54.35	40.45	45.00	40.00

DETAILS	1987	1988	1989	1990	1991	1987	1988	1989	1990	1991
	VAVA'U & NORTH					HA'APAI				
Catch (tonnes)	47.68	66.53	27.13	1.69	2.56	45.65	34.00	16.14	19.66	29.08
Effort - trips	201	171	74	13	10	109	81	42	44	68
- reel-hours	16742	11961	5572	447	1275	9065	6079	3120	9480	8165
cpue (kg / reel-hour)	2.85	5.56	4.87	3.78	2.01	5.04	5.59	5.17	2.07	3.56
Species Composition	%	%	%	%	%	%	%	%	%	%
P. filamentosus	6.3%	35.9%	13.4%	41.8%	21.3%	3.5%	25.2%	23.7%	10.8%	2.2%
P. flavipinnis	2.3%	10.9%	4.0%	1.7%	10.9%	3.6%	4.1%	4.1%	3.7%	0.5%
E. coruscans	30.6%	17.4%	44.5%	33.4%	60.9%	24.5%	18.9%	16.9%	41.4%	58.5%
E. carbunculus	29.7%	8.4%	19.2%	0.3%	2.2%	30.9%	12.0%	6.6%	18.8%	12.1%
E. morhua	3.5%	2.7%	1.3%	1.2%	0.6%	4.8%	2.1%	1.2%	3.2%	0.6%
E. septemfasciatus	16.5%	5.7%	10.3%	0.0%	3.6%	13.4%	9.4%	0.9%	2.0%	21.5%
L. chrysostomus	2.8%	4.1%	0.9%	10.0%	0.0%	6.3%	8.9%	16.7%	5.2%	0.3%
Sp 8	0.2%	0.4%	0.3%	0.0%	0.0%	0.6%	0.0%	0.1%	0.1%	0.0%
L. rub	0.0%	0.2%	0.1%	2.2%	0.0%	0.1%	4.4%	10.4%	1.4%	0.0%
G. jap	1.3%	0.4%	0.2%	0.2%	0.0%	24.8%	0.7%	4.5%	1.5%	0.1%
oths	7.7%	13.8%	5.9%	9.1%	0.6%	12.1%	14.4%	14.7%	11.9%	4.2%
Mean depth (m)	239	196	265	205	337	256	177	199	274	325
Mean no. species	7	11	8	5	2	11	13	26	13	5
	HA'APAI S & TONGA N					TONGA & SOUTH				
Catch (tonnes)	159.50	242.68	142.13	48.87	89.18	309.83	138.96	247.43	167.55	136.54
Effort - trips	579	548	311	129	245	520	291	452	304	275
- reel-hours	40356	48592	32635	13778	30833	57384	24145	45389	35636	30683
cpue (kg / reel-hour)	3.95	4.99	4.36	3.55	2.89	5.40	5.75	5.45	4.70	4.45
Species Composition	%	%	%	%	%	%	%	%	%	%
P. filamentosus	20.5%	11.2%	13.0%	17.7%	15.1%	35.5%	27.4%	26.1%	6.4%	11.9%
P. flavipinnis	4.7%	1.6%	2.2%	3.1%	4.1%	4.7%	7.5%	4.4%	0.7%	1.0%
E. coruscans	6.2%	7.5%	5.2%	19.4%	23.9%	17.2%	29.0%	38.8%	64.2%	56.3%
E. carbunculus	9.3%	3.1%	1.9%	7.8%	7.5%	4.1%	4.9%	3.9%	5.1%	9.2%
E. morhua	3.7%	1.1%	0.9%	1.4%	1.6%	3.0%	4.8%	3.1%	0.4%	1.6%
E. septemfasciatus	14.1%	3.1%	1.4%	3.6%	5.5%	29.0%	12.4%	14.0%	19.4%	15.9%
L. chrysostomus	18.7%	26.1%	24.6%	18.1%	14.9%	0.3%	0.8%	0.4%	0.1%	0.4%
Sp 8	1.1%	0.2%	0.1%	0.2%	0.8%	0.1%	2.1%	1.2%	0.0%	0.0%
L. rub	1.3%	16.6%	20.9%	11.8%	6.6%	0.0%	0.2%	0.7%	0.0%	0.0%
G. jap	82.8%	5.2%	8.8%	5.4%	4.9%	0.9%	0.2%	0.4%	0.0%	0.1%
oths	18.5%	24.4%	21.1%	11.4%	15.0%	6.0%	10.7%	7.0%	3.7%	3.5%
Mean depth (m)	157	128	132	171	225	195	213	288	364	312
Mean no. species	12	17	16	17	11	8	12	8	5	5

Note that details presented for all locations are an analysis of all information - the sum of catch and effort by location may not equal the total in 'all locations' due a number of records of unknown location

Table 6 : To indicate the number of fishing trips sampled by fishing location (grid square and sea mount) for the period November 1986 - December 1991 (Note only 10 records occur for 1986)

LOCN	Vava'u and north						Ha'apai		HS & TN		Tongatapu south						
GRID ->	1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	UNK	TOTAL
MOUNT																	
0	3	0	0	0	1	0	1	1	2	10	0	4	4	1	0	2	29
1	0	6	0	1	7	3	13	15	23	15	3	19	53	45	12	0	215
2	0	0	0	0	3	5	27	18	19	22	2	59	24	6	0	0	185
3	3	0	1	11	4	0	8	0	114	174	4	2	82	4	0	0	407
4	4	0	0	1	11	0	4	2	13	43	2	37	3	23	0	1	144
5	0	0	0	0	4	0	5	0	99	5	1	4	5	10	0	0	133
6	0	0	0	0	30	0	3	0	14	26	0	50	22	2	0	0	147
7	0	0	0	0	2	0	5	0	6	18	0	18	0	0	0	0	49
8	0	0	0	0	10	0	13	0	21	9	0	2	0	0	0	0	55
9	0	0	0	1	71	0	8	0	33	6	0	34	0	0	0	1	154
10	0	0	0	0	1	0	10	0	17	15	0	23	0	0	0	0	66
11	0	0	0	0	1	0	1	0	0	1	0	14	0	0	0	0	17
12	0	0	0	0	0	0	1	0	0	7	0	5	0	0	0	0	13
13	0	0	0	0	0	0	0	0	0	1	0	5	0	0	0	0	6
14	0	0	0	0	0	0	0	0	0	9	0	1	0	0	0	0	10
16	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	3
17	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
18	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	8
19	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2
20	0	0	0	0	0	0	0	0	0	0	0	126	0	0	0	0	126
21	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
30	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
TOTAL	10	6	1	14	145	8	99	36	362	361	12	418	193	91	12	4	1772
Tot locn						184		135		723					726	4	1772

TABLE 7 : Summary of annual fishing details by depth range

DETAILS	1987	1988	1989	1990	1991	1987	1988	1989	1990	1991
	1 - 101 m					**101 - 200 m**				
Catch (tonnes)	49.26	158.18	91.36	19.52	21.86	246.44	190.33	120.65	29.82	49.32
Effort - trips	176	335	183	44	48	667	432	250	76	110
- reel-hours	10776	28236	19399	5244	6815	57971	36622	24964	8640	13705
cpue (kg / reel-hour)	4.57	5.60	4.71	3.72	3.21	4.25	5.20	4.83	3.45	3.60
Species Composition										
P. filamentosus	29.0%	10.0%	13.6%	14.7%	25.5%	40.5%	36.9%	43.1%	21.2%	34.2%
P. flavipinnis	4.3%	1.4%	1.7%	2.1%	4.0%	6.5%	8.1%	8.3%	3.5%	4.5%
E. coruscans	2.7%	0.7%	0.2%	2.7%	2.2%	7.2%	9.2%	9.3%	36.9%	18.8%
E. carbunculus	1.3%	0.4%	0.2%	2.2%	1.5%	3.9%	3.1%	1.5%	5.7%	4.2%
E. morhua	3.0%	0.7%	0.3%	0.6%	0.9%	3.4%	3.0%	4.1%	1.9%	3.1%
E. septemfasciatus	2.7%	1.6%	0.1%	0.5%	1.4%	17.0%	5.0%	2.7%	6.5%	3.1%
L. chrysostomus	26.8%	30.0%	26.5%	30.0%	25.2%	7.3%	10.7%	8.2%	7.8%	9.8%
Epinephelus sp.	0.4%	0.2%	0.1%	0.4%	2.0%	0.8%	1.3%	2.0%	0.0%	0.4%
L. rubriopeculatus	2.0%	22.5%	27.3%	25.6%	16.4%	0.4%	3.4%	4.4%	2.2%	2.7%
G. japonicus	2.7%	6.0%	9.5%	8.2%	8.9%	0.8%	2.0%	3.2%	2.8%	3.4%
others	25.1%	26.5%	20.6%	12.9%	12.2%	12.1%	17.4%	13.1%	11.3%	15.8%
Mean depth	83	74	75	82	86	162	153	160	153	163
Mean no. species	12	16	17	16	15	11	15	13	18	13
	201 - 300 m					**301 - 400 m**				
Catch (tonnes)	187.24	93.22	110.14	49.88	60.33	58.26	38.29	64.75	76.35	114.77
Effort - trips	390	228	227	107	168	122	90	133	167	255
- reel-hours	41438	19087	20888	12482	21100	9338	6230	12858	19067	27410
cpue (kg / reel-hour)	4.52	4.88	5.27	4.00	2.86	6.24	6.15	5.04	4.00	4.19
Species Composition										
P. filamentosus	16.0%	11.1%	20.9%	16.4%	8.5%	1.3%	2.5%	2.8%	2.8%	2.6%
P. flavipinnis	3.1%	4.6%	3.5%	2.0%	2.1%	0.5%	2.7%	0.5%	0.7%	1.0%
E. coruscans	27.2%	39.6%	33.9%	51.1%	51.0%	23.0%	53.4%	66.1%	68.6%	62.5%
E. carbunculus	11.9%	11.2%	6.8%	4.9%	10.2%	38.0%	16.7%	10.4%	9.4%	12.0%
E. morhua	3.1%	4.2%	3.0%	1.0%	1.4%	4.2%	2.5%	1.0%	0.7%	1.0%
E. septemfasciatus	31.4%	15.0%	14.4%	12.9%	13.0%	27.4%	14.4%	14.5%	14.4%	17.0%
L. chrysostomus	1.6%	1.8%	3.6%	1.5%	3.2%	0.6%	1.2%	0.1%	0.5%	0.6%
Epinephelus sp.	0.1%	1.0%	0.5%	0.1%	0.1%	0.2%	0.2%	0.0%	0.0%	0.0%
L. rubriopeculatus	0.1%	0.1%	1.8%	0.3%	1.0%	0.0%	0.1%	0.0%	0.0%	0.1%
G. japonicus	0.2%	0.2%	0.9%	0.3%	0.9%	0.1%	0.1%	0.1%	0.2%	0.2%
others	5.2%	11.3%	10.7%	9.6%	8.4%	4.7%	6.3%	4.4%	2.7%	3.1%
Mean depth	262	257	258	261	265	340	340	350	359	361
Mean no. species	9	12	13	9	6	9	9	6	5	4
	> 400m					**> 200m**				
Catch (tonnes)	1.91	0.00	42.46	57.70	11.72	247.40	131.51	217.35	183.92	186.82
Effort - trips	4	0	77	87	20	516	318	438	360	443
- reel-hours	604	0	7471	12809	1935	51379	25317	41216	44358	50445
cpue (kg / reel-hour)	3.16		5.68	4.50	6.06	4.82	5.19	5.27	4.15	3.70
Species Composition										
P. filamentosus	23.3%		0.1%	1.3%	3.1%	12.6%	8.6%	11.5%	6.0%	4.5%
P. flavipinnis	0.0%		0.1%	0.2%	0.4%	2.5%	4.0%	1.9%	0.9%	1.3%
E. coruscans	30.7%		64.6%	62.6%	52.6%	26.3%	43.6%	49.5%	62.0%	58.1%
E. carbunculus	5.0%		5.6%	7.5%	6.8%	18.0%	12.8%	7.6%	7.6%	11.1%
E. morhua	0.5%		0.3%	0.4%	0.6%	3.4%	3.7%	1.9%	0.7%	1.1%
E. septemfasciatus	38.8%		26.3%	26.4%	34.8%	30.5%	14.8%	16.8%	17.8%	16.8%
L. chrysostomus	0.0%		0.0%	0.0%	0.5%	1.4%	1.6%	1.8%	0.6%	1.4%
Epinephelus sp.	0.0%		0.0%	0.0%	0.0%	0.1%	0.8%	0.3%	0.0%	0.1%
L. rubriopeculatus	0.0%		0.0%	0.0%	0.0%	0.1%	0.1%	0.9%	0.1%	0.4%
G. japonicus	0.0%		0.0%	0.0%	0.1%	0.2%	0.2%	0.5%	0.2%	0.4%
others	1.6%		3.0%	1.5%	1.1%	5.0%	9.9%	7.3%	4.2%	4.7%
Mean depth	410	0	538	516	447	282	280	335	368	329
Mean no. species	8	0	3	4	5	9	11	9	6	5

Table 8 . Summary of Annual fishing details for

a. Sea mounts

DETAILS	1987	1988	1989	1990	1991
Catch (tonnes)	477.62	203.65	300.80	215.84	177.95
Effort - trips	971	431	558	397	363
- reel-hours	94284	35099	55482	50067	41367
cpue (kg / reel-hour)	5.07	5.80	5.42	4.31	4.30
Species Composition					
P. filamentosus	30.0%	24.6%	25.7%	6.3%	11.6%
P. flavipinnis	4.3%	6.9%	4.3%	1.0%	1.2%
E. coruscans	18.1%	28.1%	39.9%	63.2%	56.8%
E. carbunculus	8.2%	7.7%	4.2%	6.2%	9.2%
E. morhua	3.4%	4.5%	3.1%	0.6%	1.5%
E. septemfasciatus	26.4%	12.3%	13.9%	18.4%	15.4%
L. chrysostomus	1.4%	2.0%	0.3%	0.2%	0.3%
Epinephelus sp.	0.5%	1.9%	1.1%	0.0%	0.0%
L. rubriopeculatus	0.1%	0.7%	0.3%	0.0%	0.0%
G. japonicus	0.2%	0.4%	0.3%	0.1%	0.1%
others	7.4%	10.9%	6.9%	4.1%	3.8%
Mean depth	203	209	288	361	314
Mean no. species	9	12	8	6	5

b. Banks

DETAILS	1987	1988	1989	1990	1991
Catch (tonnes)	111.22	293.76	158.58	34.58	59.67
Effort - trips	476	662	316	92	148
- reel-hours	32590	58583	34215	8050	17816
cpue (kg / reel-hour)	3.41	5.01	4.63	4.30	3.35
Species Composition					
P. filamentosus	25.8%	14.5%	14.0%	16.9%	17.9%
P. flavipinnis	5.0%	1.8%	2.2%	2.2%	3.8%
E. coruscans	2.4%	2.2%	2.0%	11.1%	19.5%
E. carbunculus	5.0%	1.3%	0.8%	4.7%	9.4%
E. morhua	2.3%	1.0%	0.5%	1.1%	0.7%
E. septemfasciatus	4.8%	1.3%	0.7%	1.5%	12.5%
L. chrysostomus	27.1%	29.0%	26.5%	25.4%	15.7%
Epinephelus sp.	0.1%	0.1%	0.2%	0.0%	0.7%
L. rubriopeculatus	1.3%	17.6%	23.5%	19.8%	6.9%
G. japonicus	2.2%	5.5%	8.4%	5.7%	5.3%
others	23.9%	25.7%	21.2%	11.4%	7.5%
Mean depth	143	109	111	126	223
Mean no. species	12	16	19	13	11

Table 9 Summary of Annual fishing details for all sea mounts by depth

	a. 1 - 199 m					b. 200 - 299 m					c. > = 300 m				
DETAILS	1987	1988	1989	1990	1991	1987	1988	1989	1990	1991	1987	1988	1989	1990	1991
Catch (tonnes)	177.15	100.40	83.02	8.91	21.52	227.65	68.85	88.52	48.81	37.89	56.53	35.01	132.18	162.77	122.37
Effort - trips	423	195	149	19	34	396	158	175	84	86	125	78	236	303	251
- reel-hours	39845	15410	14492	1820	4945	41441	14006	16882	9736	10378	11516	5487	24368	39669	26855
cpue (kg / reel-hour)	4.45	6.52	5.73	4.90	4.35	5.49	4.92	5.24	5.01	3.65	4.91	6.38	5.42	4.10	4.56
Species Composition															
P. filamentosus	52.3%	41.4%	58.4%	13.7%	54.5%	21.5%	11.3%	30.6%	17.3%	16.0%	2.5%	4.1%	0.8%	2.4%	2.5%
P. flavipinnis	6.9%	8.7%	9.9%	5.0%	2.6%	3.2%	6.1%	5.2%	1.8%	2.2%	1.6%	3.5%	0.2%	0.5%	0.6%
E. coruscans	8.6%	12.7%	8.1%	54.5%	23.7%	21.1%	36.3%	30.0%	53.1%	49.4%	32.1%	55.8%	67.5%	66.8%	65.1%
E. carbunculus	3.9%	4.3%	1.0%	8.0%	1.9%	5.9%	8.6%	4.6%	2.6%	10.8%	33.3%	13.7%	6.1%	7.3%	10.1%
E. morhua	3.9%	4.4%	5.8%	2.3%	3.6%	2.6%	5.4%	4.0%	0.6%	2.2%	4.7%	2.8%	0.6%	0.4%	0.9%
E. septemfasciatus	7.9%	8.2%	2.6%	7.4%	4.3%	40.3%	17.9%	14.1%	14.9%	14.1%	19.6%	12.9%	21.2%	20.1%	17.8%
L. chrysostomus	2.8%	3.8%	0.7%	0.2%	0.1%	0.4%	0.4%	0.3%	0.1%	1.0%	1.4%	0.2%	0.0%	0.2%	0.2%
Epinephelus sp.	1.0%	2.8%	3.3%	0.1%	0.0%	0.1%	1.5%	0.7%	0.1%	0.0%	0.3%	0.4%	0.0%	0.0%	0.0%
L. rubriopeculatus	0.2%	1.3%	0.6%	0.1%	0.0%	0.0%	0.0%	0.4%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
G. japonicus	0.3%	0.8%	0.8%	0.0%	0.0%	0.1%	0.1%	0.2%	0.0%	0.2%	0.2%	0.0%	0.0%	0.1%	0.1%
others	12.2%	11.5%	8.7%	8.7%	9.3%	4.7%	12.4%	10.0%	9.5%	3.9%	4.6%	6.6%	3.5%	2.2%	2.7%
Mean depth	147	140	157	151	173	242	244	241	240	249	327	319	415	410	356
Mean no. species	10	13	11	10	8	9	13	10	7	6	8	10	4	5	4

Table 10. Summary of Annual fishing details for all banks by depth

	a. 1 - 199 m					b. 200 - 299 m					c. > = 300 m				
DETAILS	1987	1988	1989	1990	1991	1987	1988	1989	1990	1991	1987	1988	1989	1990	1991
Catch (tonnes)	88.67	256.56	126.67	25.90	29.15	15.60	24.79	24.79	4.93	6.82	10.01	3.66	9.48	2.47	43.32
Effort - trips	349	559	258	66	71	115	82	37	22	25	36	16	21	6	101
- reel-hours	24814	50129	27974	5630	9456	5638	5982	4394	1712	3182	3046	1534	1524	695	10139
cpue (kg / reel-hour)	3.57	5.12	4.53	4.60	3.08	2.77	4.14	5.64	2.88	2.14	3.29	2.39	6.22	3.56	4.27
Species Composition															
P. filamentosus	26.9%	14.1%	12.1%	15.2%	26.8%	25.4%	23.4%	31.6%	21.7%	17.9%	6.2%	7.1%	12.8%	3.6%	6.4%
P. flavipinnis	5.5%	1.6%	1.8%	1.9%	4.4%	3.5%	5.1%	5.5%	0.5%	5.6%	1.0%	4.0%	2.5%	0.3%	2.5%
E. coruscans	1.0%	1.2%	0.3%	6.5%	3.3%	8.0%	17.7%	5.1%	34.6%	23.7%	16.9%	24.8%	37.1%	68.6%	40.0%
E. carbunculus	1.8%	0.6%	0.1%	4.0%	2.0%	12.0%	10.6%	2.9%	11.0%	16.8%	47.6%	18.2%	13.1%	12.2%	17.8%
E. morhua	2.3%	0.7%	0.3%	1.1%	1.0%	2.8%	4.6%	1.5%	2.3%	2.3%	1.5%	5.0%	3.9%	0.0%	0.2%
E. septemfasciatus	2.2%	0.5%	0.1%	1.0%	2.1%	24.3%	12.6%	0.6%	6.0%	6.6%	14.3%	25.6%	14.9%	5.2%	27.3%
L. chrysostomus	30.0%	30.1%	28.3%	28.9%	26.9%	11.9%	12.1%	19.0%	7.8%	10.0%	6.3%	5.3%	3.0%	3.1%	1.9%
Epinephelus sp.	0.1%	0.1%	0.1%	0.1%	1.4%	0.1%	0.1%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
L. rubriopeculatus	1.5%	18.7%	26.7%	24.4%	12.6%	0.4%	0.1%	2.6%	1.3%	0.8%	0.0%	0.0%	0.0%	0.0%	0.6%
G. japonicus	2.5%	5.8%	9.3%	6.5%	9.3%	0.8%	0.3%	2.2%	0.3%	2.5%	0.2%	0.0%	0.1%	0.0%	0.6%
others	26.3%	26.5%	20.8%	10.4%	10.2%	10.8%	13.4%	27.7%	14.3%	13.8%	6.0%	10.2%	12.5%	7.0%	2.7%
Mean depth	119	94	94	104	115	227	243	225	227	230	346	330	306	300	367
Mean no. species	13	17	16	13	15	9	13	54	10	11	9	10	11	11	5

3.1.4. Catch and Effort Data Analysis - estimation of biomass and yield

Annual data :

Biomass dynamic production models were fitted to annual catch and effort data using the CEDA package (MRAG, 1992a). In order to eliminate as much as possible changes in catch rate arising from target switching or location changes analyses were performed on data stratified by depth and location in addition to aggregated data : earlier analyses indicated that at depths greater than 300 m target switching between *P. filamentosus* and *E. coruscans* did not occur. Strata examined were : all locations by depth band, all sea mounts only by depth band, and Tongatapu south by depth band. By species, the analyses considered : the total catch, a guild consisting of the 6 main export species only, and individually each of the 6 main species. Effort was measured as reel-hours. For species catches no attempt was made to partition the total effort that may have been applied to that species. In addition, the data derived by Latu and Tulua (1992) for the 5 main species (*P. flavipinnis* excluded) at sea mounts only was fitted (see 3.1.3). Using the same sea mounts as Latu and Tulua (1992) catch and effort (by trip and reel-hour) for the same 5 species were derived and fitted.

CEDA offers a choice of production models and error models for fitting the data. Confidence intervals for the parameters estimated may also be derived. In the present analyses the Fox and Schaefer models performed similarly and only results from the Fox model are reported. Parameters derived include K, the carrying capacity of the system, from which B_t, the biomass at the start of time t (not necessarily the virgin biomass) was calculated from Ke^{-1}; q, the catchability coefficient for the effort applied during time t; r the intrinsic rate of growth. MSY is given by rK/4 for the Schaefer model and rKe^{-1} for the Fox model.

Detailed results of the CEDA analyses are provided in Annex 2 for those data to which a production model could be fitted. However, in the majority of cases no fit was obtained due to lack of contrast in the cpue data, triangulation or pattern in the residual plots, or strong outliers invalidating the choice of model. In some cases exclusion of the 1987 data point resulted in a viable fit[3]. The results are summarised in Table 11. Generally the models fitted the data poorly, especially for the aggregated data relating to all locations and all depths and the estimates presented should be viewed with caution. Aggregated data showed little contrast

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[3] For most of the analytical strata, catch rates are seen to increase from 1987 to 1988, then decline thereafter. January 1988 has been reported as having exceptionally good weather conditions and a bumper harvest. In 1988 the final boats were completed and joined the fishery - possibly these were more efficient than earlier vessels. In 1987 it could be that vessel owners were still learning the fishery explaining lower catch rates that year. These are some possible explanations for the lower catch rate observed in 1987 (or higher rate in 1988). In subsequent depletion / production analyses the pattern of increase followed by declining catch rates causes a problem. The question is: can 1987 justifiably be excluded?

in cpue data, ie. catch rates did not significantly decrease with increasing effort for all locations. The best fit occurred for the sea mounts at depths greater than 300 m for the total catch and guild of 6 main species for which declining catch rates were observed, although the 1987 catch rate was lower than expected. For this stratum a sustainable yield of 125 - 335 tonnes was predicted with a point estimate of 165 tonnes. For individual species the models fitted less well than for the guild of species : interactions between species, lack of information relating to actual effort targeted at each species, and target switching may affect apparent catch rates. For guilds of species these factors tend to be masked. It should also be noted that the point estimate of biomass was sometimes less than that of MSY due to the value of r being greater than 1.

The MSY estimate for the sea mounts at depths greater than 300 m may crudely be extrapolated to all depths based on the information in Table 9. If it is assumed that each depth band is equivalent (1-200 most of 6 main species caught will be at depths > 100 m, 200-300, > 300 most will be caught < 400, thus each band is approximately equivalent to 100 m) and that the catch rate for the 6 main species in each band is proportional to the relative biomass in each band, then the MSY of the 6 main species from 1-200 m is 155 tonnes, from 201 - 300 m is 170 tonnes. Thus the point estimate of total yield available from all sea mounts is 490 tonnes. This should be raised by a factor of 1.2 since the analysis only relates to known sea mounts (see 2, Table 4) giving an MSY of 588 t for all sea mounts. Similarly, assuming the proportion of each species caught represents the biomass of each species, then the yield by species at depths greater than 300 m would be approximately : *P. filamentosus*, 4.9 t, *P.flavipinnis*, 2.5 t, *E. coruscans*, 113.8 t, *E. carbunculus*, 27.8 t, *E. morhua*, 3.7 t, *E. septemfasciatus*, 36.2 t. The point estimates for *E. coruscans* and *E. septemfasciatus* derived from CEDA analyses agree with these estimates.

With respect to the analysis by Latu and Tulua (1992), no fit (in fact the R^2 value was negative) was achieved using the values given by these authors. Using only the seamounts used in that analysis and recalculating catch and effort for the 5 main species no fit was achieved when effort was expressed as reel-hours, whilst a poor estimate was derived using trips as the measure of effort.

Whilst Biomass and yield estimates have been presented, it may be concluded that none of the data sets produced an ideal fit to the models and that the information should only be considered a very rough guide and first-cut at biomass and yield estimates. A cautious approach should be taken in using yield estimates given in Table 11 for management purposes due to the relatively low level of confidence in the output. It should be noted that only 5 data points have been used to fit the production models, probably inadequate, and the analyses will benefit from future data collection. Furthermore, the nature of the fishery as it relates to movement between banks means that sequential depletion is probably occurring, hence the lack of contrast in aggregated data. Although stratification of the data reduces this problem, lack of contrast in cpue still occurs, and the use of catch rates to monitor the status of the fishery can be dangerous.

Monthly data applied to individual sea mounts :

Due to the possibility of sequential fishing on different sea mounts masking decreases in catch rate, individual sea mounts for which a reasonable number of trips had been sampled were examined. Initially raised annual catch rate data was plotted for 18 sea mounts, including those examined by Langi *et al* (1992) and Latu and Tulua (1989). The majority did not exhibit any signs of depletion. Frequently depth changes occurred with associated target species changes. The sea mounts chosen for further analysis were all those previously examined plus four others. Annex 3 provides details of the selection of sea-mounts and subsequent CEDA analyses.

A modification of Allen's (1966) model was applied to monthly catch (numbers) and effort data[4] for selected sea mounts using the CEDA Constant Recruitment model. The parameter, M, natural mortality, must be provided. This model assumes a constant recruitment rate independent of spawning stock size, and the population is assumed to be in equilibrium prior to exploitation. The parameters N_0 (initial population numbers) and q (catchability) are derived. The initial Biomass B_0 was calculated (see Annex 3).

The model was applied to data for a guild of the 6 main export species, and where appropriate, to individual species. Maximum sustainable yield was computed as 24% of B_0 for these species after Beddington and Cooke (1983) assuming representative values of $M = 0.5$, $K = 0.3$ and age at recruitment of $Tr = 3$ years for these species. Note however that for lower values of M or K this proportion will be less. The proportion of 24% is consistent with that reported in Polovina and Ralston (1986) and Langi *et al* (1992) for similar species.

Different error models were tested to fit the model to the data and only the results of the best fitting model are reported. Like Latu and Tulua the model was fitted with alternative values of M of 0.04 / month and 0.02 / month, consistent with the range of values found for these species (see 3.2.3). Of the sea mounts examined by other authors, only 1403 was found to fit the model for the extended data set (Table 12, see also Annex 3). For this sea mount sensitivity analyses were performed in relation to a range of values of M and for different values of initial proportion (Table 13). It was found that an initial proportion of 1 (no prior exploitation) and M in the range 0.02 - 0.04 gave the best fit. Sensitivity analyses were not performed on other data sets and these values were employed.

The data for seamount 1403 was stratified by depth, improving the fit of data to model (in 1990 and 1991 depth increased). Both raised and sample data were also analysed as were details for *Pristipomoides filamentosus* (Table 14). Of the other

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[4] For the selected sea mounts monthly catch and effort data by sea mount was generated without applying a raising factor : Langi *et al* (1992) indicate that the seamounts chosen had complete coverage of landings; Latu and Tulua (1989) indicate an overall sampling frequency but for their analyses of individual sea mounts have used unraised data; see also 2 above.

sea mounts which indicated depletion 1320 satisfactorily fitted the model and the results for raised and sample data for a guild of the 6 main species and for *E. coruscans* are indicated in Table 14.

For sea mounts 1403 and 1320, the only locations which fitted the model well, it was found that for different subsets of the data the point estimate of number of fish for M = 0.02 was within the range of 95 % confidence intervals for M = 0.04 in all except two cases. Biomass and yield were thus calculated using the more conservative estimates for M=0.04 (Table 15, see also Annex 3). No bathymetric survey data was available for 1320 so the estimates for this sea mount could not be translated into yield per unit length of 200 m contour. For sea mount 1403, all depths, the yield was 216-338 Kg nm^{-1} for the guild of species, and 128-441 Kg nm^{-1} for *P. filamentosus* based on the assumption that sampled data was a census of all fishing at that location. Whilst an error in the value of M used will have relatively minor effect on the estimated yield, it may be seen from Table 15 that it is critical to know if all catches from the sea mount have indeed been sampled as suggested by Langi *et al* (1992). If it is assumed that the number of trips to each sea mount are sampled in proportion to the total number of trips made, and a raising factor applied, then the estimate of yield at all depths increases to 504-766 Kg nm^{-1} for the guild.

Langi *et al* (1992) derived an MSY estimate of 737 Kg nm^{-1} based on the mean of data for three sea mounts. Latu and Tulua (1989) estimated surplus yield to be in the range 217-673 Kg nm^{-1}, also averaged over 3 locations. This author was unable to generate a viable fit to data for these same locations (Table 12) except for 1403, and the yield estimate agrees with the lower estimate of Latu and Tulua (1989). Polovina and Ralston (1986) estimate a yield of 165-279.6 Kg nm^{-1} in the Marianas. Polovina *et al* (1990) indicate a range of yields in the Pacific from reef / island fishing grounds of 40-270 kg.nm^{-1} (70-500 kg.km^{-1}) and seamounts of 160-920 kg.nm^{-1} (300-1710 kg.km^{-1}) based on biomass (B_0) estimates for reef / island fishing grounds of 200-230 kg.nm^{-1}, median value 700 kg.nm^{1} (380 kg.km^{1}) and from seamounts, 1400-8500 kg.nm^{-1}, median value 2700 kg.nm^{-1} (1460 kg.km^{-1}).The present estimates are within this range.

Langi and Langi (1987) estimated the total length of the 200 m depth contour to be 960 nm, and that of the seamounts alone, 294 nm. Based on the values derived for seamount 1403, for seamounts only the potential yield is:

- for all depths and a guild of the six principle species, 63.5-99.4 t assuming a census, and, if the sampling frequencies given in Table 5 are applied to sample data, 148.2-225.2 t. For the single species *P. filamentosus*, 37.6 - t at all depths assuming a census of fishing trips.

- for depths less than 201m, 54.7-80.6 t for the guild and 41.5-82.9 t for *P. filamentosus* assuming a census of all trips to 1403, and if the sampling frequencies given in Table 5 are applied to sample data, 97.3-184.3 t for *P. filamentosus* assuming the sampling frequencies given in Table 5.

Note that *P. filamentosus* represents approximately 24% of the catch (over all years, depths and locations). If the yield estimate for that species is extrapolated to the guild by applying this proportion, a higher estimate of the yield is derived than by applying the Allen model directly data for a multispecies guild (172-768 t, census-raised sample).

For all habitats (banks and seamounts) at a depth of 200 m the estimate ranges from 207 - 735 t applying the same criteria as above (and up to 2,508 t by extrapolating data for *P. filamentosus*). However, the applicability of the yield estimates derived from seamount data to banks in the same depth range is uncertain. Polovina et al (1990) reported lower yields from island reef areas.

Following these detailed and stratified analyses of catch and effort data the following points should be noted :

- Despite considerable effort to eliminate variability arising from depth, location and target species changes, it was still not possible to derive for annual data convincing contrast in cpue data indicating depletion. The estimate of potential yield did not differ significantly from that already reported in the literature (although the analysis reported in the literature could not be reproduced)

- The estimates for individual seamounts similarly did not differ significantly from previous estimates. These are considered more reliable than the estimates of yield derived from annual data.

- Of critical importance is the sampling frequency. Lack of knowledge of the exact number of trips to each individual seamount leads to greater uncertainty in the estimate of potential yield than potential errors in the estimate of mortality rate employed in the analyses.

- The observations of increasing catch rate from 1987 to 1988 and thereafter a decline are difficult to explain and may not reflect abundance of target species. The may be a result of changing fishing practices, interaction between species and competition for bait.

- catch and effort data relating to guilds of species tended to fit the models better than individual species - interactions may be masked.

TABLE 11: point estimates of initial population size (Biomass, tonnes) and MSY, and 95% confidence intervals for MSY obtained by fitting annual catch and effort data to the Fox biomass dynamic production model (CEDA)

DETAILS		ALL LOCATIONS					SEA MOUNTS ONLY					TONGATAPU SOUTH ONLY				
Depth	Species	Biomass tonnes	MSY Range		MSY Pt.	Fit	Biomass tonnes	MSY Range		MSY Pt.	Fit	Biomass tonnes	MSY Range		MSY Pt.	Fit
all	all					no					no					no
	main 6	612.52	139.3	841.9	308.1	p					no					no
1-100m	main 6	14.72	8.2	41.8	14.8	p					no					no
101-200m	main 6					no	243.54	7.0	16.2	10.0	p X ?					no
201-300m	main 6					no					no					no
>300m	all					no	104.85	124.8	338.4	163.0	r	112.94	84.3	472.6	148.3	p X
	main 6	435.94 *	*	*		p?	110.73	125.9	334.4	165.2	r	140.53	110.2	409.8	157.0	p/r
	p.fil					no					no					no
	p.fla					no					no					no
	e.cor	101.09	86.6	282.1	104.0	p X	65.48	58.5	334.1	98.1	p X	115.51	7.7	24.0	10.0	p
	e.car					no					no					no
	e.mor					no					no					no
	e.sep	21.34	20.9	35.9	29.6	p	41.94	16.2	170.9	29.6	p	48.19	0.7	2.8	1.2	p ?
>200m	all					no										
	main 6					no										
	p.fil					no										
	p.fla					no										
	e.cor					no										
	e.car	34.95	5.4	22.6	14.2	p										
	e.mor	10.07	0.0	11.3	1.1	p										
	e.sep	53.71	17.5	37.5	33.6	p										
all	main 5	Only sea mounts indicated by Latu and Tulua									no	reel-hours used as unit of effort				
	main 5	used in these analyses					179.16	85.2	545.7	194.2	p	trip used as unit of effort				
	main 5	Data from Latu and Tulua (1992)									no	trip used as unit of effort				

* no MSY estimate due to poor r fit
X = 1987 data excluded from analysis
p = poor fit
r = reasonable fit

TABLE 12 The modified Allen model (CEDA constant recruitment) applied to unraised catch and effort data for seamounts examined by Langi et al (1992) and Latu and Tulua (1990)

DETAILS			SEAMOUNT														
New code			1401			1501			1504			1301			1403		
Original code			901			1001			1004			801			903		
Species	M/mo	Estimate	95 % CI		Point	95 % CI		Point	95 % CI		Point	95 % CI		Point	95 % CI		Point
		Length 200m (nm)			6.8			7.4			1.2			5			35
Main 6 spp	0 04	Fit (err model, R2)	Gamma		0.652	Gamma		0.756	L Sqs		0.784	L Sq		0.973	L Sq		0.937
		q	2 4E-05	0.000138	5.6E-05	1E-05	6.9E-05	2.5E-05	0.000782	0 002467	0.001891	0.000483	0.001392	0 000828	0.00021	0.000449	0.000332
		No	11205	54863	22301	33247	184084	76905	1478	2812	1685	1676	4204	2673	9048	14159	10855
		Bo	47080	230516	93701	113158	626540	261750	5705	10855	6505	6940	17407	11068	31542	49360	37842
		MSY @ 24% Bo	11299	55324	22488	27158	150370	62820	1369	2605	1561	1666	4178	2656	7570	11846	9082
		MSY/nm	1662	8136	3307	3670	20320	8489	1141	2171	1301	333	836	531	216	338	259
Main 6 spp	0 02	Fit (err model, R2)	Gamma		0.602	Gamma		0.718	Gamma		0.572	L Sq		0.973	L Sq		0.941
		q	3.2E-05	0.00032	0.000147	2E-05	0.000275	8.8E-05	2.4E-05	0.000177	6.4E-05	0.000455	0.001283	0.00077	0.00016	0.000318	0.000236
		No	6511	44446	10191	10259	99998	23980	10431	57280	23823	1801	4467	2872	12215	18553	14687
		Bo	27357	186747	42819	34917	340348	81617	40267	221117	91964	7457	18496	11892	42583	64678	51201
		MSY @ 24% Bo	6566	44819	10277	8380	81684	19588	9664	53068	22071	1790	4439	2854	10220	15523	12288
		MSY/nm	966	6591	1511	1132	11038	2647	8053	44223	18393	358	888	571	292	444	351
			NO FIT of data to the model percentiles not evenly scattered No decrease in cpue, Model highly sensitive to value of M Attempts to improve fit by stratifying by depth and considering individual species not effective			NO FIT No decline in cpue. Percentiles uneven and show triangulation Highly sensitive to value of M Target species change			NO FIT No decline in cpue (depth changes) Same error model cannot be applied with different values of M - highly sensitive to M. Residuals / percentiles show triangulation / uneven scatter			NO FIT Although R2 value high cpue increases with time, residuals show triangulation, CI for K poor			REASONABLE FIT Catch rate decline with time . Residuals still show some triangulation but improved with M = 0.02 Not oversensitive to value of M		

Table 13 : Results of sensitivity analyses for different values of natural mortality, M, and initial proportion for the CEDA Constant Recruitment Model applied to catch and effort data relating to sea mount 1403 for different subsets of the data.

DATA SET			PARAMS VARIED		ERROR	RESULTS						
Raised/ sampled	Depth	species	M	initial %	fit	R2	K			q		
							mid	2.5%	97.5%	mid	2.5%	97.5%
sample	ALL	MS	0.10	1.00	LS	0.889	9593	6505	34233	0.000302	6.5E-05	0.00052
			0.08	1.00	LS	0.899	9725	7006	21349	0.00077	0.000115	0.000504
			0.06	1.00	LS	0.916	9896	7675	15700	0.000338	0.000164	0.000491
			0.04	1.00	LS	0.937	10855	9048	14159	0.000332	0.00021	0.000449
			0.03	1.00	LS	0.943	12197	10273	15540	0.000296	0.000195	0.000387
			0.02	1.00	LS	0.941	14687	12215	18553	0.000236	0.00016	0.000318
			0.01	1.00	LS	0.932	19034	15221	25236	0.00017	0.000112	0.00024
sample	ALL	MS	0.03	0.90	LS	0.942	12161	10433	14852	0.000331	0.000225	0.000432
			0.03	0.80	LS	0.938	12192	10541	14669	0.000372	0.00026	0.000484
			0.03	0.60	LS	0.906	12619	10890	15447	0.000459	0.000293	0.000618
			0.03	0.40	LS	0.786	14576	11793	25338	0.000464	0.000172	0.000757

Table 14 : Estimates of N0 (K) and q derived for different subsets of data from sea mounts 1403 and 1320

DATA SET				PARAMS VARIED		ERROR	RESULTS						
Sea mount	Raised/ sampled	Depth	species	M	initial %	fit	R2	K			q		
								mid	2.5%	97.5%	mid	2.5%	97.5%
1403	sample	<= 200M	MS	0.04	1.00	LS	0.970	9643	8237	12153	0.000405	0.000279	0.000521
				0.03	1.00	LS	0.975	10479	9074	12803	0.000377	0.000271	0.000476
				0.02	1.00	LS	0.976	11770	10228	14301	0.000333	0.000244	0.000419
	raised	ALL	MS	0.04	1.00	LS	0.945	25659	21063	32031	0.000137	9.3E-05	0.000187
				0.03	1.00	LS	0.951	29042	24362	35745	0.000121	8.6E-05	0.000162
				0.02	1.00	LS	0.951	35220	29296	43654	9.6E-05	6.8E-05	0.000129
	sample	ALL	S1	0.04	1.00	LS	0.859	7280	5274	16975	0.000303	9E-05	0.000499
				0.02	1.00	LS	0.887	8925	6951	13554	0.000255	0.000127	0.000377
	sample	<= 200M	S1	0.04	1.00	LS	0.959	7414	5837	11662	0.000338	0.000181	0.000483
				0.02	1.00	LS	0.958	9345	7303	14935	0.000264	0.000138	0.000378
	raised	<=200	S1	0.04	1.00	LS	0.963	16933	13685	25917	0.000147	8.2E-05	0.000204
				0.02	1.00	LS	0.922	19304	16016	24363	0.000127	8.2E-05	0.00017
1320	sample	ALL	MS	0.04	1.00	LS	0.975	23617	19160	31549	6.5E-05	4.6E-05	8.7E-05
				0.02	1.00	LS	0.977	28302	23019	38458	5.4E-05	3.8E-05	7E-05
	raised	ALL	MS	0.04	1.00	LS	0.975	54890	44680	74059	2.8E-05	2E-05	3.7E-05
				0.02	1.00	LS	0.976	65836	53819	89648	2.3E-05	1.6E-05	3E-05
	sample	ALL	S3	0.04	1.00	LS	0.981	18095	15168	22157	8E-05	6.2E-05	0.000101
				0.02	1.00	LS	0.982	21724	18276	26367	6.6E-05	5.1E-05	8.2E-05
	raised	ALL	S3	0.04	1.00	LS	0.981	42079	34877	50506	3.5E-05	2.7E-05	4.4E-05
				0.02	1.00	LS	0.982	50550	42462	60394	2.8E-05	2.3E-05	3.6E-05

TABLE 15 : The estimated number of fish, and biomass at sea mounts 1403 and 1320 with 95% confidence intervals for an initial proportion of 1 and M = 0.04

DATA SET			Number of Fish			Estimated biomass, Kg			Estimated Yield, Kg			Estimated Yield / nm, Kg		
Raised/ sampled	Depth	species	mid	2.5%	97.5%	mid	2.5%	97.5%	mid	2.5%	97.5%	mid	2.5%	97.5%
1403														
sample	ALL	MS	10855	9048	14159	37842	31542	49360	9082	7570	11846	259	216	338
sample	<= 200M	MS	9643	8237	12153	31684	27065	39931	7604	6496	9583	217	186	274
raised	ALL	MS	25659	21063	32031	89450	73428	111664	21468	17623	26799	613	504	766
sample	ALL	S1	7280	5274	16975	25698	18617	59922	6168	4468	14381	176	128	411
sample	<= 200M	S1	7414	5837	11662	26171	20605	41167	6281	4945	9880	179	141	282
raised	<=200	S1	16933	13685	25917	59773	48308	91487	14346	11594	21957	410	331	627
1320														
sample	ALL	MS	23617	19160	31549	103963	84343	138880	24951	20242	33331			
raised	ALL	MS	54890	44680	74059	241629	196684	326012	57991	47204	78243			
sample	ALL	S3	18095	15168	22157	67494	56577	82646	16199	13578	19835			
raised	ALL	S3	42079	34877	50506	156955	130091	188387	37669	31222	45213			

3.2. Length frequency data

The number of fish sampled and measured each year by depth band and location is given in Table 16 for the six major export species. Sample size was considerably greater in the two southern locations (Ha'apai south and Tongatapu north, and Tongatapu south) and data for Vava'u and Ha'apai is pooled.

3.2.1. Analysis by location

Length information for the six major species was arranged into 5 cm length classes by year and location and the proportion of the sample in each size class was calculated. The length frequency distribution for data pooled over the period 1986-1991 was compared by location for *P. filamentosus* (Fig. 57), *P. flavipinnis* (Fig. 58), *E. coruscans* (Fig. 59), *E. carbunculus* (Fig. 60), *E. morhua* (Fig. 61), and *E. septemfasciatus* (Fig. 62). Within each location annual data was compared : *P. filamentosus*, Vava'u and North (Fig. 63), Ha'apai (Fig. 64), Ha'apai south and Tonga north (Fig. 65), Tongatapu south (Fig. 66); *P. flavipinnis* (Figs 67-70); *E. coruscans* (Figs 71-74); *E. carbunculus* (Figs 75 - 78); *E. morhua* (Figs 79-82); *E. septemfasciatus* (Figs 83-86). The mean length of the sample was calculated by year and location for each species (Table 17, Figs. 87-91).

Table 18 summarises the information relating to length frequency distribution and mean length by location. With time, the range of lengths observed decreased, with no, or fewer small or large fish being sampled. This was true for all locations and species. Details relating to Vava'u and Ha'apai for each species follow the same pattern suggesting that these locations may be pooled for further analysis in order to increase the sample size. Tonga south differs considerably from the northern locations for most species, both with regard to mean length and frequency distribution (*E. morhua* is the exception). Ha'apai south & Tonga north follows the pattern observed either in the south (*E. septemfasciatus, E. carbunculus, E. coruscans*) or the north (*P. filamentosus*), or is intermediate between north and south (*P. flavipinnis*). This information tends to suggest that either different parts of the same population, or different populations are being fished in the north and south with the transition occurring in the region of Nomuka, just north of Tongatapu.

In order to examine statistical differences between size compositions by location and year, analysis of variance was applied to the sample means (Table 17). Next, hierarchical log-linear modelling was employed, a refined form of Chi^2 analysis (see eg. Marascuilo and Serlin, 1988). This analysis has the advantage that it compares the distributions and not just the means. The partial likelihood ratio Chi^2 is used. To validate the analyses it was necessary to aggregate uncommon lengths at the edges of the distributions so that the expected frequencies of all cells had values greater than one (Snedecor and Cochran, 1980). Similarly, it was necessary to exclude years or locations with insufficient data. The results of this method applied to the six major species are summarised in Table 19A for the locations : (1) Vava'u and Ha'apai (Grid locations 1 - 9), (2) southern Ha'apai & Tonga north (grid 10 -

11), and (3) Tongatapu and south (grid 12 - 16).

Analysis of variance indicated a significant difference in mean length by location for *P. filamentosus, P. flavipinnis, E. coruscans* and *E. carbunculus,* but change in mean length over time was only significant in the case of *E. carbunculus.* There was no significant difference in mean length with time or location for either of the serranid species. This is somewhat surprising for *E. septemfasciatus* for which a marked decline in length is observed over time for the data aggregated by depth and location (Fig 93). The lack of a statistically significant decline may be masked by the variation observed at individual locations (Fig 92) and uneven sampling frequency by location. This species also showed a bimodal frequency distribution with more fish in the smaller mode being sampled in 1991 (see Fig. A4.4.).

Hierarchical log linear analysis indicated that significant differences occurred in length distributions over time and by location for all species. These differences relate to the compression of the distribution over time, and differences in modal separation as described in Figs. 63-86 and Table 18.

3.2.2. Analysis by depth

Regression of fork length on depth indicated no statistically significant change in fork length with depth for any species, although the apparent trend was for length to increase with depth (Fig 94). Next length frequency information was arranged into 5 cm classes by depth and location : *P. filamentosus*, all locations (Fig. 95), Vava'u and Ha'apai (Fig. 96), Southern Ha'apai and Tongatapu north (Fig 97), Tongatapu south (Fig. 98); *P. flavipinnis* (Figs. 99-102); *E. coruscans* (Figs. 103-106); *E. carbunculus* (Figs. 107-110); *E. morhua* (Figs. 111-114); *E. septemfasciatus* (Figs. 115-118). Mean length was calculated for these sub-strata (Table 20) : *P.filamentosus* (Fig 119); *P. flavipinnis* (Fig. 120); *E.coruscans* (Fig. 121); *E.carbunculus* (Fig. 122); *E.morhua* (Fig. 123); *E. septemfasciatus* (Fig. 124). Similar analyses to those described in 3.2.1 for location were performed.

Analysis of variance applied to the sample means indicated no significant difference in mean length at depth at the 5% level ($P <= 0.05$) except for *E. carbunculus* (Table 20). Hierarchical log linear analysis, however, indicated that the distributions of the samples were significantly different at different depths over all locations (Table 19B).

To relate changes in length composition to fishing pressure it is necessary to infer that the spatial and temporal changes described are partly explained by differences in fishing effort. Direct observation is precluded since uneven sampling frequency and lack of information quantifying total versus sampled effort per sea-mount prevent similar analyses being generated against fishing effort. As a generalisation, although fishing began in the north, and more boats originally were located in the north, greater effort has been applied in the south in recent years and particularly in relation to export species. It would appear that the result of fishing pressure is to significantly compress the size range of fish caught. Differences in the modes observed relate to recruitment of strong or weak cohorts to the fishery in previous years and may or may not be related to fishing activity. Such changes were particularly apparent for *E. carbunculus* and *E. septemfasciatus*. Change in mean length was not a good indicator of fishing pressure over time within any one location. Differences between locations may be the result of fishing pressure or may be environmental. Insufficient information exists to explain these differences.

PROPRTION SAMPLED (1986-1991) BY 5 CM SIZE CLASS AND LOCATION

Fig. 57 : Pristipomoides filamentosus

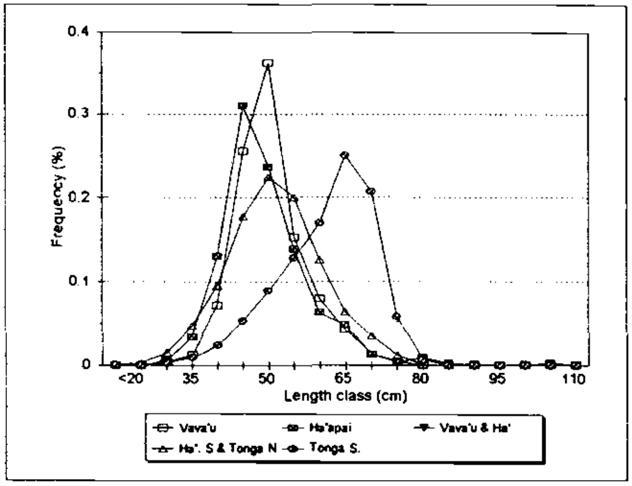


Fig. 58 : Pristipomoides flavipinnis

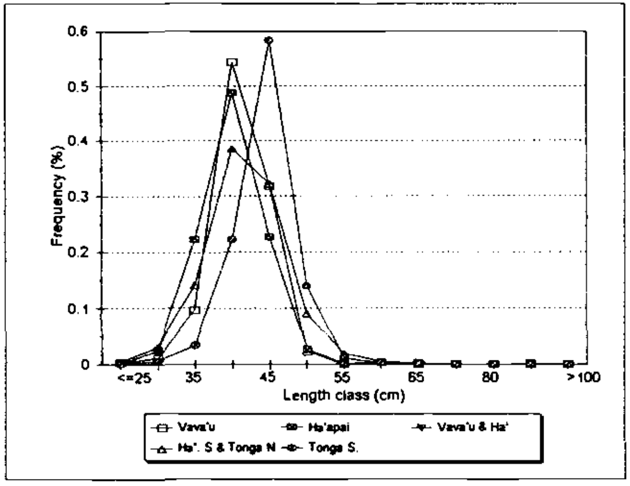


Fig. 59 : Etelis coruscans

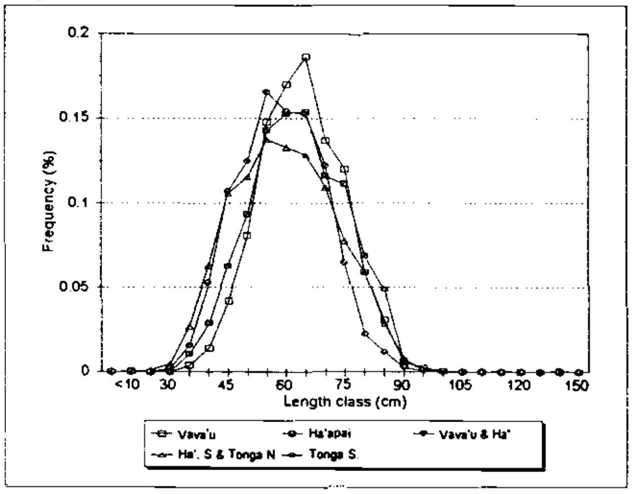


Fig. 60 : Etelis carbunculus

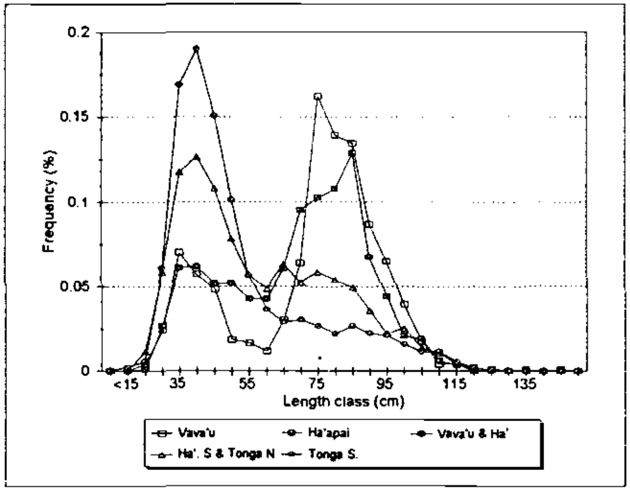


Fig. 61 : Epinephelus morhua

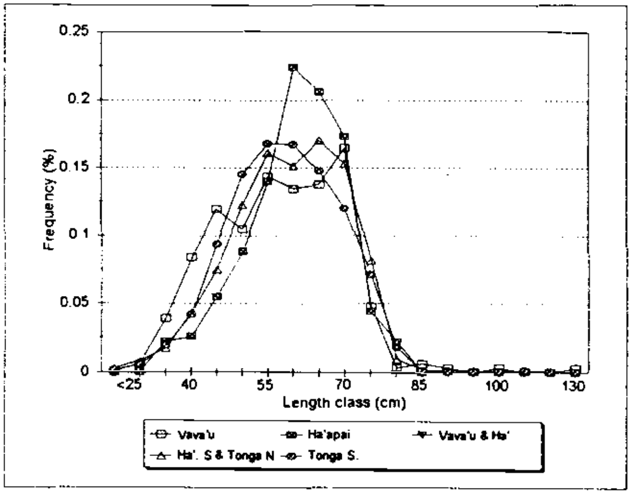
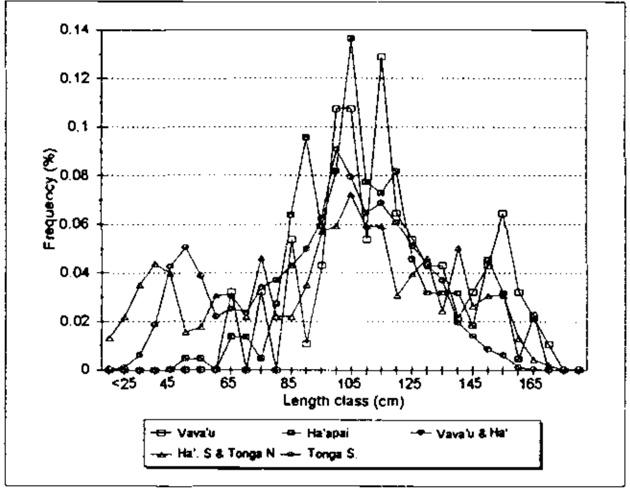


Fig. 62 : Epinephelus septemfasciatus



FORK LENGTH FREQUENCY DISTRIBUTION FOR P. FILAMENTOSUS BY LOCATION

Fig. 63 : Vava'u and North

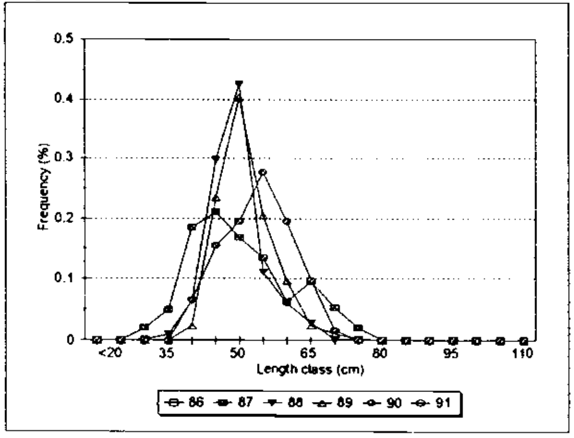


Fig. 64 : Ha'apai

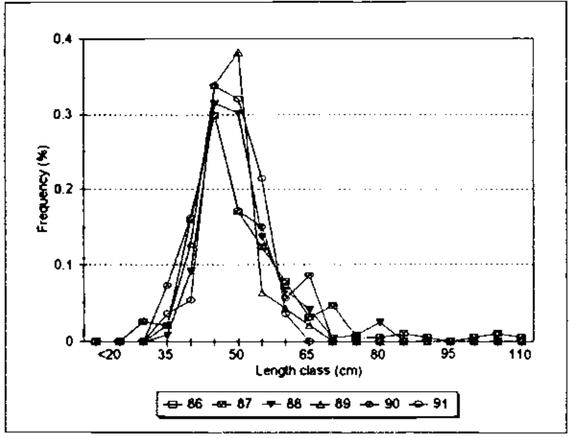


Fig. 65 : Ha'apai S & Tonga N.

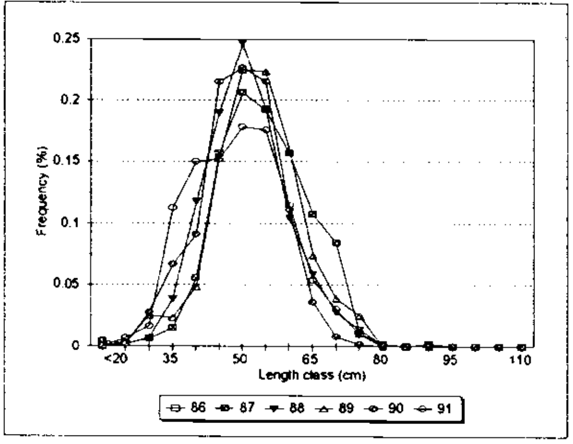
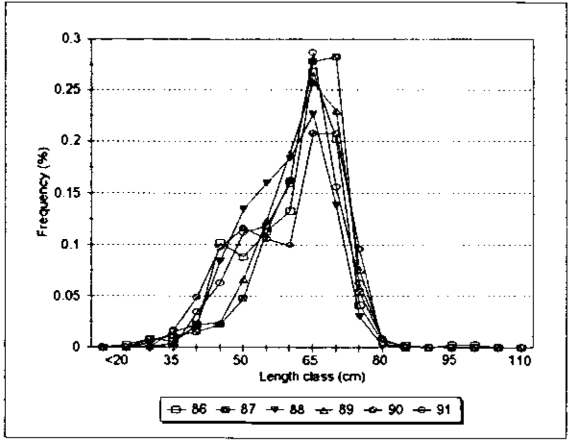


Fig. 66 : Tongatapu South



FORK LENGTH FREQUENCY DISTRIBUTION FOR P. FLAVIPINNIS BY LOCATION

Fig. 67 :Vava'u and North

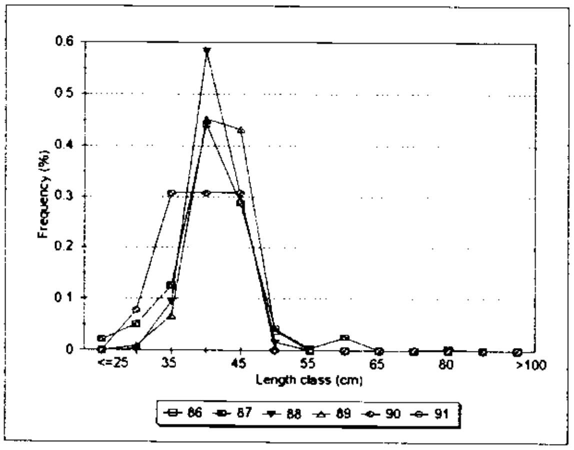


Fig. 68 : Ha'apai

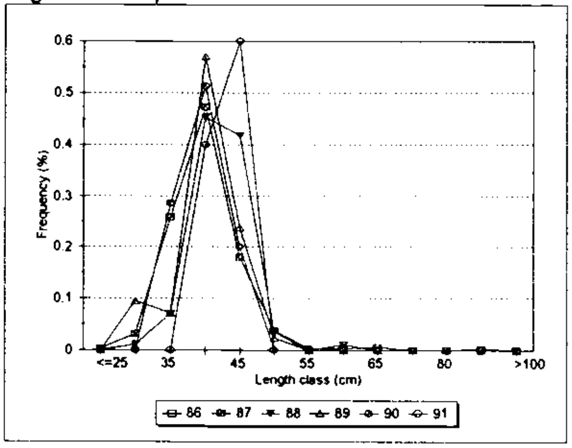


Fig. 69 : Ha'apai S & Tonga N.

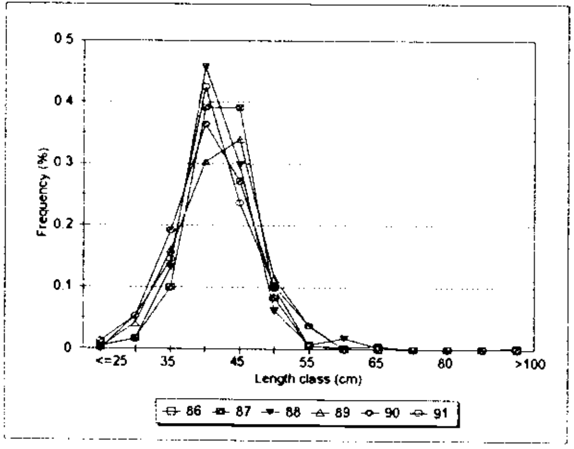
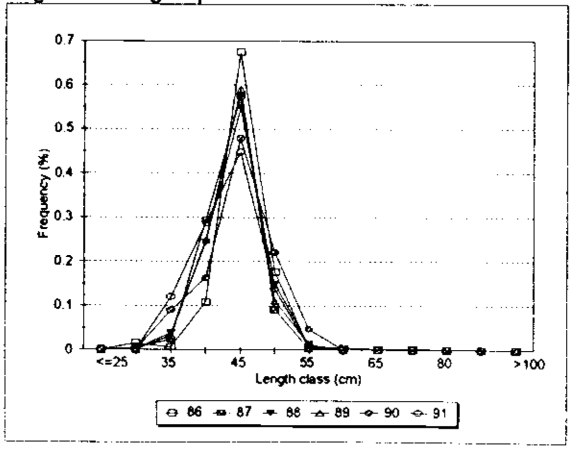


Fig. 70 : Tongatapu South



FORK LENGTH FREQUENCY DISTRIBUTION FOR E. CORUSCANS BY LOCATION

Fig. 71 : Vava'u and North

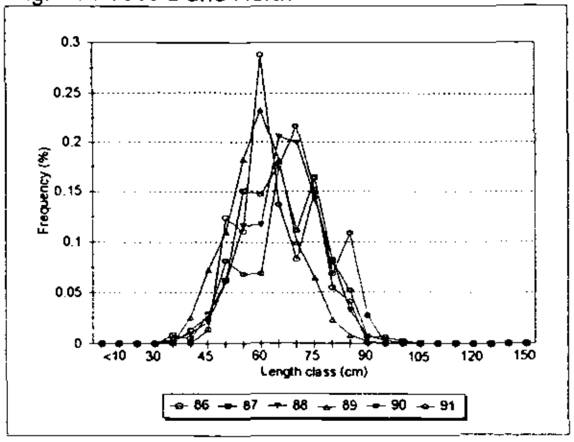


Fig. 72 : Ha'apai

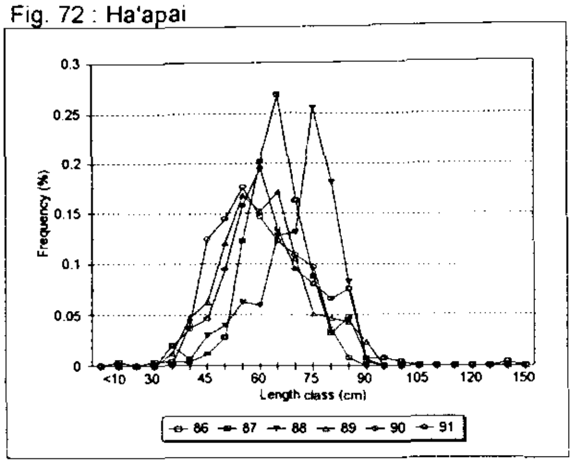


Fig. 73 : Ha'apai S & Tonga N.

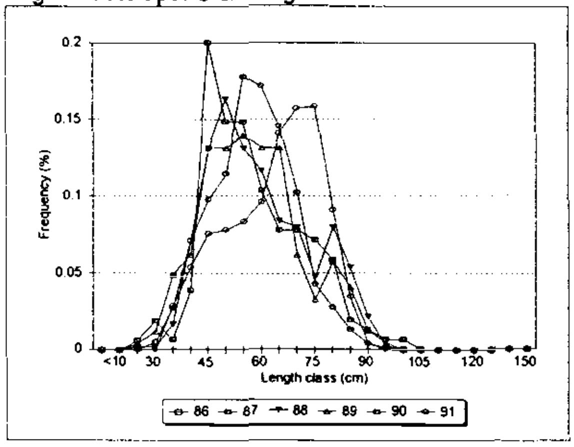
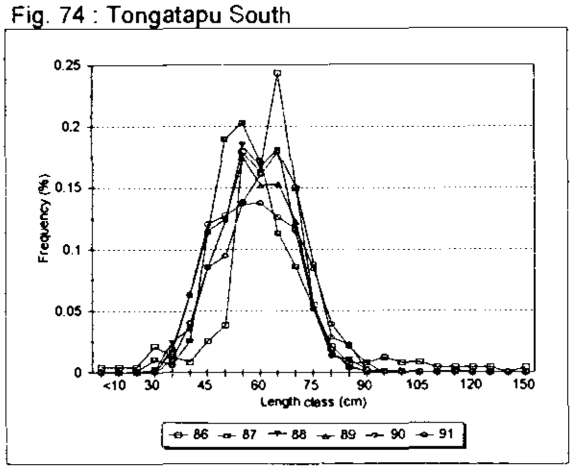


Fig. 74 : Tongatapu South



FORK LENGTH FREQUENCY DISTRIBUTION FOR E. CARBUNCULUS BY LOCATION

Fig. 75 : Vava'u and North

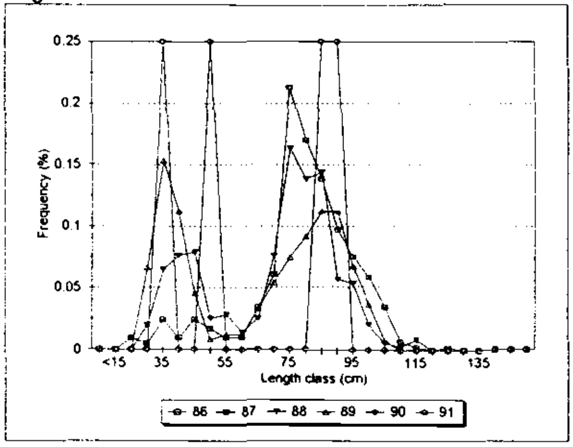


Fig. 76 :Ha'apai

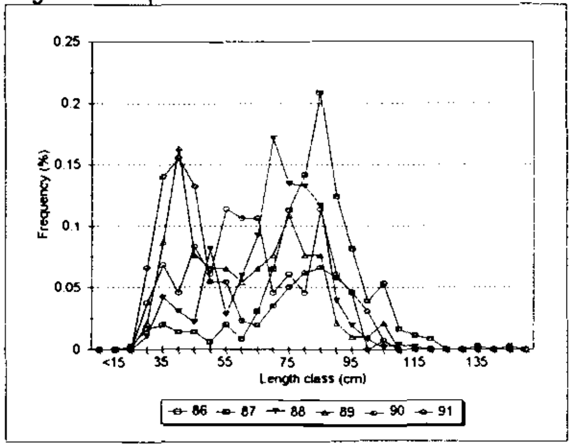


Fig. 77 : Ha'apai S & Tonga N.

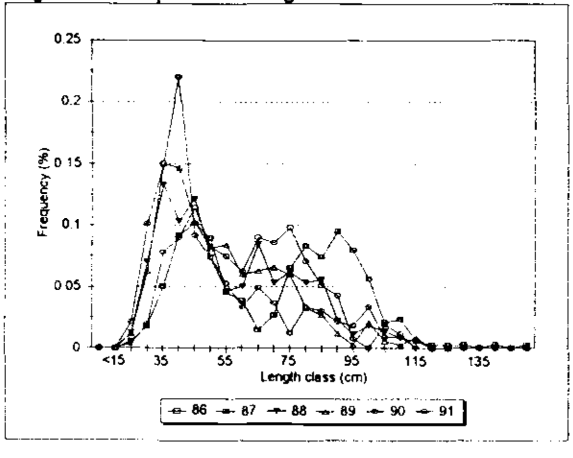
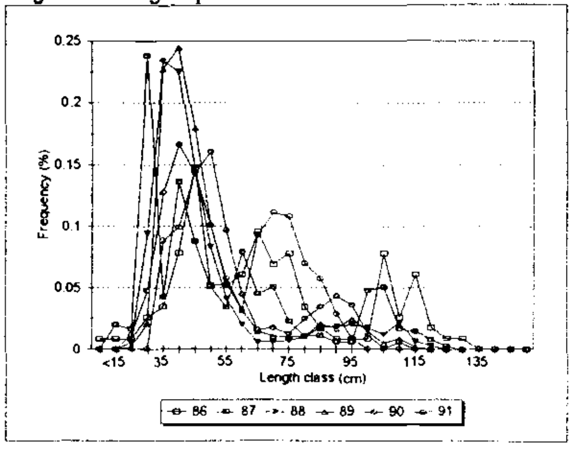


Fig. 78 : Tongatapu South



FORK LENGTH FREQUENCY DISTRIBUTION FOR E. MORHUA BY LOCATION

Fig. 79 : Vava'u and North

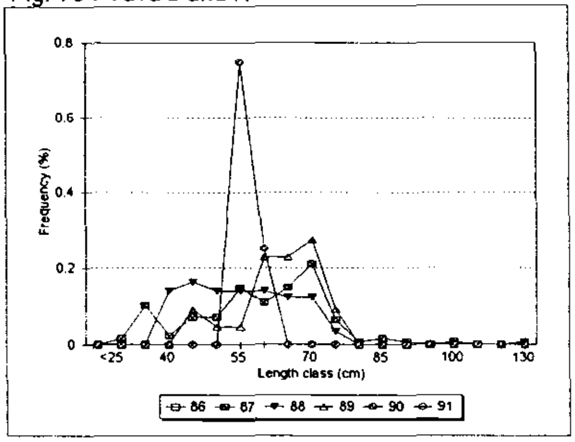


Fig. 80 : Ha'apai

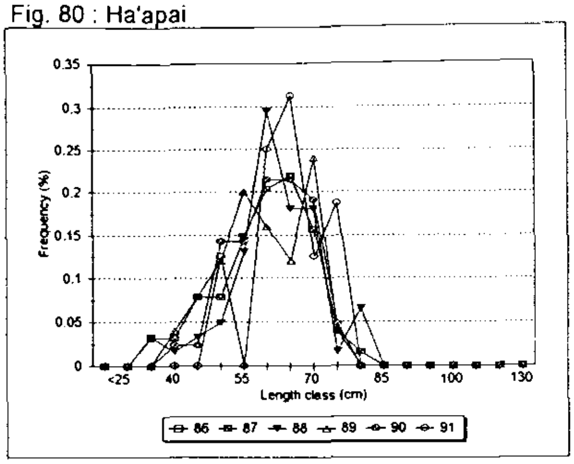


Fig. 81 : Ha'apai S & Tonga N.

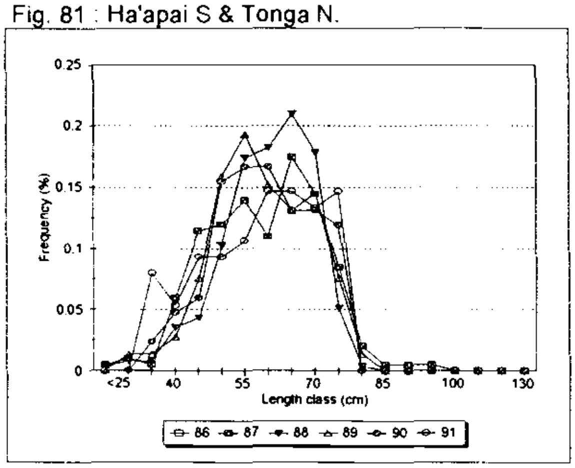
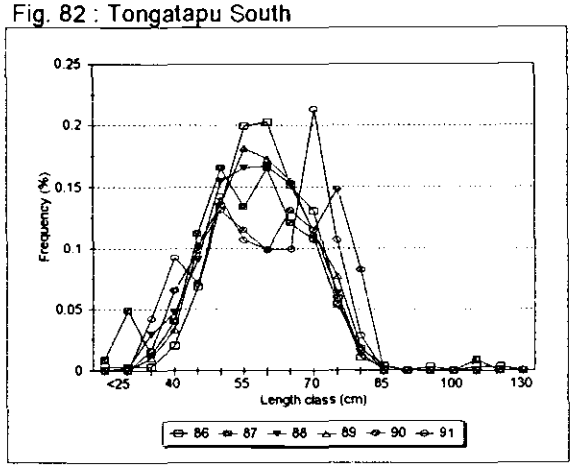


Fig. 82 : Tongatapu South



FORK LENGTH FREQUENCY DISTRIBUTION FOR E. SEPTEMFASCIATUS BY LOCATION

Fig. 83 : Vava'u and North

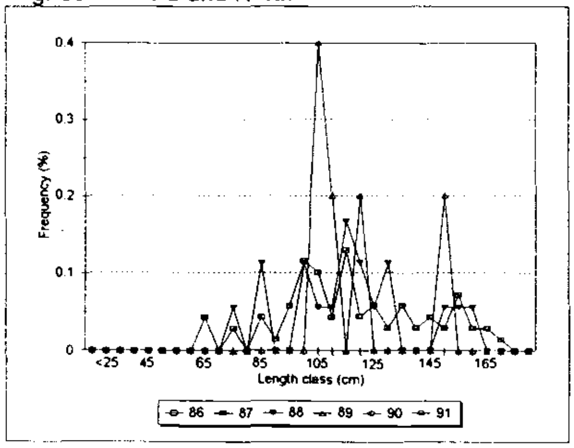


Fig. 84 : Ha'apai

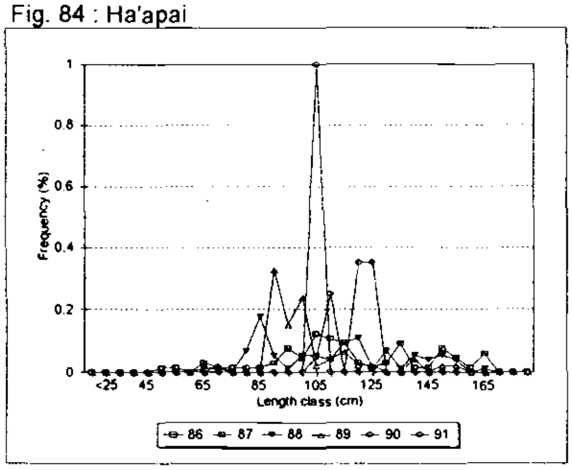


Fig. 85 :

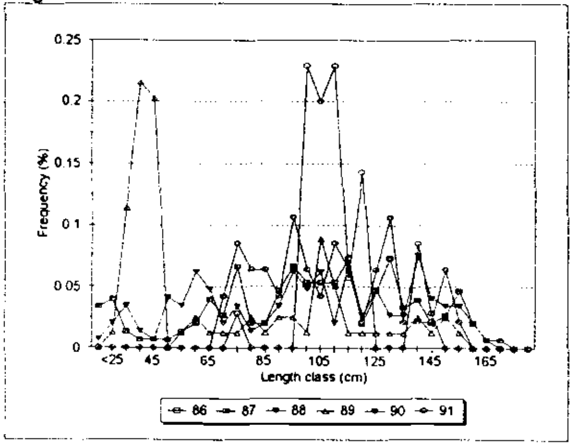
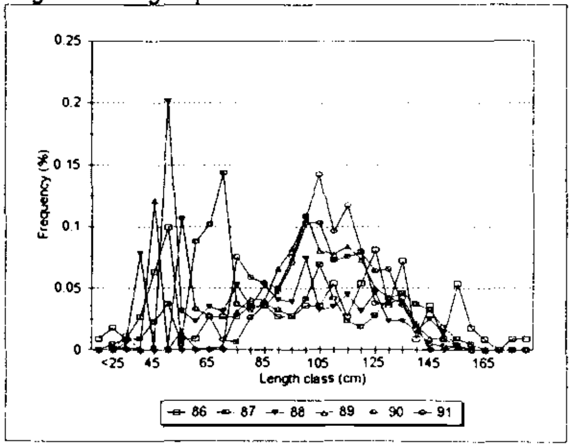


Fig. 86 : Tongatapu South



MEAN ANNUAL FORK LENGTH BY LOCATION AND SPECIES

Fig. 87 : *Pristipomoides filamentosus*

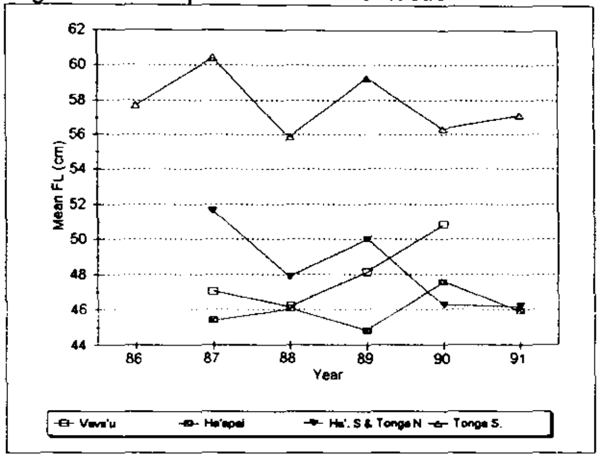


Fig. 88 : *Pristipomoides flavipinnis*

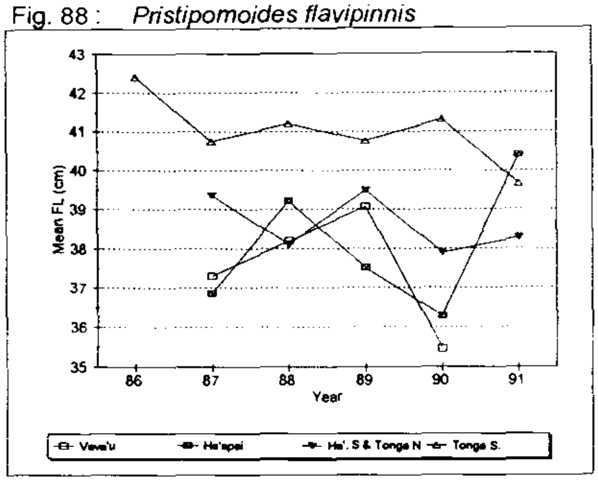


Fig. 89 : *Etelis coruscans*

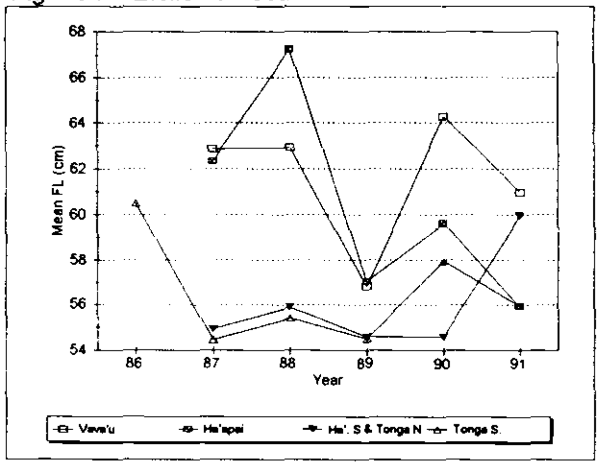


Fig. 90 : *Etelis carbunculus*

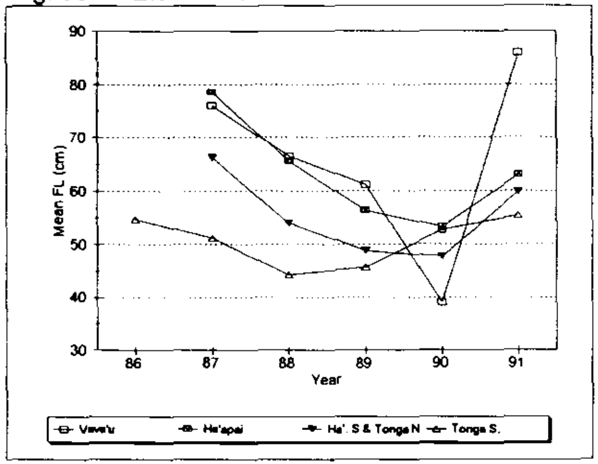


Fig. 91 : *Epinephelus morhua*

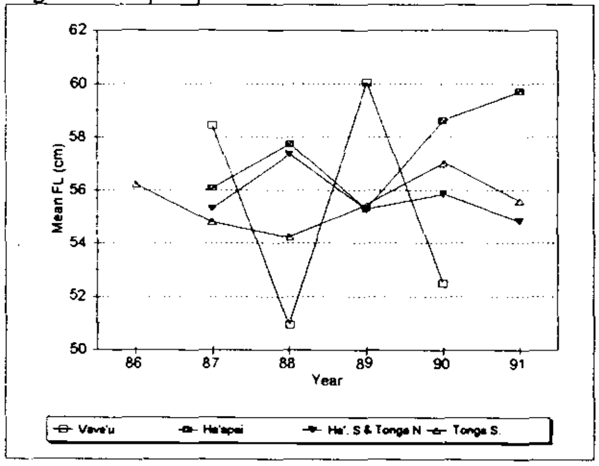


Fig. 92 : *Epinephelus septemfasciatus*

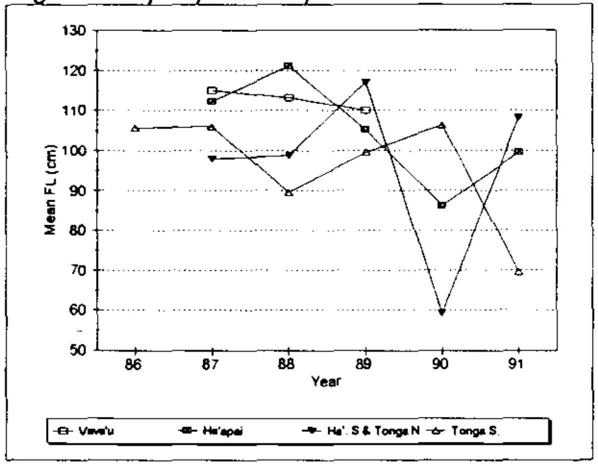


Fig. 93 : Mean length by species, all depths/locns

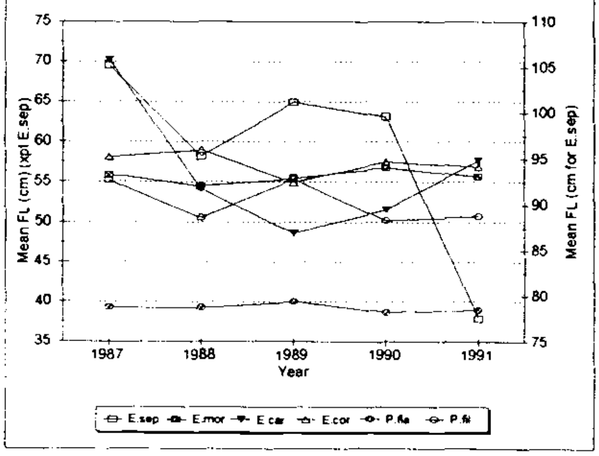
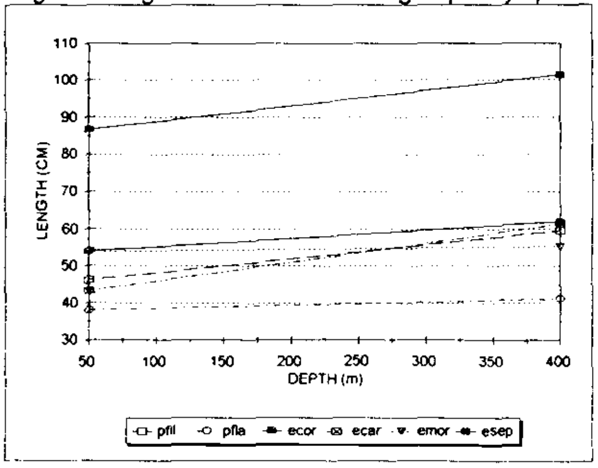


Fig. 94 : Regression of FL vs fishing depth by species



FORK LENGTH FREQUENCY DISTRIBUTION FOR P. FILAMENTOSUS BY DEPTH

Fig. 95 : All locations

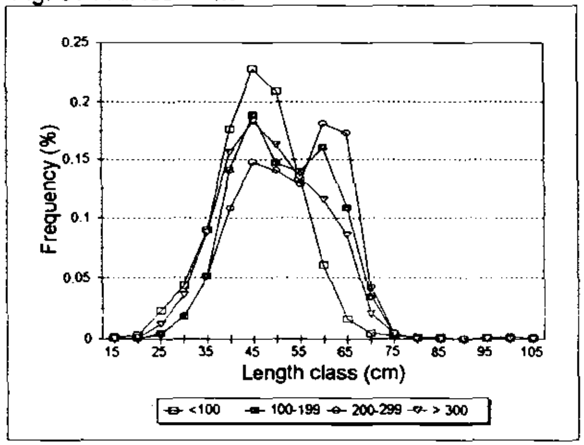


Fig. 96 : Vava'u and Ha'apai

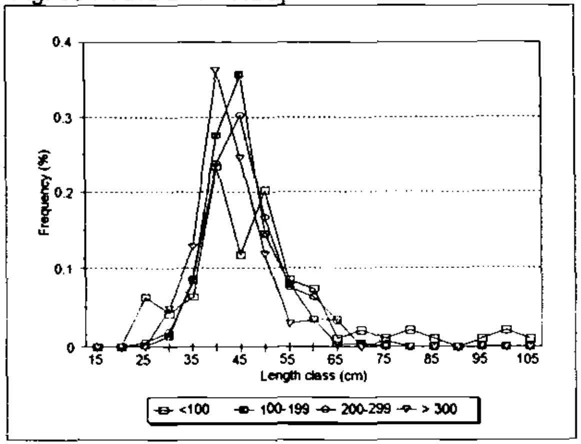


Fig. 97 : Southern Ha'apai & Tongatapu north

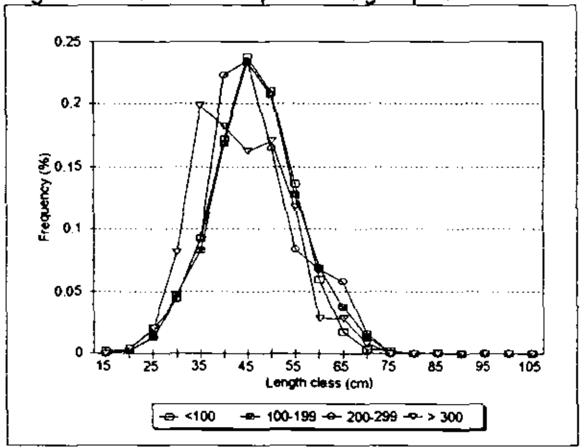
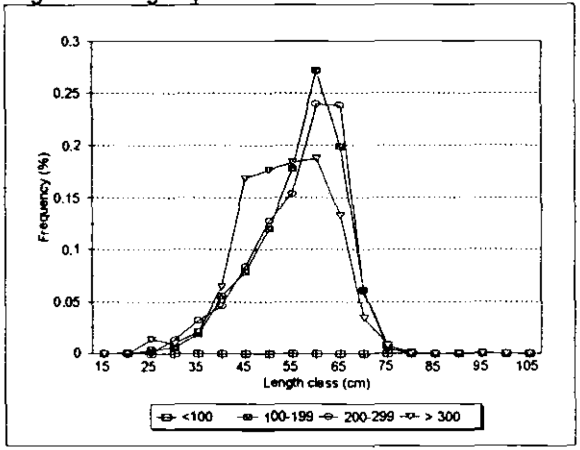


Fig. 98 : Tongatapu south



FORK LENGTH FREQUENCY DISTRIBUTION FOR P. FLAVIPINNIS BY DEPTH

Fig. 99 : All locations

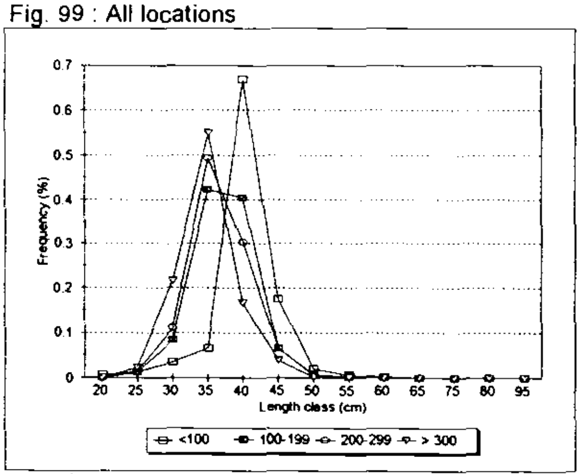


Fig. 100 : Vava'u and Ha'apai

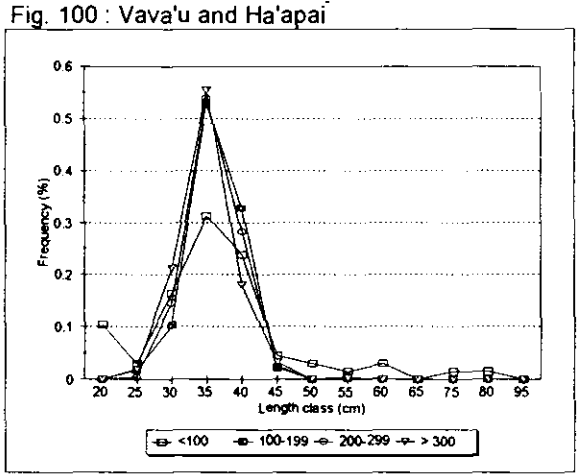


Fig 101 : Southern Ha'apai & Tongatapu north

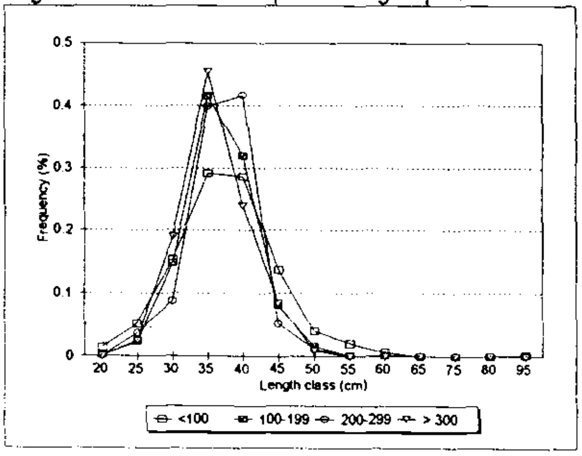
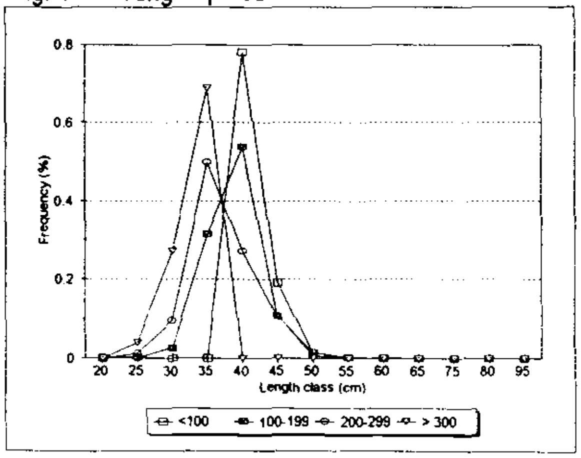


Fig. 102 : Tongatapu south



FORK LENGTH FREQUENCY DISTRIBUTION FOR E. CORUSCANS BY DEPTH

Fig. 103 : All locations

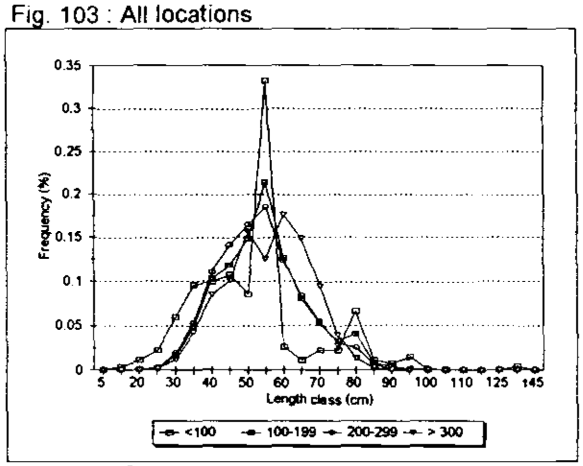


Fig. 104 : Vava'u and Ha'apai

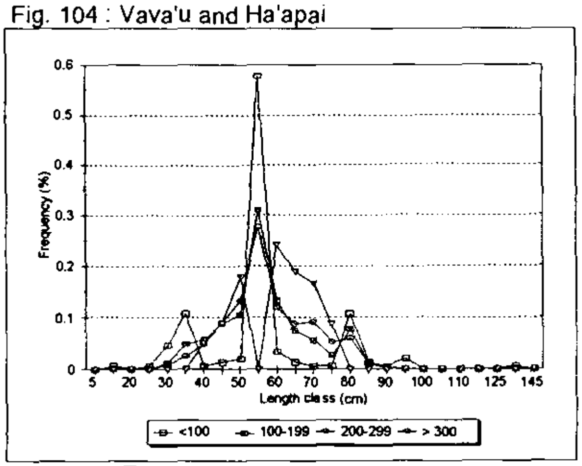


Fig. 105 : Southern Ha'apai & Tongatapu north

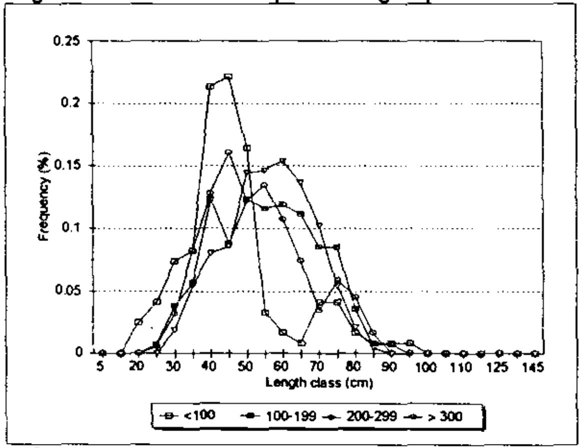
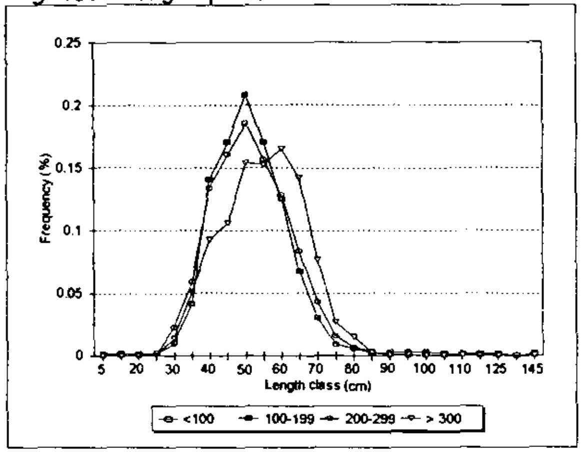


Fig. 106 : Tongatapu south



FORK LENGTH FREQUENCY DISTRIBUTION FOR E. CARBUNCULUS BY DEPTH

Fig. 107 : All locations

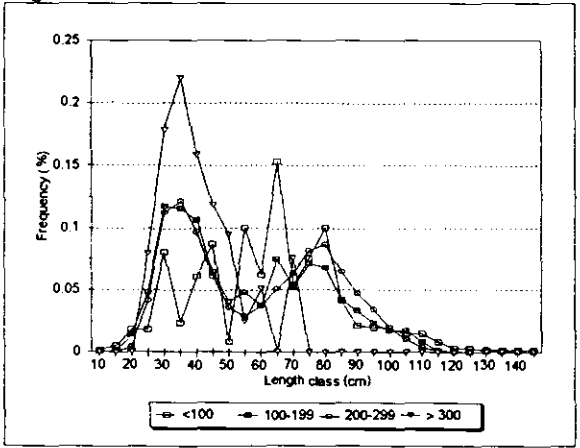


Fig. 108 : Vava'u and Ha'apai

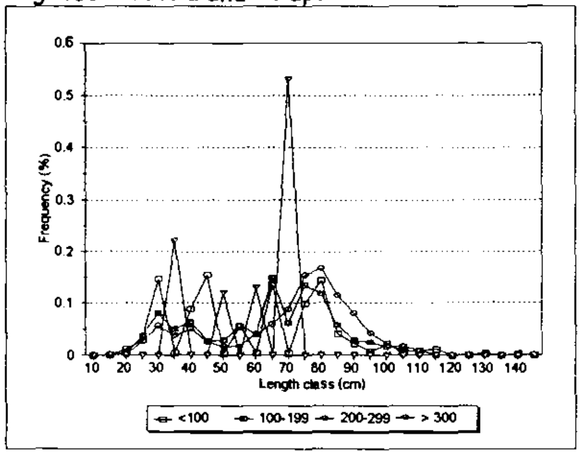


Fig. 109 : Southern Ha'apai & Tongatapu north

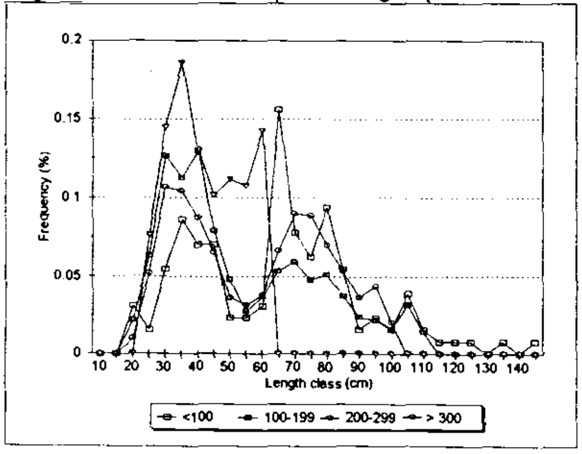
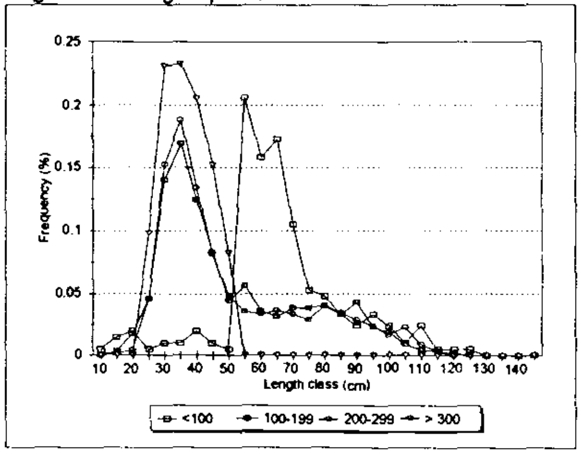


Fig. 110 : Tongatapu south



FORK LENGTH FREQUENCY DISTRIBUTION FOR E. MORHUA BY DEPTH

Fig. 111 : All locations

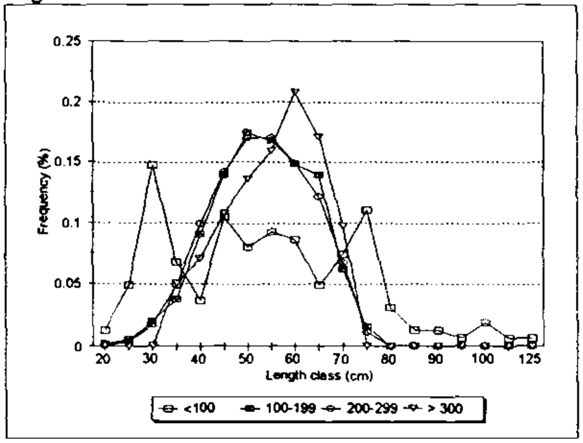


Fig. 112 : Vava'u and Ha'apai

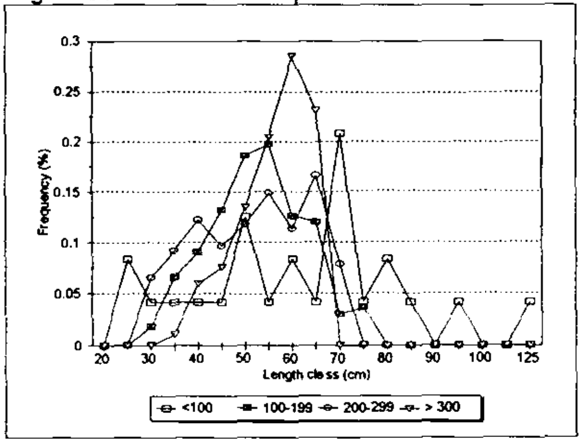


Fig. 113 : Southern Ha'apai & Tongatapu north

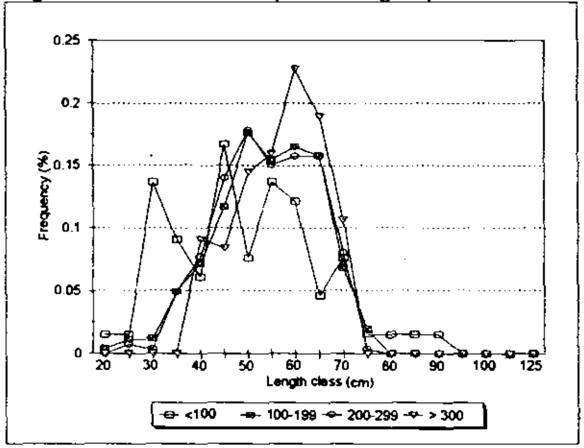
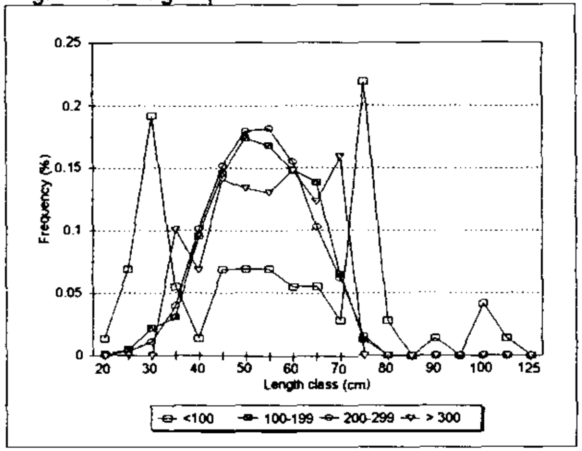


Fig. 114 : Tongatapu south



FORK LENGTH FREQUENCY DISTRIBUTION FOR E. SEPTEMFASCIATUS BY DEPTH

Fig. 115 : All locations

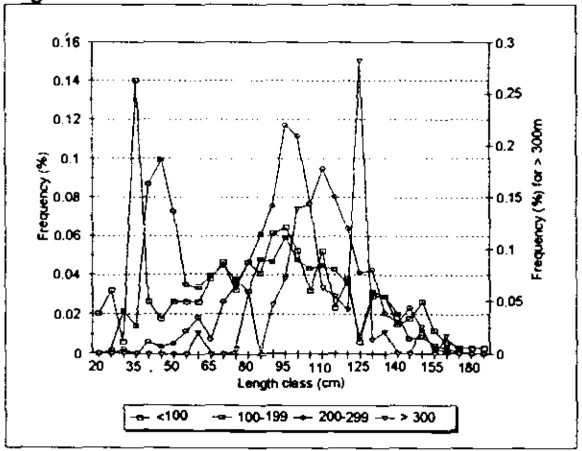


Fig. 116 : Vava'u and Ha'apai

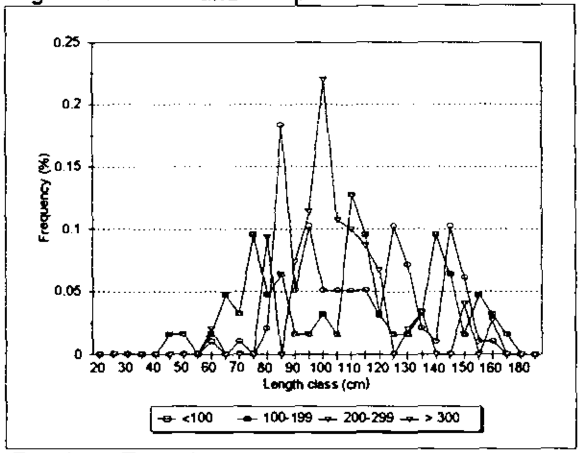


Fig. 117 : Southern Ha'apai & Tongatapu north

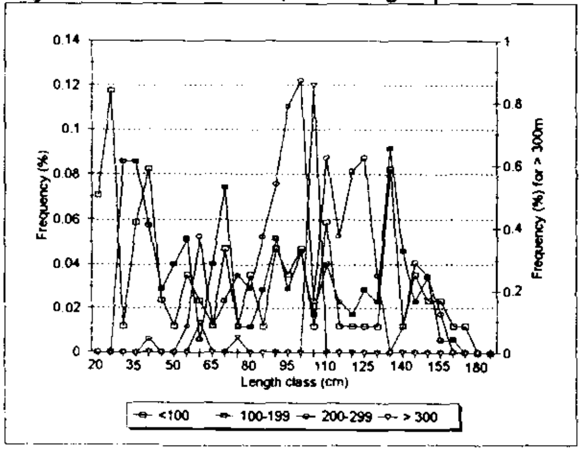
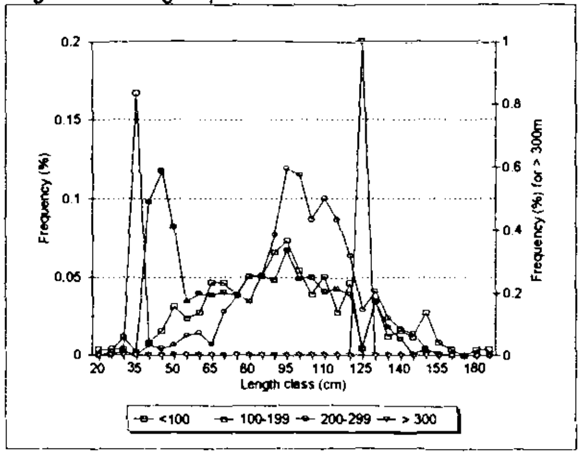


Fig. 118 : Tongatapu south



MEAN ANNUAL FORK LENGTH BY DEPTH BAND AND LOCATION BY SPECIES

Fig. 119 : P. filamentosus

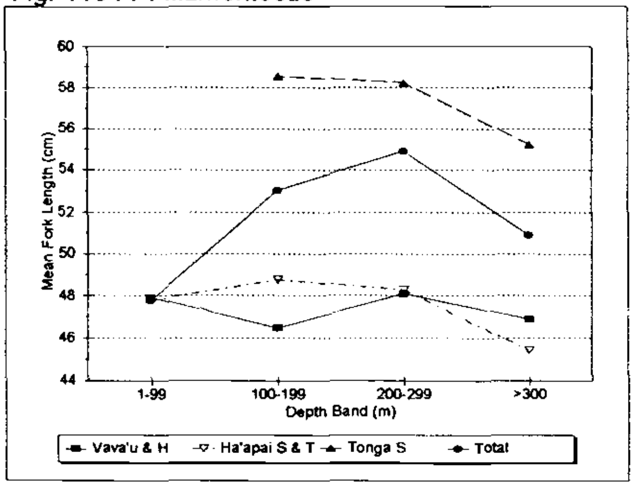


Fig. 120 : P. flavipinnis

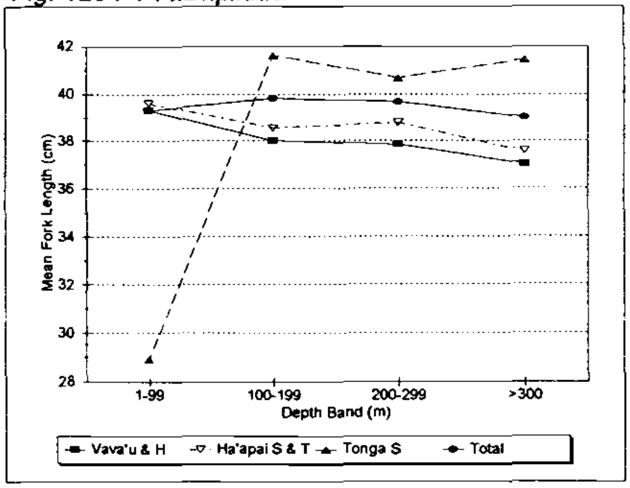


Fig. 121 : E. coruscans

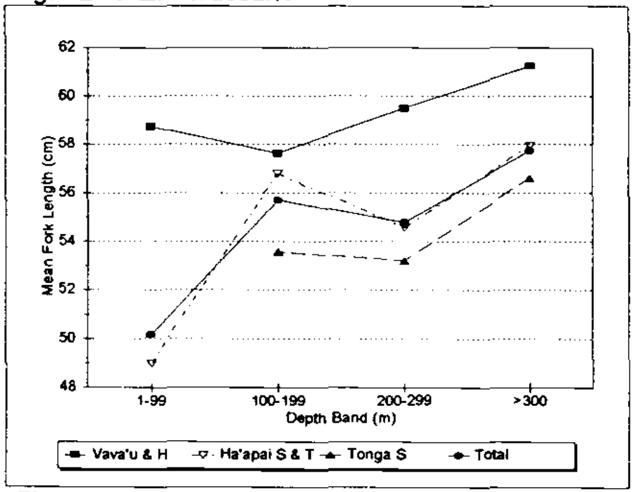


Fig. 122 :. E. carbunculus

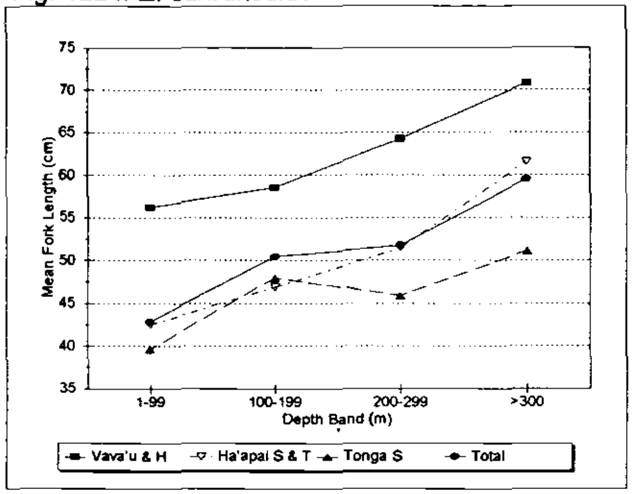


Fig. 123 :. E. morhua

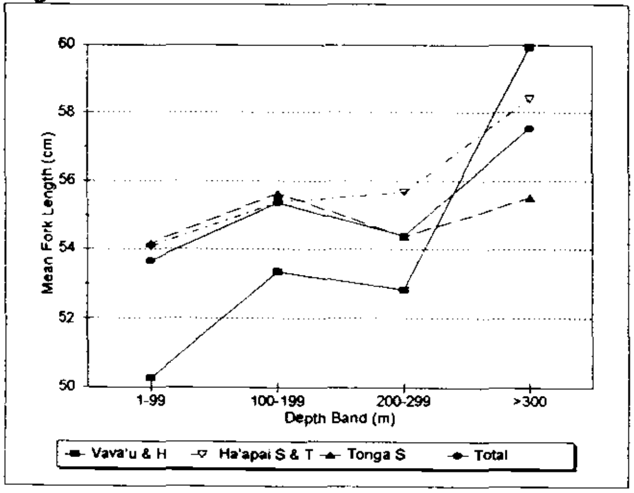


Fig. 124 : E. septemfasciatus

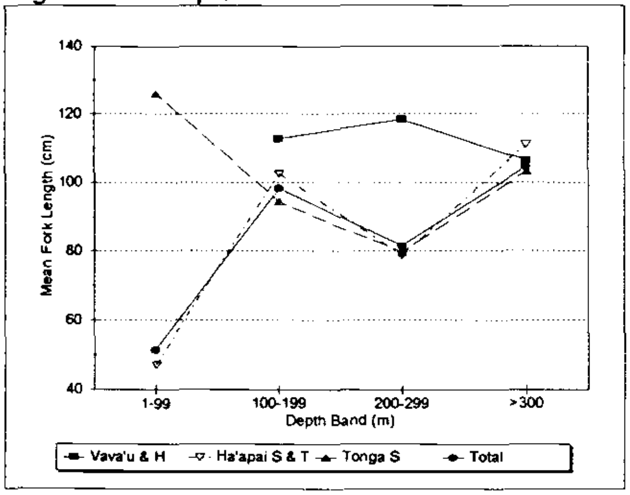


Table 16 The number of fish sampled and measured each year by depth and location

a *P filamentosus*

Year	Vava'u and Ha'apai						Ha'apai S & Tongatapu N						Tongatapu South						Total					
	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	353	0	0	353	0	0	353	0	0	353
1987	16	62	181	187	30	476	0	109	173	174	27	483	13	0	707	382	23	1125	29	171	1061	743	80	2084
1988	0	0	939	192	8	1139	34	514	540	98	4	1190	0	0	1082	306	158	1546	34	514	2561	596	170	3875
1989	0	0	478	55	64	597	0	270	270	90	6	636	0	0	838	1094	52	1984	0	270	1586	1239	122	3217
1990	0	17	68	198	103	386	91	209	227	23	64	614	0	0	0	368	130	498	91	226	295	589	297	1498
1991	0	0	0	42	15	57	0	0	235	46	146	427	0	0	105	62	164	331	0	0	340	150	325	815
Total	16	79	1666	674	220	2655	125	1102	1445	431	247	3350	13	0	3085	2212	527	5837	154	1181	6196	3317	994	11842

b *P flavipinnis*

Year	Vava'u and Ha'apai						Ha'apai S & Tongatapu N						Tongatapu South						Total					
	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	773	14	0	787	0	0	773	14	0	787
1987	0	48	178	173	150	549	0	49	199	96	15	359	43	0	320	356	0	719	43	97	697	625	165	1627
1988	0	4	941	264	66	1275	2	72	206	93	4	377	0	0	389	346	132	867	2	76	1536	703	202	2519
1989	0	0	194	41	13	248	0	198	145	55	23	421	0	10	383	299	28	720	0	208	722	395	64	1389
1990	0	5	18	49	87	159	8	28	32	23	58	149	0	0	0	123	72	195	8	33	50	195	217	503
1991	0	0	0	5	0	5	0	0	158	10	21	189	0	0	14	60	96	170	0	0	172	75	117	364
Total	0	57	1331	532	316	2236	10	347	740	277	121	1495	43	10	1879	1198	328	3458	53	414	3950	2007	765	7189

c *E coruscans*

Year	Vava'u and Ha'apai						Ha'apai S & Tongatapu N						Tongatapu South						Total					
	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99	121	0	220	0	0	99	121	0	220
1987	0	1	41	381	651	1074	0	12	29	68	42	151	13	0	173	1072	53	1311	13	13	243	1521	746	2536
1988	33	11	183	387	672	1286	30	23	94	289	31	467	0	0	35	774	542	1351	63	34	312	1450	1245	3104
1989	0	0	232	359	788	1379	0	6	41	107	87	241	0	0	288	1255	4960	6503	0	6	561	1721	5835	8123
1990	0	3	80	135	334	552	1	71	69	239	698	1078	0	0	0	135	2132	2267	1	74	149	509	3164	3897
1991	0	0	0	158	434	592	0	0	189	29	572	790	0	0	107	729	1845	2681	0	0	296	916	2851	4063
Total	33	15	536	1420	2879	4883	31	112	422	732	1430	2727	13	0	702	4086	9532	14333	77	127	1660	6238	13841	21943

d *E. carbunculus*

Year	Vava'u and Ha'apai						Ha'apai S & Tongatapu N						Tongatapu South						Total					
	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53	33	0	86	0	0	53	33	0	86
1987	0	1	48	183	530	762	0	5	41	101	187	334	8	0	81	122	2	213	8	6	170	406	719	1309
1988	23	0	242	297	245	807	2	17	166	246	269	700	7	12	216	450	280	965	32	29	624	993	794	2472
1989	0	0	42	82	212	336	0	10	86	105	123	324	0	0	106	561	640	1307	0	10	234	748	975	1967
1990	0	3	24	36	190	253	3	10	21	139	149	322	0	0	72	82	564	718	3	13	117	257	903	1293
1991	0	0	0	62	84	146	0	6	72	15	177	270	0	0	90	114	423	627	0	6	162	191	684	1043
Total	23	4	356	660	1261	2304	5	48	386	606	905	1950	15	12	618	1362	1909	3916	43	64	1360	2628	4075	8170

e *E morhua*

Year	Vava'u and Ha'apai						Ha'apai S & Tongatapu N						Tongatapu South						Total					
	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	193	94	0	287	0	0	193	94	0	287
1987	0	10	30	72	131	243	0	9	70	62	51	192	24	3	85	96	1	209	24	22	185	230	183	644
1988	0	0	109	116	23	248	2	26	95	112	22	257	7	16	431	448	120	1022	9	42	635	676	165	1527
1989	0	0	13	16	18	47	0	10	42	73	17	142	16	11	423	422	78	950	16	21	478	511	113	1139
1990	0	1	12	8	30	51	4	6	18	40	20	88	0	0	0	20	41	61	4	7	30	68	91	200
1991	0	0	0	6	11	17	0	3	48	5	23	79	0	0	27	46	73	146	0	3	75	57	107	242
Total	0	11	164	218	213	606	6	54	273	292	133	758	47	30	1159	1126	313	2675	53	95	1596	1636	659	4039

f *E septemfasciatus*

Year	Vava'u and Ha'apai						Ha'apai S & Tongatapu N						Tongatapu South						Total					
	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total	unknown	1-99	100-199	200-299	>300	Total
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	45	0	77	0	0	32	45	0	77
1987	2	0	15	29	66	112	0	2	10	70	67	149	6	0	15	92	7	120	8	2	40	191	140	381
1988	0	0	25	32	21	78	3	1	16	61	56	137	2	1	113	216	78	410	5	2	154	309	155	625
1989	0	0	2	1	9	12	0	1	5	13	7	26	0	0	33	239	447	719	0	1	40	253	463	757
1990	0	0	0	2	5	7	0	15	4	49	15	83	0	0	7	57	449	513	0	15	11	108	469	603
1991	0	0	0	3	101	104	0	0	13	3	45	61	0	0	11	385	196	592	0	0	24	391	342	757
Total	2	0	42	67	202	313	3	19	48	196	190	456	8	1	211	1034	1177	2431	13	20	301	1297	1569	3200

Table 17 : Mean fork length observed in samples by location and year, and results of two way analysis of variance (without replication) on these values.

P. filamentosus

Locn \ year	1986	1987	1988	1989	1990	1991	TOTA	ANOVAR		
Vava'u	0.0	47.0	46.2	48.1	50.9	0.0	47.2	Source of	F	df	P
Ha'apai	0.0	45.4	46.0	44.8	47.6	45.9	46.3	variation			
Ha' S & Tonga N	0.0	51.6	47.9	50.0	46.2	46.2	48.3	(for 1987 - 1990)			
Tonga S	57.7	60.4	55.9	59.3	56.3	57.1	58.1	locations	26.33	3	0.0001
TOTAL	57.7	55.2	50.6	55.3	50.2	50.7	52.8	years	0.76	3	0.5443

P. flavipinnis

Locn \ year	1986	1987	1988	1989	1990	1991	TOTA	ANOVAR			
Vava'u	0.0	37.3	38.2	39.1	35.5	0.0	38.2	Source of	F	df	P
Ha'apai	0.0	36.8	39.2	37.5	36.3	40.4	37.1	variation			
Ha' S & Tonga N	0.0	39.4	38.1	39.5	37.9	38.3	38.8	(for 1987 - 1990)			
Tonga S	42.4	40.7	41.2	40.8	41.3	39.7	41.2	locations	11.62	3	0.0019
TOTAL	42.4	39.2	39.3	40.0	38.7	39.0	39.7	years	1.99	3	0.1866

E. coruscans

Locn \ year	1986	1987	1988	1989	1990	1991	TOTA	ANOVAR			
Vava'u	0.0	62.8	62.9	56.8	64.3	61.0	60.7	Source of	F	df	P
Ha'apai	0.0	62.3	67.2	57.0	59.6	55.9	59.8	variation			
Ha' S & Tonga N	0.0	54.9	55.9	54.6	54.6	60.0	56.4				
Tonga S	60.5	54.5	55.4	54.5	57.9	56.0	55.5	locations	5.57	3	0.0125
TOTAL	60.5	58.0	59.0	54.9	57.5	56.9	56.7	years	1.40	4	0.2920

E. carbunculus

Locn \ year	1986	1987	1988	1989	1990	1991	TOTA	ANOVAR			
Vava'u	0.0	76.0	66.5	61.3	39.0	86.0	69.1	Source of	F	df	P
Ha'apai	0.0	78.6	65.6	56.4	53.2	63.0	65.8	variation			
Ha' S & Tonga N	0.0	66.2	54.0	48.9	47.7	59.9	55.0	(for 1987 - 1991)			
Tonga S	54.8	51.2	44.2	45.7	52.8	55.4	48.7	locations	3.86	3	0.0382
TOTAL	54.8	70.2	54.1	48.7	51.6	57.7	55.4	years	4.11	4	0.0253

E. morhua

Locn \ year	1986	1987	1988	1989	1990	1991	TOTA	ANOVAR			
Vava'u	0.0	58.4	50.9	60.0	52.5	0.0	54.1	Source of	F	df	P
Ha'apai	0.0	56.1	57.8	55.3	58.6	59.7	57.0	variation			
Ha' S & Tonga N	0.0	55.3	57.3	55.3	55.9	54.8	56.0	(for 1987-1990)			
Tonga S	56.2	54.8	54.2	55.4	57.0	55.6	55.1	locations	0.27	3	0.8461
TOTAL	56.2	55.9	54.5	55.5	56.8	55.6	55.3	years	0.20	3	0.8924

E. septemfasciatus

Locn \ year	1986	1987	1988	1989	1990	1991	TOTA	ANOVAR			
Vava'u	0.0	115.0	113.3	110.1	0.0	0.0	114.2	Source of	F	df	P
Ha'apai	0.0	112.4	121.2	105.3	86.1	99.5	107.7	variation			
Ha' S & Tonga N	0.0	97.9	98.7	117.1	59.2	108.2	93.6	(for 1987 - 1991, except Vava'u			
Tonga S	105.7	106.1	89.6	99.6	106.4	69.4	92.5	locations	0.54	2	0.6043
TOTAL	105.7	105.2	95.3	101.2	99.6	77.6	94.3	years	0.99	4	0.4652

L. chrysostomus

Locn \ year	1986	1987	1988	1989	1990	1991	TOTA	ANOVAR			
Vava'u	0.0	45.5	46.2	51.2	48.7	0.0	46.4	Source of	F	df	P
Ha'apai	0.0	46.4	48.7	46.0	46.9	48.8	47.3	variation			
Ha' S & Tonga N	0.0	44.5	41.0	40.0	44.2	42.0	41.5	(for 1987 - 1990)			
Tonga S	28.7	53.7	56.3	58.0	45.4	0.0	50.8	locations	6.05	3	0.0153
TOTAL	28.7	45.1	42.1	40.6	44.8	42.7	42.4	years	0.34	3	0.7999

Table 18 : Summary of observations relating to length distribution by species over time at each location.

Species	Mean Length	Length frequency distribution	
		Pooled annual data	Per year / location
P. filamentosus	> in Tonga S (56-60 cm) than other locations (45-50 cm). Decreases with time in Tonga S and Ha'apai S & Tonga N slightly.	Mode for Tonga S (65 cm) > than other locations (50 cm)	Unimodal at each location, and modes within each location approximately the same each year
P. Flavipinnis	> in Tonga S (40-42 cm) than elsewhere (37-39 cm). Slight decrease with time in Tonga S.	Mode for Tonga S (45 cm) > elsewhere (40 c Ha'apai S & Tonga N also has significant proportion at larger mode	Except at Ha'apai S & Tonga N unimodal and modes same each year. At HS & TN larger fish sampled 1987 and 1989
E. coruscans	< in Tonga S and Ha'apai S & Tonga N (54-58 than Ha'apai or Vava'u (58-64). Fluctuates with time.	Mode (60 cm) and distribution similar for all locations, but more smaller fish samples from Tonga S and Ha'apai S & Tonga N	Distribution differs each year and at each location. Modes for any one year may be similar for all locations (eg. 1988) or may diffe by location (eg. 1990)
E. carbunculus	Inconsistent over time, but Tonga S < Ha'apai S & Tonga N < Ha'apai or Vava'u Decreases 1987 - 90, increases 1991	All locations bimodal, but major mode in Vava'u and Ha'apai (85) > Tonga S and Ha'apai S and Tonga N (40 cm)	A number of modes observed each year which approximately follow same trend seen overall. In 1989 and 1990 the smaller mode was more important in Vava'u and Ha'apai
E. morhua	Similar at all locations, No consistent trend with time	Similar distribution for each location	Mode varies slightly from year to year - similar for all locations
E. septemfasciatus	Similar at all locations, decreases with time (?	Several modes observed but major mode at all locations ~ 105 cm. Tonga S and Ha'apai S & Tonga N have lesser mode ~ 45 cm.	Within locations mode varies from year to yea and larger modes more frequent in Vava'u, Ha'apai, and Ha'apai S & Tonga N. Smaller modes generally more important in Tonga S, especially 1987 and 1988. 1989 a small mode was important in HS & TN.

Table 19 : Results of Hierarchical Log-Linear analysis of fork-length distribution

A. By location and year

Species	Length range	Years	Location	Length*Location			Length*Year		
				Partial Chi2	D.F.	P	Partial Chi2	D.F.	P
P. filamentosus	< 35 - 60+	87-91	1,2,3	3542	12	< 0.00001	532	24	< 0.00001
P. flavipinnis	< 30 - 50+	87-90	1,2,3	804	10	< 0.00001	149	15	< 0.00001
E. coruscans	< 35 - 85+	87-91	1,2,3	714	22	< 0.00001	561	44	< 0.00001
E.carbunculus	< 30 - 95+	87-91	1,2,3	1208	28	< 0.00001	828	56	< 0.00001
E. morhua	< 40 - 70+	87-90	1,2,3	40	14	0.002	46	21	0.0012
E. septemfasciatus	< 70 - 150+ (a	(b-c)	1,2,3	83	18	< 0.00001	88	9	< 0.00001
E. septemfasciatus	< 90 - 140+ (a	87-91	2,3	32	6	< 0.00001	326	24	< 0.00001

B. By depth band and location.

Species	Length range	Depth bands	Location	Length * Location			Length * Depth			Depth * Location		
				Part. Chi2	D.F.	P	Part. Chi2	D.F.	P	Part. Chi2	D.F.	P
P. filamentosus	<35 - 65+	2-4	1-3	3567	14	<0.00001	118	14	<0.00001	209	4	<0.00001
	<35 - 65+	1-4	1-2	216	7	<0.00001	128.9	21	<0.00001	1031	3	<0.00001
P. flavipinnis	<30 - 45+	1-3	1-3	958	8	<0.00001	91	8	<0.00001	907	4	<0.00001
	<30 - 50+	1-3	2-3	352	5	<0.00001	81	10	<0.00001	763	2	<0.00001
E. coruscans	<35 - 85+	1-3	1-3	563	22	<0.00001	61	22	<0.00001	682	4	<0.00001
	<35 - 85+	2-4	2-3	201	11	<0.00001	455	22	<0.00001	380	2	<0.00001
E. carbunculus	<30 - 100+	1-3	1-3	714	30	<0.00001	83	30	<0.00001	83	4	<0.00001
E. morhua	<45 - 65+	1-4	1-3	17	10	0.0701	57	15	<0.00001	247	6	<0.00001
	<35 - 70+	2-3	1-3	55	16	<0.00001	7	8	0.5275	7	2	0.0256
E. septemfasciatus	<85 - 130+	2-3	1-3	137	20	<0.00001	36	10	0.0001	13	2	0.0014
	<60 - 130+	1-3	2-3	40	15	0.0005	126	30	<0.00001	60	2	<0.00001

a - E. septemfasciatus was grouped in 10 cm length classes
b - c = (1987+1988) to (1989+1990+1991)

Table 20 : Mean length at depth by location, and results of two way analysis of variance (without replication) on these values

a. *P. filamentosus*

Depth	Location				ANOVAR			
	Vava'u & H	Ha'apai S	Tonga S	Total	Source of variation	F	df	P
unknown	44.50	53.33	52.54	52.34				
1-99	47.91	47.77		47.77	(for depths > 100 m)			
100-199	46.48	48.77	58.56	53.03				
200-299	48.08	48.28	58.25	54.89	location	85.85	2	0.0005
>300	46.89	45.43	55.24	50.95	depth	4.25	2	0.1023
Total	46.95	48.30	58.13	52.84				

b. *P. flavipinnis*

Depth	Location				ANOVAR			
	Vava'u & H	Ha'apai S	Tonga S	Total	Source of variation	F	df	P
unknown	0.00	42.00	40.79	41.02				
1-99	39.32	39.61	28.90	39.31	(for depths > 1 m)			
100-199	38.03	38.57	41.62	39.84				
200-299	37.87	38.78	40.68	39.67	location	0.02	2	0.9771
>300	37.03	37.58	41.44	39.01	depth	0.47	3	0.7138
Total	37.88	38.79	41.23	39.68				

c. *E. coruscans*

Depth	Location				ANOVAR			
	Vava'u & H	Ha'apai S	Tonga S	Total	Source of variation	F	df	P
unknown	65.27	49.84	60.23	58.21				
1-99	58.73	48.98		50.13	(for depths > 100 m)			
100-199	57.63	56.80	53.57	55.70				
200-299	59.49	54.57	53.20	54.79	location	16.78	2	0.0113
>300	61.24	57.93	56.63	57.72	depth	6.60	2	0.0541
Total	60.36	56.39	55.50	56.70				

d. *E. carbunculus*

Depth	Location				ANOVAR			
	Vava'u & H	Ha'apai S	Tonga S	Total	Source of variation	F	df	P
unknown	92.04	40.20	38.73	67.42				
1-99	56.25	42.52	39.67	42.84	(for depths > 1 m)			
100-199	58.57	46.87	47.96	50.43				
200-299	64.25	51.48	45.85	51.77	location	39.27	2	0.0004
>300	70.82	61.59	51.12	59.54	depth	16.29	3	0.0027
Total	67.24	55.01	48.71	55.44				

f. *E. morhua*

Depth	Location				ANOVAR			
	Vava'u & H	Ha'apai S	Tonga S	Total	Source of variation	F	df	P
unknown	0.00	66.00	55.13	56.36				
1-99	50.27	54.07	54.17	53.66	(for depths > 1 m)			
100-199	53.34	55.38	55.63	55.35				
200-299	52.83	55.66	54.37	54.39	location	0.91	2	0.4502
>300	59.95	58.41	55.50	57.53	depth	4.00	3	0.0699
Total	55.42	56.01	55.06	55.29				

g. *E. septemfasciatus*

Depth	Location				ANOVAR			
	Vava'u & H	Ha'apai S	Tonga S	Total	Source of variation	F	df	P
unknown	65.50	112.67	121.88	111.08				
1-99		47.21	126.00	51.15	(for depths > 100 m)			
100-199	112.71	102.54	94.37	98.23				
200-299	118.42	78.61	79.63	81.47	location	2.30	2	0.2160
>300	106.45	111.05	103.25	104.60	depth	1.23	2	0.3842
Total	109.59	93.56	92.50	94.32				

3.2.3. Length frequency data analysis - estimation of demographic variables

Hilborn and Walters (1992) stress the need for representative sampling in the analysis of length frequency data and warn that often this is not achieved when commercial catches are sampled. Problems include gear selectivity, size related changes in fish distribution, and inadequate sub-sampling of catches. In contrast, Gulland and Rosenberg (1992) suggest that only by sampling different locations and times will statistically adequate data be collected fully representing the population in question.

For the Tongan data set, a single gear type has been employed, and sub-sampling has taken the form of measuring all fish caught by certain vessels. However, the preceding section indicated that significant size related changes in fish distribution occurred over time, depth and location. The Hilborn and Walters approach would suggest that in order to utilise this data in estimation of demographic variables, it is necessary to sub-stratify length frequency information prior to analysis. The Gulland and Rosenberg approach requires the data to be pooled. The latter falls down when a broad sampling programme covering many locations fails to sample all those locations equally within any time period. For a time period in which this does not happen, bias will occur due to the reported depth and location related differences (explaining, for example sudden modal changes in sequentially plotted aggregated monthly data not shown, see Annex 4). For the Tongan data set during certain months all locations were sampled, whilst in others sampling was confined to single locations. Thus, either only months when all locations were sampled should be considered, or sub-stratification by location should be performed, or the time-scale should be expanded. Hence for analyses in which monthly data is required (growth) it is appropriate to stratify the data. For analyses employing pooled annual data sets (mortality) all sampled data may be used.

Details of the methodology adopted in the present study to derive demographic parameters are described in Appendix 4. Parameters derived were the von Bertalanffy growth parameters, K (growth coefficient), $L\infty$ (the asymptotic length), t_0 (nominal time at which length of fish is 0); total mortality, Z, the instantaneous rate of natural mortality, M, and fishing mortality, F; L_c the first fully exploited length class and gear selectivity ogive parameters $L_{50\%}$ and $L_{75\%}$; L_{min}, L_{max} and L_{mean} for each data set, and L_m the length at sexual maturity.

The results of these analyses are presented by species (Tables 21 - 26) indicating the best parameter estimates obtained for each species. To summarise, a single estimate for each parameter for each species (based subjectively on the mid estimate of the ranges derived) and the range of estimates derived is presented (Table 27). Parameter estimates are presented for all depth ranges pooled for all species. For *Etelis coruscans, Etelis carbunculus, Epinephelus morhua* and *Epinephelus septemfasciatus* certain parameters are given which relate to data collected from fish caught at depths greater than 300 m only.

Pristipomoides filamentosus (Table 21)

The maximum length observed for *Pristipomoides filamentosus* was 150 cm but it is considered that this may be a data entry error and the next largest size was 106 cm. The asymptotic length derived by the method of Wetherall *et al* (1987) was in the range 76-80 cm and examination of Fig A.4.1 indicates that in fact lengths greater than 80 cm are uncommon. Von Bertalanffy growth curves were fitted to data for four years (1987 - 1990) producing similar parameter estimates. In each case the best fit was obtained using data aggregated over all locations but only for those months when sampling occurred at all locations (ALM). As indicated in Annex 4, the fit of the growth curve was to a certain extent subjective, multiple maxima (ie potential K - $L\infty$ pairs) being located. However, the growth parameters are comparable with those reported in the literature (Annex 5). For this species length converted catch curves (Jones 1984) were fitted using the annual growth parameters derived, and also with a fixed value of K and $L\infty$ (ie assuming that growth was constant over time). The values for 1988 were used in the latter case. Total mortality, Z, decreased with time in each case. Z derived from the catch curve was greater than that from the method of Beverton and Holt (1956) employing Lc derived from the catch curve as the cut off point. Natural mortality, M, varied between 0.38 and 0.45 (using the Trenkel, 1993 model) where growth was allowed to vary with time, or was constant at 0.38 where growth was constant. Fishing mortality decreased with time. This is consistent with the decreased catch and catch rate for this species (see 3.1) due in part to a shift of fishing depth and target species from *P. filamentosus* in the early years to *E. coruscans* in latter years. In order to provide 'average' values of mortality and gear selection a catch curve using data aggregated over the five year period (1987 - 1991) was employed. Results are indicated in Table 21 as are estimates of gear selection (Lc, $L_{50\%}$, $L_{75\%}$) and maturity (Lm).

Pristipomoides flavipinnis (Table 22)

Fig A.4.2. indicates that lengths greater than 60 cm were uncommon for *Pristipomoides flavipinnis*. The 96 cm fish recorded in 1987 may thus be a data entry error. The Wetherall *et al* (1987) method could only be applied to data for 1988 and 1989 and $L\infty$ was in the range 64 - 68 cm. The data were unsuitable for estimation of growth parameters using the ELEFAN method and no attempt was made to fit a growth curve. The empirical formula of Manooch (1986) was employed to estimate K, but the values derived were low compared to those in the literature (Table 28). Thus growth parameters derived in Vanuatu (Brouard and Gandperrin, 1985) and the Marianas (Polovina and Ralston, 1986) were employed in the length converted catch curve in order to derive estimates of mortality and gear selectivity. Mortality estimates were highly sensitive to the value of K and $L\infty$ chosen. Growth parameters from Vanuatu indicate high fishing mortality whilst those from the Marianas suggest low values. In each case F decreases with time consistent with observed catches (see 3.1).

Etelis coruscans (Table 23)

Length frequency data for *Etelis coruscans* has outliers which may be data entry errors (max length 138 cm 1991; 146 cm 1990) and lengths above 100 cm are uncommon (Fig A.4.3). For the data sub-set greater than 300 m (ALD3) the distribution observed is shifted to the right with greater values observed for Lc and the minimum length, although maximum lengths are similar (see also 3.2.2). L∞ from the method of Wetherall *et al* (1987) was in the range 95 -107 cm. Growth parameters were derived for 1988 and 1990, that for 1988 from SLCA and 1990 from ELEFAN in LFDA. Both estimates were similar to those in the literature (Table 28), but the former had a more appropriate value of L∞ for the Tongan data set. Mortality estimates were derived from catch curves employing both pairs of growth parameters for all data and for that greater than 300 m. Mortality was sensitive to the growth parameter values selected. The pattern observed for F was consistent with catches, starting low and increasing with time. Fishing mortality peaked in 1989 and declined slightly thereafter.

Etelis carbunculus (Table 24)

Lengths greater than 120 cm were uncommon for *Etelis carbunculus* and L∞ was found to be in the range 121 - 131 cm by the method of Wetherall *et al* (1987). The data was not suitable for estimating growth parameters, and preliminary estimates of K derived after Manooch (1986) were similar to those reported in the literature from Vanuatu (Table 28, Brouard and Grandperrin, 1985). The latter were used in the catch curve to derive estimates of mortality and gear selectivity. Length frequency distributions for this species show bi-modality with the larger mode dominant in 1987 but the smaller mode dominant subsequently (Fig A.4.4). This bi-modality was reflected in the catch curve and Z was estimated for the different size classes as described in Appendix 4. It has been suggested that this bi-modality, also observed in Papua New Guinea and Western Samoa for this species may in fact represent two species (Lokani *et al*, 1990; King *et al*, reported in Moffit, 1993).

Epinephelis morhua (Table 25)

Lengths greater than 80 cm were uncommon for *Epinephelus morhua* (Fig A.4.5) and the maxima indicated in Table 25 may be outliers or errors. L∞ was estimated to be in the range 77 - 85 cm (Wetherall *et al* (1987) method). Growth curves were fitted to the data for 1988 and 1989. The parameters for 1989 were used in the catch curve. Fishing mortality was negligible and decreased with time.

Epinephelus septemfasciatus (Table 26)

L∞ for *Epinephelus septemfasciatus* was found by the method of Wetherall *et al* (1987) to be in the range 162 - 176 cm, close to the maxima observed. The growth constant K, derived empirically was low (~0.09). The data was generally not suitable for fitting growth curves although this was attempted for data from 1988. Maxima were located for the following pairs: L∞ = 189.9, K = 0.207 Rn = 0.3188 and L∞ = 154.4, K = 0.1476, Rn = 0.202. The smaller K value pair subjectively fits the data better although the Rn value was less. Mortality was sensitive to the growth parameters used in the catch curve, and fishing mortality was low for the smaller pair of values. No data was available from the literature for comparison, and it is suggested that these estimates are viewed with caution.

Table 21 : Demographic variables estimated from length frequency data analysis of *Pristipomoides filamentosus*

Parameter	data sub set	1987	1988	1989	1990	1991	ALL	COMMENTS
DESCRIPTIVE STATISTICS								
Lmin	ALL	21	18	21	23	22	18	
Lmax	ALL	94	81	96	106	80	106	150 obs in '91 -error?
Lmean	ALL	55.2	50.6	55.3	50.2	50.7	52.9	
Lc_obs	ALL	64-66	46-48	48-50	40-42	48-50	46-48	
WETHERALL								
Linf	ALL	NA	80.5	76.2	79.5	79.1	108.5	Blanks indicate no fit
Z/K	ALL		2.66	1.48	1.95	1.93	1.30	or insuuficient data
K after Manooch		NA	0.15	0.16	0.15	0.16	0.13	
forced K	ALM		0.21	0.16	0.21			
forced To	ALM		-0.620	-0.650	-0.500			
score	ALM		0.117	0.273	0.154			
LFDA_ELEFAN								
K	ALM	0.25	0.22	0.25	0.30	NA	0.22	1988 estimate taken
Linf	ALM	77.6	77.6	76.3	74.8		77.6	to represent overall
To	ALM	-0.880	-0.440	-0.500	-0.490		-0.440	values
score	ALM	0.320	0.217	0.258	0.241		0.217	
Phi'	ALM	3.17	3.12	3.16	3.22		3.12	lit. range 2.95-3.47
BEVn HOLT								
Z_cc	ALL	0.87	0.70	0.66	0.55	0.53	0.65	
CATCH CURVE	: K - Linf VARY WITH TIME							
Z	ALL	1.03	0.84	0.70	0.64	0.56	0.72	1988 growth para-
M_pauly	ALL	0.45	0.41	0.45	0.51	0.41	0.41	meters used where
M_Trenkel		0.41	0.38	0.41	0.45	0.38	0.38	
temp C	ALL	18	18	18	18	18	18	otherwise un-
F	ALL	0.58	0.42	0.25	0.13	0.15	0.31	available
F_Trenkel		0.62	0.45	0.29	0.19	0.17	0.34	
Lc_cc	ALL	63.0	63.0	59.0	63.0	59.0	63.0	
L50%	ALL	61.7	61.5	43.3	56.9	50.6	60.2	
L75%	ALL	63.2	63.6	58.3	61.2	58.0	62.5	
CATCH CURVE	: K - Linf CONSTANT OVER TIME (K, Linf, M, Temp as indicated in column ALL above)							
Z	ALL	0.90	0.84	0.70	0.61	0.56	0.72	
F_Pauly	ALL	0.49	0.43	0.29	0.20	0.15	0.31	
F_Trenkel	ALL	0.51	0.45	0.32	0.23	0.17	0.34	
Lc_cc	ALL	63.0	63.0	61.0	63.0	59.0	63.0	
L50%	ALL	61.2	61.5	55.0	58.8	50.6	60.2	
L75%	ALL	63.2	63.6	59.7	61.9	58.0	62.5	
REPRODUCTION								
Lm (0.5 * Linf)	ALL	38.8	38.8	38.1	37.4	0.0	38.8	
Lm (0.5 * Lmax)	ALL	47.0	40.5	48.0	53.0	40.0	53.0	

Table 22 : Demographic variables estimated from length frequency data analysis of *Pristipomoides flavipinnis*

Parameter	data sub set	1987	1988	1989	1990	1991	ALL	COMMENTS
DESCRIPTIVE STATISTICS								
Lmin	ALL	20	23	22	23	24	20	
Lmax	ALL	96	63	62	60	60	96	96 CORRECT?
Lmean	ALL	39.2	39.3	40.0	38.7	39.0	39.7	
Lc_obs	ALL	40-42	40-42	40-42	40-42	38-40	40-42	
WETHERALL								
Linf	ALL	NA	64.3	67.8	NA	NA	NA	
Z/K	ALL		1.89	3.81				
K after Manooch	ALL	NA	0.18	0.17	NA	NA	NA	
LFDA_ELEFAN	NO FIT ATTEMPTED							
BEVn HOLT								
Z_cc K=0.36	ALL	1.82	1.97	1.59	1.39	1.45	1.63	
Z_cc K=0.268	ALL	0.59	0.64	0.50	0.43	0.44	0.51	
CATCH CURVE	K=0.36 Linf=58 To=0			M @ 18C	0.621	(Pauly)	0.547	(Trenkel)
Z	ALL	2.52	2.08	1.74	1.70	1.86	1.85	
F_Pauly	ALL	1.90	1.46	1.12	1.08	1.24	1.23	Growth params
F_Trenkel	ALL	1.97	1.54	1.19	1.15	1.31	1.30	from Vanuatu
Lc_cc	ALL	39.0	39.0	39.0	39.0	39.0	39.0	
L50%	ALL						37.4	
L75%	ALL						39.3	
CATCH CURVE	K=0.268 Linf=49 To=-1.01			M @ 18C	0.536	(Pauly)	0.498	(Trenkel)
Z	ALL	0.74	0.83	0.69	0.55	0.56	0.67	
F_Pauly	ALL	0.21	0.29	0.16	0.01	0.02	0.13	Growth params
F_Trenkel	ALL	0.25	0.33	0.20	0.05	0.06	0.17	from Marianas
Lc_cc	ALL	39.0	39.0	39.0	39.0	39.0	39.0	
L50%	ALL						36.7	
L75%	ALL						38.9	
REPRODUCTION								
Lm (0.5 * Lmax)		48.0	31.5	31.0	30.0	30.0	48.0	

Table 23 : Demographic variables estimated from length frequency data analysis of *Etelis coruscans*

Parameter	data sub set	1987	1988	1989	1990	1991	ALL	COMMENTS
DESCRIPTIVE STATISTICS								
Lmin	ALL	22	24	6	17	25	6	
Lmax	ALL	99	92	92	146	138	146	
Lmean	ALL	58.0	59.0	54.9	57.4	57.0	56.7	
Lc_obs	ALL	54-56	54-56	54-56	60-62	60-62	54-56	
DESCRIPTIVE STATISTICS								
Lmin	ALD3	39	29	28	20	26	20	
Lmax	ALD3	99	90	87	146	97	146	
Lmean	ALD3	63.4	62.1	55.1	56.1	58.6	57.4	
Lc_obs	ALD3	58-60	60-62	56-58	56-58	64-66	60-62	
WETHERALL								
Linf	ALL	106.6	95.0	101.7	NA	NA	NA	
Z/K	ALL	4.55	3.12	5.53				
K after Manooch		0.13	0.14	0.13	NA	NA	NA	
LFDA_ELEFAN								
K	ALM	NA	0.11	NA	0.16	NA	NA	1988 FIT = SLCA
Linf	ALM		107.2		88.8			
To	ALM		-0.636		-0.090			
score	ALM		8.970		0.305			
Phi'	ALM	NA	3.10	NA	3.10	NA	NA	Phi' from lit 2.94-3.16
CATCH CURVE	: using 1988 values fixed over time							
Z	ALL	0.52	0.47	0.73	0.64	0.63	0.62	M @ 18 C = 0.240,
F_Pauly	ALL	0.24	0.23	0.49	0.40	0.39	0.38	0.241
F_Trenkel	ALL	0.28	0.22	0.48	0.40	0.39	0.38	(Pauly; Trenkel)
Lc_cc	ALL	55.0	59.0	59.0	59.0	63.0	59.0	
L50%	ALL						56.8	
L75%	ALL						59.3	
CATCH CURVE	: using 1990 values fixed over time							
Z	ALL	0.36	0.38	0.65	0.50	0.43	0.44	M @ 18 C = 0.323
F_Pauly	ALL	0.04	0.06	0.32	0.18	0.11	0.12	0.312
F_Trenkel	ALL	0.05	0.07	0.34	0.19	0.12	0.13	(Pauly; Trenkel)
Lc_cc	ALL	55.0	59.0	63.0	59.0	63.0	59.0	
L50%	ALL						50.8	
L75%	ALL						57.6	
CATCH CURVE	: using 1988 values fixed over time							
Z	ALD3	0.51	0.44	0.71	0.66	0.63	0.66	M @ 16 C = 0.227
F_Pauly	ALD3	0.28	0.21	0.48	0.43	0.40	0.43	0.224
F_Trenkel	ALD3	0.28	0.21	0.48	0.43	0.41	0.43	(Pauly; Trenkel)
Lc_cc	ALD3	61.0	59.0	59.0	59.0	63.0	61.0	all locations at depth
L50%	ALD3						58.9	301 - 400 m
L75%	ALD3						61.2	
CATCH CURVE	: using 1990 values fixed over time							
Z	ALD3	0.34	0.33	0.58	0.58	0.44	0.40	M @ 16 C = 0.305
F_Pauly	ALD3	0.03	0.03	0.28	0.27	0.13	0.09	0.290
F_Trenkel	ALD3	0.05	0.04	0.29	0.29	0.15	0.11	(Pauly; Trenkel)
Lc_cc	ALD3	59.0	59.0	59.0	59.0	63.0	59.0	
L50%	ALD3						52.5	
L75%	ALD3						57.5	
REPRODUCTION								
Lm (0.5 * Linf)	ALL	0.0	53.6	0.0	44.4	0.0	0.0	
Lm (0.5 * Lmax)	ALL	49.5	46.0	46.0	73.0	69.0	73.0	

Table 24 : Demographic variables estimated from length frequency data analysis of *Etelis carbunculus*

Parameter	data sub set	1987	1988	1989	1990	1991	ALL	COMMENTS
DESCRIPTIVE STATISTICS								
Lmin	ALL	21	22	18	22	13	13	
Lmax	ALL	148	136	123	125	113	148	148 IN '87 -ERROR ?
Lmean	ALL	70.2	54.1	48.7	51.6	57.7	55.4	'87 distribution
Lc_obs	ALL	78-80	30-32	30-32	34-36	40-42	34-36	differs from rest
DESCRIPTIVE STATISTICS								
Lmin	ALD3	25	22	20	26	13	13	
Lmax	ALD3	148	136	123	125	13	148	
Lmean	ALD3	77.8	55.4	51.8	52.4	61.7	59.3	
Lc_obs	ALD3	80-82	32-34	32-34	36-38	40-42	32-34	
WETHERALL								
Linf	ALL	130.6	123.0	121.2	126.2	113.7	128.1	
Z/K	ALL	4.08	2.01	2.42	2.90	1.64	3.44	
K after Manooch		0.11	0.12	0.12	0.11	0.12	0.11	
LFDA_ELEFAN	Unable to fit growth curve, Vanuatu values from literature used							
BEVn HOLT								
Z_cc	ALL	0.46	0.51	0.37	0.37	0.46	0.43	
Z_cc	ALD3	0.50	0.44	0.46	0.52	0.45	0.42	
CATCH CURVE								
Z	ALL	0.48	0.58	0.44	0.39	0.47	0.45	K=0.129, Linf = 127
F_pauly	ALL	0.22	0.32	0.18	0.13	0.21	0.20	To = 1.41
F_trenkel	ALL	0.23	0.33	0.19	0.14	0.22	0.21	M @ 18 C = 0.255
Lc_cc	ALL	76.5	76.5	76.5	76.5	70.5	76.5	0.247
L50%	ALL						67.3	Due to bi-modal
L75%	ALL						73.2	nature of distributions
CATCH CURVE								difficult to select
Z	ALD3	0.52	0.50	0.41	0.81	0.55	0.45	cut off point for
F_Pauly	ALD3	0.28	0.25	0.17	0.57	0.31	0.21	catch curve
F_Trenkel	ALD3	0.29	0.27	0.18	0.58	0.32	0.22	
Lc_cc	ALD3	85.5	67.5	82.5	79.5	70.5	73.5	
L50%	ALD3						69.3	M @ 16 C = 0.241
L75%	ALD3						72.7	0.229
REPRODUCTION								
Lm (0.5 * Lmax)	ALL	74.0	68.0	61.5	62.5	56.5	74.0	

The above total mortality estimates are derived from the descending limb of the second mode of the catch curve. Below estimates are presented of the fishing mortality on the smaller mode represented in the catch and on all fish greater than the cut off length of the smaller mode. Annex 2 gives examples

BEVn HOLT								
Z_cc	ALL	0.19	0.35	0.47	0.40	0.32	0.31	
Z_cc	ALD3	0.15	0.30	0.35	0.39	0.30	0.26	
CATCH CURVE	1 = Smallest mode only; 2 = all fish > smallest Lc							
Lc_cc	ALL	37.5	31.5	31.5	34.5	40.5	31.5	
Z	ALL (1)	0.94	0.93	1.06	0.86	0.81	0.80	L50=28.6 L75=31.4
F_Pauly	ALL (1)	0.68	0.68	0.81	0.61	0.55	0.54	
F_Trenkel	ALL (1)	0.69	0.68	0.82	0.62	0.56	0.55	
Z	ALL (2)	0.32	0.37	0.38	0.36	0.35	0.37	L50=27.2 L75=29.9
F_Pauly	ALL (2)	0.07	0.11	0.13	0.11	0.09	0.11	
F_Trenkel	ALL (2)	0.08	0.12	0.14	0.11	0.10	0.12	
CATCH CURVE								
Lc_cc	ALD3	34.5	31.5	31.5	34.5	40.5	31.5	
Z	ALD3 (1)	0.84	1.12	1.01	0.89	0.68	0.86	L50=28.2 L75=31.1
F_Pauly	ALD3 (1)	0.60	0.88	0.77	0.65	0.44	0.62	
F_Trenkel	ALD3 (1)	0.61	0.90	0.79	0.66	0.45	0.63	
Z	ALD3 (2)	0.13	0.32	0.30	0.36	0.35	0.32	L50=26.2 L75=28.9
F_Pauly	ALD3 (2)		0.08	0.06	0.12	0.10	0.08	
F_Trenkel	ALD3 (2)		0.09	0.07	0.13	0.12	0.10	

Table 25 : Demographic variables estimated from length frequency data analysis of *Epinephelus morhua*

Parameter	data sub set	1987	1988	1989	1990	1991	ALL	COMMENTS
DESCRIPTIVE STATISTICS								
Lmin	ALL	24	22	21	26	23	21	
Lmax	ALL	114	125	79	88	102	125	larger values = out-
Lmean	ALL	55.9	54.5	55.5	56.8	55.6	55.3	liers, poss error?
Lc_obs	ALL	60-62	56-58	56-58	56-58	48-50	56-58	see figs
DESCRIPTIVE STATISTICS								
Lmin	ALD3	35	22	35	31	24	22	small sample size in
Lmax	ALD3	85	76	77	78	79	85	this depth band
Lmean	ALD3	59.3	55.4	57.1	58.1	56.2	57.1	
Lc_obs	ALD3	64-66	60-62	?	60-62	46-48	60-62	
WETHERALL								
Linf	ALL		84.1	77.3	84.6		81.5	XPT '89 dubious fits
Z/K	ALL		2.72	1.74	2.16			due to 0's
K after Manooch		ERR	0.15	0.16	0.15	ERR	0.15	
LFDA_ELEFAN								
K	ALM - 88	NA	0.23	0.23	NA	NA	0.23	Other years too little
Linf	ALL - 89	NA	74.1	76.6	NA	NA	76.6	data. 88/ 89 seem to
To			-0.660	-0.900			-0.900	give good fit.
score			0.386	0.211			0.211	
Phi'		NA	3.11	3.14	NA	NA	3.14	
BEVn HOLT								
Z_cc	ALL	0.44	0.42	0.39	0.29	0.29	0.34	
Z_cc	ALD3	0.40	0.36		0.33	0.27	0.32	
CATCH CURVE	: 1989 K. Linf To values used							
Z	ALL	0.52	0.46	0.41	0.37	0.27	0.38	M @ 18 C = 0.433
F_Pauly	ALL	0.09	0.03					0.395
F_Trenkel	ALL	0.13	0.07	0.01				
Lc_cc	ALL	63.0	59.0	59.0	57.0	59.0	59.0	
L50%	ALL						46.2	
L75%	ALL						55.8	
CATCH CURVE								
Z	ALD3	0.65	0.38		0.43	0.19	0.34	M @ 16 C = 0.410
F_Pauly	ALD3	0.24			0.02			0.367
F_Trenkel	ALD3	0.28	0.01		0.07			
Lc_cc	ALD3	63.0	59.0		57.0	55.0	59.0	
L50%	ALD3						52.7	
L75%	ALD3						58.2	
REPRODUCTION								
Lm (0.5 * Linf)	ALL	NA	37.1	38.3	NA	NA	38.3	
Lm (0.5 * Lmax)	ALL	57.0	62.5	39.5	44.0	51.0	62.5	

Table 26 : Demographic variables estimated from length frequency data analysis of *Epinephelus septemfasciatus*

Parameter	data sub set	1987	1988	1989	1990	1991	ALL	COMMENTS
DESCRIPTIVE STATISTICS								
Lmin	ALL	21	24	32	22	27	21	
Lmax	ALL	172	162	182	192	160	192	
Lmean	ALL	105.2	95.3	100.3	99.6	76.7	94.3	
Lc_obs	ALL						100-102	OR 42-44
DESCRIPTIVE STATISTICS								
Lmin	ALL	60	37	32	57	50	32	
Lmax	ALL	160	162	156	149	153	162	
Lmean	ALL	110.4	101.0	99.0	106.8	103.0	103.7	
Lc_obs	ALL						95-100	
WETHERALL								
Linf	ALL	168.7	166.7	176.0	161.5	168.8	175.1	
Z/K	ALL	1.76	1.90	3.51	2.96	3.18	2.94	
K after Manooch	ALL	0.094	0.095	0.092	0.097	0.094	0.092	
LFDA_ELEFAN								
K	ALM	NA	0.15	NA	NA	NA	NA	Only '88 data gave a
Linf	ALM		154.4					fit and this choice
To	ALM		-0.890					subjectively best, but
score	ALM		0.202					higher K values gave
Phi'	ALM	NA	3.55	NA	NA	NA	NA	better score
BEVn HOLT								
Z_cc, K=0.1476	ALL	0.17	0.22	0.28	0.33	0.37	0.25	
Z_cc, K=0.207	ALL	0.54	0.60	0.78	0.89	0.96	0.69	
Z_cc, K=0.1476	ALD3	0.25	0.22	0.35	0.41	0.34	0.29	
CATCH CURVE	K=0.1476 Linf=154.4, To=-0.8			M @ 18C	0.264 (Pauly)		0.247	(Trenkel)
Z	ALL	0.25	0.23	0.32	0.37	0.41	0.29	
F_Pauly	ALL			0.05	0.11	0.15	0.02	
F_Trenkel	ALL			0.07	0.12	0.16	0.04	
Lc_cc	ALL	102.5	92.5	97.5	92.5	97.5	97.5	
L50%	ALL						86.5	
L75%	ALL						93.2	
CATCH CURVE	K=0.207 Linf=189.9, To=-0.33			M @ 18C	0.31 (Pauly)		0.274	(Trenkel)
Z	ALL	0.55	0.55	0.99	0.92	1.03	0.84	This K-Linf pair
F_Pauly	ALL	0.24	0.24	0.68	0.61	0.71	0.53	gave highest score
F_Trenkel	ALL	0.28	0.27	0.72	0.64	0.75	0.57	(LFDA/ELEFAN) but
Lc_cc	ALL	102.5	92.5	97.5	97.5	97.5	97.5	K seems too high
L50%	ALL							Rn=0.3188
L75%	ALL							
CATCH CURVE	K=0.1476 Linf=154.4, To=-0.8			M @ 16C	0.25 (Pauly)		0.230	(Trenkel)
Z	ALD3	0.21	0.32	0.39	0.41	0.36	0.31	
F_Pauly	ALD3		0.07	0.14	0.16	0.11	0.06	
F_Trenkel	ALD3		0.09	0.16	0.18	0.13	0.08	
Lc_cc	ALD3	97.5	92.5	102.5	107.5	97.5	97.5	
L50%	ALD3						87.8	
L75%	ALD3						93.5	
REPRODUCTION								
Lm (0.5 * Linf)	ALL	0.0	77.2	0.0	0.0	0.0	0.0	
Lm (0.5 * Lmax)	ALL	86.0	81.0	91.0	96.0	80.0	96.0	

Table 27 : To summarise the best estimates, and present the range of estimates for demographic variables for each species derived from length frequency data.

Parameters	*Pristipomoides filamentosus*			*Pristipomoides flavipinnis*			*Etelis coruscans*			*Etelis carbunculus*			*Epinephelus morhua*			*Epinephelus septemfasciatus*		
	Best/mid value	Range of values		Best/mid value	Range of values		Best/mid value	Range of values		Best/mid value	Range of values		Best/mid value	Range of values		Best/mid value	Range of values	
Lmin	18			20			17	? to	6	13			21			32		
Lmax	106	? to	150	63	? to	96	99	? to	148	136	? to	148	102	? to	125	172	? to	192
Lmean	52.9			39.7			56.7			55.4			55.3			94.3		
Lm (0.5xLmax)	53			31.5			49.5			68	? to	74	51			86		
Lc_obs		46	48		40	42		54	56	NB : 1987	34	36		56	58		95	100
Lc50_obs										atypical								
Lc (catch curve)	63			39			59			76.5	NB : 2 modes, this		59			97.5		
L50%	60.2			37.4			56.8			67.3	data relates to		46.2			86.5		
L75%	62.5			39.3			59.3			73.2	largest mode		55 8			93 2		
Linf (Wetherall)		76.2	80.5		67.8	64.3		95	106.6		113.7	130.6		77 3	84.6		161.5	176
Linf (von B)	77.6	74.8	77.6	lit. values	49	58	107.2	also	88.8	lit. values	127		76.6	74.1	76.6	Very poor	154.4	189 9
K	0.22	0.22	0.3	used	0.268	0.36	0.11		0.16	used	0.129		0.23	0.23	0.23	fits	0.15	0.207
To	-0.44	-0.44	-0.88		-1.01		-0.636		-0.09	(Vanuatu)	1.41		-0.9	-0.66	-0.9	obtained	-0.89	-0.33
Z (Bevn Holt)	0.65	0.53	0.87	range =	0.51	1.63				0.43	See Table NN		0.34			mortality	0.17	0.96
Z (Catch curve)	0.72	0.56	1.03	mid est.	0.67	1.85	0.62	0.36	0.73	0.45	Z varies at length		0 38	0.27	0.52	depends	0.23	1 03
M (Trenkel)	0.38	0.38	0.45	for each	0.498	0.547	0.241			0.247			0.395			on growth	0.247	
F	0.34	0.17	0.62	set of	0.172	1.303	0.38	0.05	0.48	0.21			-	-	0.13	params	-	0 75
				growth												chosen		
				params														

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ANNEX 1 : Previous Analyses of the 1986 - 1991 Data Set

Summaries of analyses performed are presented in Latu and Tulua (1990a; 1992) and King (1992). All analyses refer to the six major species represented in the catch : *Pristipomoides filamentosus, P. flavipinnis, Etelis coruscans, E. carbunculus, Epinehelis morhua* and *E. septemfasciatus* which are considered deep water species. *Lethrinus chrysostomus* is the major component of the shallow water catch. Data was also collected on *L. rubriopeculatus, Gymnocranius japonicus*, a grouper spp. and 'others'.

Langi and Langi (1987) : Nine months of data are analysed. From summed length frequency data the following parameters were calculated :

Lc; Lmax; Lr (defined as size of fish at entry to fishery - Lmin?); L∞ and Z/K (from Wetherall *et al.*, 1987); Lm (from 50% L∞ (Grimes, 1986) or 50% Lmax where L∞ not available); F/M (from (Z/K)/(M/K) = F/M + 1 using values for M/K derived by Polovina and Ralston (1986) in the Marianas); K (from $\mathrm{Log}_{10}K = 1.098 - 0.658\mathrm{Log}_{10}L\infty$, where L∞ is in mm (Manooch, 1986)); maxY/R (from yield functions (Beverton and Holt, 1986); Lopt (F/M). The results are summarised in Annex 1, Table A1.1

Langi and Langi (1989) : Decreases in mean length of *Pristipomoides filamentosus*, and species composition changes were presented as indicators of fishing pressure. The mean length in Vava'u (where fishing began in 1980) was 45 cm compared to 61 cm in the south (where fishing initially occurred on the banks and then since 1986 on sea mounts). Between 1987 and 1988 no change in median length was observed for fish from northern sea mounts, but fish larger than 63 cm were absent from the catch; median length decreased from 61 to 54 cm in the south. Certain sea mounts which showed decreasing catch rates were examined. Similar decreases in mean length were observed. The changing species composition was thought to be due to a change of target depth.

Langi (1990) : Length frequency data for *P. flavipinnis* and *E. coruscans* for 1987 was not suitable for assessment of von Bertalanffy growth parameters using ELEFAN I. Data for *P. filamentosus* indicated modal progression but it was concluded that due to size differences by location, data should be stratified by area before analysis. This was not attempted. The Wetherall plot was used to estimate L∞ and Z/K - problems were encountered in applying this to *P. flavipinnis*. The results are indicated in Table A1.1.

Langi, Langi and Polovina (1988; 1992) : 8 sea mounts with complete coverage of landings were examined and 3 indicated depletion. Catchability (q, 0.0033) and recruitment (R, 693 fish/nmi/yr) of the major species were calculated using a modification of Allen's (1966) depletion model suggested by Sainsbury (1984). M was obtained from the literature (0.04 / month). Fishing mortality (0.3/yr) was next calculated from F = qf. Biomass (698 fish/nmi = 3071 kg/nmi) was estimated from cpue/q using a value of cpue from lightly exploited sea mounts. Surplus production (737 kg/nmi/yr) was estimated to be 24% of B_0. The estimate was raised to cover all sea mounts (total yield 217 t). Catches exceed this amount - are the sea mounts self recruiting or do fish recruit onto them from the larger banks? If the banks were protected could higher fishing levels be sustained?

Latu and Tulua (1989; 1990) : Two of the sea mounts examined by Langi *et al.* (1992) were re-examined over a longer time period, together with two new locations. q (avg. 0.0039 - 0.0048 / nmi), R (249 - 393 fish/nmi/yr) and F (0.2 - 1.4) were calculated in the same way but using two assumed values for M (0.02 and 0.04 / month). Initial biomass derived from Allen's model for each location was divided by the length of the 200 m contour at that location (2.2 - 7.5 t/nmi, avg. 2.4 t/nmi), and raised by 294 nmi to estimate total biomass for all sea mounts (706 t). Surplus yield (MSY 64 - 198 t/yr, equivalent to 215 - 673 kg/nmi/yr) was estimated after Pauly (1983) and Beverton and Holt (1986). The results of this analysis are compared with those of Langi *et al* (1992) in Table A1.2. F at 0.7 in 1988 and 0.9 in 1989 is considered to be 2-3 times the value of M suggesting that effort exceeds the level that achieves MSY.

(Note : Dalzell and Preston (1992) estimate total biomass including the banks using a lower value of 0.7 t/nmi for the banks (1125 t) MSY will be 113 - 338 t/yr based on this information, and present catches exceed even this value.

Latu and Tulua (1990a; 1992) :

Catch effort and species composition data are presented for the whole fishery (ie. all locations and depths pooled). Species composition changes (a shift from *Pristipomoides filamentosus* to *Etelis coruscans*) are concluded to reflect targeting rather than changes in abundance.

Length-weight relationships are presented for the 7 major species in the catch. Biological parameters derived from length frequency data are summarised in Table A1.1. The authors did not notice a significant reduction in mean lengths for data covering the whole of the Kingdom.

Yield estimates were derived in two ways:

i) Latu and Tulua (1990a) repeated the depletion analysis for selected seamounts using 50 months of data (see Table A1.2). The median estimate of biomass for these seamounts was 6.4 t/nmi. Total biomass for all seamounts was estimated to be 1881.6 t (M=0.04) - 2764 t (M=0.02). MSY was in the range 169 - 773 t.

ii) Latu and Tulua (1990a) applied surplus production models to the total catch and effort data for all locations, depths and species pooled without success. Data for individual species pooled by depth and location could not be fitted to these models. Latu and Tulua (1992) applied these models to the five main species only. They indicate that seamount catch and effort data was separated from shallow banks fishery data for the analysis. However, the catch value they used in the analysis was the sum of the total catch of the five main species from all locations. In justification they indicate that 92% of the catch of these species derives from seamounts and suggest that the remaining 8% was probably due to errors in identification of location. The effort value (trips) employed apparently related to seamounts only. Production models estimated a sustainable yield of 350 t for the five species. Similar analyses estimated the MSY for *P. filamentosus* and *E. coruscans* to be 214 t.

Economic analyses of the fishery were also presented. MEY was found to occur at lower levels of catch and effort than those required to achieve MSY.

King (1992) : This report summarises available information. It also attempts to partition catch and effort by depth by assuming 4 species (*E. coruscans, E. carbunculus, E. septemfasciatus, E. morhua*) represent the catch from > 200 m and the rest < 200 m. Effort > 200 m = E(total) x C(>200 m)/C(total). Production models based on this data estimate sustainable yields of 255 - 284 t for deep water species

Annex 1 Table A1.1 A summary of demographic variable estimated for the six major species of the Tongan sea-mount fishery

SPECIES	REPRODUCTIVE PARAMETERS				GROWTH PARAMETERS				MORTALITY			RECRUITMENT			W = qL^b		Y/R ANAL.		SOURCE
	Lm	Lm50	Lm%Loo	spawning	Lmax	Loo	Z/K	K	M	F/M	M/K	Lmin	Lr	Lc	q	b	Lopt(F/M)	Lr/Linf maxY/R	
Pristipomoides filamentosus	38.6				75	80 77.2	2.8 4.1	0.16		0.6	2.5		56	65	0.00013914	2.49	29.3	0.46	Latu and Tulua (1991/92) Langi and Langi (1987)
Pristipomoides flavipinnis	28.8				57	57 57.5	4.69 11.5	0.19		1.5	4.6		39	43	0.00007120	2.67	18.4	0.15	Latu and Tulua (1991/92) Langi and Langi (1987)
Etelis coruscans	49.6				96	116 99.3	5.92 3.33	0.13		0.5	2.2		44	59	0.00007485	2.62	39.7	0.99	Latu and Tulua (1991/92) Langi and Langi (1987)
Etelis carbunculus	57'				114	120	2.08						59	70	0.00001940	2.98	45.6	0.95	Latu and Tulua (1991/92) Langi and Langi (1987)
Epinephelus morhua	37.1				80	92 74.2	3.77 1.33	0.16					48	60	0.00003167	2.83	29.7	0.76	Latu and Tulua (1991/92) Langi and Langi (1987)
Epinephelus septemfasciatus	86'				172	198	4.52						108	120	0.00022713	2.45	68.8	0.8	Latu and Tulua (1991/92) Langi and Langi (1987)
Lethrinus chrysostomus	38'				76								44	54	0.00005119	2.72	30.4	0.87	Latu and Tulua (1991/92) Langi and Langi (1987)

Annex 1: Table A1.2 : A summary of the results of Allen depletion analyses applied to Tongan sea mount data

Seamount	Length 200m	Value M used	Time period	q	q/nm	R/nmi/yr	source
801	5.0	0.02/mth	Jan 87 - Jun 89	0.0009	0.0045	197	Latu and Tulua, 199
801	5.0	0.04/mth	Jan 87 - Jun 89	0.0010	0.0050	344	Latu and Tulua, 199
801	5.0	0.02/mth	Nov 86 - Dec 90	0.0009	0.0045	193	Latu and Tulua, 199
801	5.0	0.04/mth	Nov 86 - Dec 90	0.0090 ?	0.0045	382	Latu and Tulua, 199
901	6.8	0.04/mth	Oct 86 - Dec 88	0.0009	0.0060	231	Langi et al 1992
901	6.8	0.02/mth	Jan 87 - Jun 89	0.0004	0.0027	137	Latu and Tulua, 199
901	6.8	0.04/mth	Jan 87 - Jun 89	0.0007	0.0048	201	Latu and Tulua, 199
901	6.8	0.02/mth	Nov 86 - Dec 90	0.0001	0.0008	217	Latu and Tulua, 199
901	6.8	0.04/mth	Nov 86 - Dec 90	0.00003 ?	0.0002	2187	Latu and Tulua, 199
903	35.0	0.02/mth	Jan 87 - Jun 89	0.0002	0.0070	118	Latu and Tulua, 199
903	35.0	0.04/mth	Jan 87 - Jun 89	0.0002	0.0063	265	Latu and Tulua, 199
903	35.0	0.02/mth	Nov 86 - Dec 90	0.0002	0.0063	133	Latu and Tulua, 199
903	35.0	0.04/mth	Nov 86 - Dec 90	0.0002	0.0078	219	Latu and Tulua, 199
1001	7.4	0.04/mth	Oct 86 - Dec 88	0.0002	0.0015	921	Langi et al 1992
1004	1.2	0.04/mth	Oct 86 - Dec 88	0.0020	0.0024	926	Langi et al 1992
1004	1.2	0.02/mth	Jan 87 - Jun 89	0.0016	0.0019	493	Latu and Tulua, 199
1004	1.2	0.04/mth	Jan 87 - Jun 89	0.0025	0.0030	762	Latu and Tulua, 199
1004	1.2	0.02/mth	Nov 86 - Dec 90	0.0013	0.0016	554	Latu and Tulua, 199
1004	1.2	0.04/mth	Nov 86 - Dec 90	0.0021	0.0025	794	Latu and Tulua, 199

ANNEX 2 : CEDA analyses applied to annual catch and effort data.

The Fox and Schaefer biomass dynamic production models were applied to stratified data from the Tongan deep slope fishery as described in 3.1.4 using the CEDA package (MRAG, 1992a) :

Fox model:

$$B_{t+1}=B_t+r(B_{t-L})(1-\ln(B_{t-L})/\ln(K))-C_t$$

Schaefer model:

$$B_{t+1}=B_t+r(B_{t-L})(1-(B_{t-L})/K)-C_t$$

Where B_t is the population biomass at the start of time t; r is the intrinsic rate of growth; L is the time lag; K is the carrying capacity and C_t is the total catch during t.

CEDA requires that a parameter, 'Initial proportion', is entered. This reflects the degree of exploitation of the stock before data collection began. For the Tonga data set this was normally set at 0.8. A choice of error model for fitting data to the model is also required (Least squares, Gamma or Log normal). A more complete explanation with equations for the error models is provided in MRAG (1992a).

Table 11 of the text indicates for which sub strata the model was found to fit the data. Of the models tested (ie Fox / Schaefer by 3 different error models, by different initial proportions) only the best fitting combination is presented as indicated in Table A.2.1. Figures A.2.1 - A.2.X indicate the range of values for 95% confidence intervals of K, q and r.

Generally, full sensitivity tests were not performed on all data sets in relation to the initial proportion since, apart from the volume of analyses required, it was considered that 0.8 was a reasonable figure indicating that 20% of the stock had been removed prior to data collection, and K did not vary considerably with changing initial proportion, although the fit (residuals) was sometimes improved. However, a range of values for initial proportion were tested in each case to see if a significantly better fit could be achieved. Occasionally values as low as 0.35 gave the best results (eg. Tonga south, all species > 300 m), but these were discarded since it was considered unlikely that 65% of the stock had been removed prior to the start of the data collection programme.

TABLE A.2.1. : DETAILS OF CEDA ANALYSES (AND FOLLOWING FIGURES) APPLIED TO STRATIFIED DATA FROM THE TONGAN DEEP SLOPE FISHERY

Figure	Data sub set	species	model	fit	initial %	time-lag	cpue timing	R2	Good fit?	1987 Excluded
A.2.1	ALAD	MS	FOX	LS	0.8	0	Middle	0.901	POOR	
A.2.2	ALD1	MS	FOX	LS	0.8	0	Middle	0.552	POOR	
A.2.3	ALD>3	S3	FOX	LS	0.8	0	Middle	0.986	V POOR	YES
A.2.4	ALD>3	S6	FOX	LS	1.0	0	Middle	0.941	POOR	
A.2.5	ALD>2	S4	FOX	LS	0.8	0	Middle	0.685	POOR	
A.2.6	ALD>2	S5	FOX	LOG	0.8	0	Middle	0.771	POOR	
A.2.7	ALD>2	S6	FOX	LS	0.8	0	Middle	0.307	V. POOR	
A.2.8	SMD2	MS	FOX	LS	0.8	0	Middle	0.986	POOR	YES
A.2.9	SMD>3	ALL	FOX	LS	0.8	0	Middle	0.956	**FAIR**	
A.2.10	SMD>3	MS	FOX	LS	0.8	0	Middle	0.965	**FAIR**	
A.2.11	SMD>3	S3	FOX	LS	0.8	0	Middle	0.939	POOR	YES
A.2.12	SMD>3	S6	FOX	LOG	0.8	0	Middle	0.984	POOR	
A.2.13	TSD>3	ALL	FOX	LS	0.9	0	Middle	0.961	POOR	YES
A.2.14	TSD>3	MS	FOX	LS	0.8	0	Middle	0.987	FAIR ?	
A.2.15	TSD>3	S3	FOX	LS	0.8	0	Middle	0.990	POOR	
A.2.16	TSD>3	S6	FOX	LS	0.8	0	Middle	0.972	POOR	
A.2.17	L&T 92	5 SPP	FOX	LS	0.8	0	Middle	-0.681	NO FIT	
A.2.18	SMAD (t)	5 SPP	FOX	LS	0.8	0	Middle	0.693	V POOR	

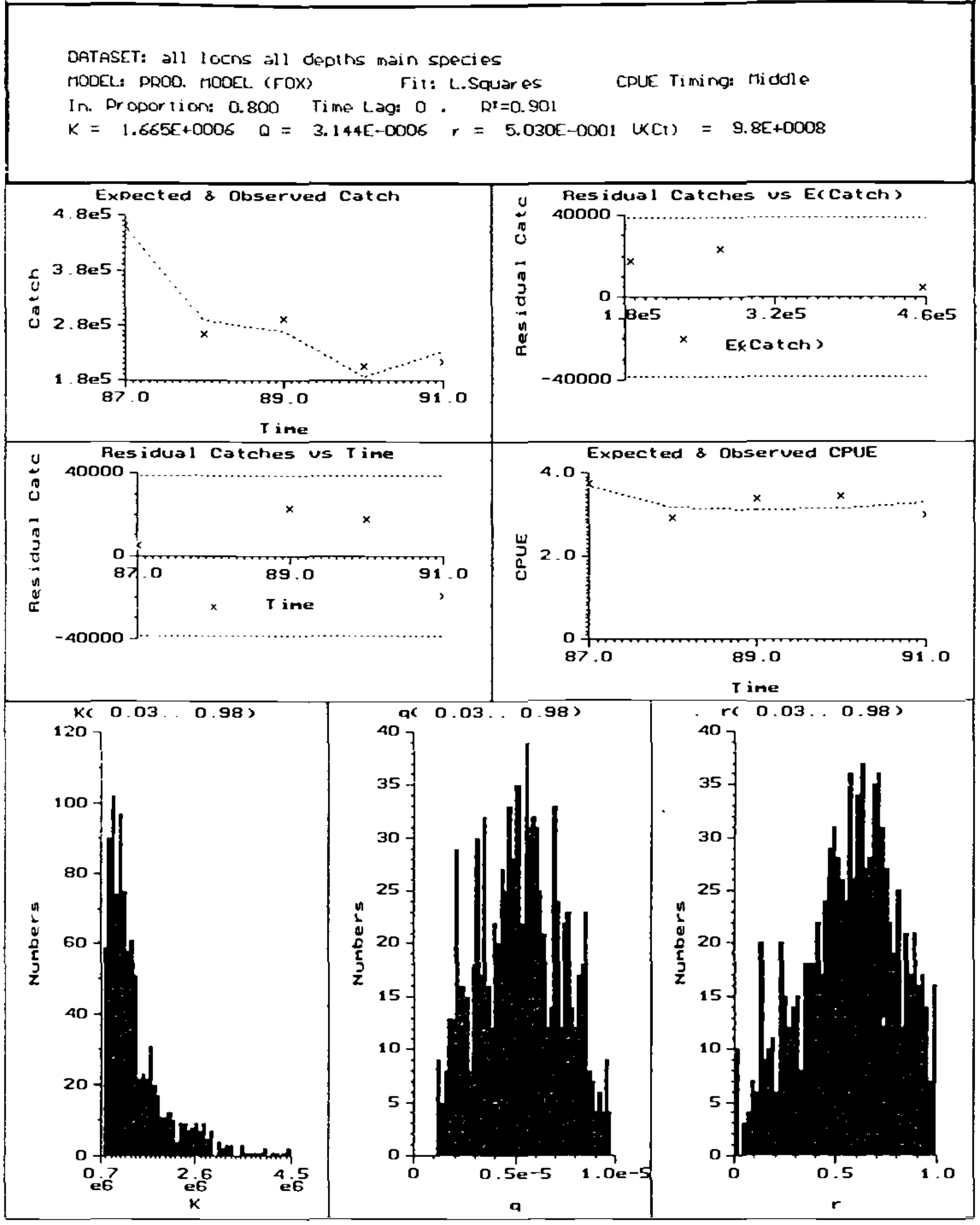
AL = ALL LOCATIONS
SM = SEA MOUNTS
TS = TONGA SOUTH
(t) = EFFORT PER TRIP

AD = ALL DEPTHS
D1 = 1-100 M
D2 = 101 - 200 M
D>2 = DEPTHS > 200M
D>3 = DEPTHS >300M

MS = MAIN 6 EXPORT SPECIES
5 SPP = MS EXCEPT P. FLAVIPINNIS
S3 = E. CORUSCANS
S4 = E. CARBUNCULUS
S5 = E. MORHUA
S6 = E. SEPTEMFASCIATUS

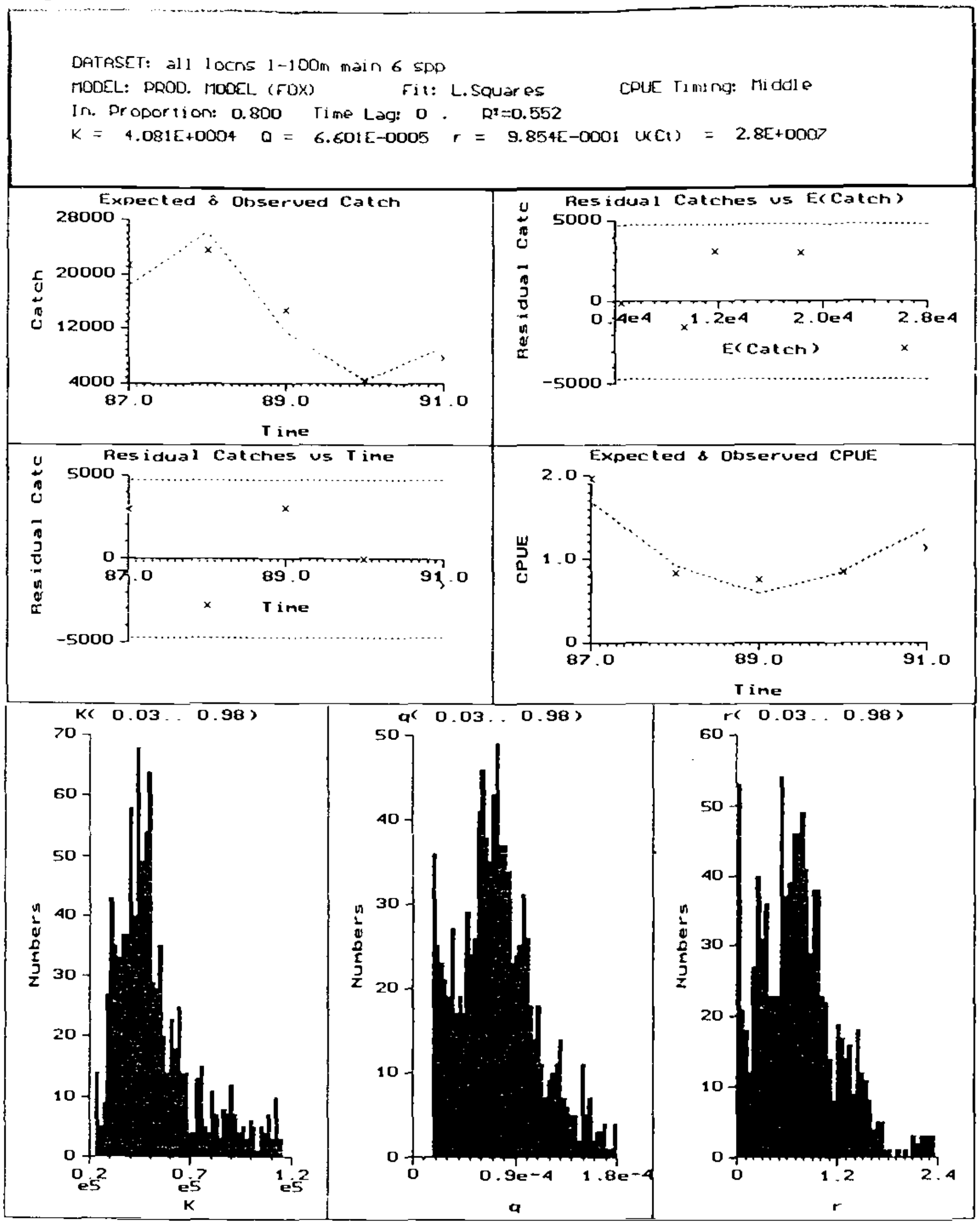
LS = LEAST SQUARES
LOG = LOG NORMAL

Fig. A.2.1.



```
PARAMETER ESTIMATES
-------------------

     K =           1665249
     q =     3.144296E-0006
     r =     5.029924E-0001
  V(Ct)   =   9.8E+0008


Confidence Intervals
--------------------
                 2.50%                 97.50%
     K =           752575                4549597
     q =     1.1[illegible]E-0006        9.810089E-0006
                                   [illegible]
```

Fig. A.2.2.

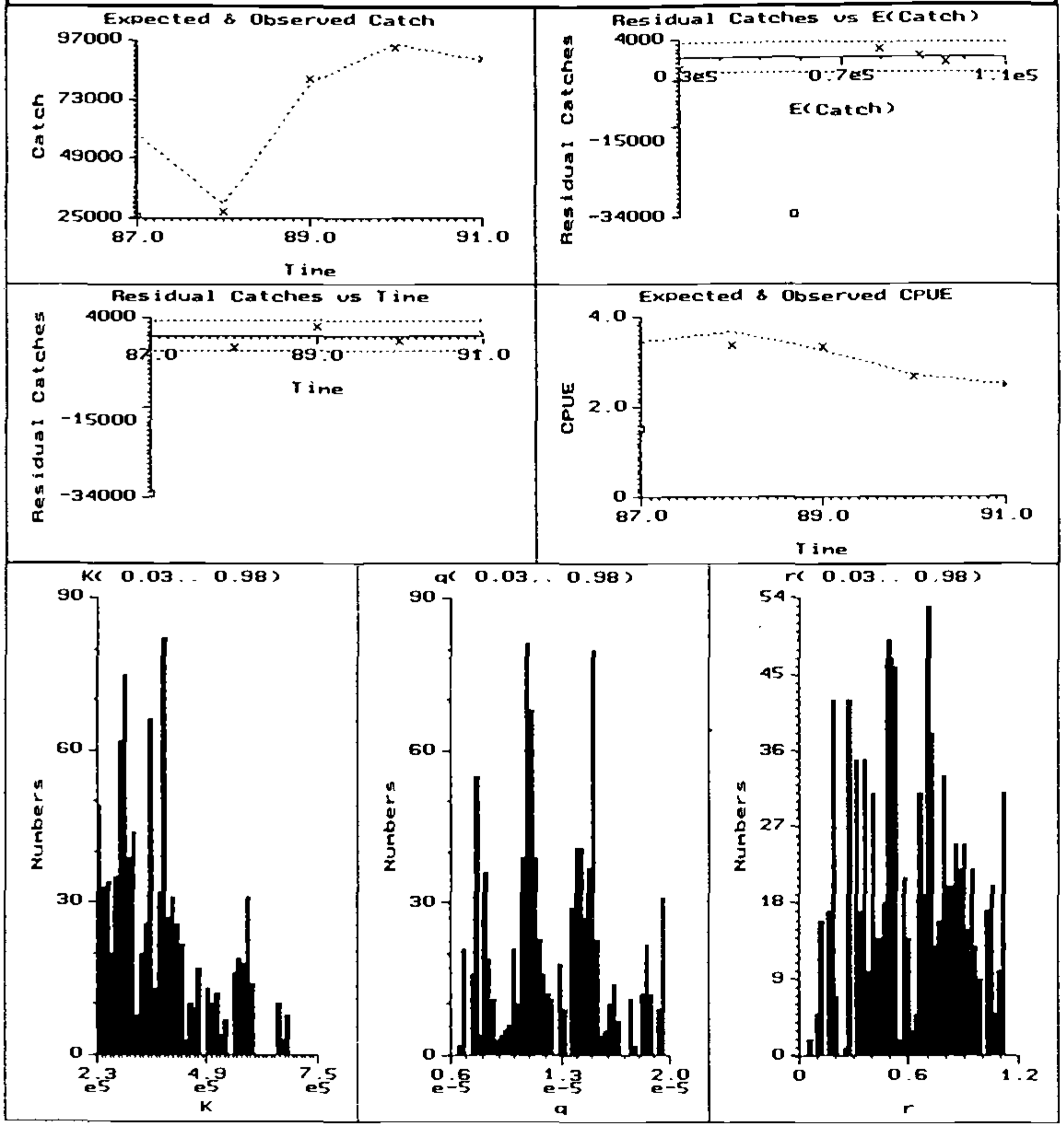


```
DATASET: all locns 1-100m main 6 spp
MODEL: PROD. MODEL (FOX)        Fit: L.Squares        CPUE Timing: Middle
In. Proportion: 0.800   Time Lag: 0 .   R²=0.552
K =  4.081E+0004  Q =  6.601E-0005  r =  9.854E-0001 V(Ct)  =  2.8E+0007
```

```
PARAMETER ESTIMATES
-------------------

      K =          40809
      q =  6.601186E-0005
      r =  9.853961E-0001
  V(Ct)  =   2.8E+0007


Confidence Intervals
--------------------
                2.50%              97.50%
      K =           22729               115243
      q  =  1.709714E-0005      1.810270E-0004
      r  =  2.196101E-0007      2.366326E+0000
```

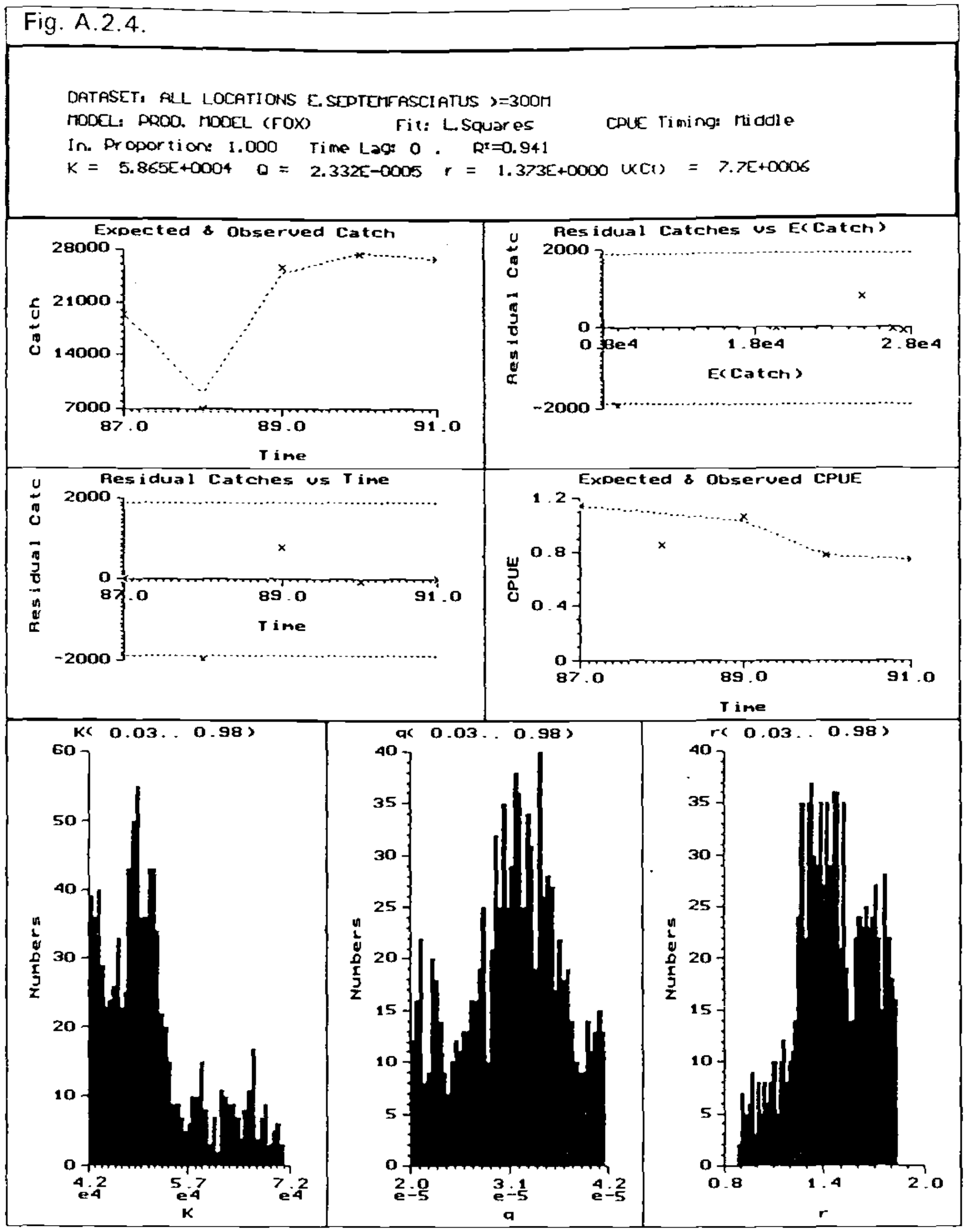
Fig. A.2.3.

```
DATASET: ALL LOCATIONS E. CORUSCANS )=300M
MODEL: PROD. MODEL (FOX)          Fit: L.Squares        CPUE Timing: Middle
In. Proportion: 0.800   Time Lag: 0 .    R²=0.986
K =  2.748E+0005  Q =  1.490E-0005  r =  1.028E+0000 V(Ct)  =  3.1E+0007
```



```
PARAMETER ESTIMATES
-------------------

     K  =          274784
     q  =  1.489892E-0005
     r  =  1.028404E+0000
  V(Ct)   =   3.1E+0007


Confidence Intervals
--------------------
             2.50%              97.50%
     K  =          228835             745562
     q   =  6.433930E-0006      1.971728E-0005
     r   =  4.684471E-0002      1.129259E+0000
```

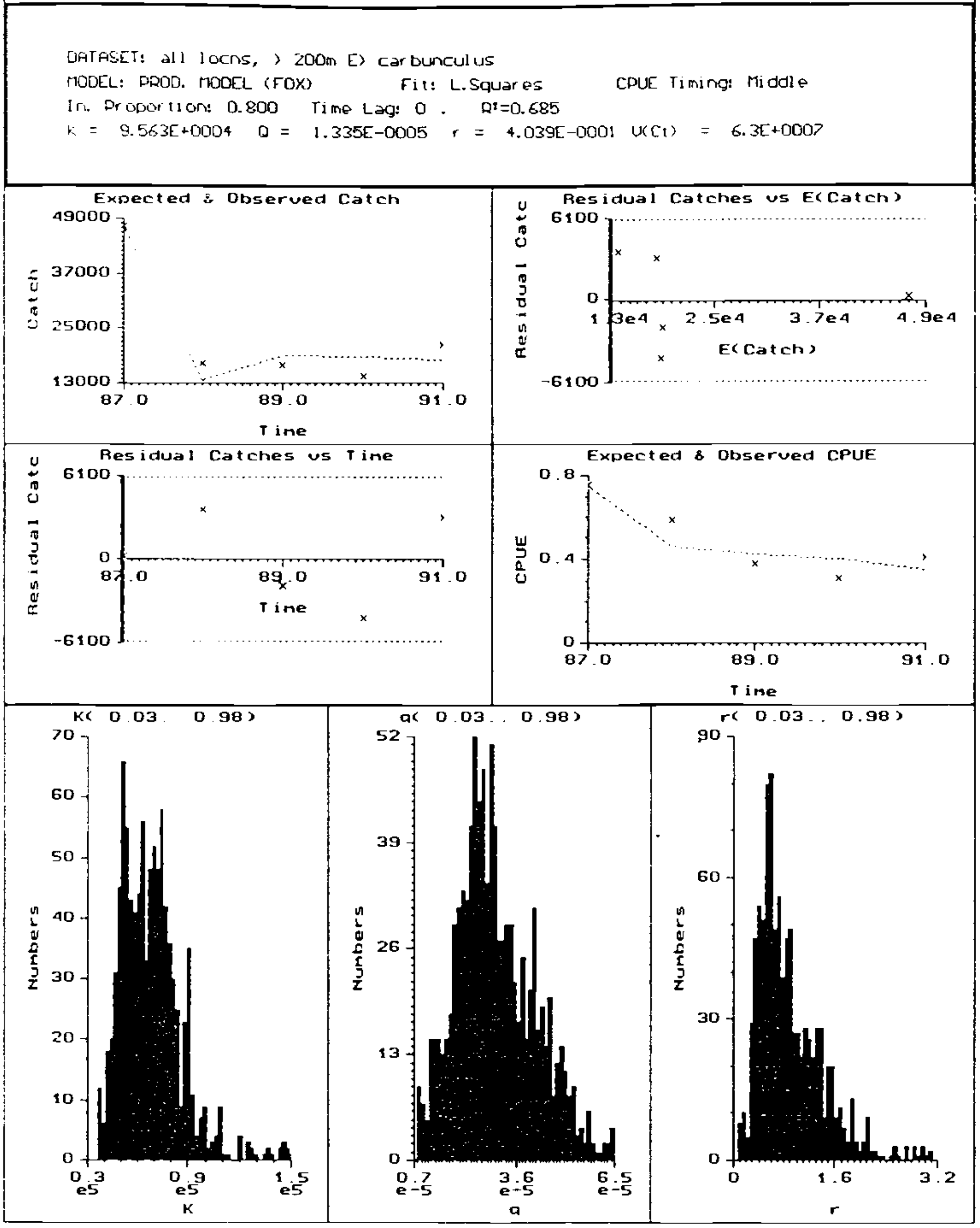
Fig. A.2.4.



```
DATASET: ALL LOCATIONS E.SEPTEMFASCIATUS >=300M
MODEL: PROD. MODEL (FOX)          Fit: L.Squares          CPUE Timing: Middle
In. Proportion: 1.000   Time Lag: 0 .   R²=0.941
K =  5.865E+0004   Q =  2.332E-0005   r =  1.373E+0000  V(Ct)  =  7.7E+0006
```

```
PARAMETER ESTIMATES
-------------------

     K  =          58647
     q  =  2.331681E-0005
     r  =  1.373331E+0000
 V(Ct)  =    7.7E+0006


Confidence Intervals
--------------------
               2.50%                97.50%
    K  =           41467                  71028
    q  =  1.962903E-0005      4.171351E-0005
    r  =  8.832277E-0001      1.835768E+0000
```

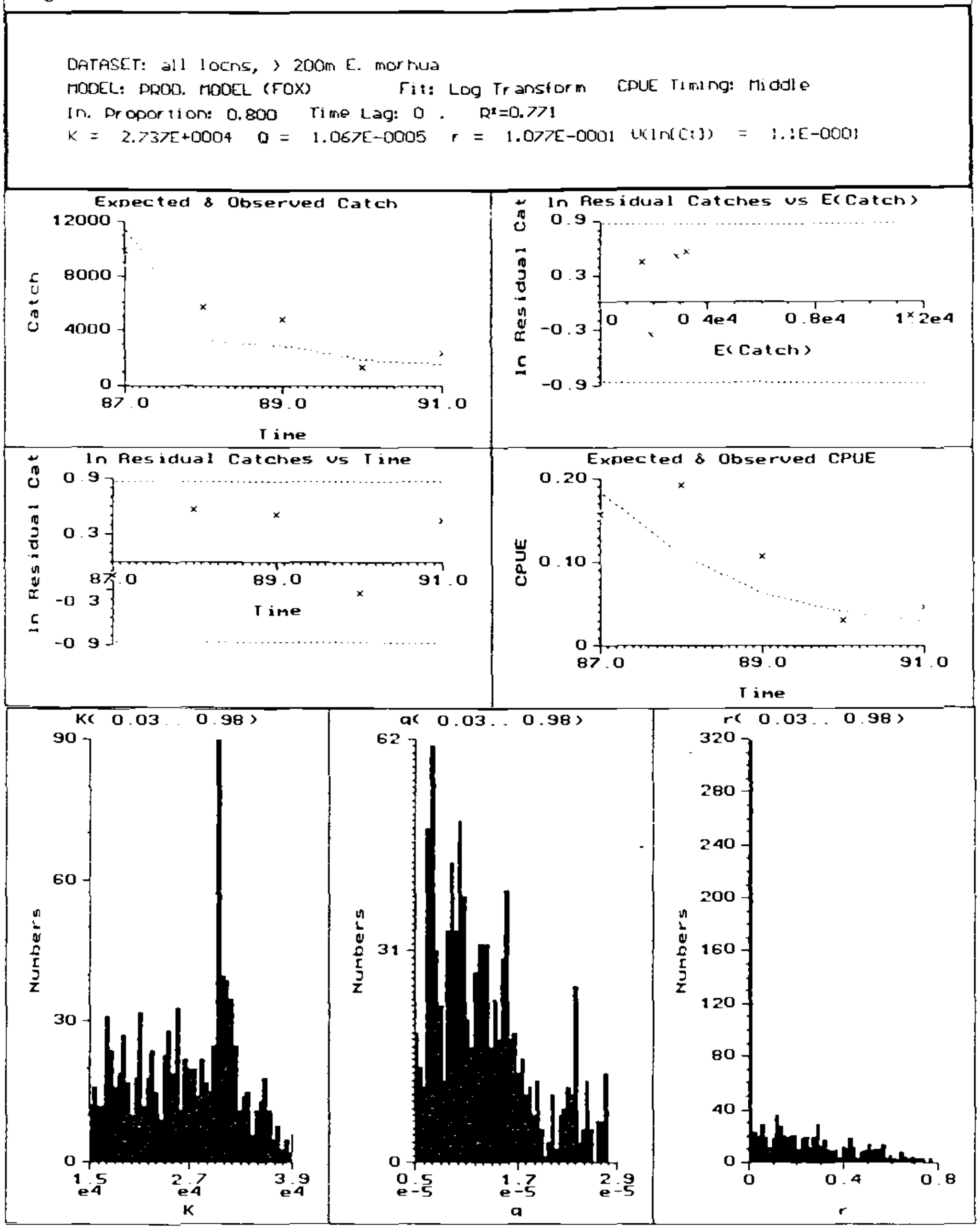
Fig. A.2.5.



```
DATASET: all locns, > 200m E) carbunculus
MODEL: PROD. MODEL (FOX)          Fit: L.Squares        CPUE Timing: Middle
In. Proportion: 0.800    Time Lag: 0 .    R²=0.685
k =  9.563E+0004   Q =  1.335E-0005  r =  4.039E-0001  V(Ct)  =  6.3E+0007
```

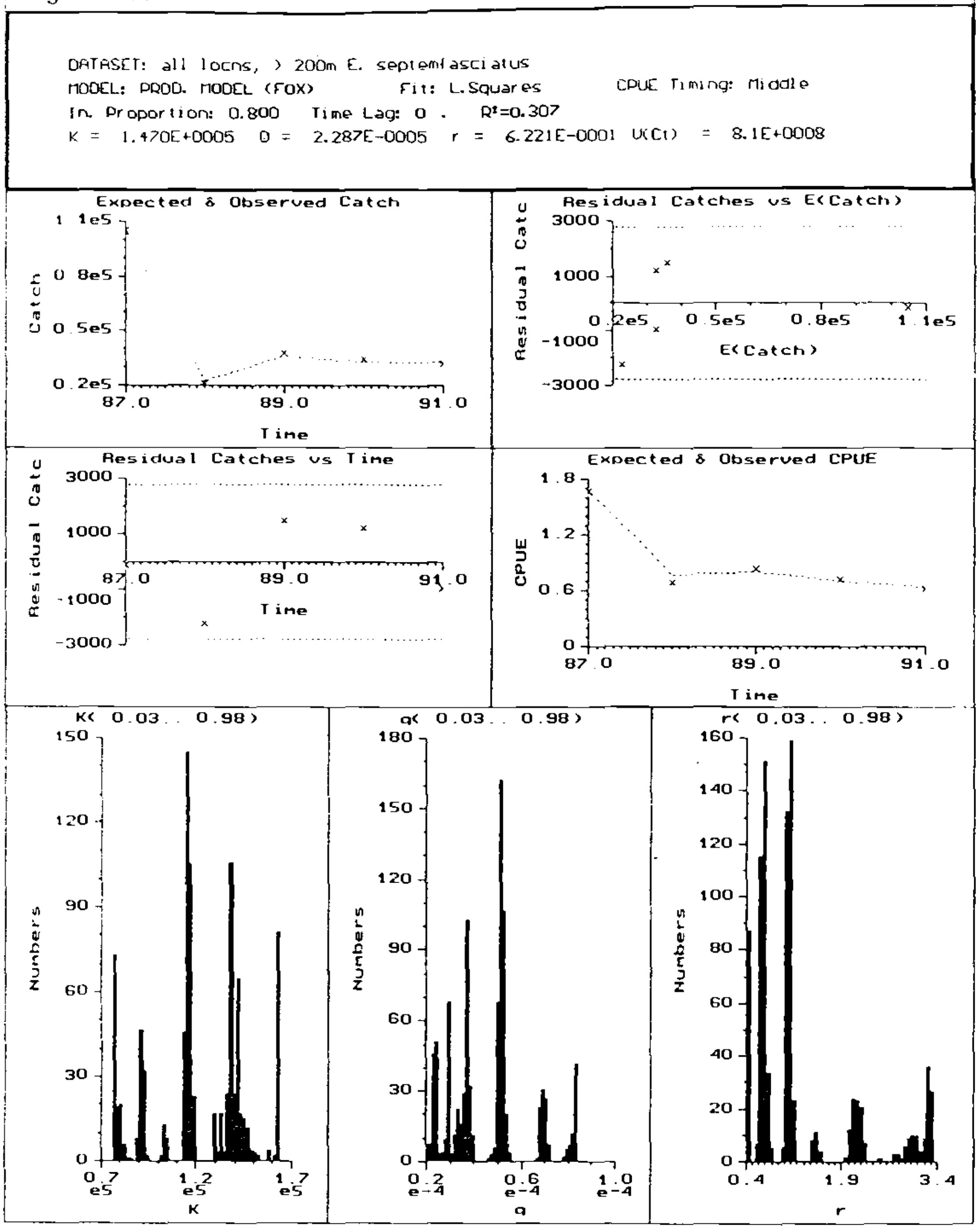
```
PARAMETER ESTIMATES
-------------------

     K  =            95630
     q  =  1.334933E-0005
     r  =  4.039457E-0001
  V(Ct)   =  6.3E+0007


Confidence Intervals
--------------------
                 [illegible]                 97.50%
     K  =        [illegible]                  151835
     q  =        [illegible]          6.491748E-0005
     r  =        [illegible]          [illegible]
```

Fig. A.2.6.



```
PARAMETER ESTIMATES
-------------------

     K =           27366
     q =   1.066964E-0005
     r =   1.076990E-0001
 V(ln[Ct])  =   1.1E-0001


Confidence Intervals
--------------------
              2.50%                 97.50%
    K =            14907                  39560
    q   =  4.975189E-0006        2.792010E-0005
    r   =  [illegible]93109E-0009        7.753414E-0001
```

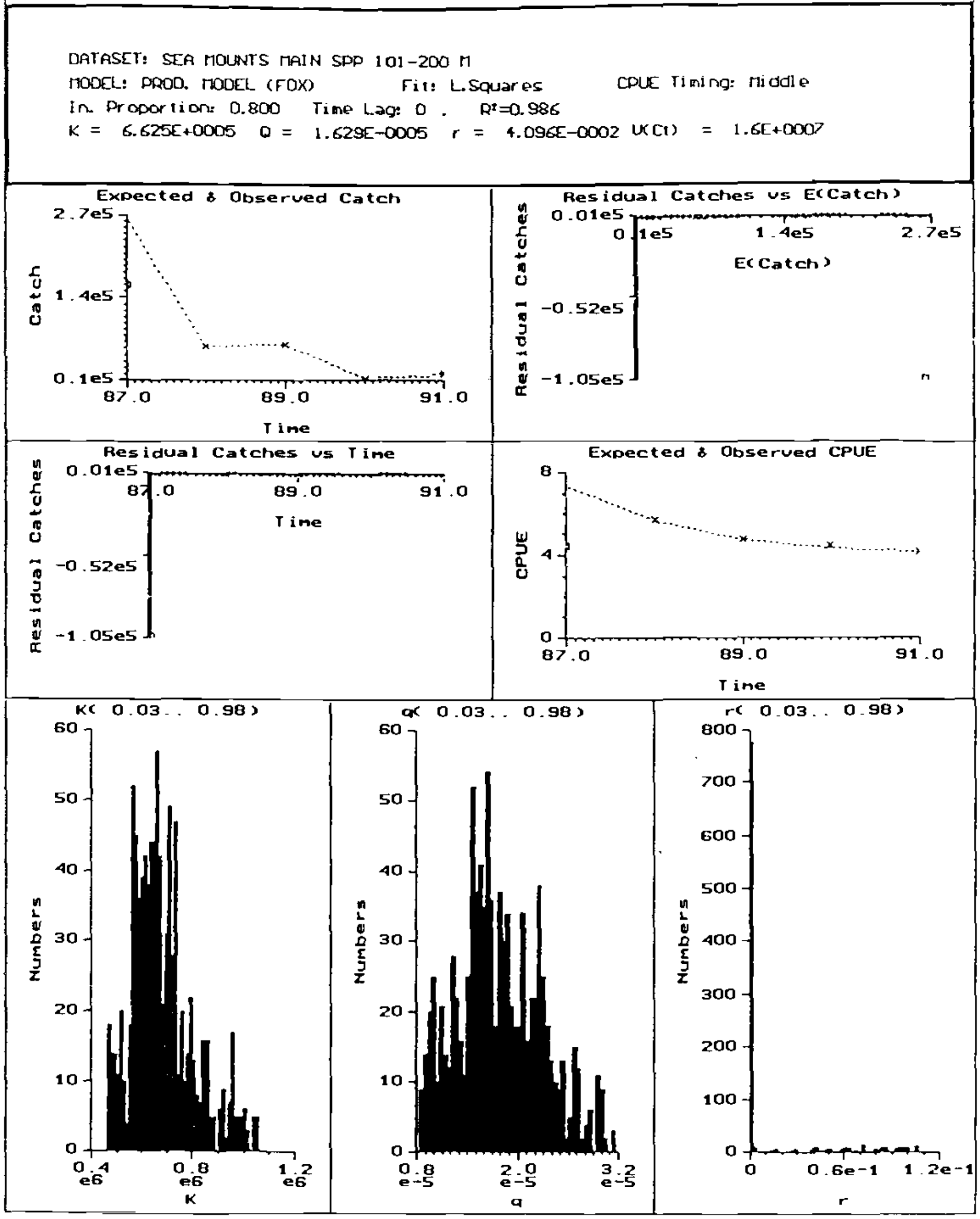
Fig. A.2.7.



```
DATASET: all locns, > 200m E. septemfasciatus
MODEL: PROD. MODEL (FOX)          Fit: L.Squares        CPUE Timing: Middle
In. Proportion: 0.800    Time Lag: 0 .    R²=0.307
K =  1.470E+0005   Q =  2.287E-0005   r =  6.221E-0001  V(Ct)  =  8.1E+0008
```

```
PARAMETER ESTIMATES
-------------------

     K  =           146959
     q  =  2.286817E-0005
     r  =  6.221147E-0001
 V(Ct)   =   8.1E+0008


Confidence Intervals
--------------------
               2.50%                97.50%
     K  =           76392                163835
     q  =  [illegible]        8.431524E-0005
     r  =  [illegible]        3.348978E+0000
```

Fig. A.2.8.

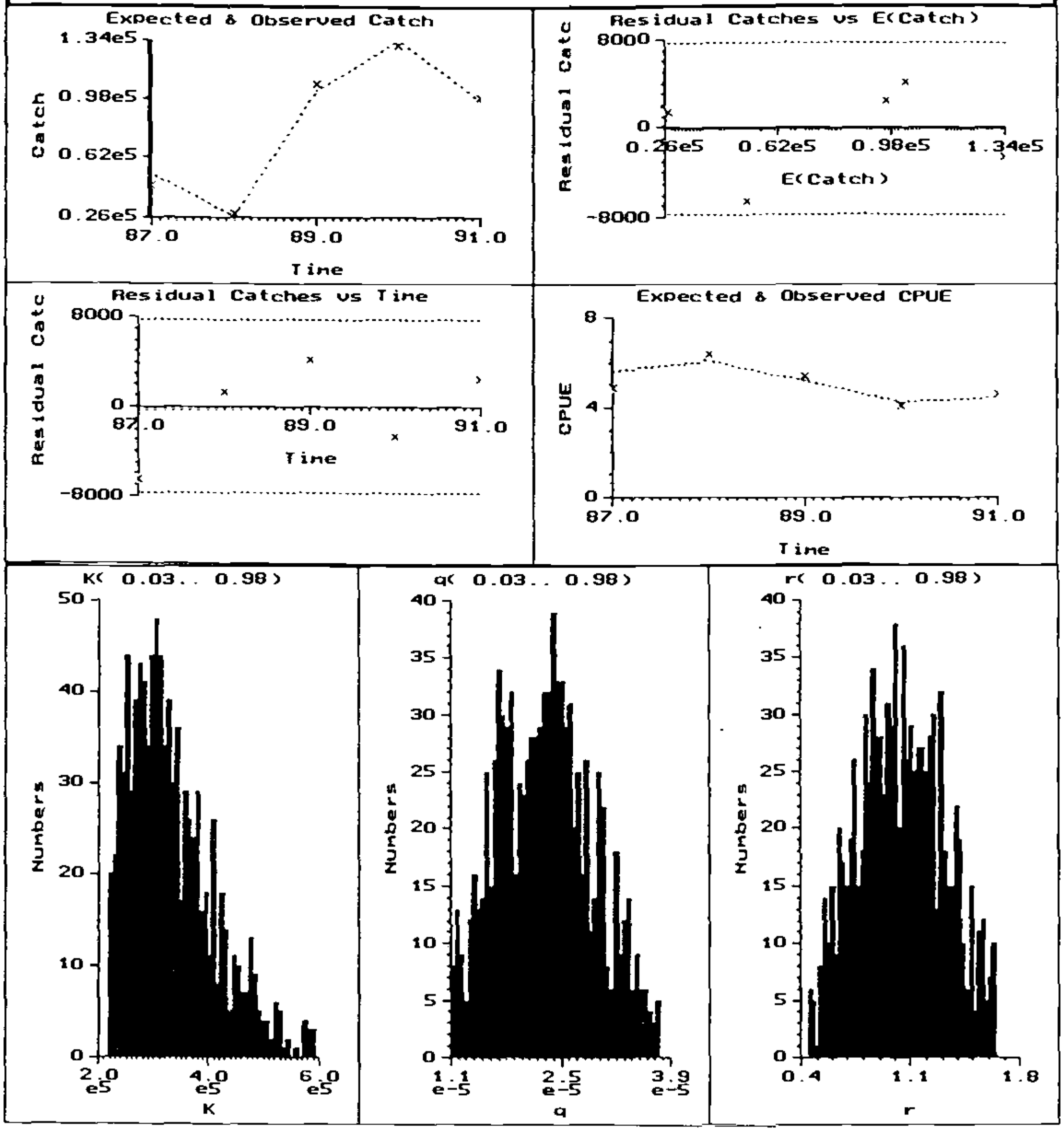


```
DATASET: SEA MOUNTS MAIN SPP 101-200 M
MODEL: PROD. MODEL (FOX)          Fit: L.Squares        CPUE Timing: Middle
In. Proportion: 0.800   Time Lag: 0 .   R²=0.986
K =  6.625E+0005  Q =  1.629E-0005  r =  4.096E-0002 V(Ct)  =  1.6E+0007
```

```
PARAMETER ESTIMATES
-------------------

     K =          662473
     q =  1.629028E-0005
     r =  4.095734E-0002
  V(Ct)  =  1.6E+0007


Confidence Intervals
--------------------
              2.50%                97.50%
     K =          463245                1073938
     q  =  8.448012E-0006        3.169679E-0005
     r  =  3.133567E-0009        1.070189E-0001
```

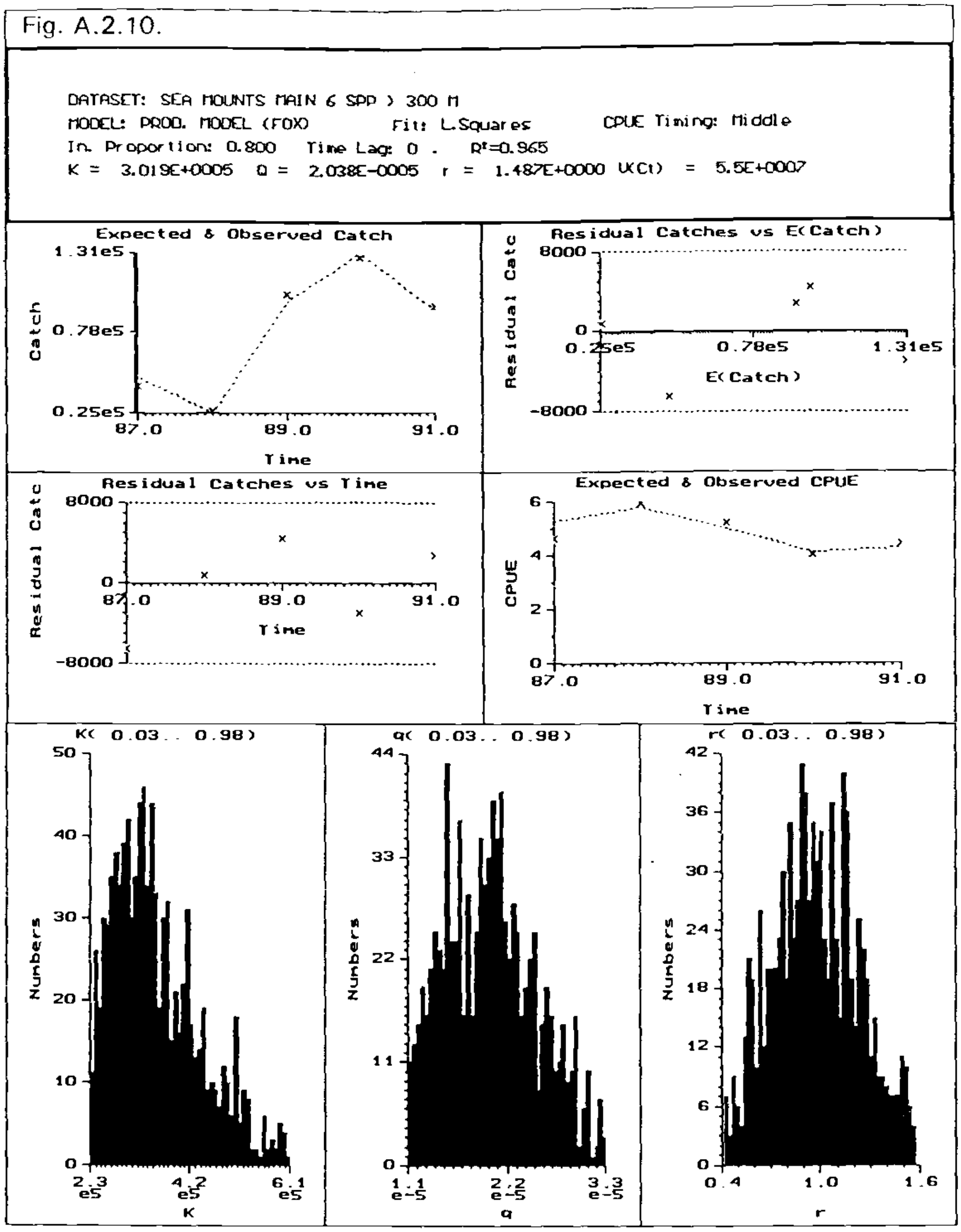
Fig. A.2.9.

```
DATASET: SEA MOUNTS ONLY, ALL SPECIES > 300M
MODEL: PROD. MODEL (FOX)            Fit: L.Squares          CPUE Timing: Middle
In. Proportion: 0.800    Time Lag: 0 .     R²=0.956
K =   2.858E+0005  Q =  2.285E-0005   r  =   1.550E+0000 V(Ct)  =  7.0E+0007
```



```
PARAMETER ESTIMATES
-------------------

      K =          285790
      q =  2.284764E-0005
      r =  1.550487E+0000
  V(Ct)   =  7.0E+0007


Confidence Intervals
--------------------
             2.50%                97.50%
      K =          218775                593231
      q  =  1.108421E-0005       3.769193E-0005
      r  =  4.478195E-0001       1.649506E+0000
```

Fig. A.2.10.



```
DATASET: SEA MOUNTS MAIN 6 SPP > 300 M
MODEL: PROD. MODEL (FOX)          Fit: L.Squares       CPUE Timing: Middle
In. Proportion: 0.800    Time Lag: 0 .    R²=0.965
K =   3.019E+0005   Q =   2.038E-0005   r  =   1.487E+0000  V(Ct)  =  5.5E+0007
```

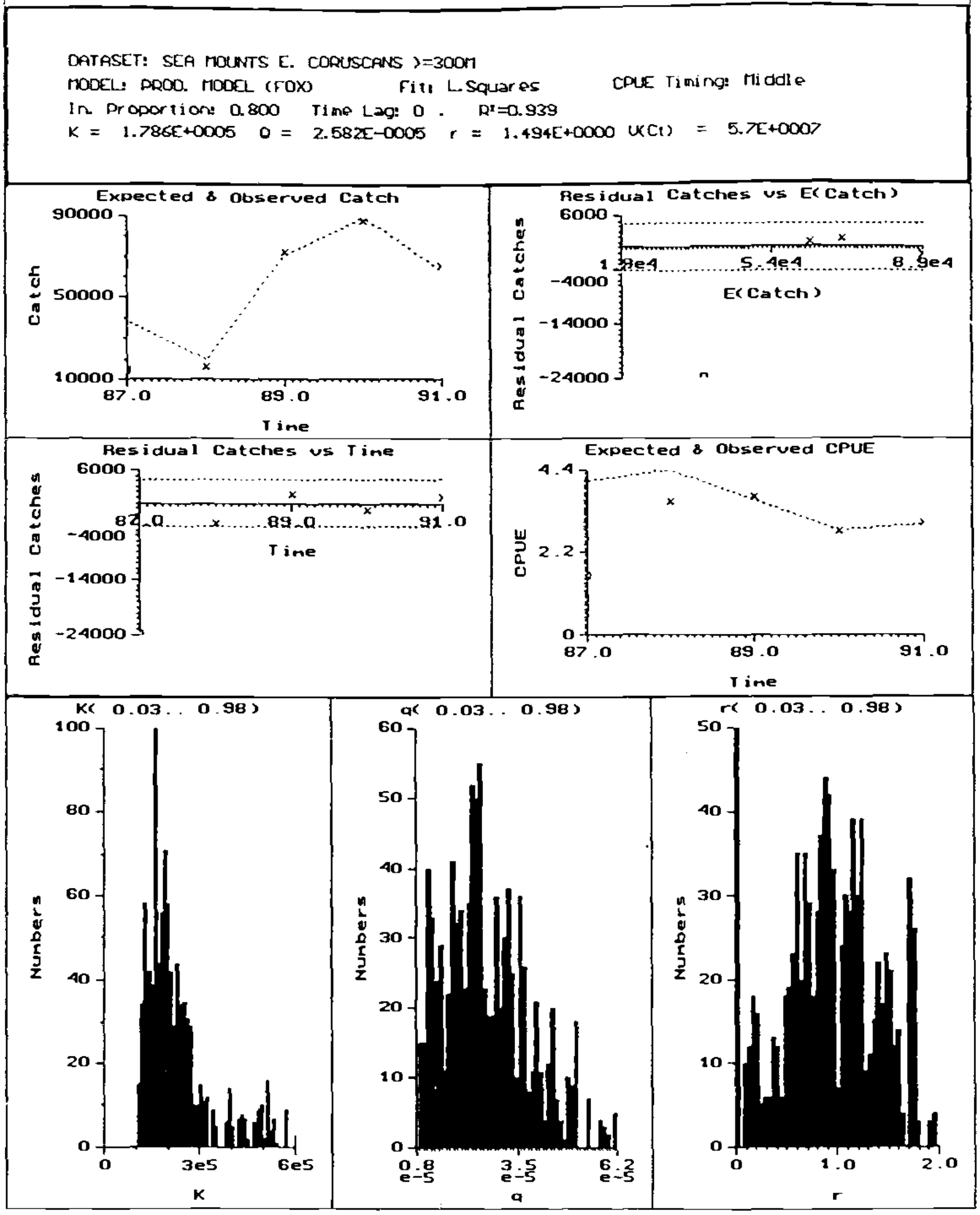
PARAMETER ESTIMATES

```
      K  =           301890
      q  =   2.037636E-0005
      r  =   1.487173E+0000
  V(Ct)  =    5.5E+0007
```

Confidence Intervals

	2.50%	97.50%
K =	230085	611226
q =	1.011285E-0005	3.316508E-0005
r =	4.158752E-0001	1.571296E+0000

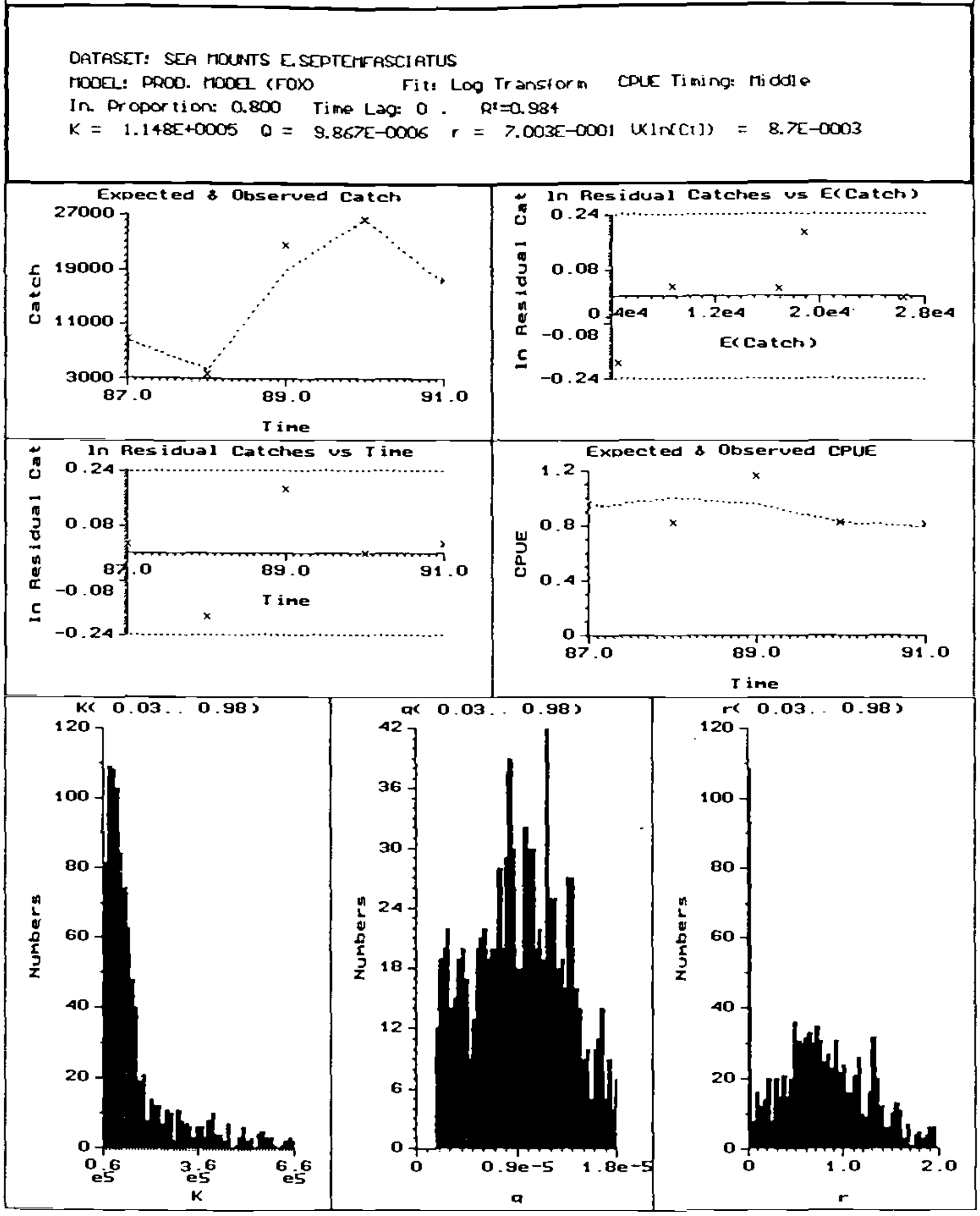
Fig. A.2.11.



```
DATASET: SEA MOUNTS E. CORUSCANS >=300M
MODEL: PROD. MODEL (FOX)            Fit: L.Squares         CPUE Timing: Middle
In. Proportion: 0.800   Time Lag: 0 .   R²=0.939
K =  1.786E+0005  Q =  2.582E-0005  r =  1.494E+0000 V(Ct)  =  5.7E+0007
```

```
PARAMETER ESTIMATES
-------------------

    K =          178604
    q =  2.581714E-0005
    r =  1.493560E+0000
 V(Ct)  =  5.7E+0007


Confidence Intervals
--------------------
                2.50%                97.50%
    K =          106390                608131
    q  =  8.748943E-0006       6.232561E-0005
    r  =  6.039433E-0007       1.981362E+0000
```

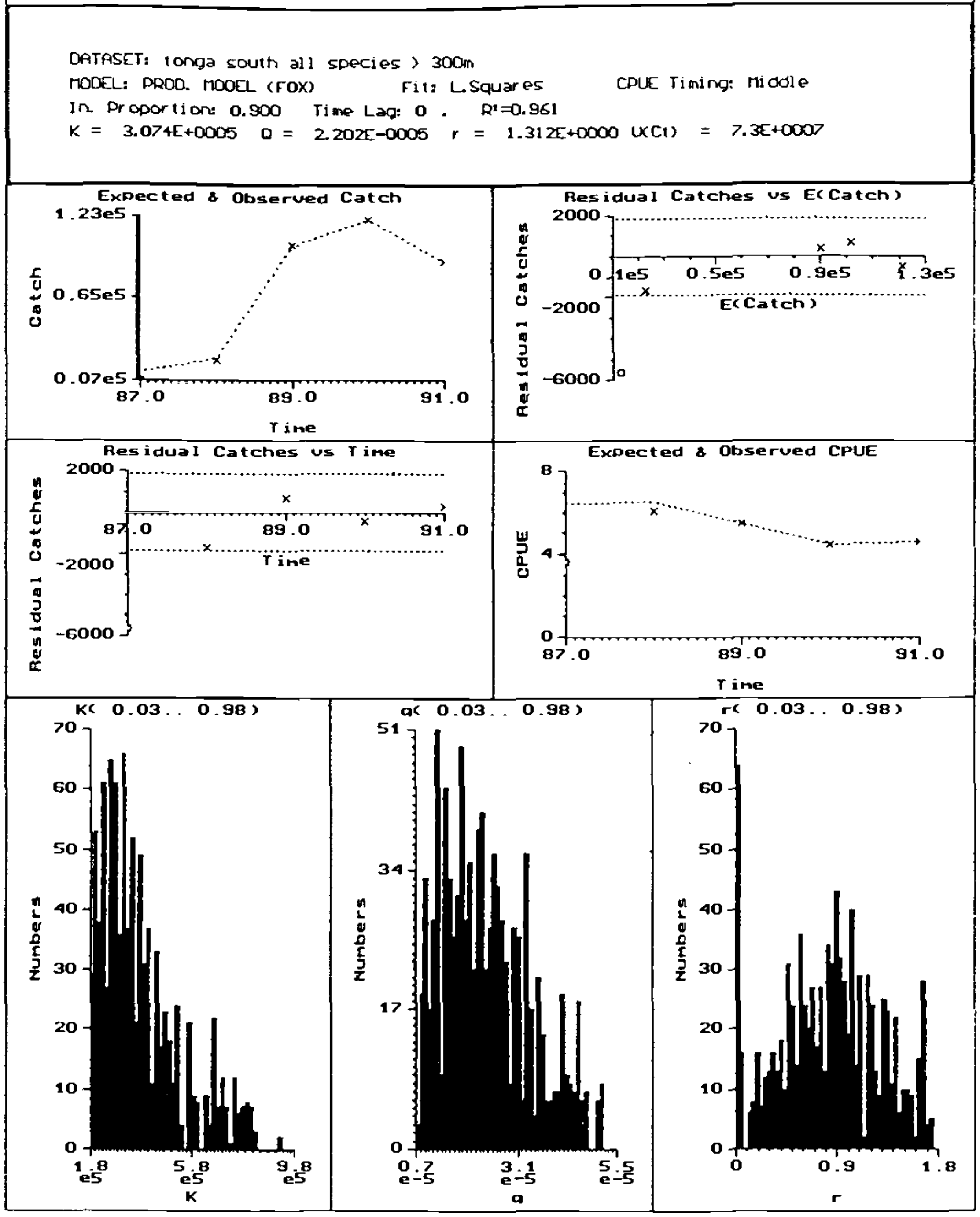
Fig. A.2.12.



```
DATASET: SEA MOUNTS E.SEPTEMFASCIATUS
MODEL: PROD. MODEL (FOX)            Fit: Log Transform   CPUE Timing: Middle
In. Proportion: 0.800   Time Lag: 0 .   R²=0.984
K =  1.148E+0005  Q =  9.867E-0006  r =  7.003E-0001 V(ln[Ct])  =  8.7E-0003
```

```
PARAMETER ESTIMATES
------------------

         K =           114794
         q =   9.866707E-0006
         r =   7.003478E-0001
  V(ln[Ct])  =   8.7E-0003


Confidence Intervals
-------------------
                2.50%                97.50%
         K =            62922                663302
         q  =  1.720659E-0006       1.821353E-0005
         r  =  1.555403E-0007       1.973704E+0000
```

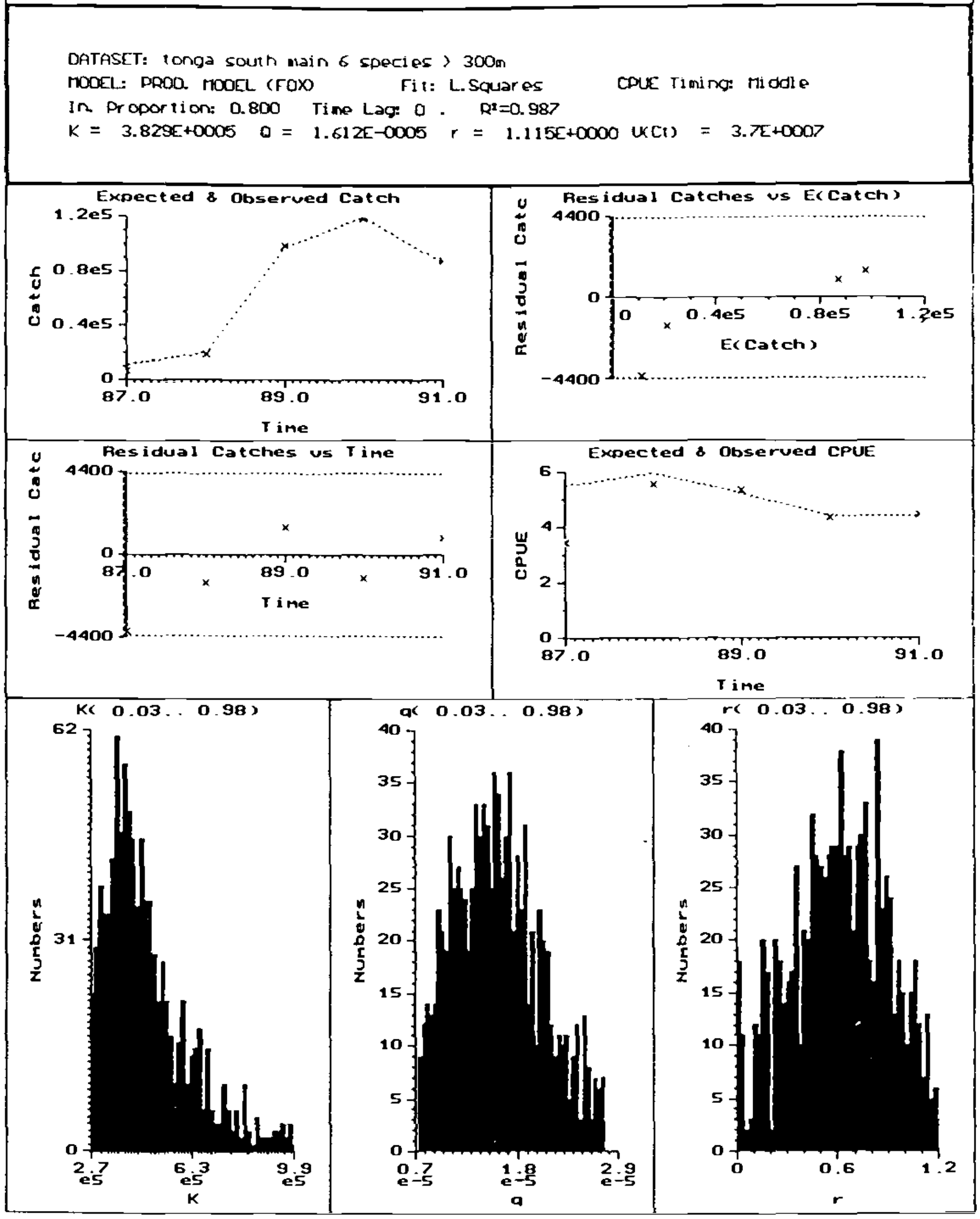
Fig. A.2.13.



```
DATASET: tonga south all species > 300m
MODEL: PROD. MODEL (FOX)          Fit: L.Squares        CPUE Timing: Middle
In. Proportion: 0.900    Time Lag: 0 .    R²=0.961
K =   3.074E+0005   Q =   2.202E-0005   r =   1.312E+0000  V(Ct)  =   7.3E+0007
```

```
PARAMETER ESTIMATES
-------------------

      K  =          307368
      q  =   2.202321E-0005
      r  =   1.311658E+0000
   V(Ct)   =   7.3E+0007


Confidence Intervals
--------------------
                 2.50%                97.50%
      K  =             174698               979452
     q   =   6.950954E-0006        5.475101E-0005
     r   =   4.378041E-0007        1.757019E+0000
```

Fig. A.2.14.



```
DATASET: tonga south main 6 species > 300m
MODEL: PROD. MODEL (FOX)          Fit: L.Squares          CPUE Timing: Middle
In. Proportion: 0.800   Time Lag: 0 .    R²=0.987
K =  3.829E+0005  Q =  1.612E-0005  r =  1.115E+0000 V(Ct)  =  3.7E+0007
```

PARAMETER ESTIMATES

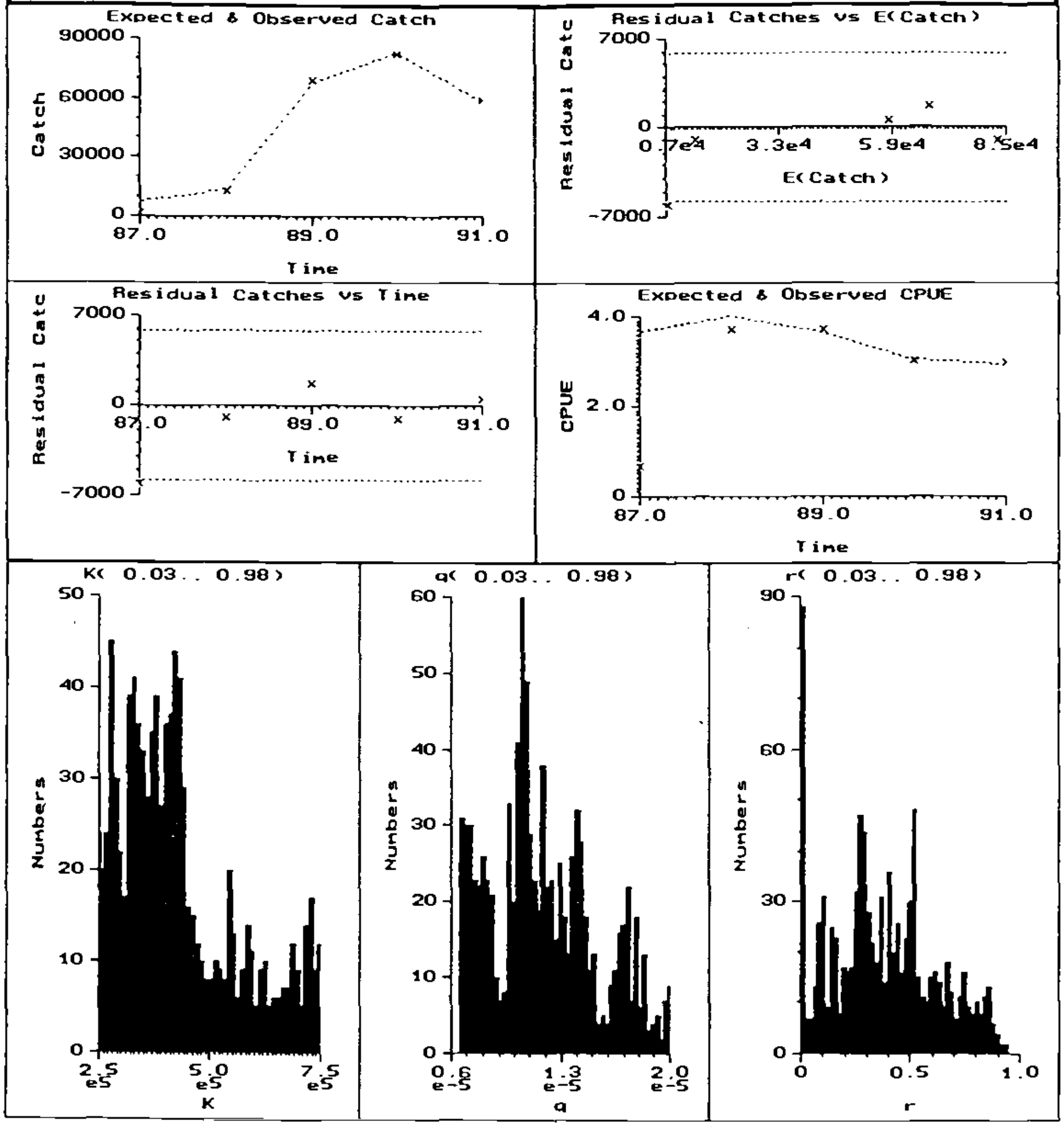
```
    K =          382869
    q =  1.612061E-0005
    r =  1.114853E+0000
 V(Ct)  =  3.7E+0007
```

Confidence Intervals

```
              2.50%                 97.50%
    K =          268807                  999187
    q  =  7.351980E-0006        2.756411E-0005
    r  =  1.582385E-0006        1.223276E+0000
```

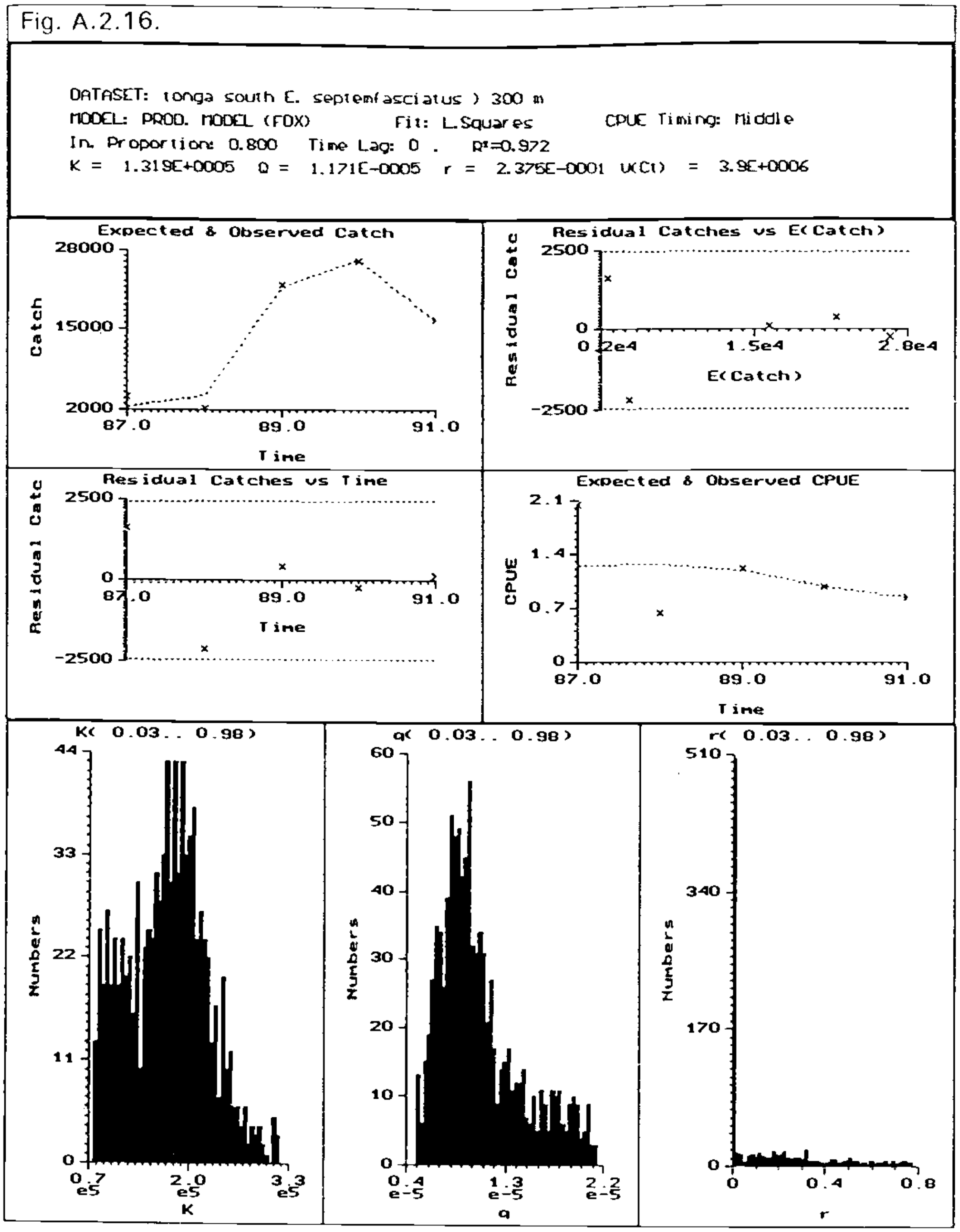
Fig. A.2.15.

```
DATASET: tonga south, E. coruscans > 300 m
MODEL: PROD. MODEL (FOX)          Fit: L.Squares        CPUE Timing: Middle
In. Proportion: 0.800   Time Lag: 0 .   R²=0.990
K =  3.141E+0005  Q =  1.334E-0005  r =  8.630E-0001 V(Ct)  =  2.0E+0007
```



```
PARAMETER ESTIMATES
-------------------

    K =           314140
    q =  1.333867E-0005
    r =  8.630320E-0001
 V(Ct)  =  2.0E+0007


Confidence Intervals
-------------------
              2.50%                97.50%
    K =           242274                754428
   q  =  6.572429E-0006       2.014610E-0005
   r  =  5.733722E-0007       9.462939E-0001
```

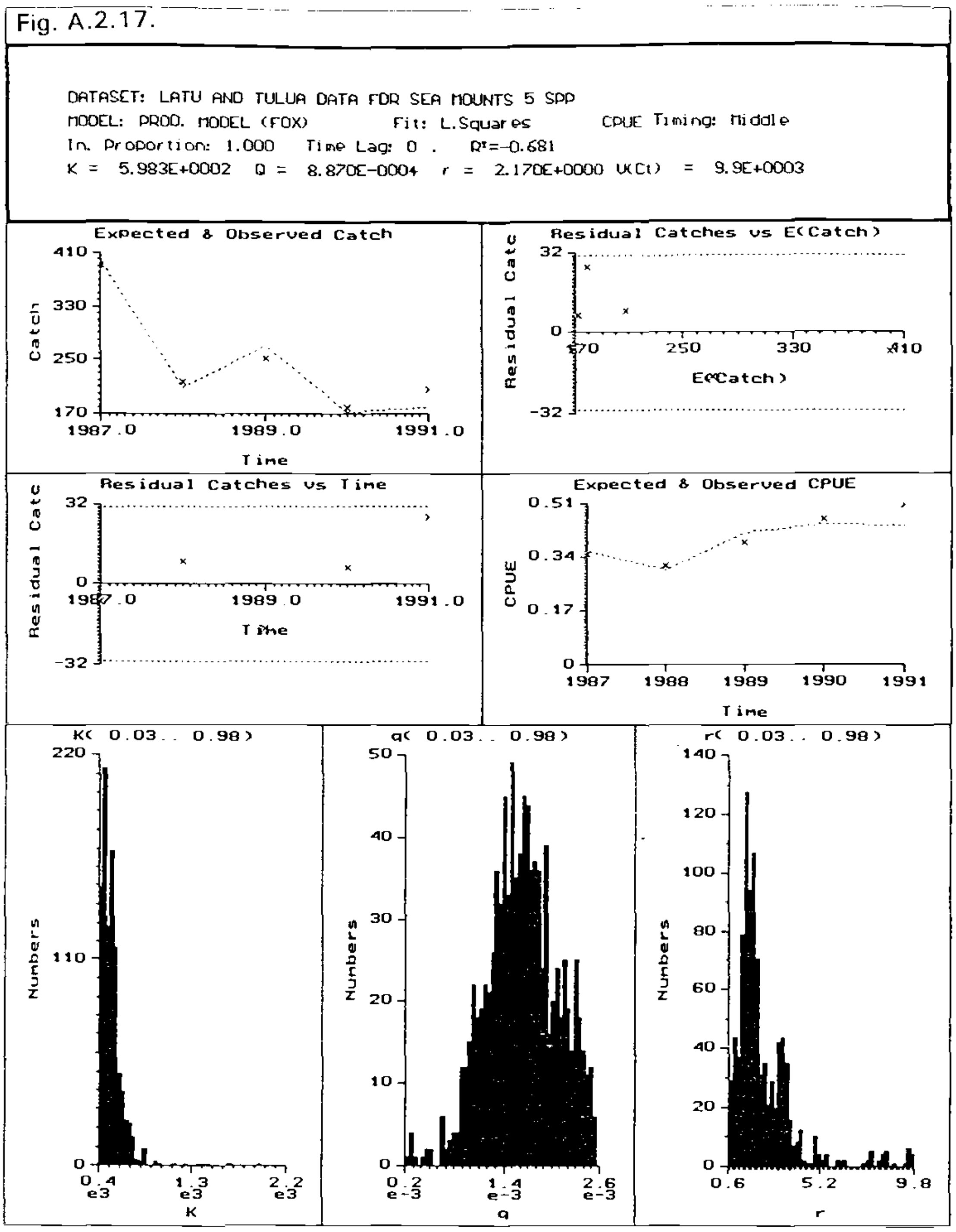
Fig. A.2.16.



```
DATASET: tonga south E. septemfasciatus ) 300 m
MODEL: PROD. MODEL (FOX)          Fit: L.Squares        CPUE Timing: Middle
In. Proportion: 0.800   Time Lag: 0 .   R²=0.972
K =  1.319E+0005  Q =  1.171E-0005  r =  2.375E-0001  V(Ct)  =  3.9E+0006
```

```
PARAMETER ESTIMATES
-------------------

    K  =           131919
    q  =   1.170900E-0005
    r  =   2.375278E-0001
 V(Ct)  =   3.9E+0006


Confidence Intervals
--------------------
                 2.50%                97.50%
    K  =             76660                318805
    q  =   4.908762E-0006       2.143594E-0005
    r  =   3.652553E-0008       7.769049E-0001
```

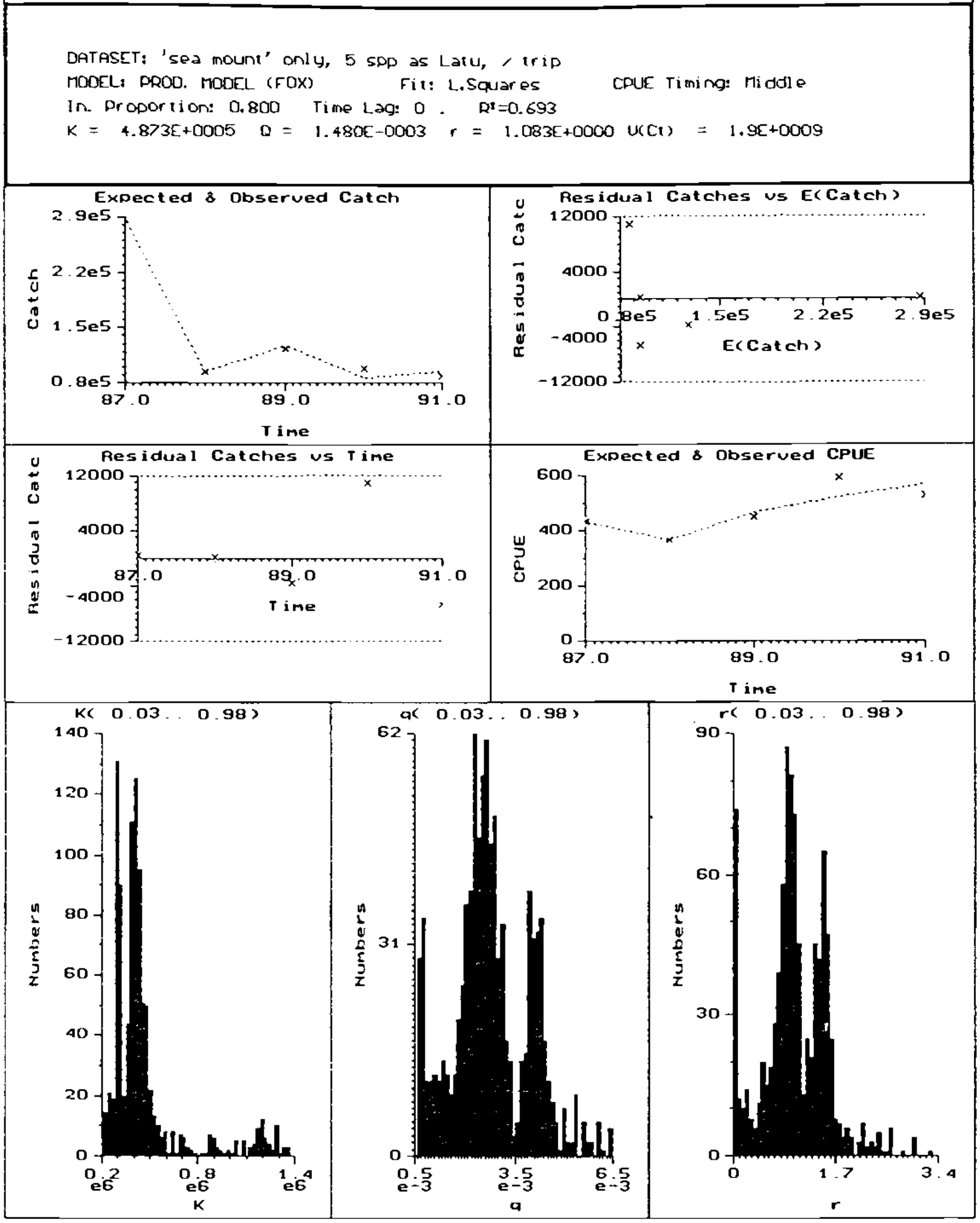
Fig. A.2.17.



```
DATASET: LATU AND TULUA DATA FOR SEA MOUNTS 5 SPP
MODEL: PROD. MODEL (FOX)           Fit: L.Squares        CPUE Timing: Middle
In. Proportion: 1.000    Time Lag: 0 .    R²=-0.681
K =  5.983E+0002  Q =  8.870E-0004  r =  2.170E+0000  V(Ct)  =  9.9E+0003
```

```
PARAMETER ESTIMATES
-------------------

     K =              598
     q =  8.870169E-0004
     r =  2.170269E+0000
  V(Ct)  =  9.9E+0003


Confidence Intervals
--------------------
             2.50%                97.50%
     K =              397                 2175
     q =  2.134791E-0004      2.556146E-0003
     r =  6.[illegible]4071E-0001      3.808403E+0000
```

Fig. A.2.18.



```
DATASET: 'sea mount' only, 5 spp as Latu, / trip
MODEL: PROD. MODEL (FOX)          Fit: L.Squares          CPUE Timing: Middle
In. Proportion: 0.800     Time Lag: 0 .     R²=0.693
K =  4.873E+0005   Q =  1.480E-0003   r =  1.083E+0000  V(Ct)  =  1.9E+0009
```

```
PARAMETER ESTIMATES
-------------------

     K =           487254
     q =  1.479976E-0003
     r =  1.083251E+0000
 V(Ct)  =  1.9E+0009


Confidence Intervals
--------------------
              2.50%                  97.50%
     K =           213754                1369437
     q =  5.873438E-0004         6.497159E-0003
          [illegible]            [illegible]
```

ANNEX 3 : Ceda Analyses applied to monthly catch and effort data from individual sea mounts

Table A.3.1 summarises the observations from annual catch rate data described in Figures A.3.1-18 relating to sea mounts for which considerable sample data exists. With the exception of seamounts already examined by other authors, only those at which depletion was observed were considered for further analysis, and details are not shown for the other 9 sea mounts examined (0506, 0509, 1009, 1103, 1104, 1302, 1306, 1309, 1406)

A modification of Allen's (1966) model was applied to monthly catch (numbers) and effort sample data (see Text) for selected sea mounts using the CEDA Constant Recruitment model :

$$N_{t+1} = e^{-M}N_t - e^{-1/2M}C_t + R_t$$

where

$$R_t = (1-e^{-M})N_0$$

The parameter,M, natural mortality, must be provided. N_t is the population number at time t, R_t is the recruitment index and C_t is the total catch during t.

The model derives estimates of the initial number of fish, N_0, and catchability, q. The mean weight of individual fish of each species from 1986 when the stock was assumed to be lightly exploited[5] (Table A.3.2) was applied to the estimated number (N_0) of each species to derive the initial Biomass B_0. Where the number N_0 related to a guild of species the proportion by numbers of each species in the sampled catch for each sea mount (Table A3.3) was applied to estimate the initial number by species. This was multiplied by the mean weight for each species and B_0 for the guild was computed as the sum of these values (Tables A.3.4 & A.3.5). Initially a guild consisting of the 6 main species was examined, and where appropriate, individual species data were tested.

An initial proportion of 1 was employed (ie. no previous exploitation) with values of M of 0.04 and 0.02 per month. Of the sea mounts examined by other authors, the data was not considered to fit the model for sea mounts 1401, 1501, 1504 or 1301. Details of the analysis for these mounts is given in Figures A3. 19-22 respectively, for M= 0.04 / month only, as an example (see also Table 12 of Text). For sea mount 1401 stratification of the data by depth, and examination of individual species data did not improve the fit, and these results are not shown. Of the sea mounts not previously examined no viable fit was found for a guild of 'other-species' (ie, shallow water species) for 1003, or 1005. Other - species at

---

[5] For E. carbunculus the mean value over 5 years was applied due to the bi-modality found to exist for this species resulting in significantly different mean weights from year to year

1106 apparently fitted the model (Fig A.3.23) when stratified by depth band but the cpue was considered flat and no further analysis of this data set is presented.

TABLE A.3.1. Sea mounts chosen for analysis using the Constant recruitment model (CEDA) applied to monthly catch and effort data (original codes indicated in parentheses)

SEA MOUNT	DETAILS
Examined previously	
1401 (0901)	Depth constant (200-300 m) from 1986 - 1989 and individual species (E. coruscans, E.septemfasciatus, P. filamentosus (?)) indicate depletion although not obvious for guild of 6 main species. Depth increases in 1990-91 and catch rates increase / target species change. Analysis by depth and species proposed.
1501 (1001)	Depth increases only in the last year (1989) and target species changes over time. No evidence of depletion and unlikely candidate for further analysis.
1504 (1004)	Depth changes considerably each year thus apparent depletion relating to guild of 6 main species may be an artefact
1301 (0801)	Depth increases. No evidence of depletion. Not a suitable candidate for further analysis.
1403 (0903)	Depth 100-200 m 1987 - 1989 and increases 1990 - 1991. Good sample size and depletion evident for guild of 6 main species and for *P. filamentosus*
Other sea mounts	
1003	Depth constant. Guild shows declining catch rate but predominantly shallow water species caught
1320	Depth > 300 m, strong evidence of depletion of guild, *E. coruscans* and possibly *E. septemfasciatus*
1005	After 1987 consistently shallow. Depletion of shallow water species evident.
1106	Depth shallow 1987 - 1989 but increases thereafter. Possibly depletion of shallow water species initially.

Thus only two data sets were considered to fit the model : Sea mount 1403, previously examined by Latu and Tulua (1989) produced a viable fit to the CEDA no recruitment model, as did the data for sea mount 1320. For seamount 1403 sensitivity analyses were performed to investigate the effect of changing both M and initial proportion (Table 13 of Text) The Least squares error model produced the best fit. Comparing R^2 values for different values of M and a fixed initial proportion of 1, M=0.03 / month produced the best fit, but examination of the residual plots indicated that there was little to choose between the goodness of fit for any of the values of M between 0.02 and 0.04. With M fixed at 0.03 the initial proportion was varied. A value of 1 gave the best fit. These sensitivity analyses support the choice of initial proportion = 1 and a choice of M between 0.02 and 0.04. The data was not oversensitive to the choice of M.

Next the data for seamount 1403 was stratified by depth (Table 14). This marginally improved the fit of data to the model as might be expected (during 1990-91 depth increased). Similarly, stratification by depth improved the fit for the analysis of *P. filamentosus*. Raised data was analysed and significantly increased estimates of K for both the guild of species and *P. filamentosus*. Similar analyses were applied to sea mount 1320 for a guild of the main species and *Etelis coruscans* (Table 14). Figures A.3.24-27 are provided as examples of the fit of the data for 1403 (main species and *P. filamentosus*) and 1320 (main species and *E. coruscans*) respectively. Figures are not provided for all the information represented in Tables 13 and 14.

Examination of Tables 13 and 14 indicates that the point estimate of K at M = 0.02 lies within the 95 % confidence intervals for M = 0.04 in all except two cases (sampled and raised data sets at all depths for the guild of species at sea mount 1403). Biomass was thus conservatively estimated using the values for M = 0.04 in the manner described above (Table A.3.6, and Table 15 of text). Yield was estimated as 24% of biomass.

Figs A.3. 1-6 : RAISED SEA MOUNT DATA EXAMINED BY LANGI ET AL / LATU AND TULUA

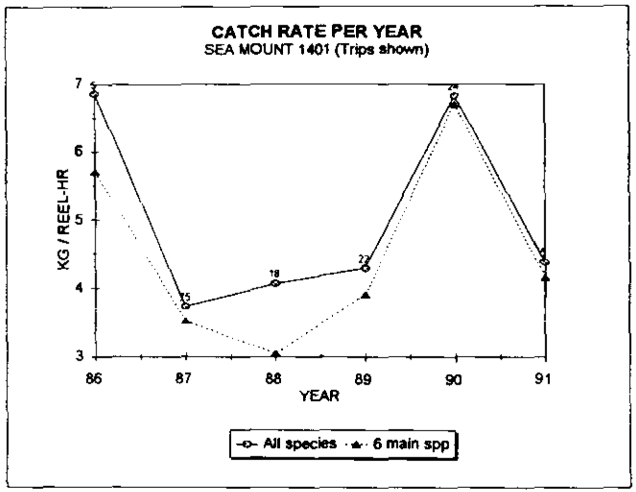

CATCH RATE PER YEAR
SEA MOUNT 1401 (Trips shown)

Fig. 1

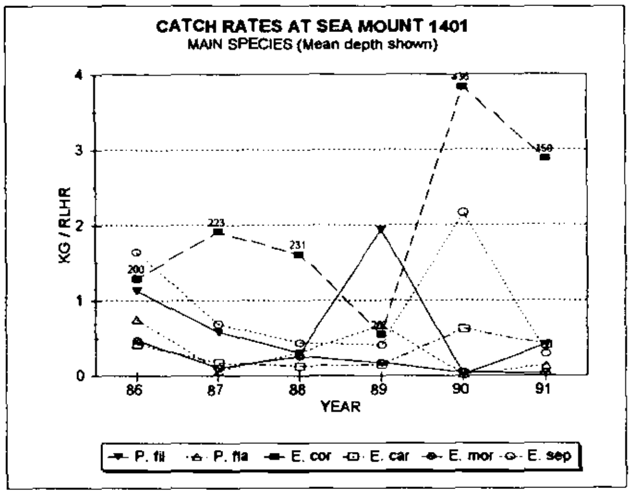

CATCH RATES AT SEA MOUNT 1401
MAIN SPECIES (Mean depth shown)

Fig. 2

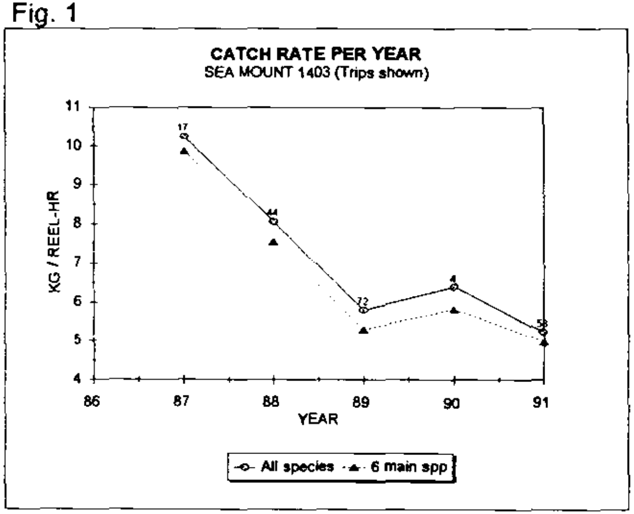

CATCH RATE PER YEAR
SEA MOUNT 1403 (Trips shown)

Fig. 3

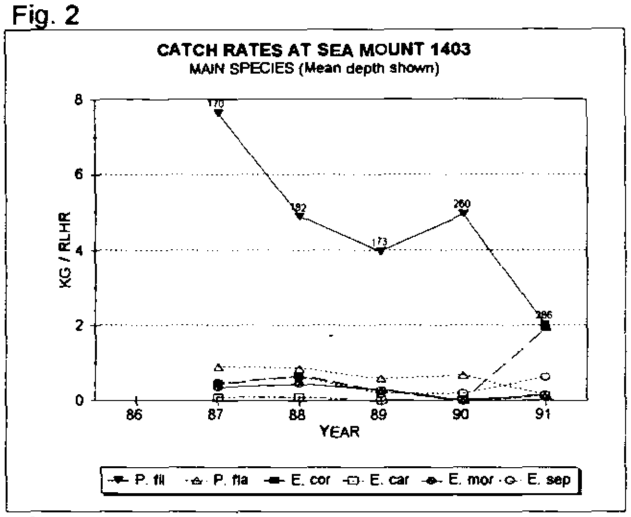

CATCH RATES AT SEA MOUNT 1403
MAIN SPECIES (Mean depth shown)

Fig. 4

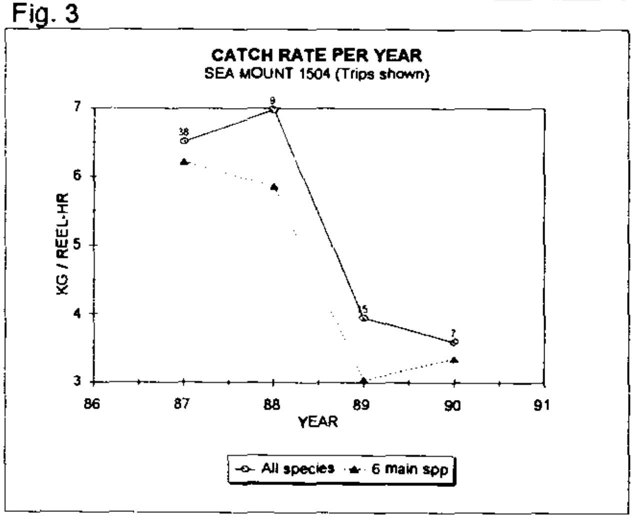

CATCH RATE PER YEAR
SEA MOUNT 1504 (Trips shown)

Fig. 5

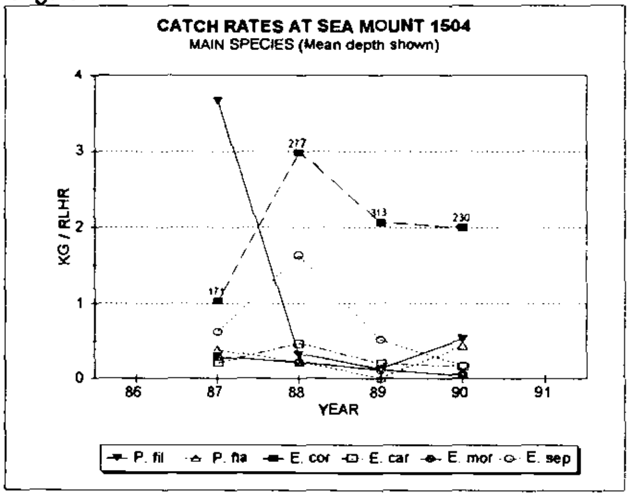

CATCH RATES AT SEA MOUNT 1504
MAIN SPECIES (Mean depth shown)

Fig. 6

Figs A.3. 7 - 10 :RAISED SEA MOUNT DATA EXAMINED BY LANGI ET AL / LATU AND TULUA

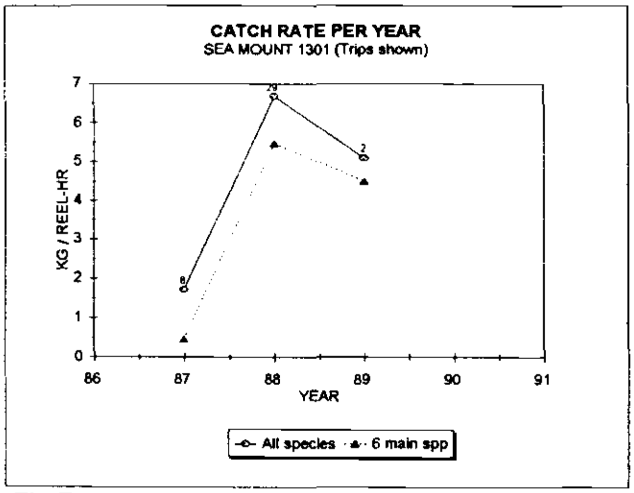


Fig 7

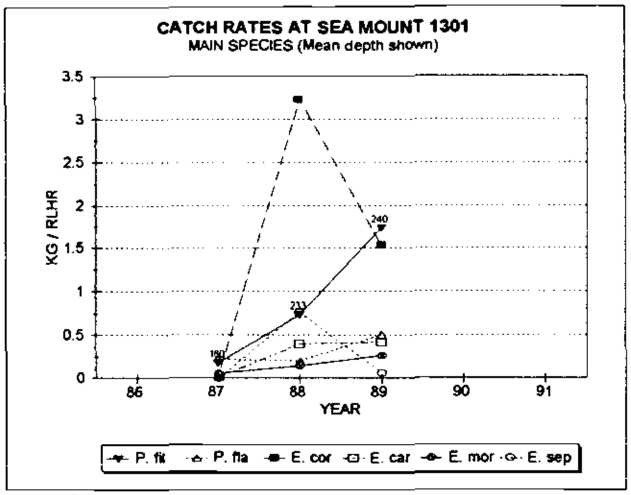


Fig. 8

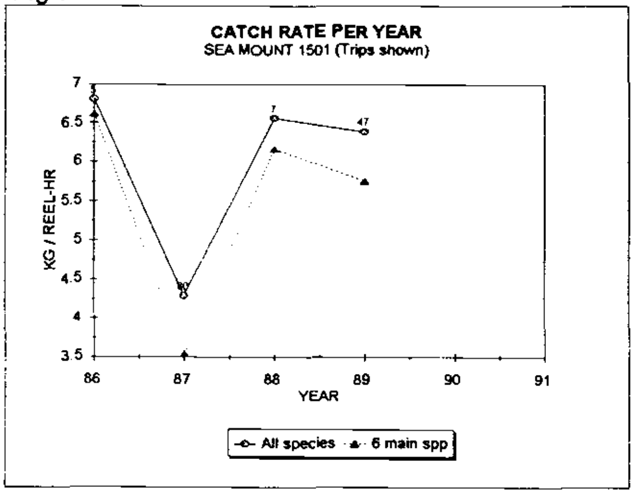


Fig 9

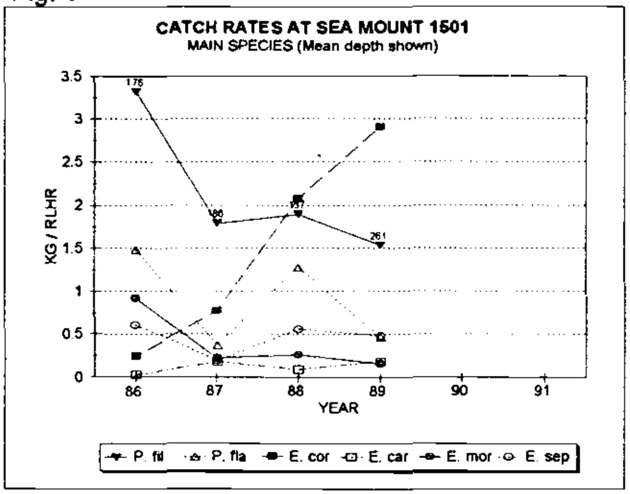


Fig. 10

Figs A.3. 11 - 18 : SEA MOUNTS INDICATING DEPLETION

Deep water species

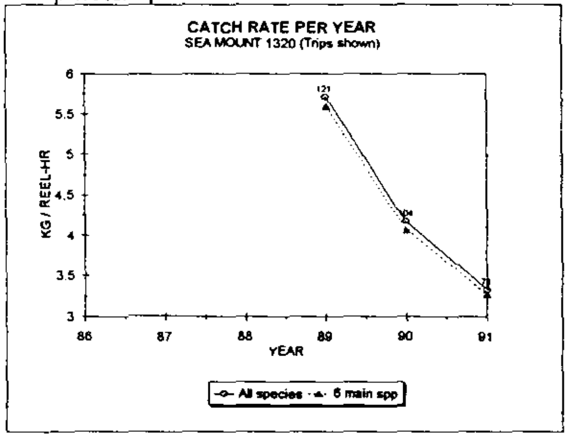


Fig 11

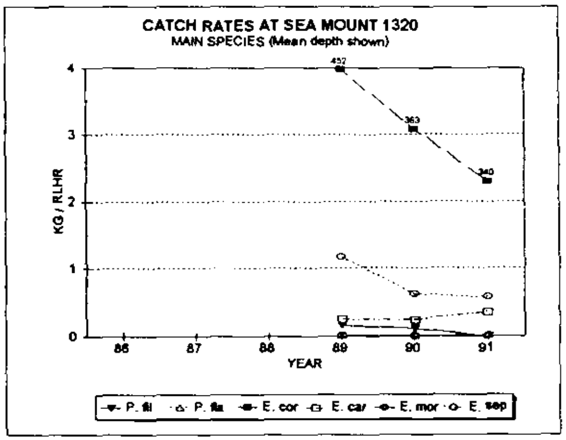


Fig. 12

Shallow water species

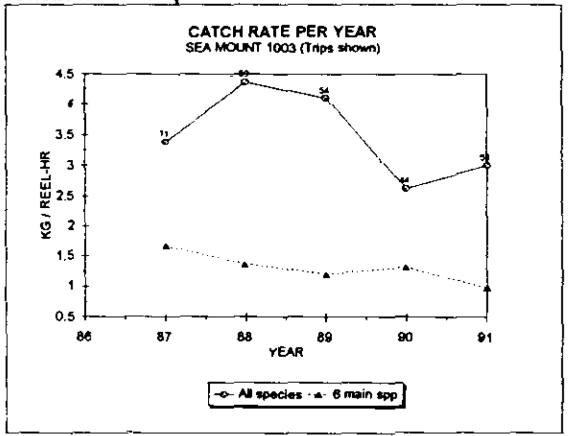


Fig. 13

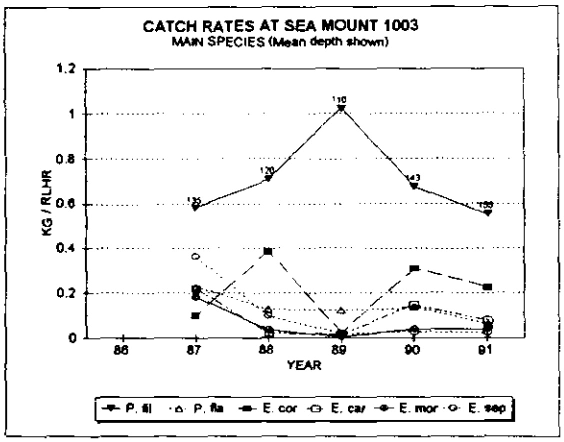


Fig. 14

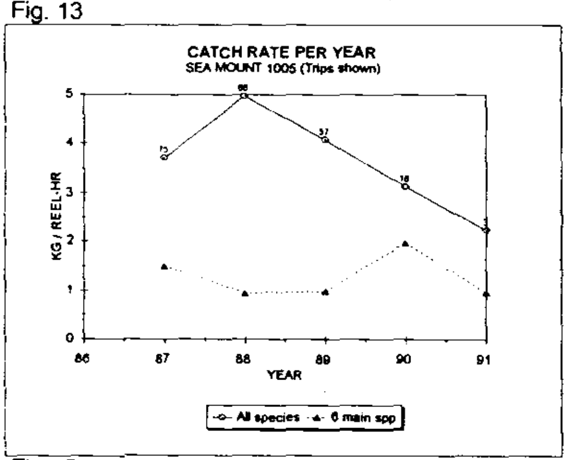


Fig 15

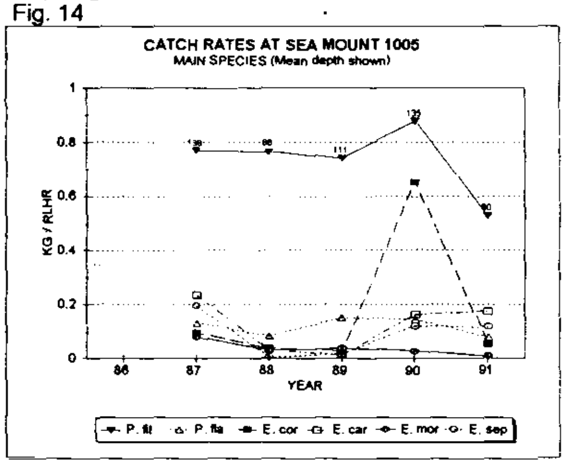


Fig 16

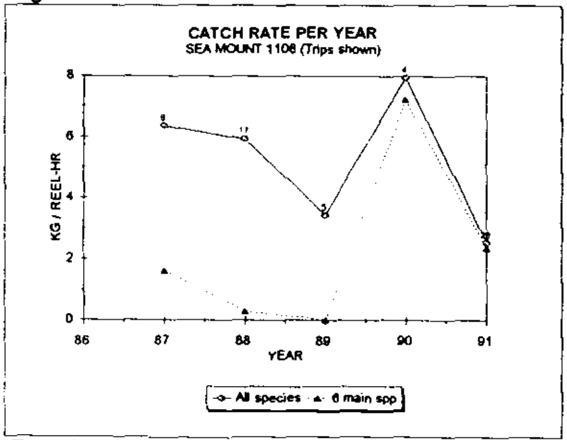


Fig. 17

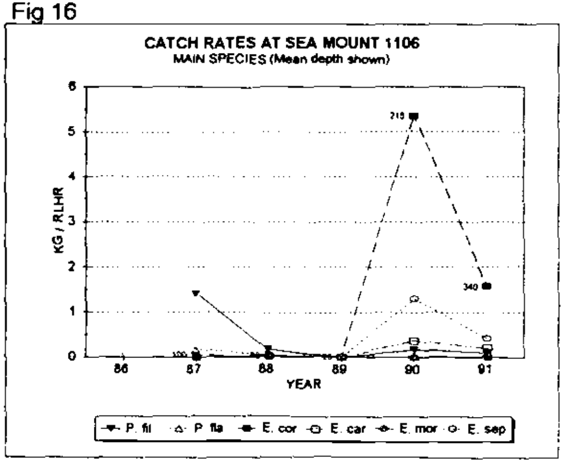
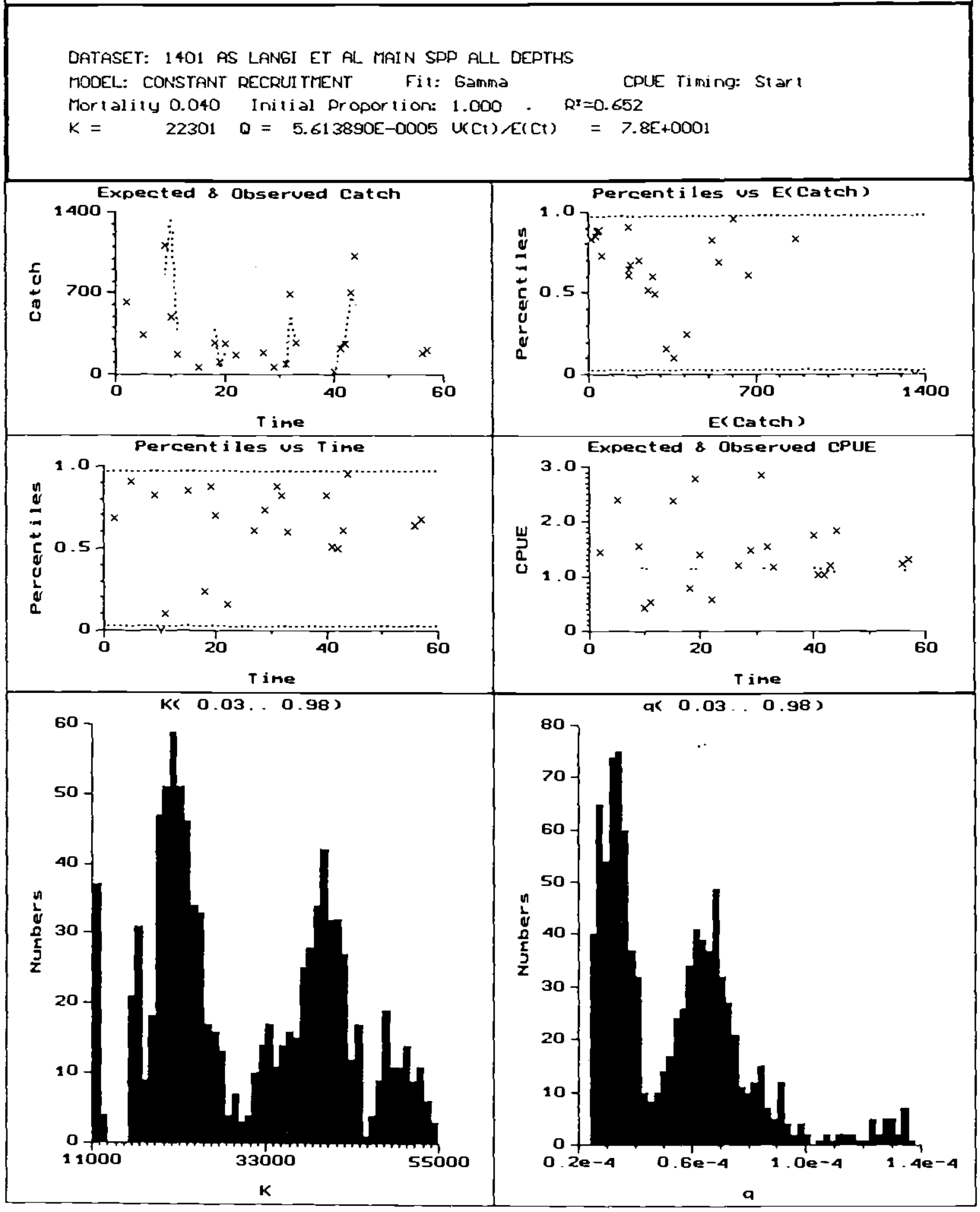


Fig. 18

Fig. A.3.19.

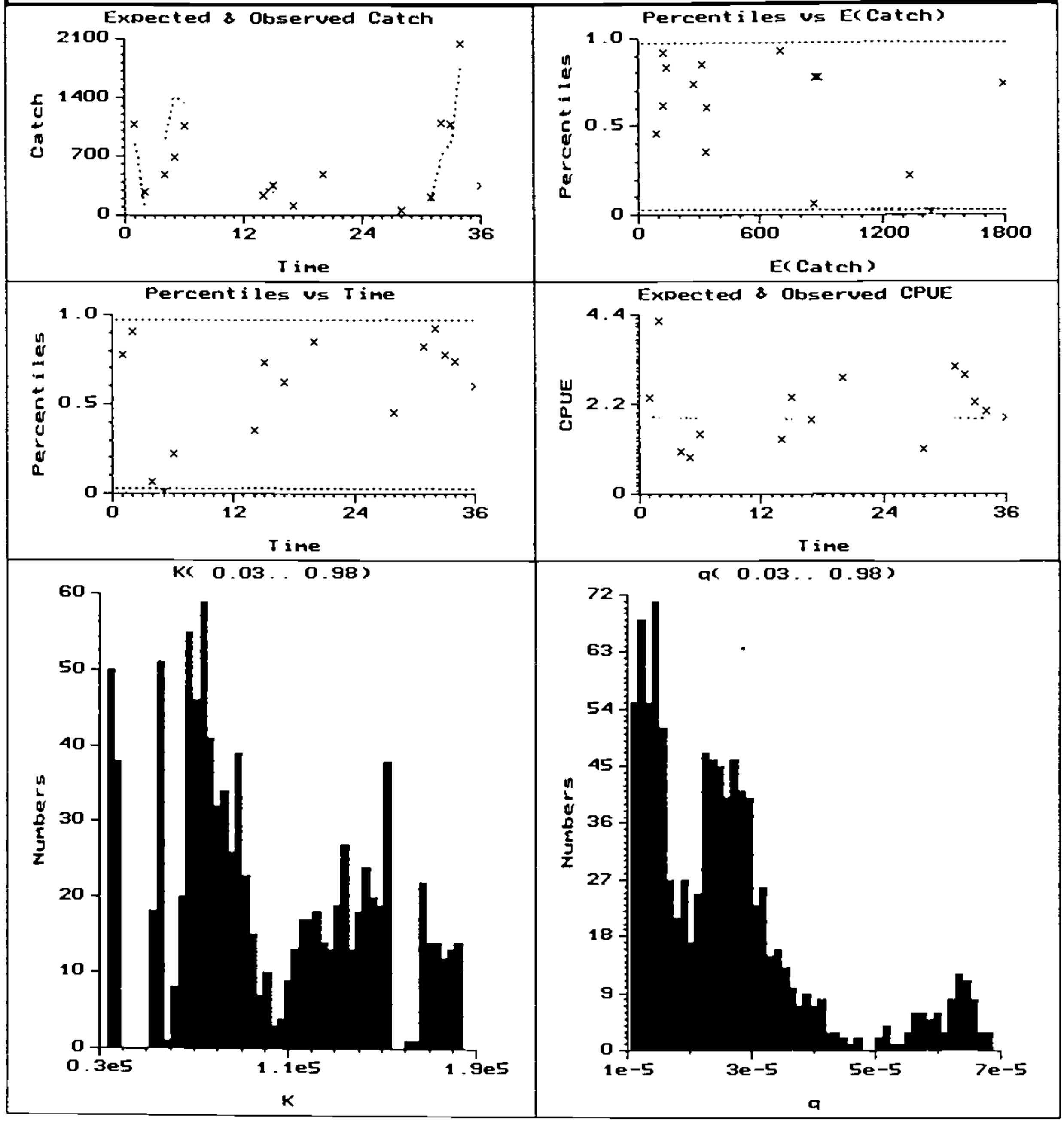


```
DATASET: 1401 AS LANGI ET AL MAIN SPP ALL DEPTHS
MODEL: CONSTANT RECRUITMENT      Fit: Gamma          CPUE Timing: Start
Mortality 0.040   Initial Proportion: 1.000  .   R²=0.652
K =       22301  Q =  5.613890E-0005  V(Ct)/E(Ct)   =  7.8E+0001
```

```
PARAMETER ESTIMATES
-------------------

      K =            22301
      q =  5.613890E-0005
 V(Ct)/E(Ct)   =   7.8E+0001


Confidence Intervals
--------------------
              2.50%                 97.50%
      K =            11205                  54863
     q   =  2.403315E-0005      1.379315E-0004
```

Fig. A.3.20.

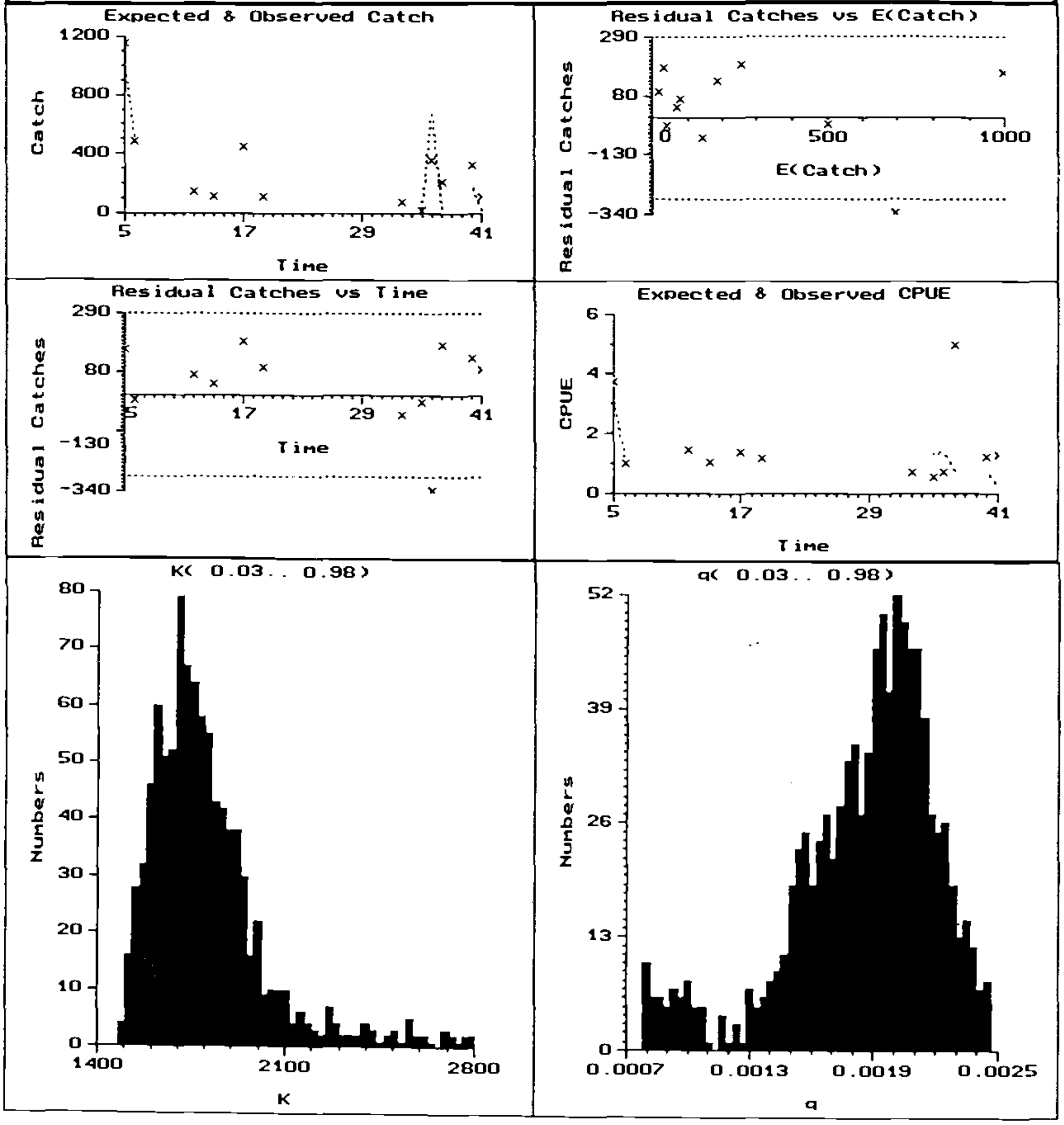
```
DATASET: 1501 AS LANGI ET AL MAIN SPP ALL DEPTHS
MODEL: CONSTANT RECRUITMENT      Fit: Gamma            CPUE Timing: Start
Mortality 0.040   Initial Proportion: 1.000  .   R²=0.756
K =       76905   Q =  2.491085E-0005  V(Ct)/E(Ct)   =  9.3E+0001
```



```
PARAMETER ESTIMATES
-------------------

      K =            76905
      q =   2.491085E-0005
   V(Ct)/E(Ct)   =   9.3E+0001


Confidence Intervals
--------------------

             2.50%                  97.50%
      K =            33247               184084
      q  =  1.046492E-0005      6.860834E-0005
```

Fig. A.3.21.

```
DATASET: 1504 AS LANGI ET AL MAIN SPP ALL DEPTHS
MODEL: CONSTANT RECRUITMENT       Fit: L.Squares       CPUE Timing: Start
Mortality 0.040    Initial Proportion: 1.000   .     R²=0.784
K =         1685   Q =   1.890524E-0003  V(Ct)    =  2.1E+0004
```



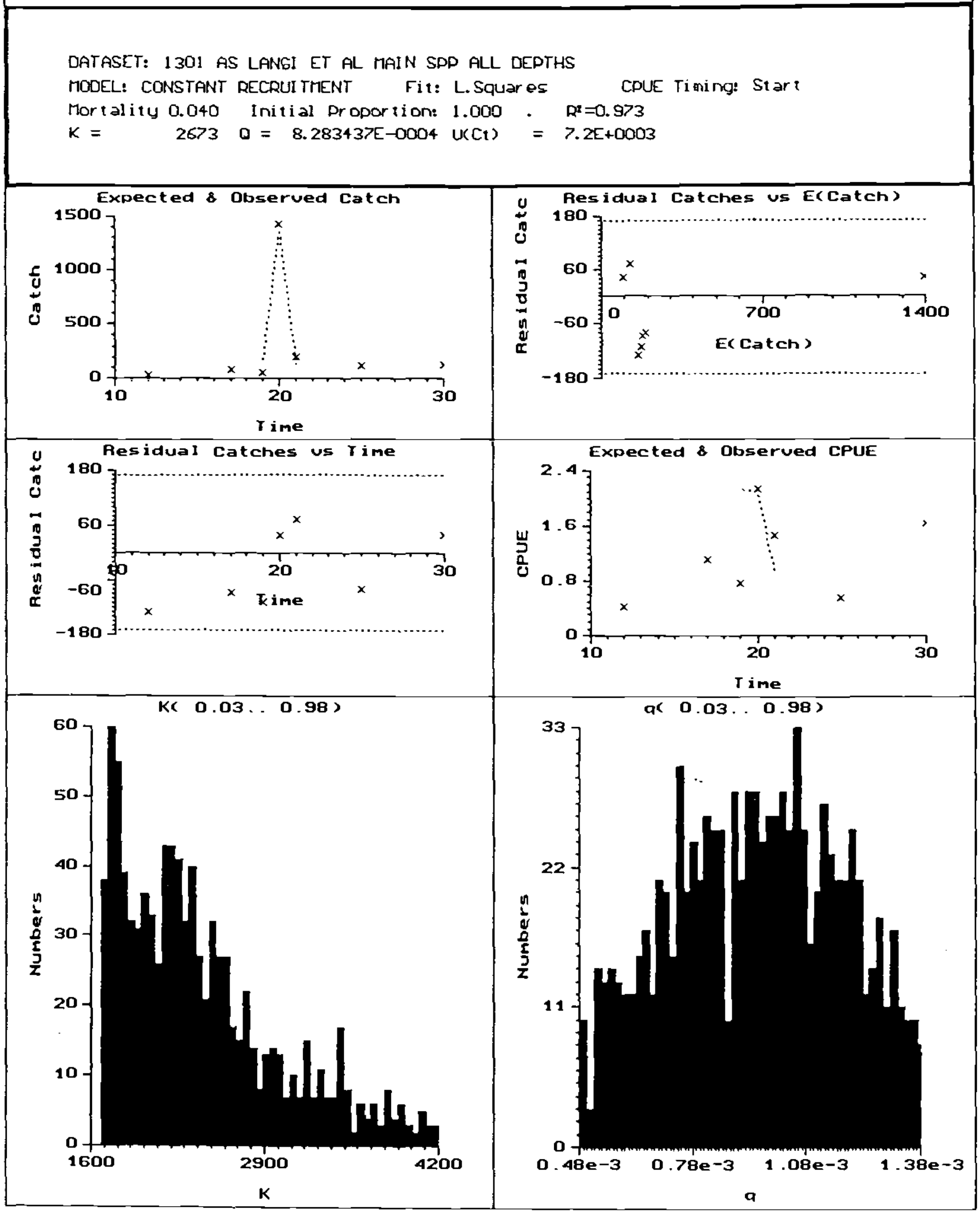
PARAMETER ESTIMATES

```
     K =            1685
     q =   1.890524E-0003
 V(Ct)   =   2.1E+0004
```

Confidence Intervals

```
             2.50%                    97.50%
     K =              1478                   2812
     q  =   7.823915E-0004       2.466622E-0003
```

Fig. A.3.22.

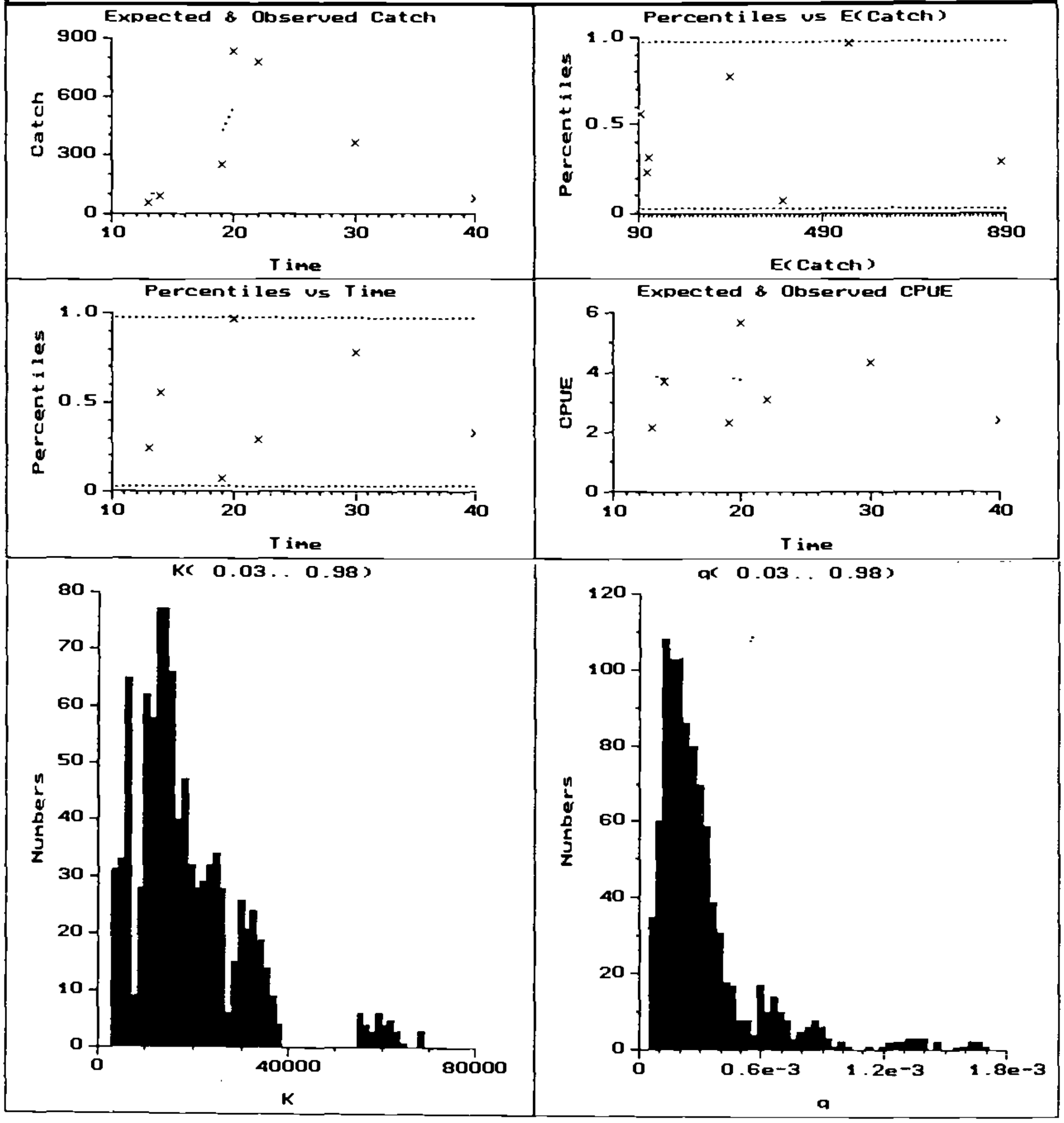


```
DATASET: 1301 AS LANGI ET AL MAIN SPP ALL DEPTHS
MODEL: CONSTANT RECRUITMENT      Fit: L.Squares        CPUE Timing: Start
Mortality 0.040    Initial Proportion: 1.000  .   R²=0.973
K =        2673  Q =  8.283437E-0004  V(Ct)   =  7.2E+0003
```

```
PARAMETER ESTIMATES
-------------------

     K =             2673
     q =  8.283437E-0004
 V(Ct)  =   7.2E+0003


Confidence Intervals
--------------------
             2.50%                  97.50%
   K =              1676                    4204
   q  =  4.833913E-0004       1.391846E-0003
```

Fig. A.3.23.

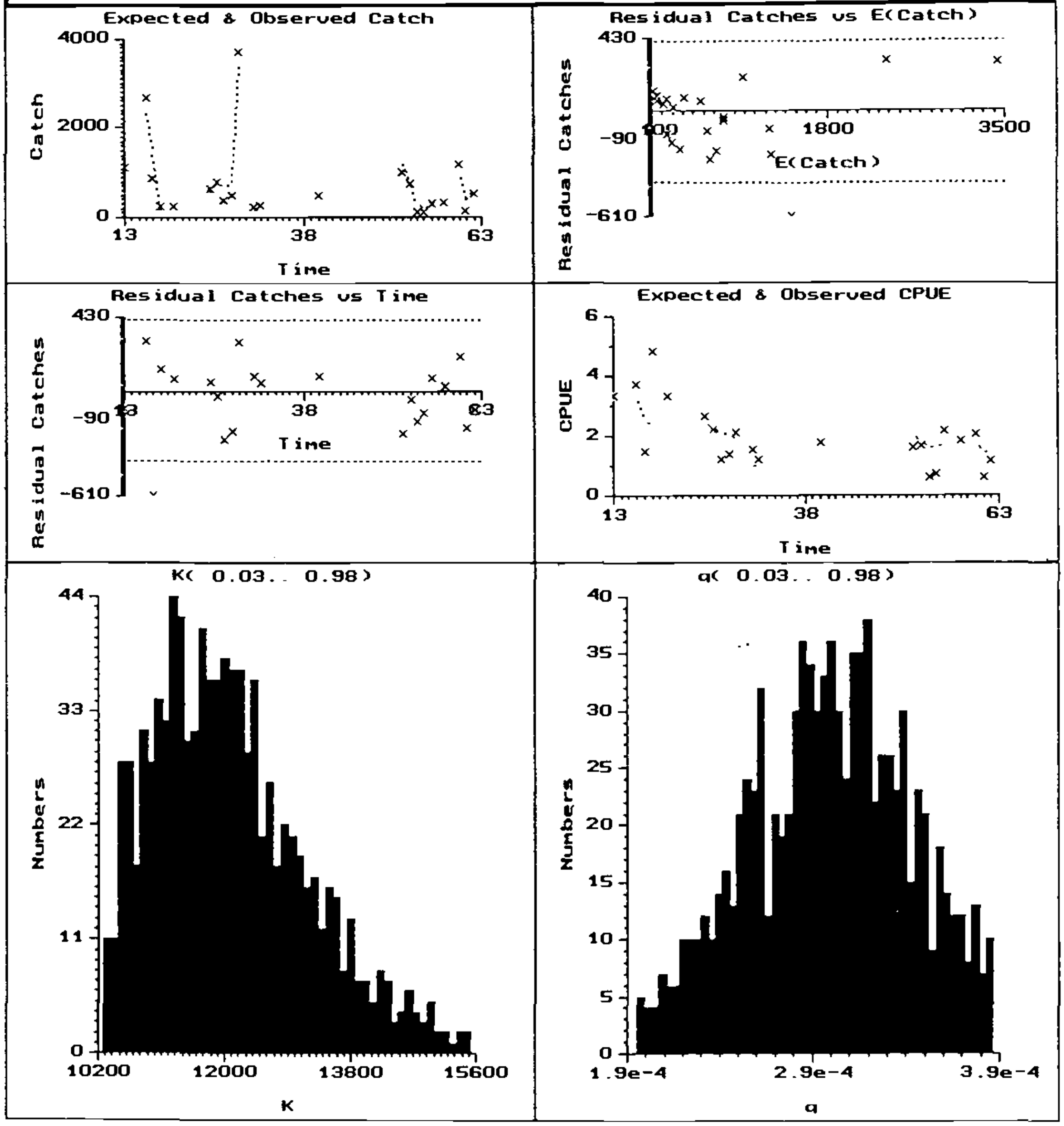
```
DATASET: 1106 UNRAISED DATA OTHER SPP <= 200M
MODEL: CONSTANT RECRUITMENT       Fit: Gamma           CPUE Timing: Start
Mortality 0.040   Initial Proportion: 1.000  .   R²=0.865
K =        13203  Q =  2.930466E-0004  V(Ct)/E(Ct)   =  3.6E+0001
```



```
PARAMETER ESTIMATES
-------------------

        K =           13203
        q =   2.930466E-0004
  V(Ct)/E(Ct)   =   3.6E+0001


Confidence Intervals
--------------------
                2.50%                 97.50%
   K =                2967                 69156
   q  =   4.579876E-0005       1.710206E-0003
```

Fig. A.3.24.

DATASET: 1403 AS LATU&TULUA MAIN SPP ALL DEPTHS
MODEL: CONSTANT RECRUITMENT Fit: L.Squares CPUE Timing: Start
Mortality 0.030 Initial Proportion: 1.000 . R²=0.943
K = 12197 Q = 2.959015E-0004 V(Ct) = 4.2E+0004



PARAMETER ESTIMATES

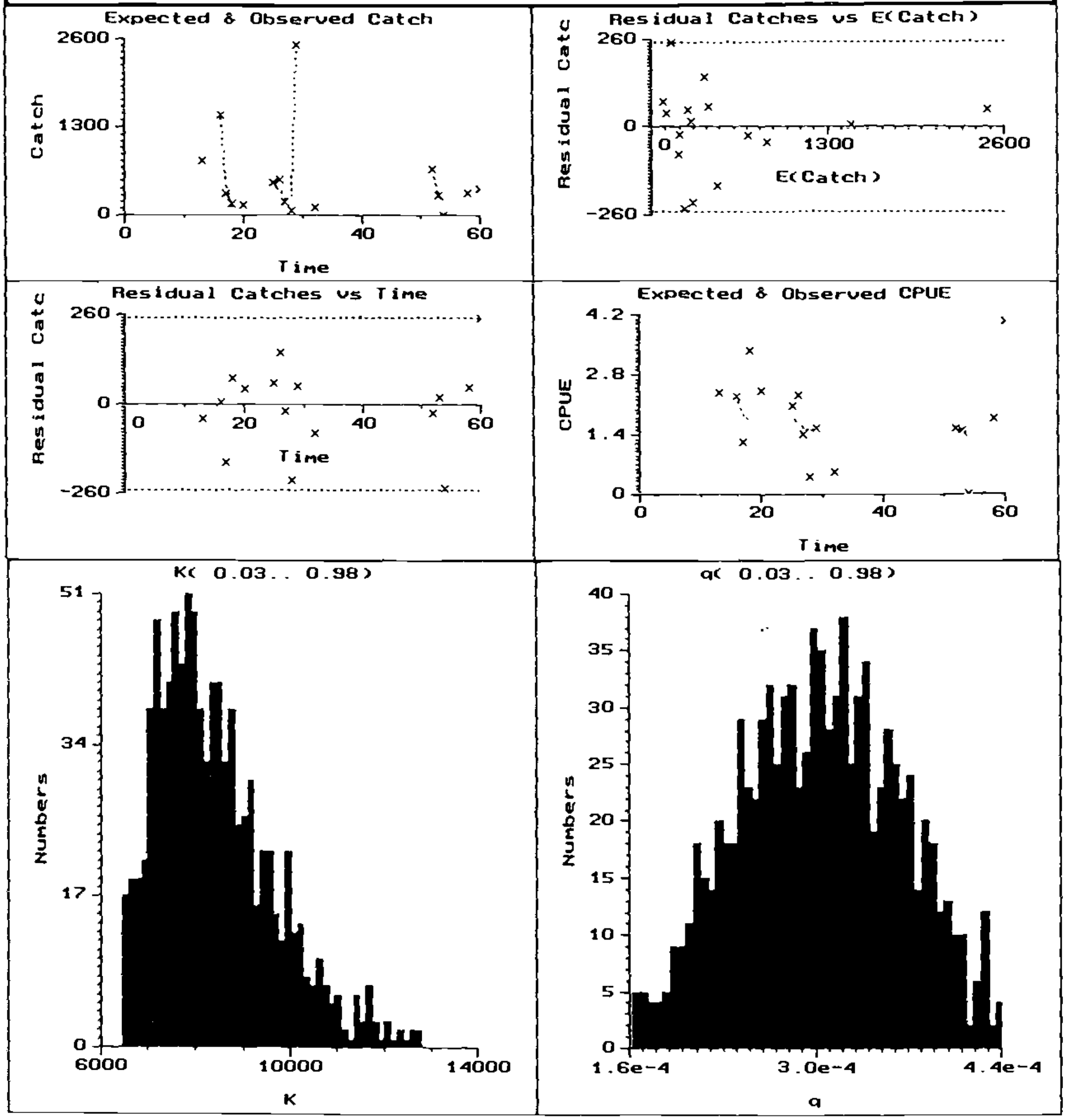
K = 12197
q = 2.959015E-0004
V(Ct) = 4.2E+0004

Confidence Intervals

	2.50%	97.50%
K =	10273	15540
q =	1.954059E-0004	3.868744E-0004

Fig. A.3.25.

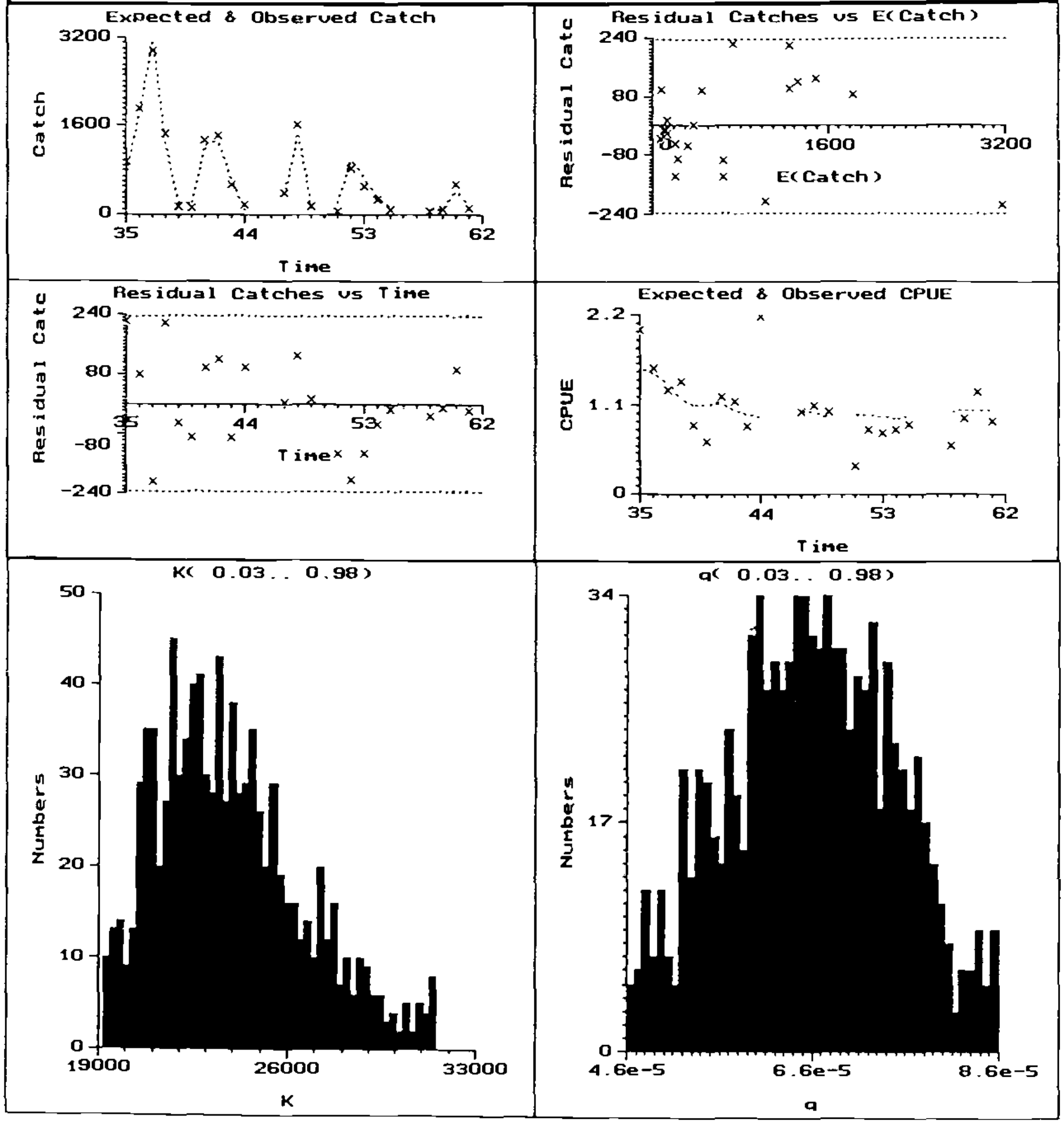
```
DATASET: 1403 UNRAISED P. FILAMENTOSUS <=200 M
MODEL: CONSTANT RECRUITMENT      Fit: L.Squares        CPUE Timing: Start
Mortality 0.030   Initial Proportion: 1.000  .   R²=0.960
K =        8167  Q =  3.068502E-0004  V(Ct)   =  1.6E+0004
```



```
PARAMETER ESTIMATES
-------------------

     K =            8167
     q =  3.068502E-0004
  V(Ct)  =  1.6E+0004


Confidence Intervals
--------------------
              2.50%                97.50%
     K =            6463                 13074
     q  =  1.628885E-0004      4.419550E-0004
```

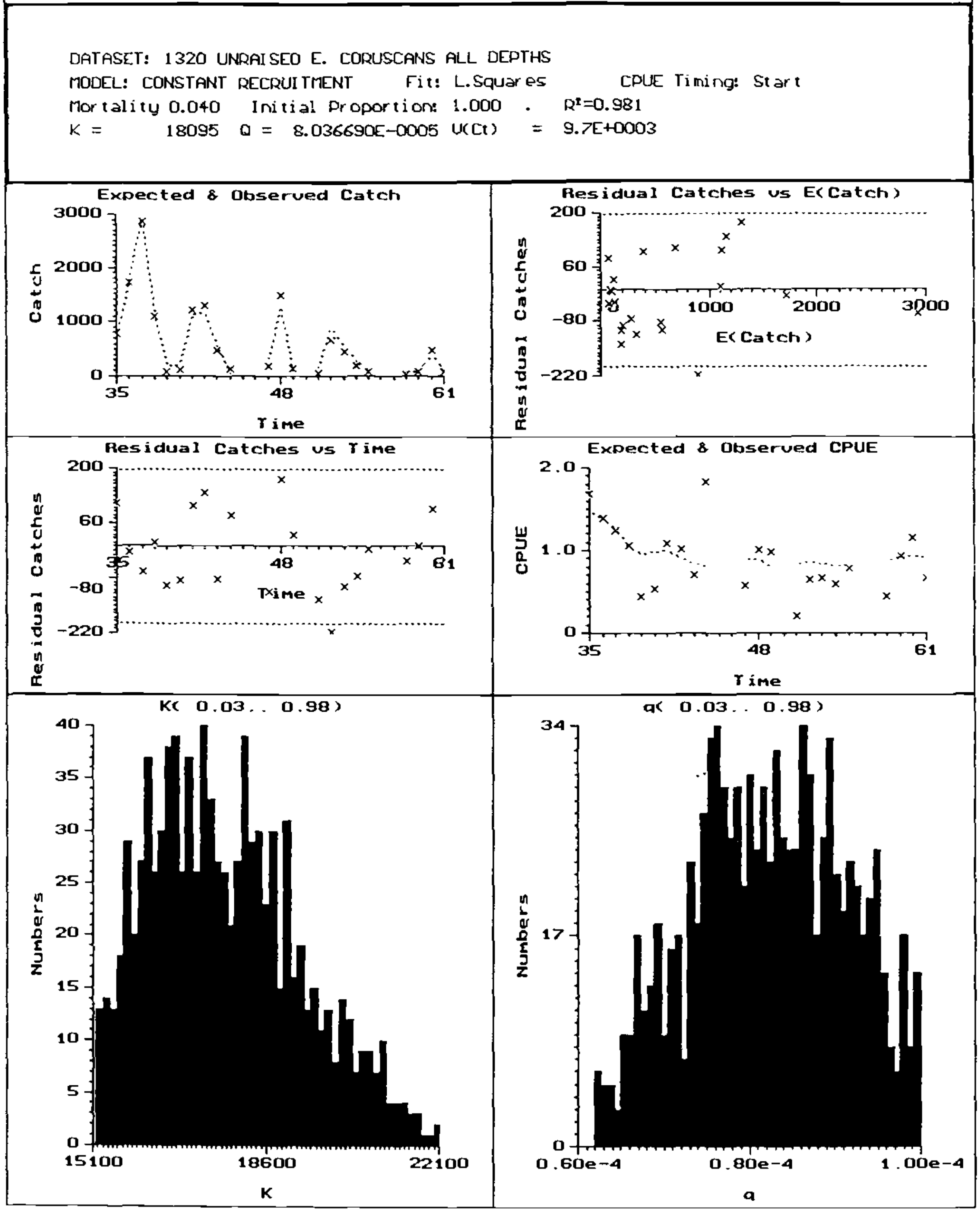
Fig. A.3.26.

```
DATASET: 1320 UNRAISED MAIN SPP ALL DEPTHS
MODEL: CONSTANT RECRUITMENT       Fit: L.Squares        CPUE Timing: Start
Mortality 0.040    Initial Proportion: 1.000   .    R²=0.975
K =        23617  Q =  6.543532E-0005  V(Ct)    =  1.4E+0004
```



```
PARAMETER ESTIMATES
-------------------

      K =           23617
      q =  6.543532E-0005
  V(Ct)  =   1.4E+0004


Confidence Intervals
--------------------

              2.50%                    97.50%
     K =               19160                     31549
     q   =  4.602170E-0005      8.673463E-0005
```

Fig. A.3.27.



```
DATASET: 1320 UNRAISED E. CORUSCANS ALL DEPTHS
MODEL: CONSTANT RECRUITMENT       Fit: L.Squares         CPUE Timing: Start
Mortality 0.040   Initial Proportion: 1.000   .    R²=0.981
K =       18095  Q =  8.036690E-0005 V(Ct)   =  9.7E+0003
```

```
PARAMETER ESTIMATES
-------------------

       K =          18095
       q =  8.036690E-0005
   V(Ct)   =  9.7E+0003


Confidence Intervals
--------------------
                2.50%                97.50%
      K =            15168                  22157
      q  =  6.187542E-0005      1.007097E-0004
```

TABLE A.3.2. : The mean weight (Kg) of individual fish by species each year derived from length converted data using Length-Weight relationships given in Latu and Tulua (1992)

Year	P.fil	P.fla	E.cor	E.car	E.mor	E.sep	L.chy	Total
86	3.53	1.60	3.73	3.59	3.02	22.99	0.55	3.46
87	3.22	1.32	3.36	7.71	3.06	23.19	1.72	3.99
88	2.58	1.31	3.54	4.25	2.86	18.94	1.45	3.00
89	3.22	1.39	2.92	3.35	2.96	19.90	1.36	3.37
90	2.61	1.29	3.31	3.91	3.24	19.95	1.69	4.15
91	2.65	1.31	3.29	4.76	3.16	12.26	1.48	4.06
Total	2.90	1.36	3.20	4.59	2.97	18.38	1.49	3.54

TABLE A.3.3: Proportion of the catch (numbers) of the 6 main species represented by each specie (from unraised data pooled over entire period, 86 - 91)

Mount	Depth	P.fil	P.fla	E.cor	E.car	E.mor	E.sep
1401	all	16.85%	13.64%	55.33%	5.86%	4.27%	4.02%
1501	all	31.79%	22.36%	35.38%	4.40%	4.95%	1.09%
1301	all	18.40%	11.03%	53.61%	10.69%	3.07%	3.17%
1504	all	36.11%	13.10%	39.10%	4.68%	4.54%	2.45%
1403	all	60.37%	18.53%	13.97%	1.12%	4.47%	1.52%
1320	all	3.07%	0.99%	87.29%	4.87%	0.34%	3.41%
1003	all	55.65%	20.14%	14.48%	5.67%	3.21%	0.83%
1005	all	66.22%	19.94%	6.59%	4.06%	2.69%	0.48%
1401	<=200m	29.14%	23.74%	33.16%	5.75%	6.17%	2.01%
1403	<=200m	69.93%	20.60%	3.30%	0.51%	4.78%	0.85%

Table A.3.4 : Biomass estimates for the guild of 6 main species, with 95% CI and M = 0.04 per month, from the sum of individual species biomass estimates derived from values in Tables A.3.2. and A.3.3 and No for the guild

Mount	Detail		No	P.fil	P.fla	E.cor	E.car	E.mor	E.sep	Total
	mean wt			3.53	1.60	3.73	4.59	3.02	22.99	
1401	Point		22301	13274	4860	46083	6000	2875	20611	93701
	lower		11205	6669	2442	23154	3015	1444	10356	47080
	upper		54863	32655	11956	113368	14760	7072	50704	230516
1501	Point		76905	86361	27473	101616	15535	11493	19272	261750
	lower		33247	37335	11877	43930	6716	4968	8331	113158
	upper		184084	206719	65761	243235	37186	27509	46130	626540
1301	Point		2673	1737	471	5352	1312	248	1948	11068
	lower		1676	1089	295	3356	823	155	1221	6940
	upper		4204	2732	741	8417	2063	390	3064	17407
1504	Point		1685	2149	353	2461	362	231	949	6505
	lower		1478	1885	309	2158	318	203	832	5705
	upper		2812	3587	589	4106	604	385	1584	10855
1403	Point		10855	23149	3214	5663	558	1465	3793	37842
	lower		9048	19295	2679	4721	465	1221	3162	31542
	upper		14159	30195	4192	7387	728	1911	4948	49360
1320	Point		54890	5953	868	178941	12272	563	43032	241629
	lower		44680	4845	707	145656	9990	459	35027	196684
	upper		74059	8031	1171	241431	16558	760	58059	326012
1403D2	Point		9643	23820	3174	1188	226	1392	1884	31684
	lower		8237	20347	2711	1015	193	1189	1610	27065
	upper		12153	30021	4000	1498	285	1754	2375	39931

Table A.3.5 : Biomass estimates for the guild of 6 main species, with 95% CI and M = 0.02 per month, from the sum of individual species biomass estimates derived from values in Tables A.3.2. and A.3.3 and No for the guild

Mount	Detail		No	P.fil	P.fla	E.cor	E.car	E.mor	E.sep	Total
1401	Point		10191	6066	2221	21059	2742	1314	9419	42819
	lower		6511	3875	1419	13454	1752	839	6017	27357
	upper		44446	26455	9686	91843	11957	5730	41077	186747
1501	Point		23980	26929	8566	31685	4844	3584	6009	81617
	lower		10259	11520	3665	13555	2072	1533	2571	34917
	upper		99998	112294	35723	132130	20200	14944	25059	340348
1301	Point		2872	1867	506	5750	1410	266	2093	11892
	lower		1801	1171	317	3606	884	167	1313	7457
	upper		4467	2903	787	8944	2192	414	3255	18496
1504	Point		23823	30388	4986	34788	5119	3265	13418	91964
	lower		10431	13305	2183	15232	2241	1430	5875	40267
	upper		57280	73064	11988	83643	12307	7851	32263	221117
1403	Point		14687	31320	4348	7663	755	1982	5132	51201
	lower		12215	26049	3616	6373	628	1648	4269	42583
	upper		18553	39565	5493	9680	954	2504	6483	64678
1403D2	Point		11770	29075	3874	1451	276	1698	2300	38673
	lower		10228	25266	3366	1261	239	1476	1999	33606
	upper		14301	35327	4707	1763	335	2064	2795	46989

Table A.3.6 : Biomass estimates for the guild of 6 main species, with 95% CI and M = 0.04 per month, from the sum of individual species biomass estimates derived from values in Tables A.3.2. and A.3.3 and No for the guild for different sub sets of data from sea mounts 1403 and 1320

Mount	Depth	Estimate	No	P.fil	P.fla	E.cor	E.car	E.mor	E.sep	Total
1403	all	point	10855	23149	3214	5663	558	1465	3793	37842
sample		lower	9048	19295	2679	4721	465	1221	3162	31542
		upper	14159	30195	4192	7387	728	1911	4948	49360
1403	<=200m	point	9643	23820	3174	1188	226	1392	1884	31684
sample		lower	8237	20347	2711	1015	193	1189	1610	27065
		upper	12153	30021	4000	1498	285	1754	2375	39931
1403	all		25659	54719	7596	13387	1319	3463	8966	89450
raised			21063	44917	6236	10989	1083	2842	7360	73428
			32031	68307	9483	16712	1647	4323	11193	111664
1320	all	point	23617	2561	374	76991	5280	242	18515	103963
sample		lower	19160	2078	303	62461	4284	197	15021	84343
		upper	31549	3421	499	102849	7054	324	24733	138880
1320		point	54890	5953	868	178941	12272	563	43032	241629
raised	all	lower	44680	4845	707	145656	9990	459	35027	196684
		upper	74059	8031	1171	241431	16558	760	58059	326012

ANNEX 4. METHODOLOGY EMPLOYED IN ESTIMATION OF DEMOGRAPHIC PARAMETERS FROM LENGTH FREQUENCY INFORMATION.

Length based approaches to fish stock assessment are frequently employed in the tropics where traditional age based methods developed for temperate water species are difficult to apply (eg. see Pauly and Morgan, 1987; Sparre *et al.*, 1989; Gulland and Rosenberg, 1992). Length information may be used to describe the size composition of the catch (descriptive statistics, length frequency distributions), to investigate growth, mortality, gear selectivity, and size at sexual maturity. In the present report, a detailed description of the methodologies employed is not presented, and the reader should consult the sources cited for more detail.

Length frequency data were collected for the 6 major species caught in the Tongan deep slope fishery (See Text, 2). Length frequency data are described in 3.2.1 and 3.2.2 and sample sizes by species depth and location are shown in Table 16. Aggregated annual data are illustrated for *P. filamentosus* (Fig A.4.1), *P. flavipinnis* (Fig A.4.2), *E. coruscans* (A.4.3), *E. carbunculus* (Fig. A.4.4), *E. morhua* (Fig A.4.5) and *E. septemfasciatus* (Fig. A.4.6). For each species the following steps were taken in the estimation of demographic parameters given in Tables 21-7 of the text :

1. For the following data sub-sets, length information was arranged into 2 cm size classes by month and year for each species (5 cm classes for *E. septemfasciatus*) and plotted sequentially (not shown) to allow visual inspection of the data :

    - all (locations and depths, ALL);
    - all (locations and depths) for months where sampling occurred at all locations (ALM);
    - Tongatapu south only (all depths TSO).

    Within any year it was considered reasonable to pool data by depth since fishing depth increased gradually over the 5 year period. However, for certain species, length data stratified by depth and location was also examined.

2. Sheppard (1987) described four types of length frequency distribution and their suitability for assessment using length based methods.

    Type A : Single mode always in the same position. Little information may be extracted by length based methods.

    Type B : A single mode, increasing in length steadily with time.Ideal situation usually observed with fast growing short lived species. Growth easily obtainable, mortality more difficult.

    Type C : Several modes, most distinguishable amongst the smaller fish. This information is potentially suitable for assessment using all kinds of length based methods.

Type D : Only one mode but with an extended right hand limb, probably an extreme Type C with overlapping modes. Difficult to assess growth, but relative mortality rates (K/Z, Z/K and L∞) may be assessed.

Using these criteria as a guide, the information for each year and each species was visually assessed for its suitability for further analysis :

Pristipomoides filamentosus

Type C / D distribution. Large modes up to 20 cm apart unlikely to represent year classes. Modes not always consistent month to month and ability to follow change in size of modes in doubt. In stratified data still find that modes inconsistent, probably due to nature of fishery shifting from mount to mount - population structure on different mounts may vary. Sequences marked * worth attempting to fit a von Bertalanffy growth curve.

YEAR	ALL DATA	ALL MONTHS WHEN ALL LOCN SAMPLED	Tonga SOUTH ONLY
1987	Modes do not show progressive sequence	3 months only, latter 2 may show progression	Months 6, 12 diff. mode to rest (*?)
1988	Reasonable (*)	Reasonable (*)	Major mode diff. month 2, 12 (*?)
1989	Inconsistent - major mode diff month to month	2 months only, inconsistent	poor (*?)
1990	Major mode inconsistent (*?)	Poor (*?)	Insufficient data
1991	Inconsistent (*?)	1 month only	inconsistent

Pristipomoides flavipinnis

Essentially type A (or extreme D) distributions. Inadequate for showing modal progression. No data appear suitable for estimation of growth parameters.

Etelis coruscans

Type C / D distribution. Large modes up to 20 cm apart unlikely to represent year classes. Tendency for modes to overlap. Distribution not always consistent month to month and ability to follow change in size of modes in doubt. In stratified data still find that modes inconsistent, probably due to nature of fishery shifting from mount to mount - population structure on different mounts may vary. Sequences marked * worth attempting to fit a von Bertalanffy growth curve, *? could try.

E. coruscans

YEAR	ALL DATA	ALL MONTH WHEN ALL LOCN SAMP	Tonga SOUTH ONLY	DEPTH STRATIFICATION
1987	Modes overlap (type D)	Modes overlap, months 9, 12 only (*? if include 2,5,9, 12)	Poor (*?)	Depth > 300 m Insufficient data
1988	Inconsistent	Modes overlap, and 12 differs from 2,5,8 (*?)	Mode diff. mon - mon too big for growth (*?)	As Tonga S (*?)
1989	Modes overlap, diff. to see progression (*?)	3 months. inconsistent	Inconsistent (*?)	Modes inconsistent
1990	As 1989 (*? but exclude month 6)	3 months only (*?)	4 months, (*?)	Only 4 mths, progression, but too big for growth? (*)
1991	Major modes inconsistent	2 months only	Apparent progression too big for growth? (*?)	Inconsistent

Etelis carbunculus

Two major modes but each mode behaves like type A distribution Suggest try fitting growth curves only to 1988, 1989 all data for months at all locations, 1988, 1989(*) Tongatapu south (* appears to show good progression).

Epinephelus morhua

Type C / D data. Attempt fits for 1988, 1989 all data, all location-months

Epinephelus septemfasciatus

Type C data. None of the data sets show modal progression. 2 cm size groups may be too small - try 5 cm

3. DESCRIPTIVE STATISTICS

For each data subset, the minimum, maximum and average lengths observed were computed.

4. WETHERALL et al (1987) METHOD, L∞, Z/K

For all species this method was applied to the annual aggregated data (ALL) in order to obtain estimates of L∞ and relative mortality, Z/K.

The method often required a high degree of subjectivity, and the parameters derived must be viewed with caution.

5. GROWTH PARAMETERS, K, L∞, To

A preliminary estimate of K was derived from L∞ (obtained by the method of Wetherall *et al* (1987)) using the empirical formula :

$$\text{Log10 } K = 1.098 - 0.658 \times \text{Log 10 } L_\infty \qquad \text{(Manooch. 1986)}$$

where L∞ is expressed in mm.

The ELEFAN routine of Pauly and David (1981) in the LFDA (MRAG, 1992b) package was used to fit von Bertalanffy growth curves to the length frequency distributions where possible (see Annex 4.2). Other methods were also attempted (SLCA, Sheppard 1987; PROJMAT, Basson *et al* 1988). Maximisation (ie. a search for the best fit of model to the data) allowed both K and L∞ to vary. In no case was a good fit obtained and multiple maxima always occurred (see MRAG, 1992b) indicating that any number of potential K - L∞ combinations apparently fit the data. This is not un-surprising - the methods were developed for short lived fast growing species with obvious modal progression. For the long lived slow growing species such as those in the Tongan deep slope fishery, modes tend to overlap.

The LFDA package does not allow for seasonal variations in growth. However, in tropical waters these will be minimal and Gulland and

Rosenberg (1992) suggest further that for long lived species no great errors are likely to be introduced by examining annual average values.

The choice of the paired K - L∞ parameters from the multiple maxima derived was based subjectively on :

- how close L∞ was to Lmax / L∞ from Wetherall *et al* method
- how close K was to similar estimates for the same species reported in the literature
- How close Munro's Phi' was to that derived for K-L∞ pairs reported in the literature

The pair chosen was not always that returning the highest Rn value (a method of scoring the goodness of fit for the ELEFAN method). Whilst different sub sets of data were examined in an attempt to improve parameter estimation, only one pair of K - L∞ values are presented in this report for each year : since the choice of parameter estimates was subjective any differences observed in data stratified by depth and location should not be interpreted as resulting from different environmental conditions and to avoid such misinterpretation, only one estimate is presented. This argument may also be applied to estimates derived each year. Whilst growth might be expected to change from year to year as a result of fishing pressure, the analyses are not considered to be sufficiently robust to indicate this. As a consequence, a single pair of values is also subjectively chosen for each species as the most appropriate fit from the annual estimates.

Examples of von Bertalanffy growth curves fitted to stratified monthly length frequency data as described are given for *P. filamentosus* (Fig A.4.7a-d), *E. coruscans* (Fig. A.4.8a-b), *E. morhua* (Fig. A.4.9a-b), and *E. septemfasciatus* (Fig. A.4.10a-b)

6. TOTAL MORTALITY, Z

Total fishing mortality (Z) was estimated from all data aggregated annually (ALL), and, to investigate changes in fishing mortality by depth / location where appropriate, from data aggregated annually for that data subset. The following methods were used :

(i) From mean length (Beverton and Holt 1956) using the cut off length derived from the catch curve as Lc.

(ii) From a length converted catch curve (Jones, 1984) using firstly the von-Bertalanffy growth parameters derived for each year (growth may vary with time), and secondly the best estimate for the growth parameters (growth constant over time). The routine 'ELEFAN II' in the Compleat ELEFAN package was used (Gayanillio *et al*, 1988) Examples are given for *P.*

filamentosus (Fig. A.4 11) and *P. flavipinnis* (Fig A.4.12). *E. carbunculus*, due to the bimodal nature of the length frequency distribution was treated differently from the other species :

Two major modes occur (34-36 cm and 80-82 cm, Fig A.4.4) which are not thought to be age classes (cohorts). In 1987 the larger mode was predominant whilst in subsequent years it was the smaller. Estimation of Z from mean length greater than Lc (the first fully exploited length class) is highly dependant upon the value of Lc. Similarly, estimation of Z from a catch curve is complicated due to this bi-modality.

Z was estimated from the smallest mode only (Fig A.4.13), from the largest mode only (Fig. A.4.14 ie. assumes that different fishing mortalities are exerted on the different length classes), and from all lengths greater than the smallest mode (Fig A.4.15, ie. a 'mean' mortality for all lengths greater than Lc).

7. NATURAL MORTALITY, M

Instantaneous coefficients of natural mortality (M) were estimated using Pauly's (1980) empirical formula, and a water temperature of 18°C for all data aggregated over depth (ALL, TSO), or if a particular depth band was examined, the temperature appropriate to that depth (see Text, 1) was applied. Trenkel (1993) modified the original model of Pauly (1980) using an enlarged data set for fish species living in water temperatures above 5°C. This model was also applied. Trenkel (1993) indicates that whilst these empirical methods are often the only way of estimating natural mortality the result is often imprecise and 95% confidence intervals may be 4 times greater or smaller than the central estimate. Sparre (1989) suggests that whilst empirical models may be used in the absence of alternatives, the result should be considered an educated guestimate.

Fishing mortality (F) was derived from (Z-M) using the value of Z derived from the catch curve.

8. GEAR SELECTIVITY Lc, $L_{50\%}$ $L_{75\%}$

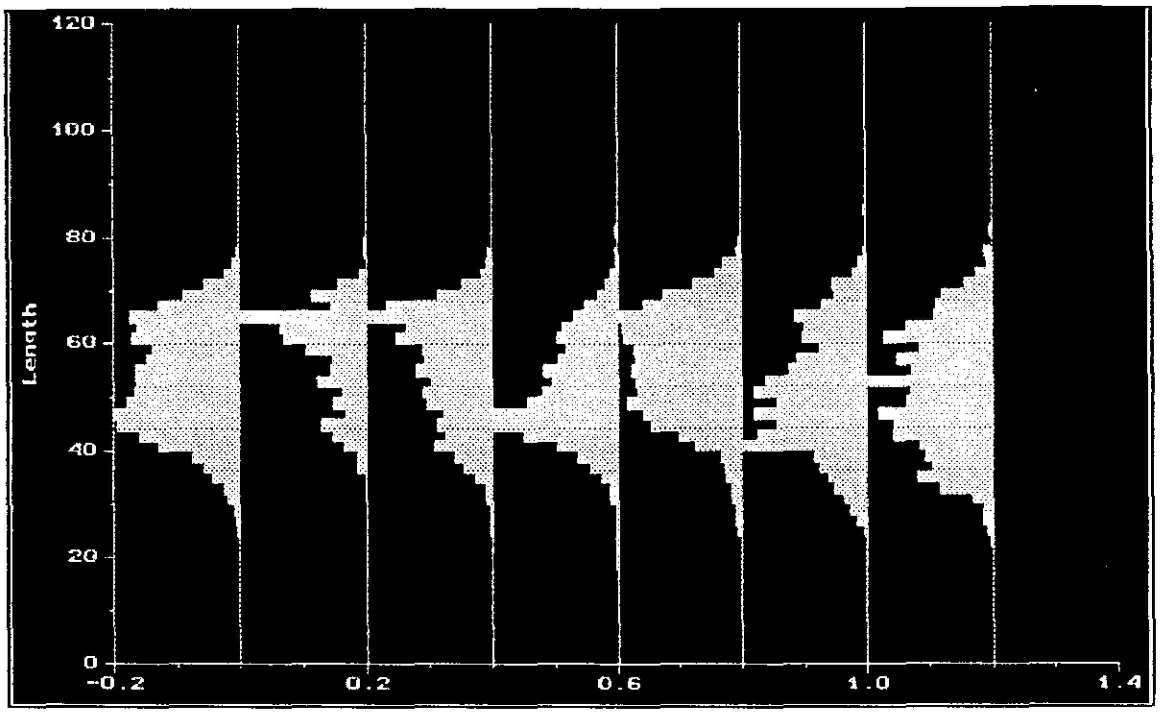
Lc, the first fully exploited length class, was selected as the cut off length derived from the catch curve. Lc was also subjectively chosen by examination of the aggregated length distributions annually and over the entire period Figs A.4.1-6). This latter estimate was frequently less than that derived from the catch curve. The ELEFAN II routine was employed, fitting a running average, to derive the selectivity ogive parameters $L_{50\%}$ and $L_{75\%}$.

9. REPRODUCTIVE PARAMETERS $Lm_{50\%}$

In the absence of direct observation, length at maturity, $Lm_{50\%}$ was assumed to be half the maximum length observed. Grimes (1987) indicated that for Lutjanids length at maturity corresponded to 51% of the maximum length observed for island populations. This was also applied to Serranidae, although it should be noted they have a different reproductive strategy. Data from the literature was also examined.

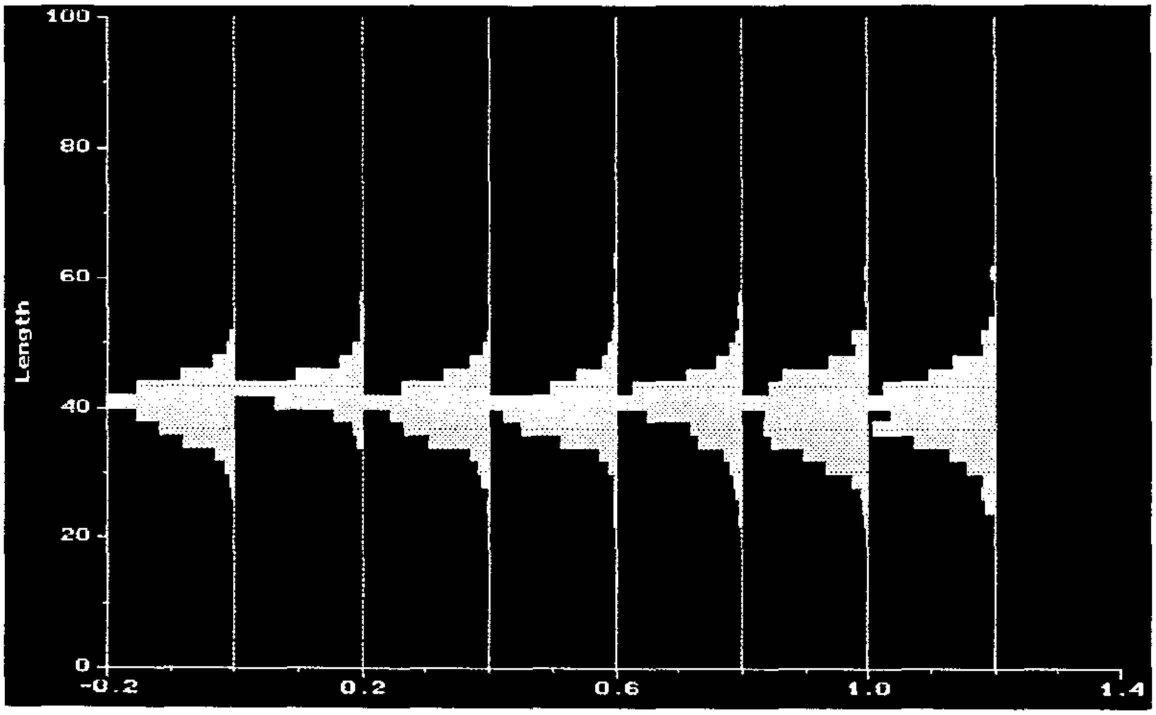
The results of these analyses are presented in the text (3.2.3)

Fig A4.1 *Pristipomoides filamentosus*: Annual length frequency distributions, ALL. (N = 11843, Min = 18, Max = 106 / 150 Mean = 52.85 cm FL)



YEAR 1986-91 1986 1987 1988 1989 1990 1991

Fig A4.2 : *Pristipomoides flavipinnis* : Annual length frequency distributions, ALL. (N = 7189, Min = 20, Max = 96, Mean = 39.68 cm FL)



YEAR 1986-91 1986 1987 1988 1989 1990 1991

Fig A.4.3 : *Etelis coruscans* : Pooled annual length frequency distributions, all data (N = 22045, Min = 6, Max = 146, Mean = 56.75 cm FL)

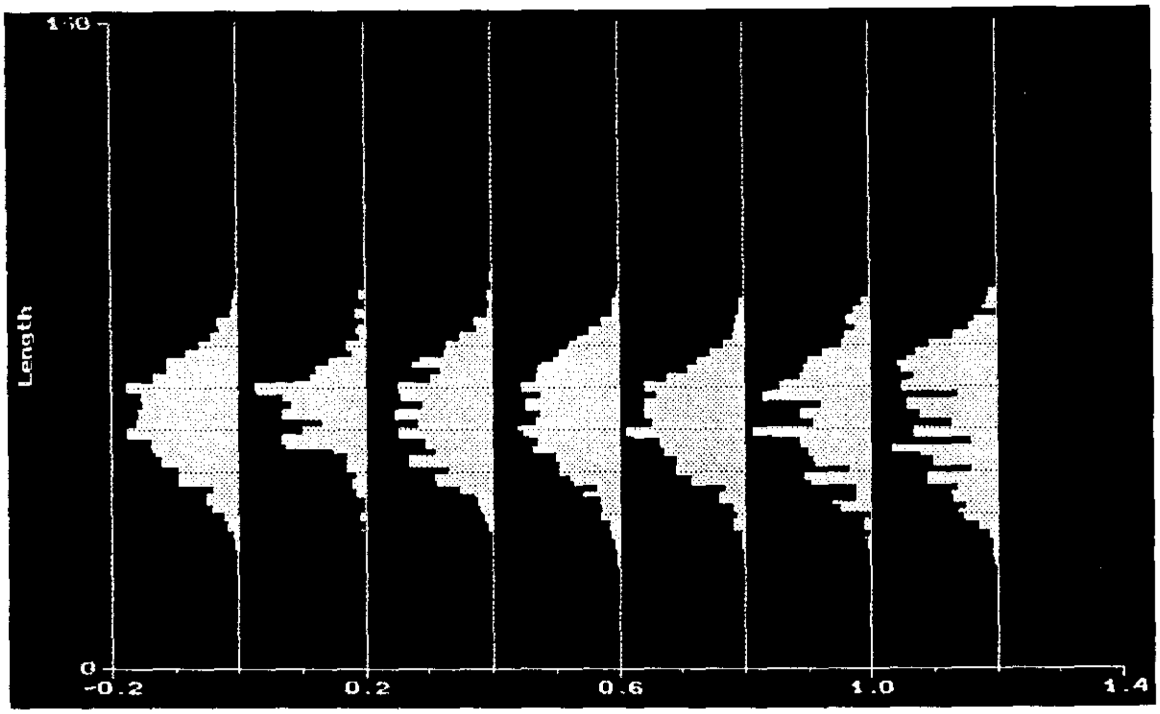


Fig. A.4.4 : *Etelis carbunculus* : Annual length frequency distributions, all data (N= 8173, Min = 13, Max = 148, Mean = 55.43 cm FL)

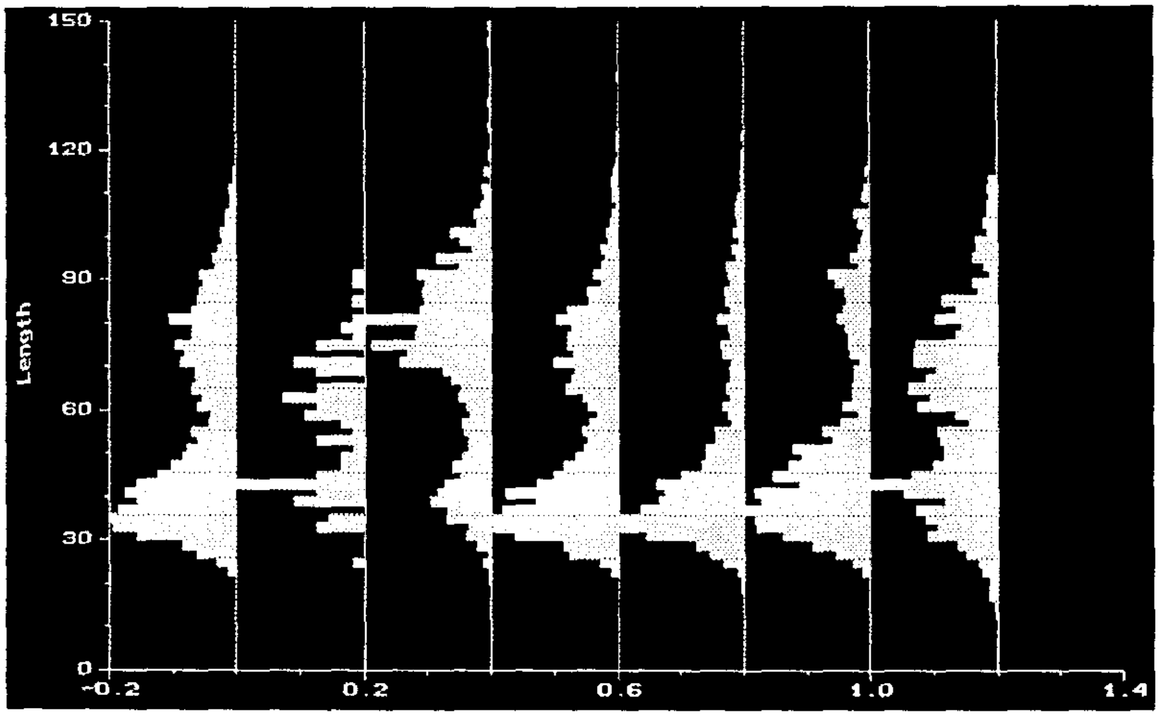


Fig. A.4.5 : *Epinephelus morhua* : Annual length frequency distributions, ALL (N = 4053, Min = 21, Max = 125, Mean = 55.28 cm TL)

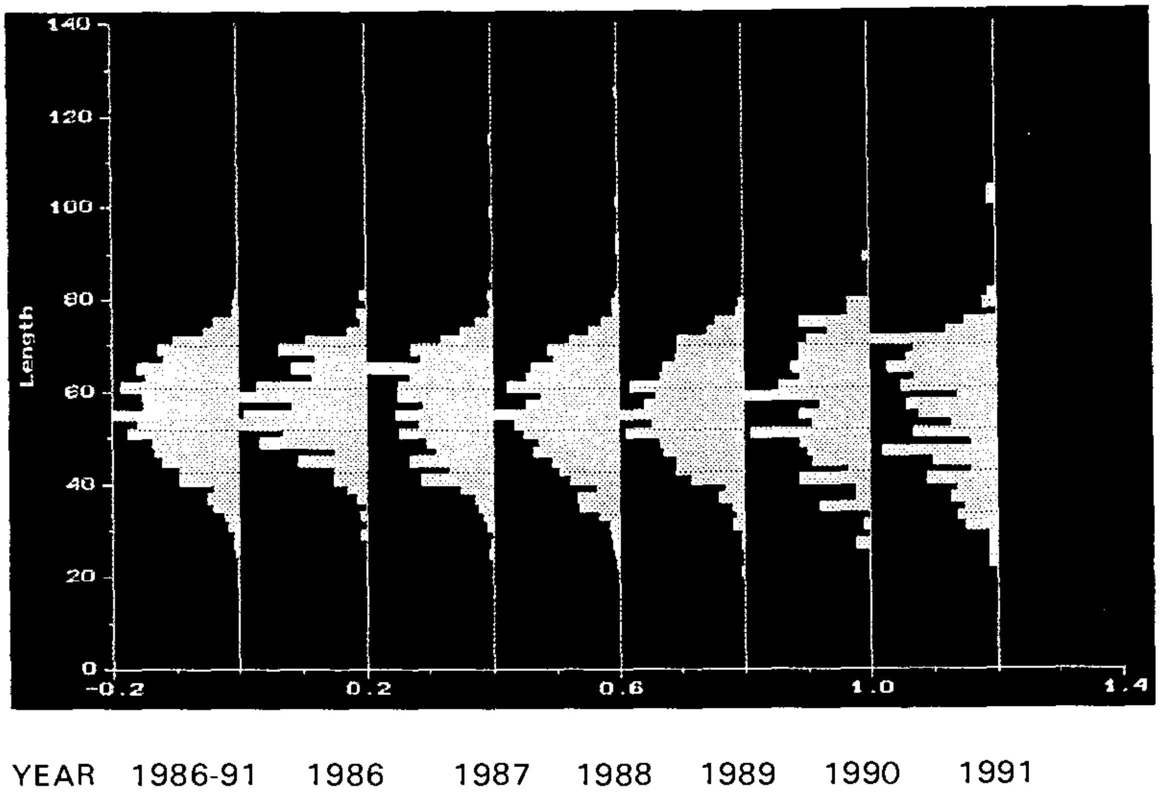
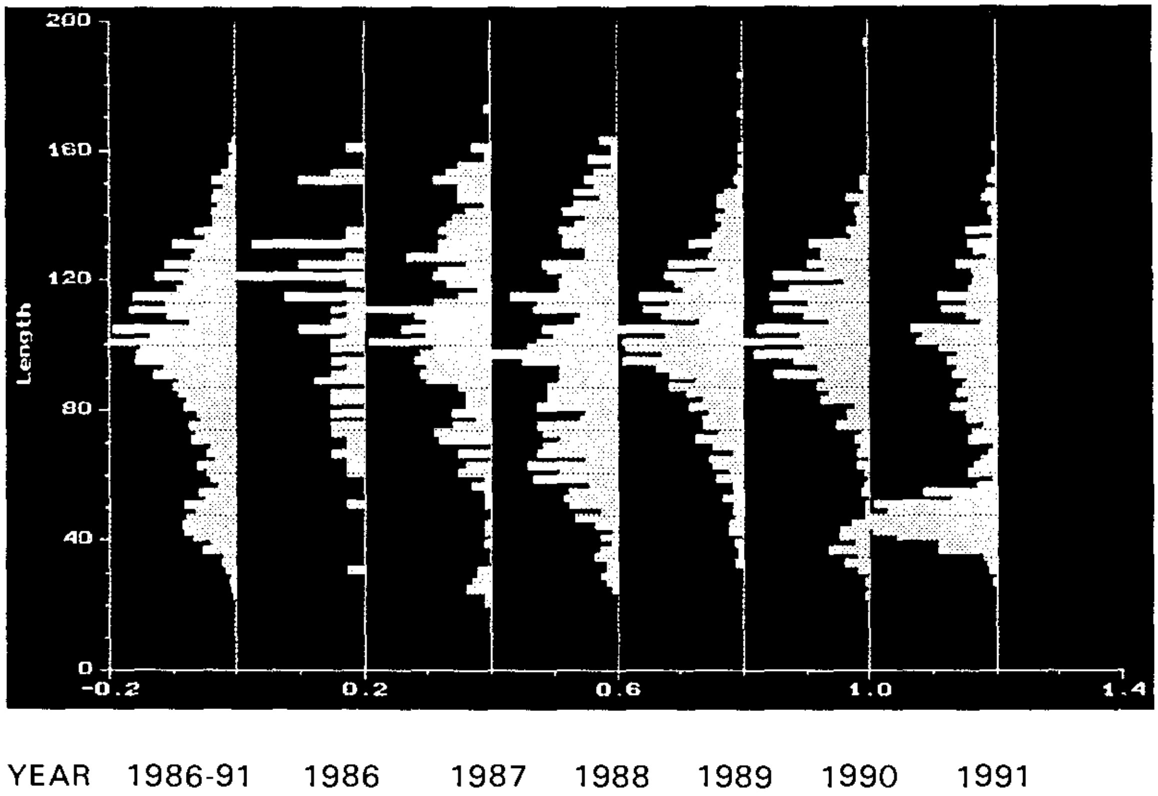
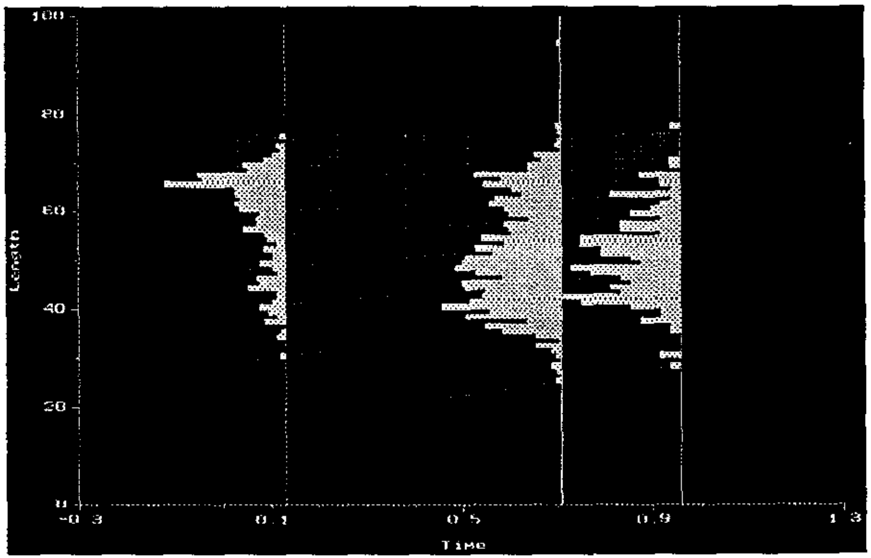


Fig A4.6: *Epinephelus septemfasciatus* : Annual length frequency distributions, ALL (N = 3207, Min = 21, Max = 192, Mean = 94.73 cm TL)

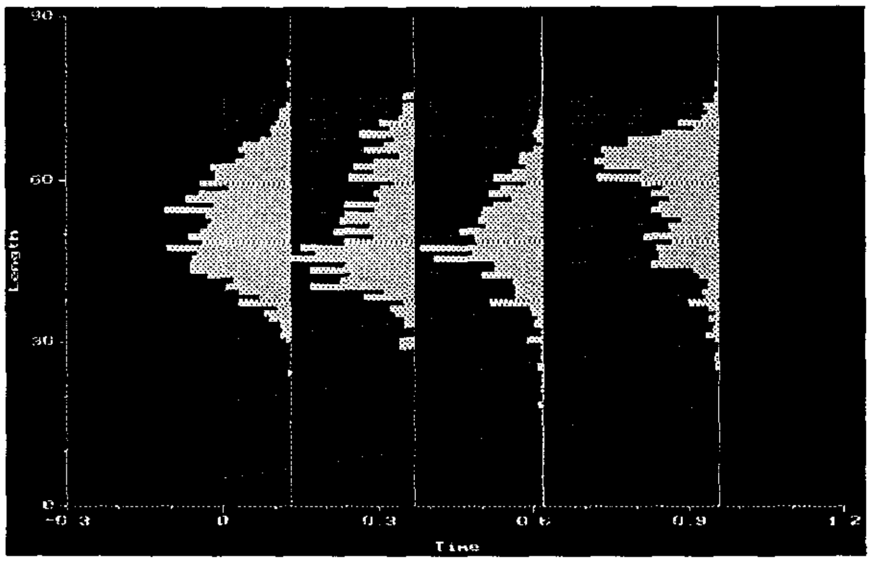


Figs. A.4.7-A.4.10 : Examples of Von Bertalanffy growth curves fitted to monthly length frequency data.

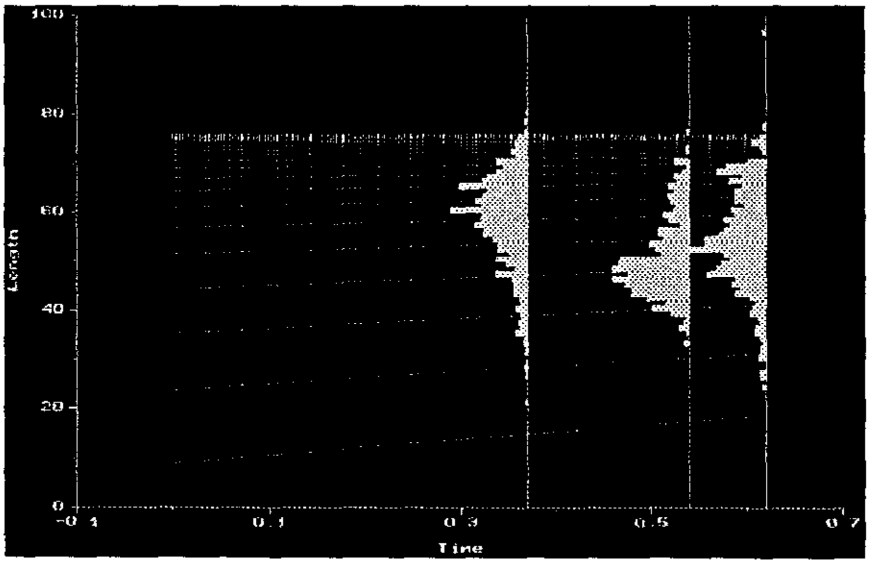
Fig A.4.7a: *P. filamentosus*, 1987, ALM, K = 0.25, Linf = 77.6, To = -0.88



b. *Pristipomoides filamentosus*, 1988, ALM, K = 0.22, Linf = 77.6, To = -0.44



c. *Pristipomoides filamentosus*, 1989, ALM, K = 0.25, Linf = 76.3, To = -0.50



d. *Pristipomoides filamentosus*, 1990, ALM, K = 0.30, Linf = 74.8, To = -0.49

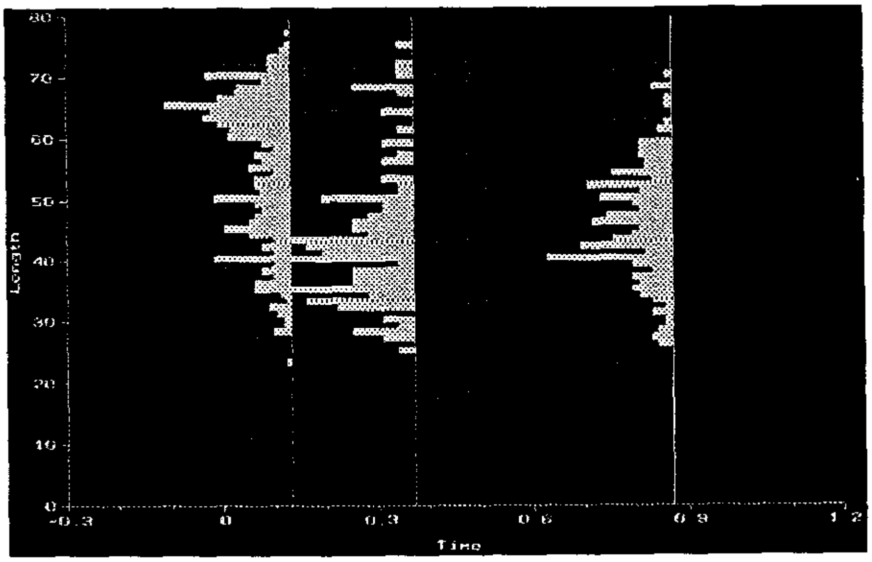
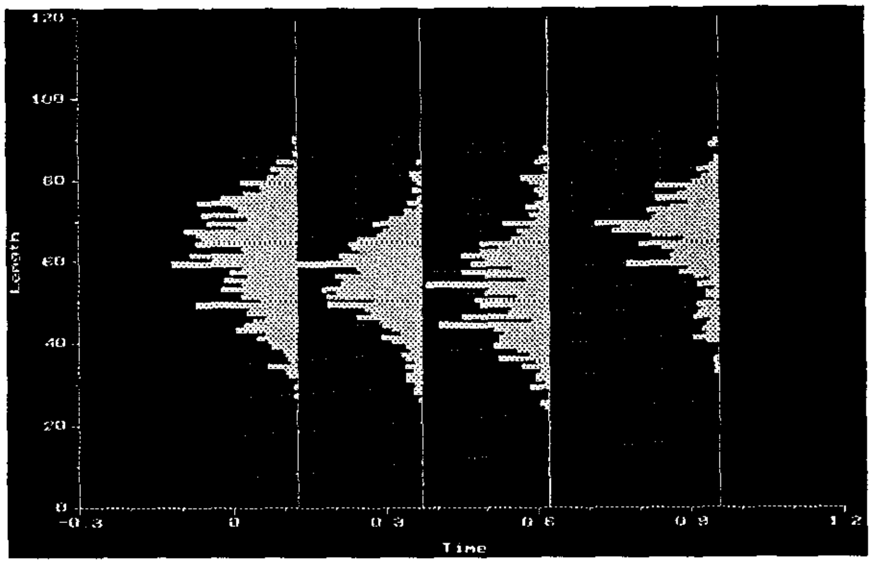


Fig A.4.8 a : *Etelis coruscans*, 1988, ALM, K = 0.11, Linf = 107.2, To = -0.636



b. *Etelis coruscans*, 1990, ALM, K = 0.16, Linf = 88.8, To = -0.09

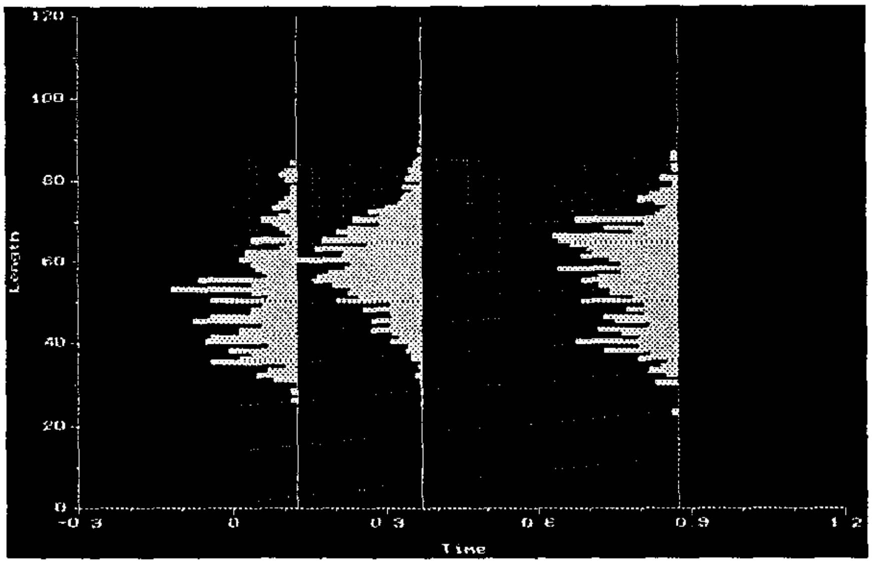
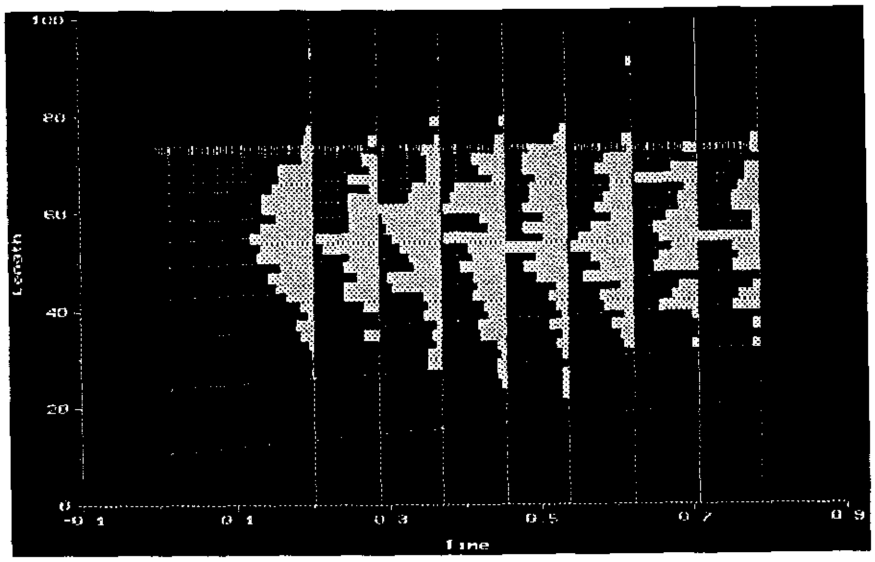


Fig A.4.9 :

a. *Epinephelus morhua*, 1988, ALM, K = 0.23, Linf = 74.1, To = -0.66



b. *Epinephelus morhua*, 1989, ALL, K = 0.23, Linf = 76.6, To = -0.90

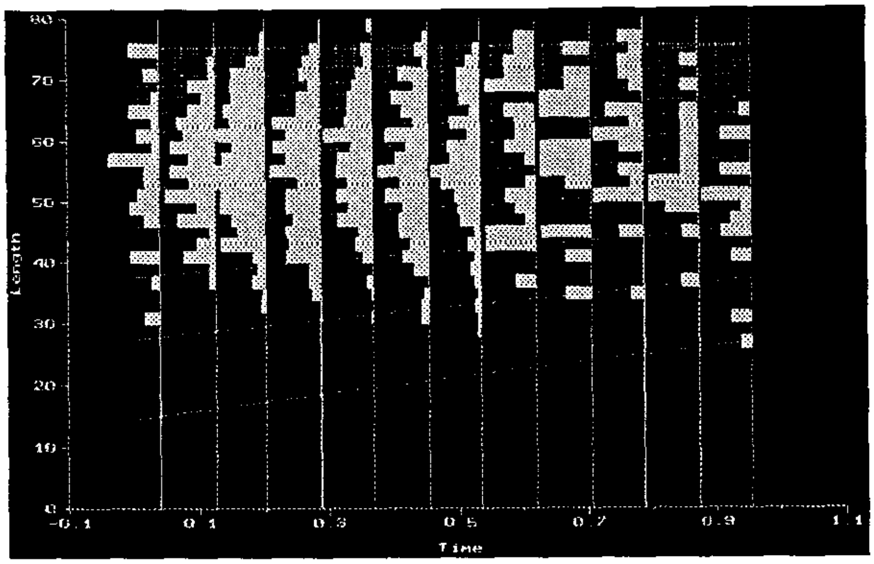
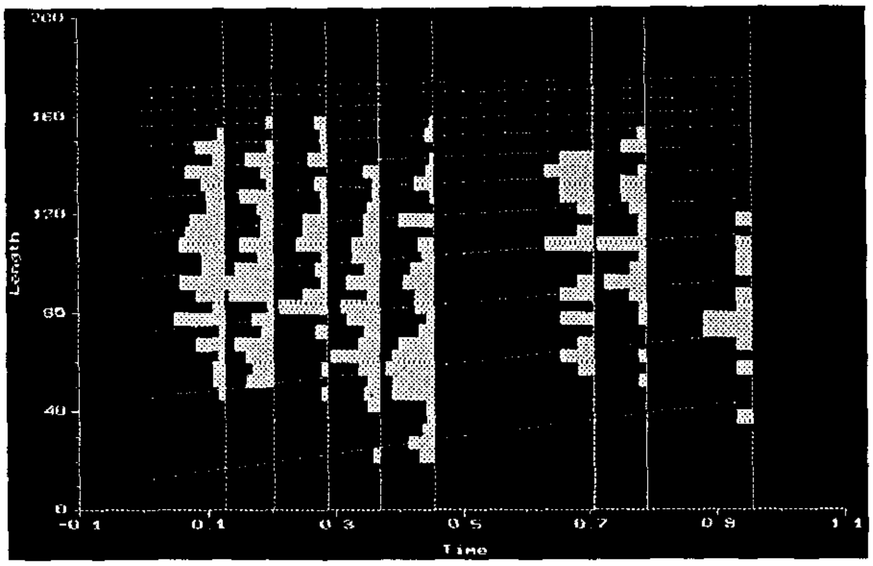
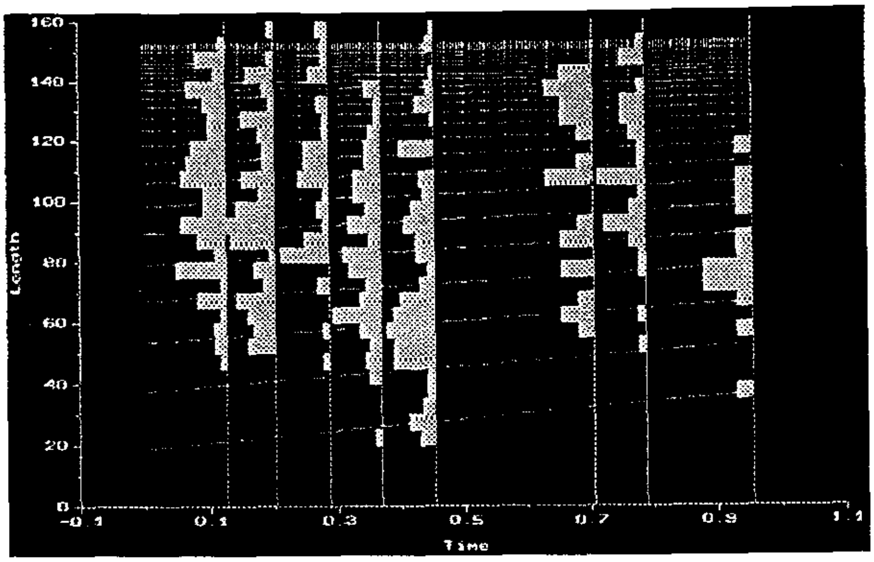


Fig A.4.10*a: E. septemfasciatus*, 1988, ALM, K= 0.207, Linf = 189.9, To=-0.33



b. *Epinephelus septemfasciatus,* 1988, ALM, K= 0.15, Linf = 154.4, To = -0.89



Figs A.4.11-12 : Examples of Length converted catch curves derived from aggregated annual length frequency data

Fig a.4.11. *Pristipomoides filamentosus,* 1988, ALL, K= 0.2196, Linf = 77.55, To = -0.44, Z = 0.84

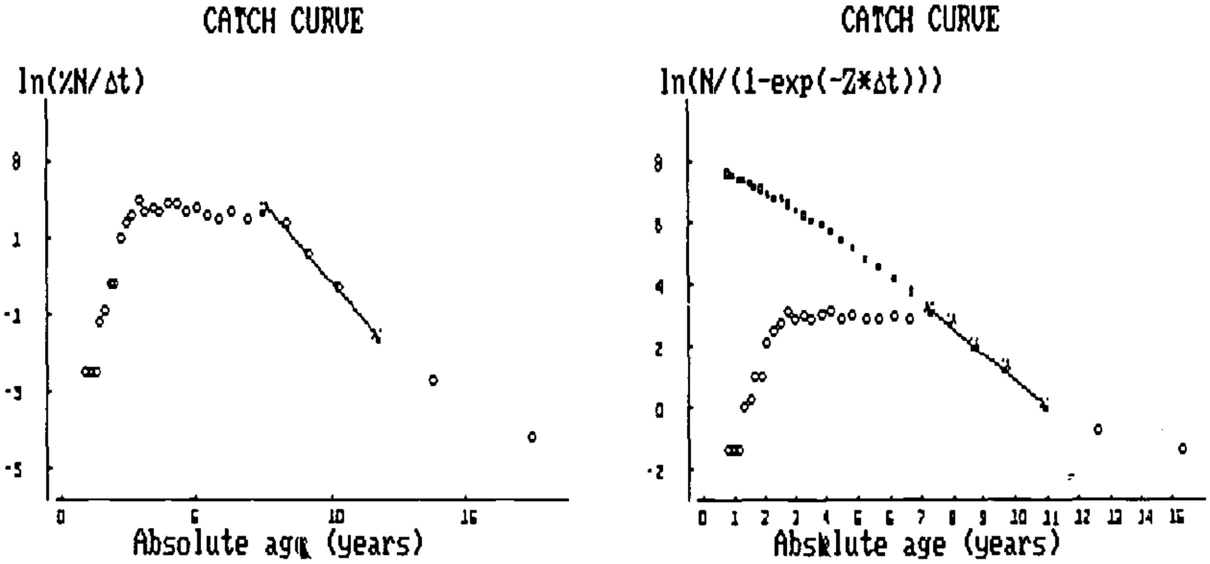
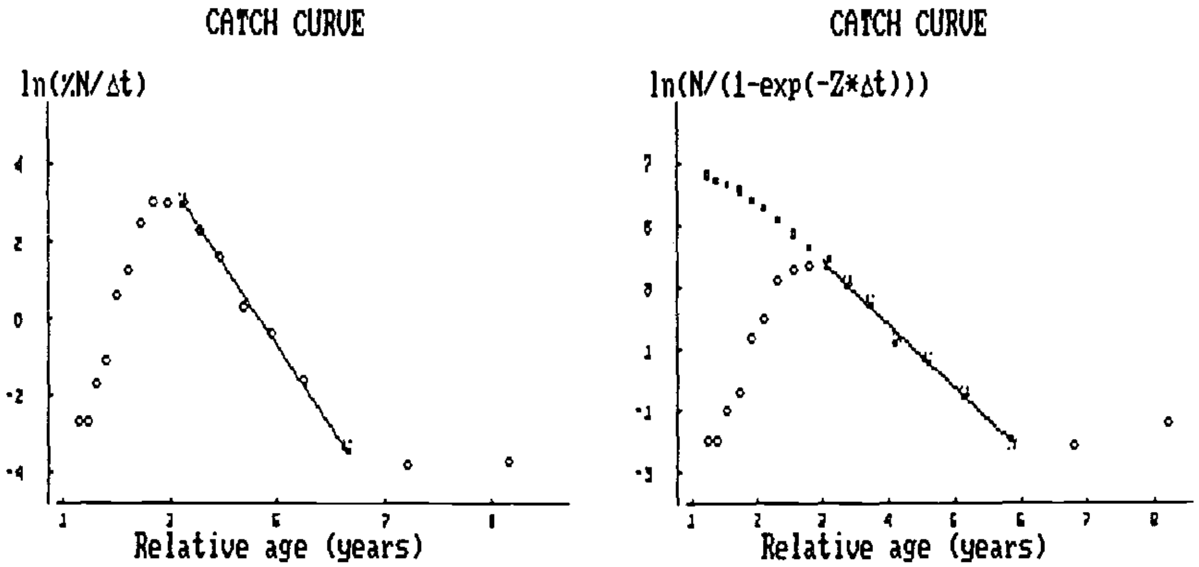


Fig A.4.12: *Pristipomoides flavipinnis*, 1988, ALL, K = 0.36, Linf = 58, Z = 2.08



Figs. A.4.13-15 : Examples of the application of the catch curve to length frequency data for 1989 for *Etelis carbunculus* from the 301-400m depth band (all locations)

Fig. A.4.13 : Catch curve for *E. carbunculus* : Z from smallest mode

Cut off point, Lc = 31.5, CC Z = 1.014, B+H Z = 0.349

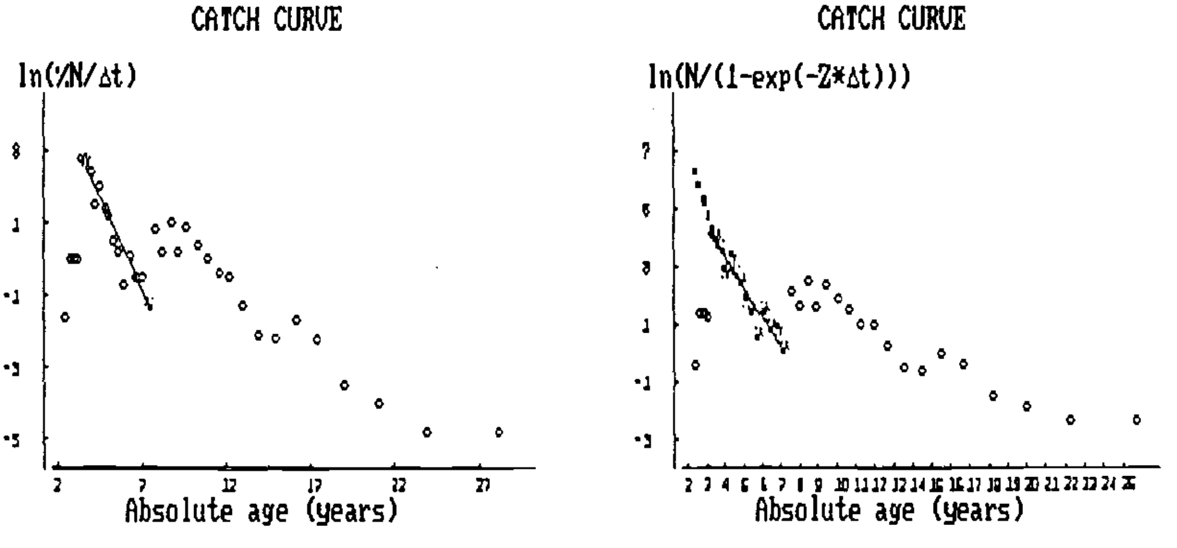


Fig. A.4.14 : Catch curve for *E. Carbunculus* : Z from largest mode

Cut off point, Lc = 82.5, CC Z = 0.414, B+H Z = 0.457

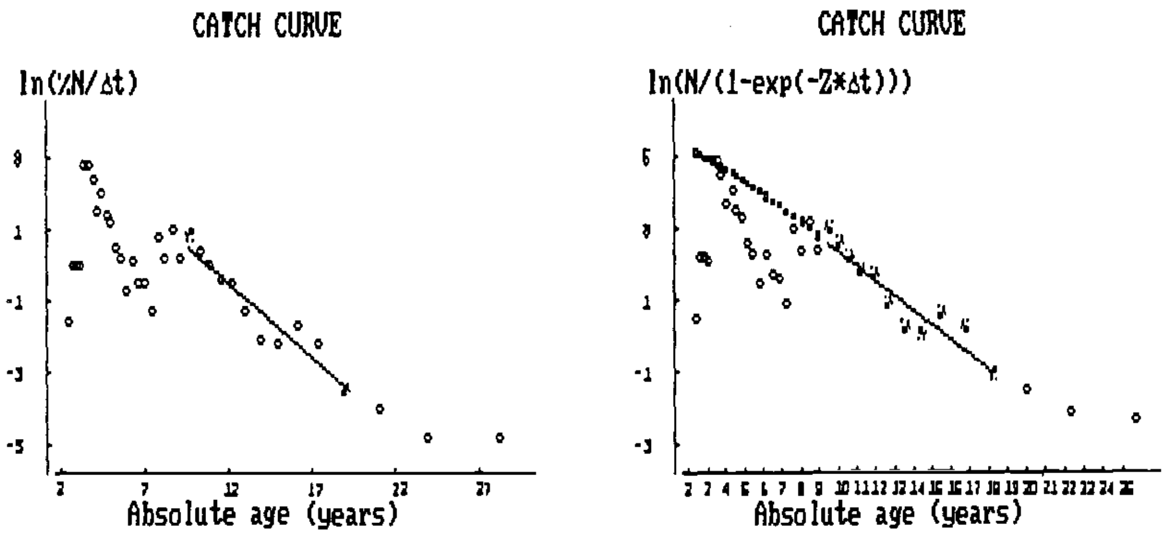
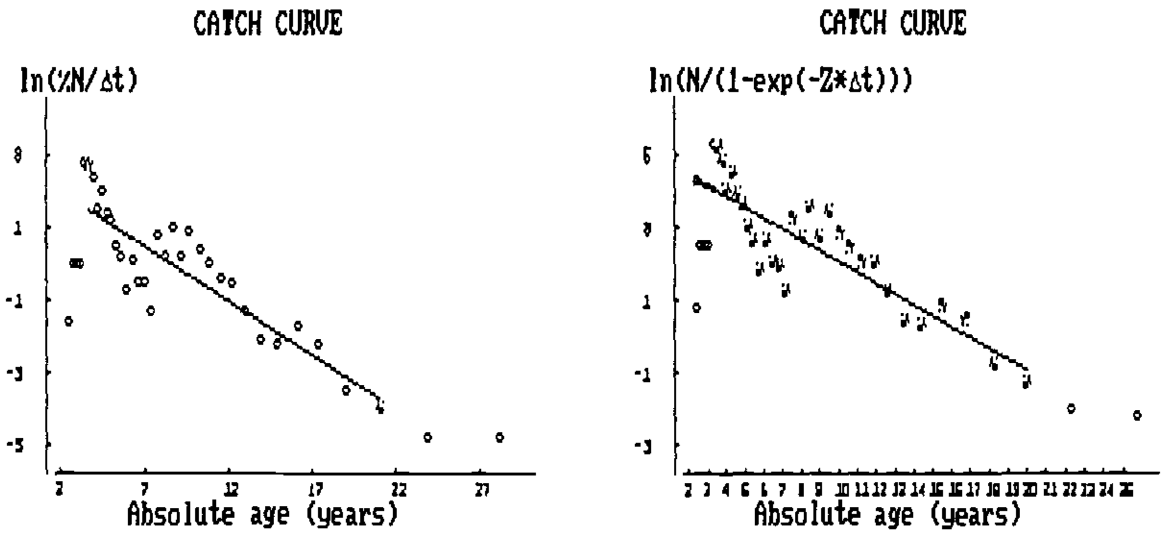


Fig. A.4.15. Catch curve for *E. carbunculus* : Z from all lengths > smallest mode

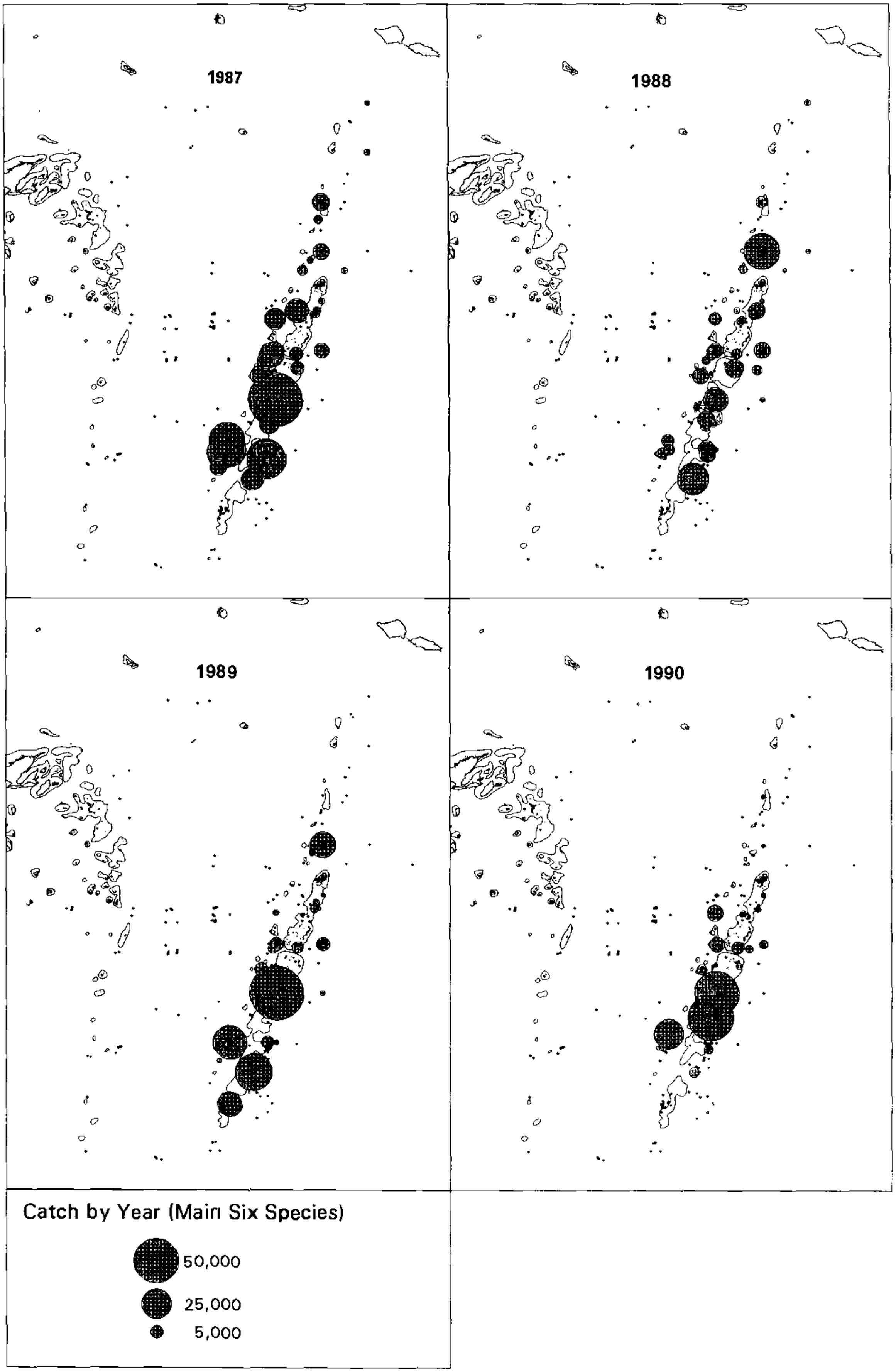
Cut off point, Lc = 31.5, CC Z = 0.299, B+H Z = 0.349



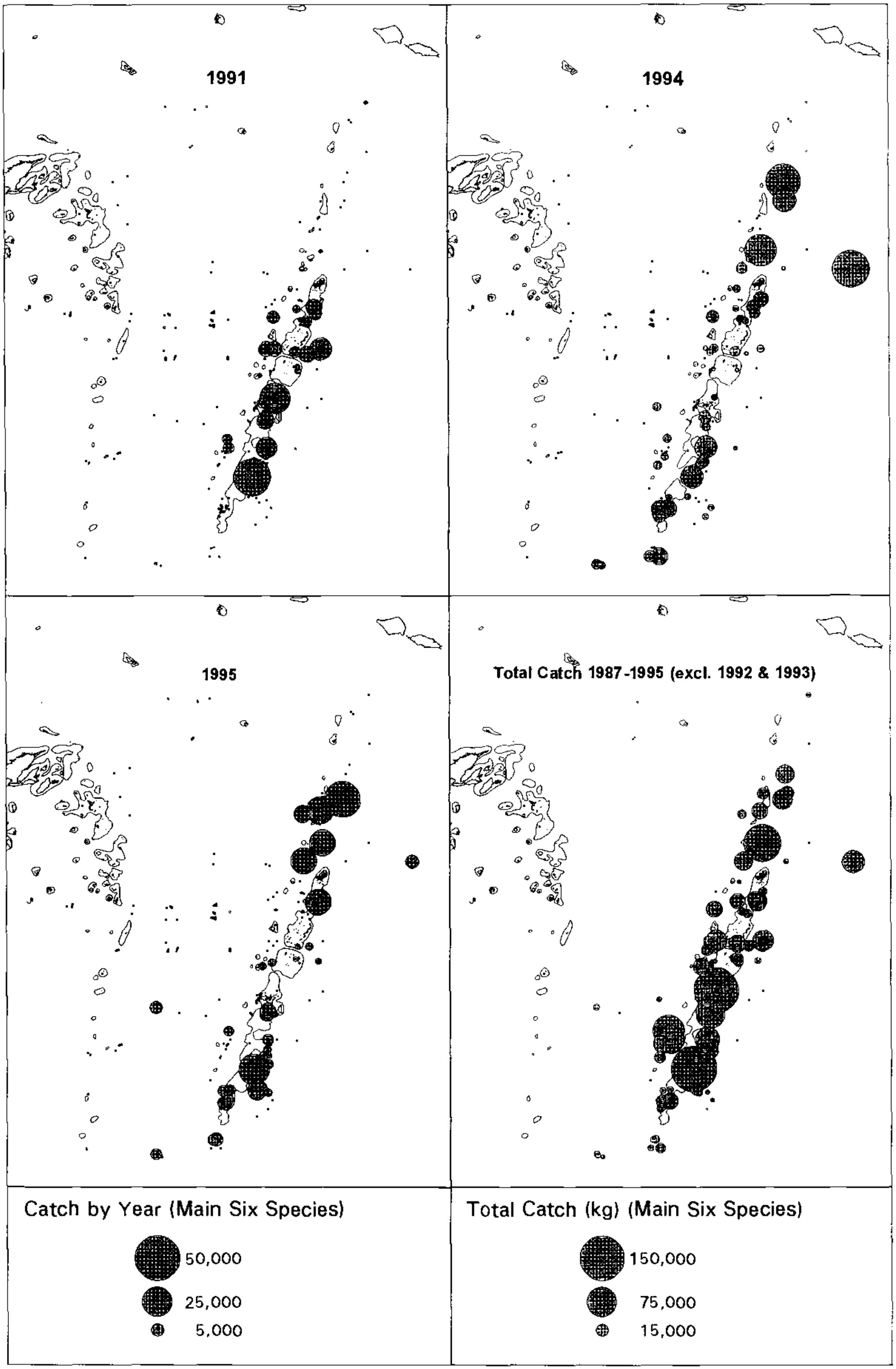
ANNEX 5 : Spatial distribution of seamount and banks species catches, 1987-1991 and 1994

The following figures indicate the annual catch (kg) taken from individual seamount and bank locations. Data for 1995 relates to the period January-August only. The location of all known seamounts are indicated (small circles). Catch per seamount is indicated according to the size of circle drawn over that seamount. Some seamounts have a Tonga Ministry of Fisheries code but the position of the seamount (latitude and longitude), except within a one degree square, is not known. Catch and effort data are available for these locations. This is represented in the top right hand corner of a one degree square and results in the concentric circles in some of the figures (ie, each circle relates to a different seamount).

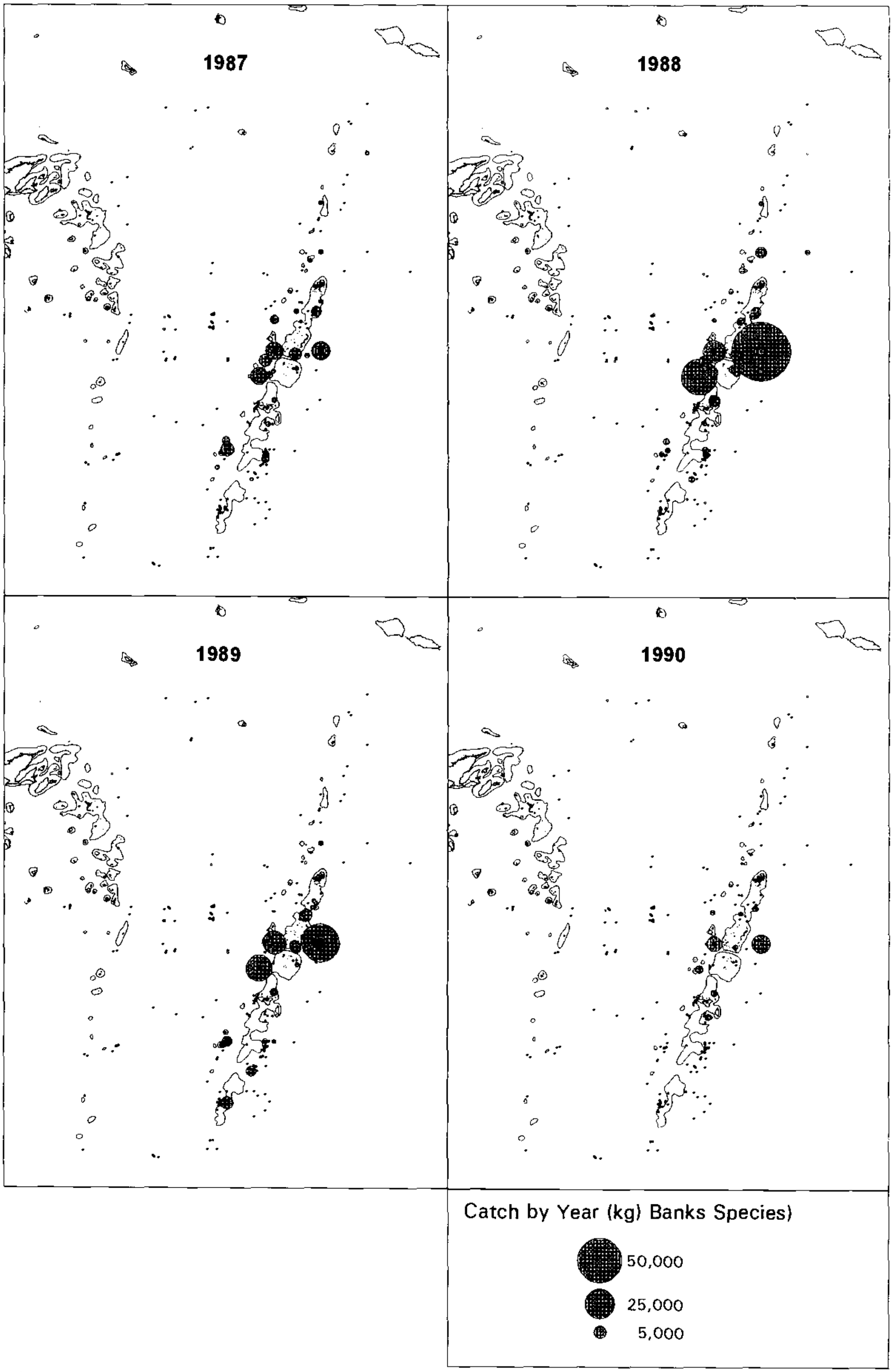
Evidence for depletion at individual seamounts was found for only two locations (see 3.1.4) and the following figures infer the movement of the fleet over time, also discussed in Section 3.1.1. Fishing effort was originally concentrated in the north at the start of the fishery (1980). By 1987 most of the effort and catch was in the south of the Tongan Archipelago, with seamounts in the extreme south being fished in 1989. By 1994 and 1995, catch and effort was more widely dispersed (perhaps reflecting the greater range of the new vessels introduced into the fishery during the early 1990's), with new seamount locations west of Tongatapu being exploited for the first time. Also noticable is the greater catch from the north of the Archipelago during those years.



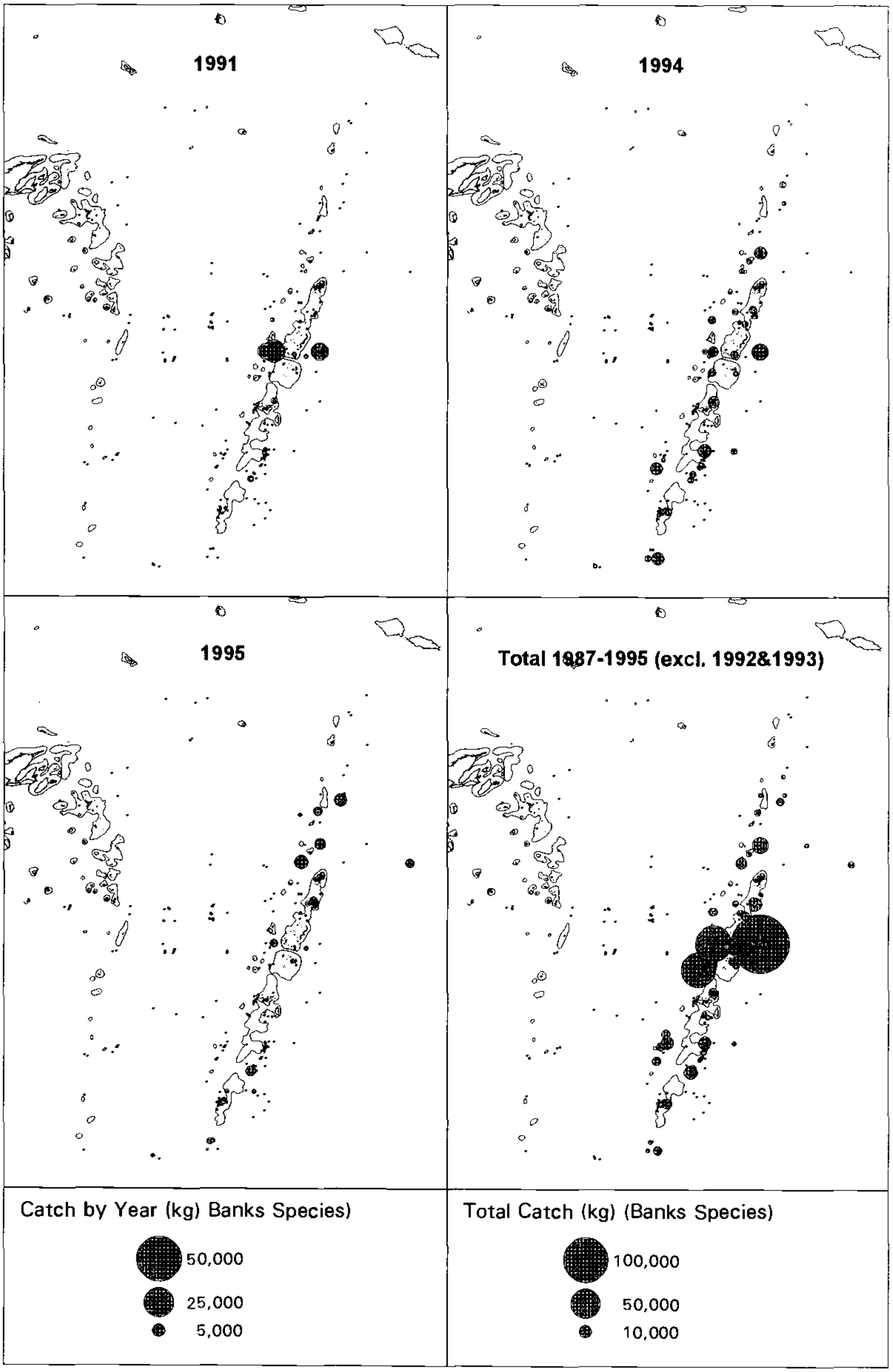
Annual catch by bank or seamount location, and the total catch for the period 1987-1995 (excluding 1992 and 1993) for a guild of all main six species in the catch.



Annual catch by bank or seamount location, and the total catch for the period 1987-1995 (excluding 1992 and 1993) for a guild of all main six species in the catch.



Annual catch by bank or seamount location, and the total catch for the period 1987-1995 (excluding 1992 and 1993) for a guild of all banks species in the catch.



Annual catch by bank or seamount location, and the total catch for the period 1987-1995 (excluding 1992 and 1993) for a guild of all banks species in the catch.