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DEPTH DISTRIBUTIONS, GROWTH, AND MORTALITY OF DEEP SLOPE FISHES FROM THE MARIANA ARCHIPELAGO

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U.S. DEPARTMENT OF COMMERCE
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ABSTRACT

Detailed summaries are presented for the intermediate computational steps of a tropical multispecies yield assessment conducted in the Marianas from April 1982 to May 1984, including depth distribution data for 22 species, growth curves (developed from the numerical integration of daily increment width data) for 11 species, and length-frequency analyses for 7 species. Results show that in the Marianas the size structure of most bottom fishes changes little with depth of capture. This facilitates the analysis of length-frequency data to estimate vital rates. Moreover, the Marianas bottom fish community (composed primarily of lutjanids, serranids, and carangids) is found in the 80 to 150 fathom depth range, with most fishes caught between 100 and 125 fathoms. Von Bertalanffy growth parameters estimated from the joint analysis of otoliths and length-frequency data indicate that lutjanid growth coefficients ($\underline{K}$) range from 0.13 to 0.26 yr^{-1}. These are inversely related to asymptotic sizes ($\underline{L}_\infty$), which range from 428 to 981 mm fork length. Likewise, there is evidence of a positive correlation between natural mortality rates ($\underline{M}$) and growth coefficients among the lutjanids. The single carangid, Caranx lugubris, for which detailed information exists did not fit the pattern characterizing the lutjanids.

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INTRODUCTION

The Resource Assessment Investigation of the Mariana Archipelago (RAIOMA) was a 5-yr program initiated by the Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, in 1980 to quantify the distribution and sustainable yield of insular fishery resources with commercial potential in the Mariana Archipelago. In particular, offshore pelagic species, bottom fishes, deepwater shrimps, and mackerel scad, *Selar crumenophthalmus*, were the subjects of studies aimed at identifying spatiotemporal variations in distribution and determining archipelago-wide yield potentials. A third goal of the program was to contribute information that would enhance our overall understanding of the basic biology of species from this region.

A number of reports and publications were produced as a result of the RAIOMA program: Eldredge (1983); Moffitt (1983); Uchida (1983); Polovina (1985, 1986); Polovina et al. (1985); Ralston (1985, 1986, in press b); Polovina and Ralston (1986); Moffitt and Polovina (1987); Polovina and Roush[1]; Polovina and Shippen[2]; Ralston and Shiota[3]; Ralston and Williams[4]. Many of the data summaries and analytical results completed during the program remain unpublished. This is unfortunate because, as a multispecies tropical yield assessment, the program was in many ways innovative and unique. Moreover, most of the species studied are distributed extensively throughout the Indo-Pacific region. Thus, the fisheries management efforts of many developing South Pacific countries would stand to benefit substantially from the detailed results of the RAIOMA program, were they available.

In particular, a major focus of the program involved in-depth analyses of the age and growth of commercial fish species through the examination of otolith microstructure (i.e., daily increments). Likewise, standardized mortality estimations were generated from the joint analysis of length-frequency data and von Bertalanffy growth curves. Lastly, numerous depth distributions of deep slope species were described. All three kinds of information are invaluable in the study of population dynamics and represent

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[1]Polovina, J. J., and R. C. Roush. 1982. Chartlets of selected fishing banks and pinnacles in the Mariana Archipelago. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Admin. Rep. H-82-19, 15 p.

[2]Polovina, J. J., and N. T. Shippen. 1983. Estimates of the catch and effort by Japanese longliners and baitboats in the fishery conservation zone around the Mariana Archipelago. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Admin. Rep. H-83-1, 42 p.

[3]Ralston, S., and P. M. Shiota. The effect of hook size on the catch size structure of Marianas bottom fish. Manuscr. in prep. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.

[4]Ralston, S., and H. A. Williams. Numerical integration of daily growth increments: an efficient means of aging tropical fishes for stock assessment. Manuscr. in prep. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.

the first description of population parameters for many if not most of the lutjanids, serranids, and carangids studied. The intent of this paper is to summarize these significant biological findings.

MATERIALS AND METHODS

All sampling was conducted from the NOAA ship Townsend Cromwell from April 1982 to May 1984. Six 40-d cruises were completed, and samples were obtained during all months of the year except March, September, and October. Fishing was done throughout the Mariana Archipelago, including the offshore seamounts of the west Mariana Ridge.

Virtually all the specimens were caught during daylight hours by hook-and-line gear operated from hydraulically powered fishing gurdies. Equal numbers of No. 20 and 28 Izuo[5] circle fish hooks, baited with cut squid, were always used during fishing operations. The fishing gear consisted of four hooks attached by short (50 cm) gangions to a braided, prestretched Dacron line (400 m long) weighted with a 2-kg piece of rebar. There were four such lines, each spooled on a Pacific King fishing reel powered by a Charlin hydraulic motor. Fishing was targeted between 75 and 140 fathoms,[6] although some catches were made both shallower and deeper. The depth of capture was recorded with a Raytheon fathometer. In addition to this method of sampling, specimens of *S. crumenophthalmus* (Carangidae) and *Lutjanus kasmira* (Lutjanidae) were obtained at anchored 20-fathom night-light stations by using light Dacron handlines equipped with small feathered jigs.

All fish landed were identified to species, measured to the nearest millimeter fork length (FL) on a measuring board, and weighed to the nearest 0.01 kg on a balance scale. Where possible, the sex of each fish was determined at the time of capture by gross examination of the gonads. Likewise, sagittal otoliths from the more abundant species were collected by frontal section through the cranium, rinsed in fresh water, and stored dry in glass vials with labels.

Otolith Studies

In the laboratory, otoliths were examined for the presence of daily increments (Campana and Neilson 1985). To prepare the otoliths for viewing, they were first embedded in casting resin, which was allowed to harden completely. Cast otoliths were sectioned on a Buehler ISOMET low speed jewelry saw. Thin (0.70 mm) sections were made through the focus along a frontal plane to the most distal portion of the postrostrum. Sections were polished

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[5]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[6]Depths are given in fathoms, the unit provided on bathymetric charts and used by depth sounders. One fathom is 1.83 m.

sequentially on a Buehler ECOMET polisher/grinder with 180 and 600 grit abrasive disks. Samples were then briefly etched for 5–30 s in a dilute solution of 1% hydrochloric acid, washed in water, and dried. Prepared sections were mounted on glass slides with Euparol or Flotexx and cover slips and allowed to clear and harden completely prior to viewing (approximately 2 wk).

Mounted otolith sections were examined with a compound binocular microscope using transmitted light at a magnification of 200 or 400X. The total length of the otolith, i.e., the distance in micrometers between the focus and the postrostral margin, was measured with a calibrated ocular micrometer. Individual readings were then made at selected points along the postrostral growth axis, wherever increment microstructure was unambiguously developed. At these locations, the average width of presumptive daily growth increments was determined by counting a small number of clearly defined increments and measuring the axial length of the short segment in which they occurred. In addition, the axial distance between the midpoint of each segment and the otolith focus was measured. Up to 12 readings were made from each preparation, subject to the constraint that counts and measurements only be made in regions where increment microstructure was clearly expressed.

The data were summarized by computing the ratio of segment length in micrometers to the included number of increments at each specific site examined, providing an estimate of the average increment width at some measured distance from the otolith focus. Under the assumption that one increment forms each day, these data can be used to estimate the instantaneous growth rate of the otolith (Ralston and Miyamoto 1981, 1983; Ralston 1985).

To estimate age, a simple form of numerical integration was employed. Starting at the focus, the data were subdivided into 500-μm intervals of otolith length (_OL_). For each interval, the arithmetic mean growth rate of the otolith was calculated based upon the number of readings falling therein. Average growth rates were then divided into 500 μm to provide estimates of the number of days needed to complete passage through each interval of otolith growth. These were then sequentially accumulated away from the focus, and finally divided by 365.25 to convert age estimates to years. The estimated age upon completion of growth through interval $\underline{k}$ can be expressed more formally as

$$\text{Age}_k = \frac{1}{365} \sum_{i=1}^{k} \frac{\Delta(\text{OL})}{\text{d}(\text{OL})/\text{dt}_i} \quad ,$$

where $\Delta(\underline{OL})$ is 500 μm in all the applications presented here and $\underline{d}(\underline{OL})/\underline{dt}_{\underline{i}}$ is the mean otolith growth rate in each of the $\underline{i}$ intervals leading up to interval $\underline{k}$.

After performing a regression of the natural logarithm of FL on the logarithm of total otolith length, the size of the otolith upon completion of growth through each interval was used to predict the corresponding FL of the fish. These data (age in years and FL in millimeters) were then fitted to the von Bertalanffy growth equation (Ricker 1979) by using a nonlinear regression routine (NLIN procedure, SAS 1979). Because this model provides a poor description of growth during the early life history, only data representing ages $\geq$0.8 yr were used in the regression. Also, statistical weighting was desirable because (1) sample sizes for estimating mean otolith growth rates within otolith length intervals varied, (2) variances in otolith growth rates typically were heterogeneous (proportional to the square of the mean), and (3) compounding of error occurred because of additive nature of the age estimator. Statistical weights were therefore calculated as the reciprocal of the sum of standard errors of the growth rate means through interval k. A more detailed exposition of this method and an example of its application and validation to *Pristipomoides zonatus* is presented in footnote 4.

Length-Frequency Analysis

The regression method of Wetherall et al. (1987) was used to study vital rates and estimate growth and mortality parameters. For species caught in sufficient numbers ($N > 150$), these analyses were based on the combined length-frequency distributions (FL rounded to the nearest centimeter) of all individuals sampled (see Ralston (in press a) for a discussion of the effects of pooling length data taken at different times of the year).

Initially, this method requires determination of the minimum length wherein fish are fully represented in the catch ($\ell_{c,min}$). For this purpose, the first length category larger than the mode was assumed to be the smallest size fully sampled (e.g., Ricker 1975). Moreover, for this and any larger cutoff value ($\ell_{c,i}$), we were able to compute the mean size of fully vulnerable fish in the catch ($\bar{\ell}_i$). This is, by definition, the average length of those fish greater than $\ell_{c,i}$. As $\ell_{c,i}$ was successively incremented through the fully vulnerable size range, the mean and variance in size of larger fish were recalculated at each step, and a series of ordered pairs was developed. The actual estimation procedure involved regressing values of $\bar{\ell}_i$ against successive values of $\ell_{c,i}$. The inverse of the standard error of $\bar{\ell}_i$ was used as a statistical weight for each point, leading to the best linear, unbiased estimates of the slope (δ) and intercept (ξ). With the resulting regression statistics, the formulas provided in Wetherall et al. (1987) were used to obtain point estimates of the ratio of total instantaneous mortality rate to the von Bertalanffy growth coefficient (Z/K) and the von Bertalanffy asymptotic size parameter (L_∞). In particular, they showed that $Z/K = \delta/(1 - \delta)$ and $L_\infty = \xi/(1 - \delta)$. Likewise, error estimates for these statistics were calculated as well.

RESULTS

A total of 40 species were caught at the RAIOMA deep-sea handline fishing stations (Table 1). Species in the snapper family (Lutjanidae) easily outnumbered all others, accounting for 14 of the 40 species caught

Table 1.--Summary of species caught during research sampling at handline fishing stations in the Mariana Archipelago, April 1982-May 1984.

Species	Frequency	Percent
Triaenodon obesus	1	0.0
Polymixia sp.	1	0.0
Beryx decadactylus	1	0.0
Unidentified serranid	9	0.1
Epinephelus sp.	12	0.2
Epinephelus fasciatus	6	0.1
Epinephelus lanceolatus	38	0.5
Epinephelus morrhua	13	0.2
Cephalopholis sp.	3	0.0
Cephalopholis igarashiensis	10	0.1
Cephalopholis aurantia	4	0.1
Cephalopholis sexmaculata	3	0.0
Variola louti	19	0.3
Saloptia powelli	43	0.6
Elagatis bipinnulata	2	0.0
Seriola sp.	54	0.8
Carangoides orthogrammus	8	0.1
Caranx lugubris	237	3.4
Aphareus rutilans	66	1.0
Aprion virescens	7	0.1
Pristipomoides sieboldii	53	0.8
Pristipomoides filamentosus	173	2.5
Pristipomoides argyrogrammicus	20	0.3
Pristipomoides auricilla	1,072	15.4
Pristipomoides flavipinnis	400	5.8
Pristipomoides zonatus	3,561	51.3
Etelis coruscans	187	2.7
Etelis carbunculus	821	11.8
Lutjanus bohar	13	0.2
Lutjanus kasmira	3	0.0
Paracaesio sordida	4	0.1
Paracaesio xanthura	7	0.1
Gymnocranius japonicus	16	0.2
Lethrinus rubrioperculatus	35	0.5
Unidentified mullid	1	0.0
Gymnosarda unicolor	5	0.1
Pontinus macrocephala	4	0.1
Dactyloptena orientalis	1	0.0
Triodon macropterus	27	0.4
Unidentified diodontid	2	0.0
Total	6,942	100.0

(35%). Moreover, 10 of these were members of the subfamily Etelinae and 6 were of the genus *Pristipomoides*. Among the various other families represented in the catch, the sea basses (Serranidae), with 11 species, were the richest. These were composed largely of representatives from the subfamily Epinephelinae (10 species). Of the remaining 15 species, 4 were jacks (Carangidae) and 2 were emperorfishes (Lethrinidae).

Likewise, the eteline snappers dominated the catch in terms of the number of individuals caught (92%), with the genus *Pristipomoides* again leading the way (76% of all fish). In fact, the species *P. zonatus* alone accounted for over half (51%) the catch. Other numerically important species included *P. auricilla*, *P. flavipinnis*, *P. filamentosus*, *Etelis carbunculus*, *E. coruscans*, and *Caranx lugubris*. These seven species jointly comprised 93% of all fish caught.

Depth Distributions

In yield assessments, it is important to examine depth distributions to determine whether age or size classes are distributed heterogeneously along this spatial dimension. If larger fish tend to be found in deeper water, demonstrating Heincke's Law (Harden Jones 1968), problems will arise when analyzing size structure for the purpose of estimating mortality rates. To examine this possibility, correlations were calculated between FL (in millimeters) and depth of capture (in fathoms) for all species with sample sizes greater than two. The resulting distribution of correlation coefficients had a median value of 0.08, and the interquartile range, encompassing half the data, was -0.18 to 0.23. Thus, for most species examined, the depth of capture accounted for <6% of the total variation in FL. Moreover, of the 33 correlations, only 4 were significant ($P < 0.05$). The species concerned were *P. zonatus* ($r = 0.22$), *P. flavipinnis* ($r = 0.19$), *Aphareus rutilans* ($r = 0.30$), and *C. lugubris* ($r = 0.23$). Note that in none of these four correlations did depth explain more than 10% of the total variation in FL and significance was due primarily to greater statistical power resulting from large sample sizes (see Table 1). Thus, for deep slope bottom fishes of the Marianas, Heincke's Law was the exception rather than the rule, and when it did occur, it was weakly expressed.

The overall depth distribution for each of 22 different species was plotted to examine centers of abundance (Appendix A). Note, for example, among the six species of *Pristipomoides*, there were distinctive differences in depth distribution. The shallowest species was *P. filamentosus*, which was encountered mainly at depths of <100 fathoms. *Pristipomoides flavipinnis* was characterized by an asymmetrical distribution skewed to greater depths, where the two deeper dwelling species were found (*P. sieboldii* and *P. argyrogrammicus*). The two most commonly caught species (*P. zonatus* and *P. auricilla*) had nearly identical depth distributions that were centered around 110 fathoms.

The remaining 16 species were characterized by a number of shallow forms (Lutjanus bohar, Aprion virescens, Variola louti, Carangoides orthogrammus, Gymnocranius japonicus, and Lethrinus rubrioperculatus), some mid-depth forms (Aphareus rutilans, Epinephelus morrhua, Cephalopholis igarashiensis, Saloptia powelli, and Seriola sp.), and a few distinctively deeper occurring species (Etelis carbunculus, E. coruscans, Epinephelus lanceolatus, and Pontinus macrocephala). One species (Caranx lugubris) showed an exceptionally broad distribution with depth, being commonly caught anywhere between 50 and 150 fathoms (see also Ralston et al. 1986).

Age and Growth

Otoliths from 11 of the most abundant species were examined for the presence of daily increments. These included Pristipomoides zonatus, P. auricilla, P. flavipinnis, P. filamentosus, P. sieboldii, Etelis carbunculus, E. coruscans, Aphareus rutilans, Lutjanus kasmira, Caranx lugubris, and Selar crumenophthalmus. As indicated in the methods section, L. kasmira and S. crumenophthalmus were caught in shallow water during anchored night-light fishing stations.

For all species examined, there was a definitive pattern of decreasing otolith growth rate with increasing otolith length (upper panels in Appendix B). The data for each species were summarized by 500-μm length intervals and numerically integrated (Table 2), providing estimates of age upon completion of growth through each interval of otolith length. Moreover, for each species, a regression of the logarithm of FL (in millimeters) on the logarithm of otolith length (in micrometers) provided a statistical basis for estimating the concomitant length of the fish (middle panels in Appendix B; Table 3). Next, the integrated data were transformed with the regression equation to produce ordered pairs of age at estimated FL, and each value weighted appropriately for sample size and variance (Table 4). Finally, the data were fitted to the von Bertalanffy growth equation (lower panels in Appendix B), and the three parameters of the model (K, L_∞, and t_0) estimated for each species (Table 5). Note that, because of inadequate degrees of freedom, no reasonable determination of error could be derived for the fit to the data from S. crumenophthalmus.

Length-Frequency Analysis

Of the 40 species sampled, 7 were caught in sufficient numbers to permit application of the Wetherall et al. (1987) regression method: P. zonatus, P. auricilla, P. flavipinnis, P. filamentosus, Etelis carbunculus, E. coruscans, and Caranx lugubris (Table 6; upper panels in Appendix C). For each of these species the results of the Wetherall et al. (1987) regression (lower panels in Appendix C; Table 7) provide the basis for estimating the ratio of total instantaneous mortality rate (Z) to the von Bertalanffy growth coefficient (K) and the von Bertalanffy asymptotic size (L_∞) (see Table 8).

Table 2.--Summary of otolith growth rates and numerical integration of daily increment width data for 11 species from the Mariana Archipelago.

Otolith length (µm)	N	Otolith growth rate: Mean (µm/d)	Otolith growth rate: SD	Interval duration (d)	Age (yr)
		Pristipomoides zonatus			
500	3	28.03	6.26	18	0.0
1,000	30	27.89	9.50	18	0.1
1,500	55	21.53	6.54	23	0.2
2,000	60	18.43	6.46	27	0.2
2,500	83	10.94	5.71	46	0.4
3,000	71	5.97	3.57	84	0.6
3,500	54	5.52	2.10	91	0.8
4,000	49	3.99	1.27	125	1.2
4,500	110	3.98	1.48	126	1.5
5,000	99	3.36	1.31	149	1.9
5,500	95	3.01	1.24	166	2.4
6,000	78	2.87	1.01	174	2.9
6,500	39	2.29	0.86	218	3.5
7,000	18	2.03	0.67	247	4.1
7,500	7	1.51	0.40	331	5.0
		Pristipomoides auricilla			
500	3	29.04	6.29	17	0.0
1,000	14	20.05	8.35	25	0.1
1,500	11	18.88	8.05	26	0.2
2,000	22	7.99	3.81	63	0.4
2,500	25	5.55	2.64	90	0.6
3,000	34	4.92	1.77	102	0.9
3,500	17	3.92	1.31	127	1.2
4,000	35	3.41	0.96	147	1.6
4,500	38	2.28	0.74	219	2.2
5,000	14	1.78	0.58	282	3.0
5,500	6	1.64	0.39	304	3.8
6,000	1	1.53	--	327	4.7

Table 2.--Continued.

Otolith length (µm)	N	Otolith growth rate: Mean (µm/d)	SD	Interval duration (d)	Age (yr)
		Pristipomoides flavipinnis			
500	5	21.35	4.04	23	0.1
1,000	21	19.36	6.94	26	0.1
1,500	16	12.08	8.07	41	0.2
2,000	14	5.21	1.99	96	0.5
2,500	19	5.74	6.36	87	0.7
3,000	16	5.31	2.44	94	1.0
3,500	14	3.38	1.36	148	1.4
4,000	19	3.82	1.53	131	1.8
4,500	26	3.39	1.50	148	2.2
5,000	34	2.55	0.81	196	2.7
5,500	20	2.46	0.80	204	3.3
6,000	14	1.66	0.52	301	4.1
6,500	4	1.50	0.21	333	5.0
7,000	1	1.11	--	449	6.2
7,500	1	2.67	--	187	6.7
		Pristipomoides filamentosus			
500	16	22.92	3.48	22	0.1
1,000	22	17.54	5.47	29	0.1
1,500	24	11.05	6.99	45	0.3
2,000	13	5.57	1.72	90	0.5
2,500	22	4.88	1.65	102	0.8
3,000	26	4.18	1.22	120	1.1
3,500	22	4.47	1.25	112	1.4
4,000	26	4.57	1.40	109	1.7
4,500	23	3.94	1.52	127	2.1
5,000	35	2.98	0.88	168	2.5
5,500	30	2.56	0.70	195	3.1
6,000	25	2.32	0.61	215	3.7
6,500	15	1.89	0.42	265	4.4
7,000	6	1.59	0.65	314	5.2
7,500	2	1.78	0.31	281	6.0

Table 2.--Continued.

Otolith length (μm)	N	Otolith growth rate Mean (μm/d)	SD	Interval duration (d)	Age (yr)
		Pristipomoides sieboldii			
500	11	18.76	5.17	27	0.1
1,000	9	21.82	6.04	23	0.1
1,500	15	10.76	7.03	46	0.3
2,000	17	4.34	1.83	115	0.6
2,500	22	4.56	1.83	110	0.9
3,000	21	4.50	1.43	111	1.2
3,500	18	3.74	1.15	134	1.5
4,000	25	3.49	1.05	143	1.9
4,500	24	2.91	0.86	172	2.4
5,000	9	2.40	0.88	208	3.0
5,500	4	2.17	0.11	230	3.6
6,000	1	1.78	--	281	4.4
		Etelis carbunculus			
500	5	19.90	7.93	25	0.1
1,000	15	18.90	5.21	26	0.1
1,500	29	10.48	3.01	48	0.3
2,000	26	6.85	2.31	73	0.5
2,500	40	5.03	1.84	99	0.7
3,000	48	3.42	1.44	146	1.1
3,500	47	2.45	1.04	204	1.7
4,000	33	2.05	0.86	244	2.4
4,500	9	1.30	0.23	383	3.4
		Etelis coruscans			
500	13	12.71	2.80	39	0.1
1,000	19	13.12	8.07	38	0.2
1,500	25	8.99	6.99	56	0.4
2,000	21	4.48	1.62	112	0.7
2,500	38	3.58	1.14	140	1.1
3,000	31	3.08	1.08	162	1.5
3,500	33	2.66	0.91	188	2.0
4,000	28	2.49	1.17	200	2.6
4,500	27	1.81	0.30	276	3.3
5,000	16	1.89	0.37	264	4.0
5,500	13	1.66	0.30	301	4.9
6,000	10	1.56	0.21	321	5.7
6,500	13	1.39	0.23	360	6.7
7,000	3	1.41	0.26	354	7.7
7,500	3	1.34	0.22	374	8.7

Table 2.--Continued.

Otolith length (µm)	N	Otolith growth rate: Mean (µm/d)	SD	Interval duration (d)	Age (yr)
		Aphareus rutilans			
500	15	22.47	3.70	22	0.1
1,000	18	20.77	3.44	24	0.1
1,500	16	12.53	5.27	40	0.2
2,000	13	5.76	3.54	87	0.5
2,500	11	4.56	1.21	110	0.8
3,000	20	4.95	2.29	101	1.1
3,500	14	5.80	2.26	86	1.3
4,000	14	4.44	1.43	113	1.6
4,500	12	4.42	1.84	113	1.9
5,000	20	3.63	1.06	138	2.3
5,500	28	3.58	1.13	140	2.7
6,000	25	2.92	0.91	171	3.1
6,500	18	2.56	0.63	195	3.7
7,000	19	2.52	0.58	198	4.2
7,500	8	2.06	0.53	243	4.9
8,000	7	1.94	0.31	258	5.6
8,500	5	2.27	1.01	220	6.2
9,000	4	1.61	0.22	310	7.0
		Lutjanus kasmira			
500	16	24.38	4.55	21	0.1
1,000	18	18.29	6.00	27	0.1
1,500	8	12.99	5.95	39	0.2
2,000	8	7.40	8.87	68	0.4
2,500	22	3.37	1.84	148	0.8
3,000	38	3.10	1.44	161	1.3
3,500	38	3.19	1.72	157	1.7
4,000	49	2.50	0.79	200	2.2
4,500	36	2.30	0.79	217	2.8
5,000	21	1.81	0.52	276	3.6
5,500	5	1.93	0.55	259	4.3

Table 2.--Continued.

Otolith length (µm)	$\underline{N}$	Otolith growth rate: Mean (µm/d)	Otolith growth rate: SD	Interval duration (d)	Age (yr)
		Caranx lugubris			
500	12	16.45	3.39	30	0.1
1,000	21	12.75	4.37	39	0.2
1,500	20	6.96	3.92	72	0.4
2,000	20	4.52	2.62	111	0.7
2,500	31	3.37	1.23	148	1.1
3,000	31	2.46	0.65	203	1.7
3,500	23	1.80	0.54	278	2.4
4,000	11	1.76	0.55	284	3.2
4,500	2	1.22	0.16	408	4.3
5,000	2	1.45	0.16	345	5.3
		Selar crumenophthalmus			
500	10	33.55	8.30	15	0.0
1,000	43	26.93	11.79	19	0.1
1,500	28	16.34	13.13	31	0.2
2,000	47	5.42	5.61	92	0.4
2,500	120	3.01	1.37	166	0.9
3,000	97	2.26	0.80	222	1.5
3,500	16	1.56	0.44	320	2.4

Table 3.--Summary of regressions of the natural logarithm of fork length (mm) on the natural logarithm of otolith length (µm).

Species	$\underline{N}$	Slope	SE	Intercept	SE	$\underline{r}^2$
Pristipomoides zonatus	94	1.0737	(0.0634)	-3.7831	(0.5665)	0.757
Pristipomoides auricilla	51	0.9225	(0.1248)	-2.2134	(1.0807)	0.527
Pristipomoides flavipinnis	57	0.8351	(0.0872)	-1.3802	(0.7674)	0.625
Pristipomoides filamentosus	42	0.9166	(0.1310)	-1.9619	(1.1629)	0.551
Pristipomoides sieboldii	17	0.9911	(0.1662)	-2.7408	(1.4348)	0.703
Etelis carbunculus	62	0.9836	(0.1277)	-2.5157	(1.0799)	0.497
Etelis coruscans	62	1.0013	(0.1190)	-2.2803	(1.0534)	0.541
Aphareus rutilans	26	1.1397	(0.1520)	-3.6258	(1.3700)	0.701
Lutjanus kasmira	33	1.0712	(0.1183)	-3.6601	(0.9949)	0.726
Caranx lugubris	25	1.6774	(0.1694)	-7.6247	(1.4067)	0.810
Selar crumenophthalmus	71	0.7486	(0.0602)	-0.4855	(0.4812)	0.692

Table 4.--Predicted age-length relationships for 11 species of fishes from the Mariana Archipelago. See methods for explanation of statistical weights.

Age (yr)	Fork length (mm)	Statistical weight
	Pristipomoides zonatus	
0.8	145.30	0.100009
1.2	167.69	0.097973
1.5	190.30	0.096663
1.9	213.09	0.095521
2.4	236.06	0.094494
2.9	259.17	0.093435
3.5	282.43	0.092259
4.1	305.82	0.090765
5.0	329.34	0.089025
	Pristipomoides auricilla	
0.9	176.37	0.086731
1.2	203.32	0.084398
1.6	229.98	0.083056
2.2	256.37	0.082234
3.0	282.54	0.081216
3.8	308.51	0.079824
4.7	334.30	0.076831
	Pristipomoides flavipinnis	
1.0	201.51	0.110670
1.4	229.20	0.106834
1.8	256.24	0.103299
2.2	282.72	0.100811
2.7	308.72	0.099289
3.3	334.30	0.097454
4.1	359.49	0.096085
5.0	384.35	0.093884
6.2	408.88	0.090914
6.7	433.13	0.083807
	Pristipomoides filamentosus	
1.1	216.35	0.220541
1.4	249.19	0.207713
1.7	281.63	0.196936
2.1	313.74	0.188020
2.5	345.55	0.182976
3.1	377.09	0.178538
3.7	408.40	0.174345
4.4	439.49	0.170164
5.2	470.38	0.164901
6.0	501.09	0.155570

Table 4.--Continued.

Age (yr)	Fork length (mm)	Statistical weight
	Pristipomoides sieboldii	
0.9	150.50	0.143936
1.2	180.31	0.138420
1.5	210.07	0.134025
1.9	239.80	0.130789
2.4	269.49	0.128272
3.0	299.16	0.125190
3.6	328.80	0.121335
4.4	358.41	0.115776
	Etelis carbunculus	
1.1	212.65	0.156591
1.7	247.46	0.153813
2.4	282.19	0.151154
3.4	316.86	0.148087
	Etelis coruscans	
1.1	258.25	0.203440
1.5	309.97	0.197351
2.0	361.71	0.192860
2.6	413.45	0.188624
3.3	465.21	0.186041
4.0	516.97	0.182572
4.9	568.73	0.179511
5.7	620.51	0.176443
6.7	672.29	0.174247
7.7	724.07	0.169740
8.7	775.86	0.165783
	Aphareus rutilans	
1.1	244.46	0.190176
1.3	291.41	0.175265
1.6	339.31	0.165385
1.9	388.06	0.155936
2.3	437.57	0.150483
2.7	487.78	0.146223
3.1	538.63	0.142745
3.7	590.08	0.139329
4.2	642.08	0.136209
4.9	694.61	0.132486
5.6	747.62	0.128940
6.2	801.11	0.124318
7.0	855.03	0.120901
7.5	909.37	0.110717

Table 4.--Continued.

Age (yr)	Fork length (mm)	Statistical weight
	Lutjanus kasmira	
0.8	112.29	0.142073
1.3	136.51	0.138086
1.7	161.02	0.134208
2.2	185.78	0.131640
2.8	210.76	0.128979
3.6	235.94	0.126323
4.3	261.31	0.120905
	Caranx lugubris	
1.1	244.49	0.245345
1.7	331.95	0.238770
2.4	429.90	0.233877
3.2	537.83	0.227328
4.3	655.31	0.218279
5.3	781.99	0.208046
	Selar crumenophthalmus	
0.9	215.26	0.112028
1.5	246.74	0.110772
2.4	276.93	0.108717

DISCUSSION

The results presented here provide a variety of useful information for developing management programs for the bottom fish resources of the tropical Pacific Ocean. The determination of growth and mortality rates of these important commercial species is especially critical to understanding their population dynamics and to developing an appreciation of their yield potentials.

Separate and independent estimates of the von Betalanffy asymptotic size parameter (L_∞) were developed from the study of otoliths (Table 5) and from the analysis of length-frequency distributions (Table 8). In some cases, the two differed substantially, as for example with *Caranx lugubris* (Table 9). An obvious question arises as to which of the two procedures is better. In the former analysis (i.e., otoliths), the L_∞ parameter is estimated from an extrapolation of data acquired from relatively early stages of

Table 5.--Summary of nonlinear von Bertalanffy regressions of fork length (mm) on age (yr). Standard errors are in parentheses.

Species	$\underline{N}$	$\underline{K}$ (yr $^{-1}$)		L_{∞} (mm)		t_0 (yr)	
Pristipomoides zonatus	9	0.234	(0.018)	442	(14.85)	-0.89	(0.078)
Pristipomoides auricilla	7	0.357	(0.071)	383	(22.35)	-0.88	(0.249)
Pristipomoides flavipinnis	10	0.268	(0.028)	486	(15.27)	-1.01	(0.163)
Pristipomoides filamentosus	10	0.289	(0.024)	584	(16.84)	-0.54	(0.099)
Pristipomoides sieboldii	8	0.351	(0.030)	441	(14.65)	-0.30	(0.070)
Etelis carbunculus	4	0.347	(0.039)	403	(14.80)	-1.06	(0.137)
Etelis coruscans	11	0.123	(0.013)	1,091	(55.65)	-1.19	(0.138)
Aphareus rutilans	14	0.163	(0.018)	1,229	(68.57)	-0.36	(0.104)
Lutjanus kasmira	7	0.212	(0.038)	396	(36.09)	-0.75	(0.139)
Caranx lugubris	6	0.075	(0.027)	2,216	(601.9)	-0.47	(0.140)
Selar crumenophthalmus	3	0.606	--	319	--	-0.96	--

growth (lower panels in Appendix B). Hirschhorn (1974) has shown that, for the $\underline{L}_{\infty}$ parameter to be accurately determined, large, old fish must be represented in the data. Values for asymptotic size derived solely from the study of otolith microstructure are therefore suspect. Conversely, when length samples are not biased by the selective properties of the gear (footnote 3), the regression method provides a robust method of estimating this parameter (Wetherall et al. 1987). Of the two, the $\underline{L}_{\infty}$ estimate obtained from the analysis of length frequency is preferred.

The age and length data (Table 4) were then refitted to the von Bertalanffy growth equation while constraining the $\underline{L}_{\infty}$ parameter to the value determined from the analysis of length-frequency data (Table 8). The resulting estimate of $\underline{K}$ (yr $^{-1}$) is given for each of the seven species of bottom fish in Table 9. The growth coefficient was then used to separate the ratio of mortality to growth ($\underline{Z}/\underline{K}$), providing an estimate of mortality rate. Among the snappers (family Lutjanidae), there is an inverse relationship between the growth coefficient and the asymptotic size (upper panel in Appendix D). Not unexpectedly, *C. lugubris* (family Carangidae) does not fit the pattern characterizing the snappers.

Ralston (1987) showed that among the snappers and groupers a linear relationship exists between the natural mortality rate ($\underline{M}$) and the von Bertalanffy growth coefficient. Specifically, a compilation and comparison of the results of 19 studies showed that $\underline{M}$ is approximately twice $\underline{K}$. Most of the stocks reported on here represent largely virgin populations. Thus, the total mortality rates presented in Table 9 can be considered estimates of the natural mortality rate of each species. These were plotted against values of the growth coefficient (lower panel in Appendix D) to examine the

Table 6.--Length-frequency distributions of the seven most frequently caught species of bottom fish in the Mariana Archipelago (ZONA = _Pristipomoides zonatus_, AURI = _P. auricilla_, FLAV = _P. flavipinnis_, FILA = _P. filamentosus_, CARB = _Etelis carbunculus_, CORU = _E. coruscans_, LUGU = _Caranx lugubris_).

Fork length (mm)	Species frequency						
	ZONA	AURI	FLAV	FILA	CARB	CORU	LUGU
190	1	--	--	--	--	--	--
200	--	--	--	--	--	--	--
210	2	--	--	--	1	--	--
220	1	--	--	--	--	--	--
230	5	1	--	--	1	--	--
240	9	2	--	--	2	--	--
250	10	3	--	1	1	--	--
260	30	11	--	--	6	--	--
270	37	19	--	--	5	--	--
280	43	24	--	--	18	--	1
290	76	40	--	3	16	--	--
300	78	72	1	2	43	--	1
310	118	68	7	2	32	--	8
320	159	99	5	2	45	--	2
330	185	100	12	3	65	--	2
340	197	100	8	--	94	--	4
350	251	116	18	1	81	--	3
360	293	127	20	--	73	--	5
370	318	87	34	1	86	--	5
380	369	91	53	5	66	--	2
390	333	55	48	3	51	--	11
400	286	41	56	1	47	--	5
410	277	13	45	8	26	--	7
420	203	2	19	8	18	--	6
430	161	--	28	8	14	--	10
440	81	--	21	6	8	--	5
450	26	--	10	11	10	1	11
460	10	--	6	8	4	--	5
470	1	--	5	9	1	--	4
480	--	--	--	14	3	--	8
490	1	1	2	8	1	--	3
500	--	--	2	11	--	--	2
510	--	--	--	3	1	--	3
520	--	--	--	10	--	--	5
530	--	--	--	11	1	--	7
540	--	--	--	4	1	3	6
550	--	--	--	6	--	--	7
560	--	--	--	6	--	1	5
570	--	--	--	4	--	1	5
580	--	--	--	4	--	1	10

Table 6.--Continued.

Fork length (mm)	Species frequency						
	ZONA	AURI	FLAV	FILA	CARB	CORU	LUGU
590	--	--	--	4	--	4	7
600	--	--	--	--	--	2	3
610	--	--	--	2	--	1	5
620	--	--	--	1	--	3	7
630	--	--	--	1	--	2	4
640	--	--	--	2	--	5	9
650	--	--	--	--	--	2	3
660	--	--	--	--	--	8	5
670	--	--	--	--	--	8	4
680	--	--	--	--	--	6	9
690	--	--	--	--	--	5	4
700	--	--	--	--	--	8	2
710	--	--	--	--	--	10	8
720	--	--	--	--	--	3	3
730	--	--	--	--	--	14	--
740	--	--	--	--	--	5	4
750	--	--	--	--	--	12	--
760	--	--	--	--	--	10	--
770	--	--	--	--	--	6	1
780	--	--	--	--	--	8	--
790	--	--	--	--	--	6	--
800	--	--	--	--	--	8	--
810	--	--	--	--	--	4	--
820	--	--	--	--	--	4	--
830	--	--	--	--	--	2	--
840	--	--	--	--	--	8	--
850	--	--	--	--	--	9	--
860	--	--	--	--	--	2	--
870	--	--	--	--	--	2	--
880	--	--	--	--	--	1	--
890	--	--	--	--	--	2	--
900	--	--	--	--	--	3	--
910	--	--	--	--	--	2	--
920	--	--	--	--	--	3	--
930	--	--	--	--	--	--	--
940	--	--	--	--	--	1	--
950	--	--	--	--	--	--	--
960	--	--	--	--	--	1	--

Table 7.--Summary of Wetherall et al. (1987) regressions applied to bottom fishes from the Mariana Archipelago. Standard errors of the statistics are in parentheses.

Species	Number fish	Regression sample size	Slope	Intercept	r^2
Pristipomoides zonatus	1,379	9	0.6966 (0.0217)	14.0886 (0.8826)	0.993
Pristipomoides auricilla	290	6	0.7093 (0.0427)	12.4348 (1.6030)	0.986
Pristipomoides flavipinnis	138	8	0.8227 (0.0228)	9.6419 (0.9809)	0.995
Pristipomoides filamentosus	77	14	0.7174 (0.0101)	18.9293 (0.5583)	0.998
Etelis carbunculus	492	17	0.8767 (0.0191)	7.7440 (0.7207)	0.993
Etelis coruscans	99	20	0.6997 (0.0125)	29.4587 (1.0261)	0.994
Caranx lugubris	193	35	0.5383 (0.0062)	34.5961 (0.3682)	0.996

Table 8.--Regression method estimates of the mortality to growth ratio (Z/K) and asymptotic size for bottom fishes from the Mariana Archipelago. Standard errors of the statistics are in parentheses.

Species	Z/K	L_∞ (mm)
Pristipomoides zonatus	2.30 (0.235)	464 (4.25)
Pristipomoides auricilla	2.44 (0.505)	428 (7.85)
Pristipomoides flavipinnis	4.64 (0.727)	544 (15.12)
Pristipomoides filamentosus	2.54 (0.126)	670 (4.54)
Etelis carbunculus	7.11 (1.256)	628 (39.39)
Etelis coruscans	2.33 (0.139)	981 (7.11)
Caranx lugubris	1.17 (0.029)	749 (2.47)

Table 9.--Summary of growth and mortality parameter estimates from the study of otoliths and length-frequency distributions.

	Regression method		Otoliths		Constrained	
Species	Z/K	L_∞ (mm)	L_∞ (mm)	K (yr^{-1})	K (yr^{-1})	Z (yr^{-1})
Pristipomoides zonatus	2.30	464	442	0.234	0.209	0.48
Pristipomoides auricilla	2.44	428	383	0.357	0.256	0.62
Pristipomoides flavipinnis	4.64	544	486	0.268	0.192	0.89
Pristipomoides filamentosus	2.54	670	584	0.289	0.203	0.52
Etelis carbunculus	7.11	628	403	0.347	0.127	0.90
Etelis coruscans	2.33	981	1,091	0.123	0.154	0.36
Caranx lugubris	1.17	749	2,216	0.075	0.500	0.58

dependency of natural mortality rate on growth rate. Not surprisingly, *C. lugubris* did not fit the pattern evidenced by snappers. Also, the location of the point for *P. flavipinnis* (K = 0.19 yr^{-1}, Z = 0.89 yr^{-1}) deviates from the primary locus of snapper points because of significant fishing mortality. This species is found only in the southern portion of the archipelago in proximity to populated areas and is believed to be more heavily exploited than the other species (Polovina 1985).

Among the remaining snappers, *Etelis carbunculus* (K = 0.13 yr^{-1}, Z = 0.90 yr^{-1}) represents a clear outlier. Unlike the remaining four snappers, the catch size structure for this species (upper panel in Appendix C) was characterized by substantial concavity in the descending limb of the length-frequency distribution. Moreover, size data for *E. carbunculus* from many areas throughout the Pacific indicate its maximum size can vary extensively. In Vanuatu, individuals as large as 1,100 mm FL have been observed (Brouard and Grandperrin 1985), whereas in the Hawaiian Islands, this species does not exceed 650 mm FL (Everson 1984). Our data from the Marianas showed a maximum size of 540 mm FL out of 821 measured fish. With these irregularities, it is evident that the population biology of this species is poorly understood at present and requires further study.

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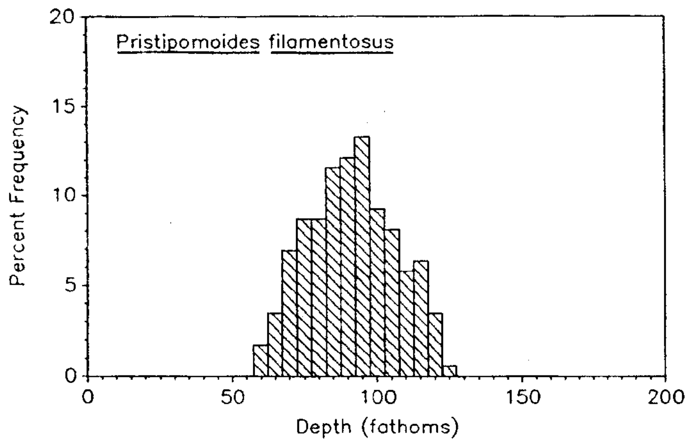
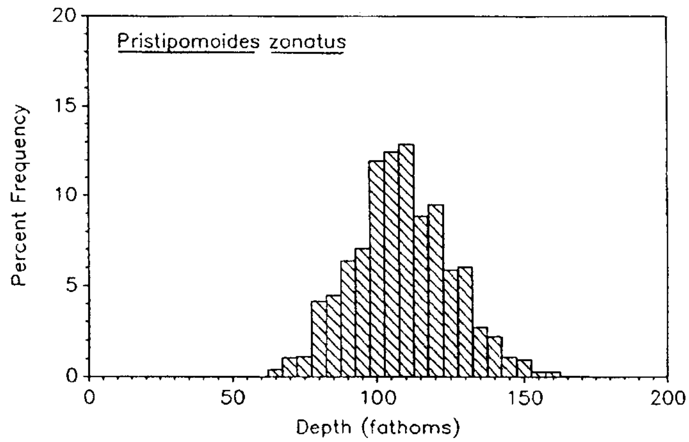
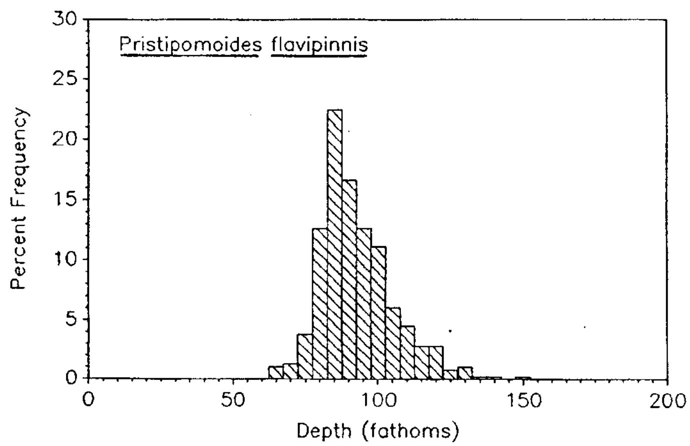
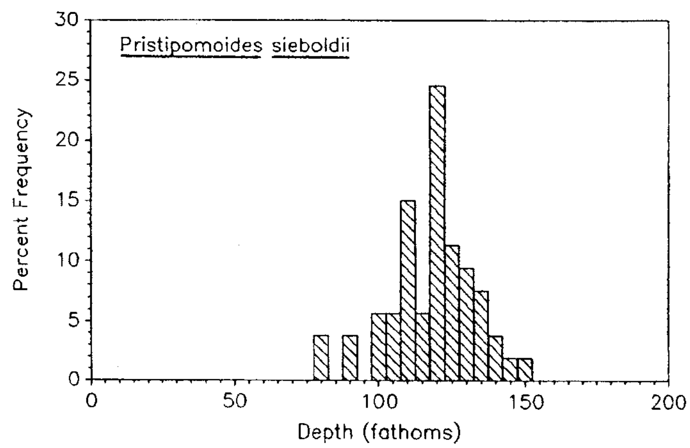
APPENDIXES

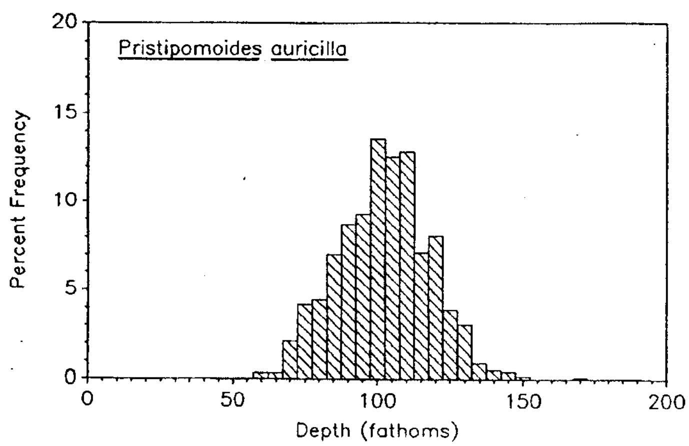
Appendix A.--Depth distributions for 22 species of Marianas bottom fishes.

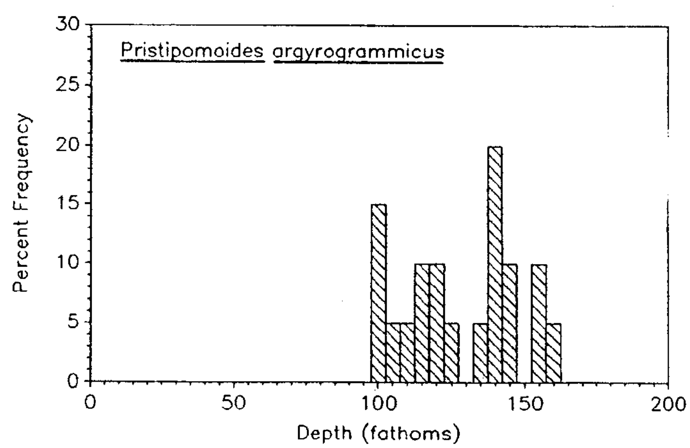




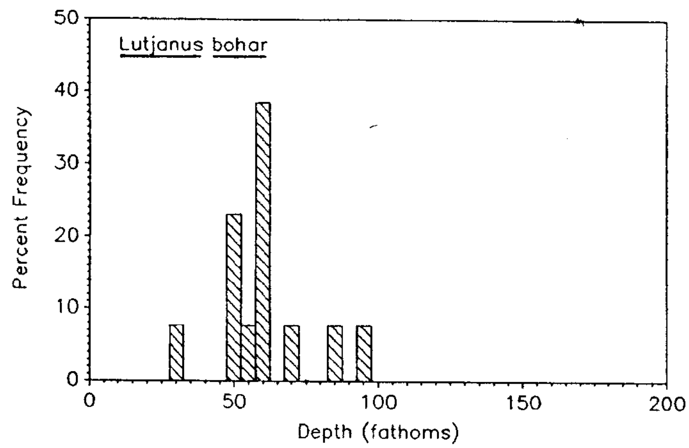


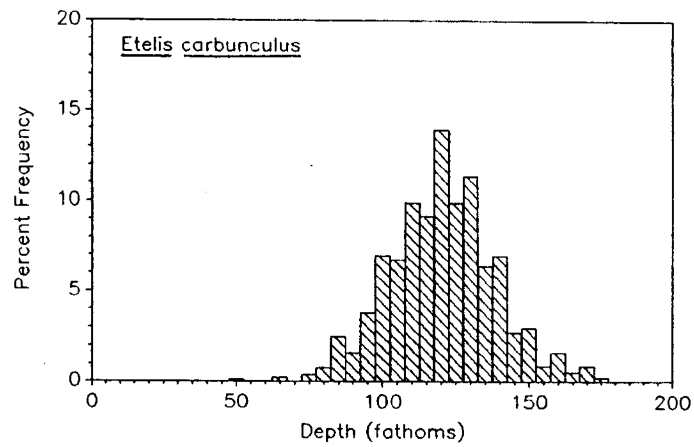


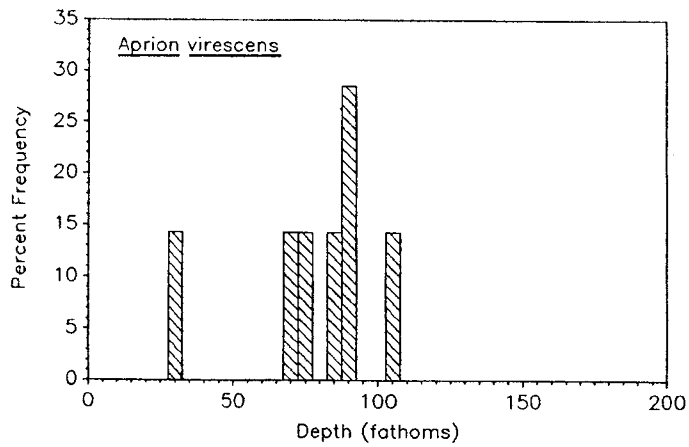


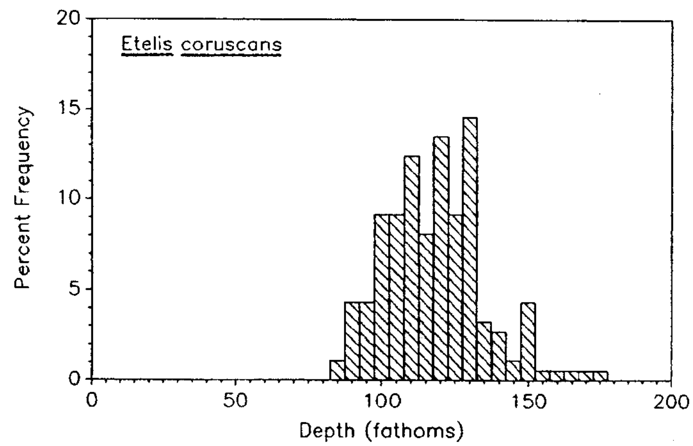


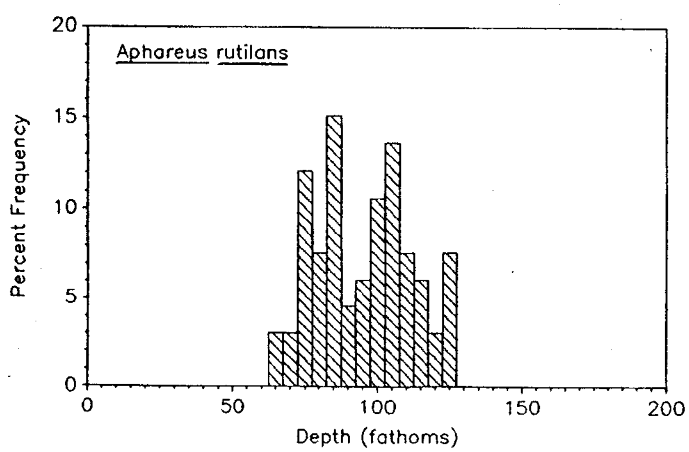
Appendix A.--Continued.











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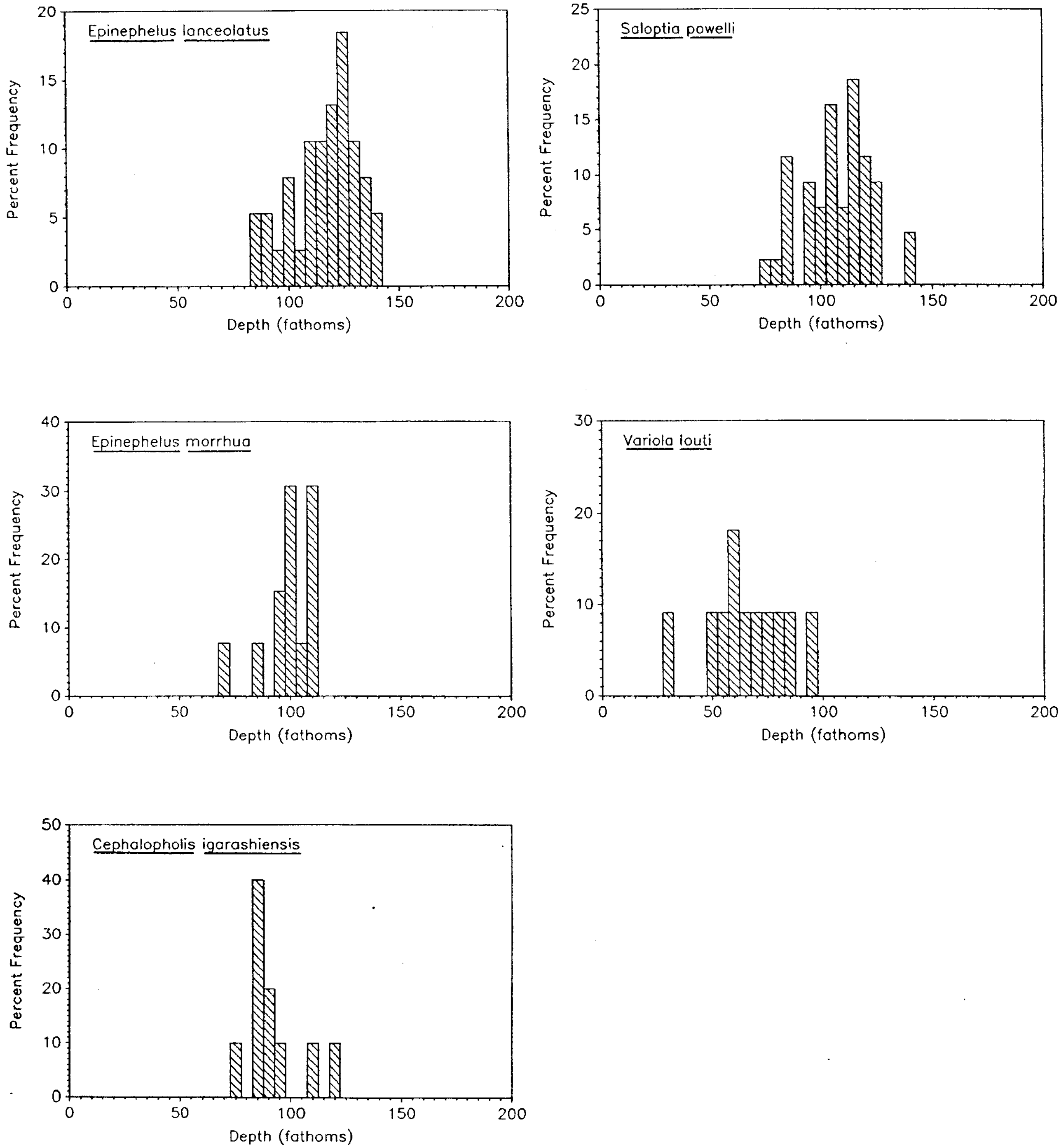

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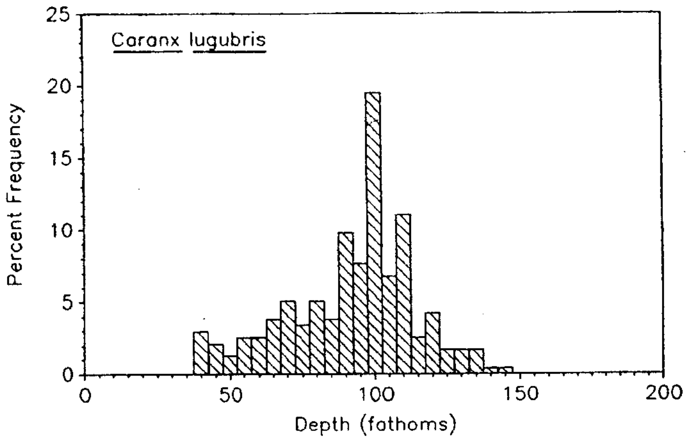
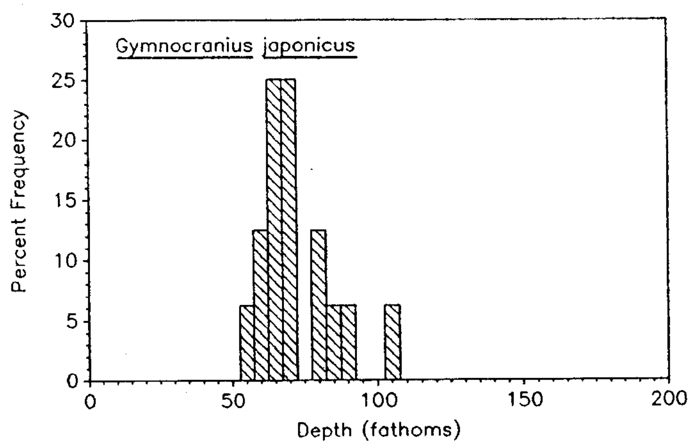
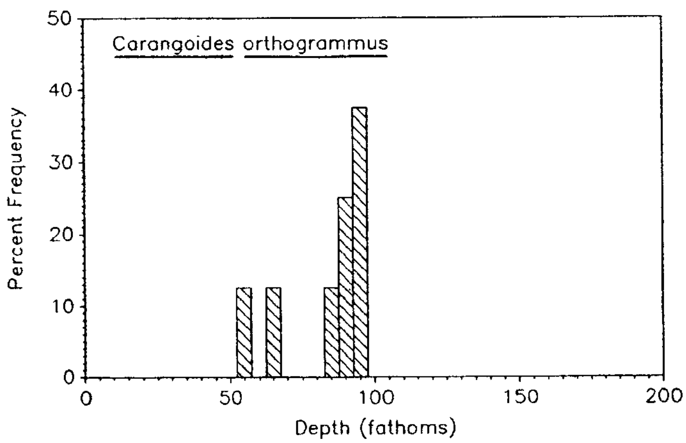
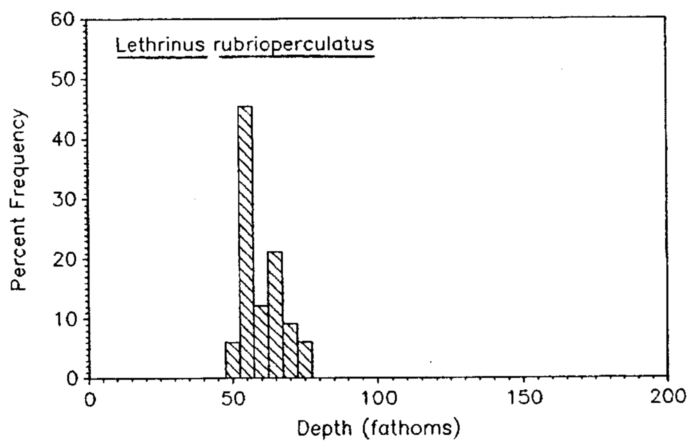
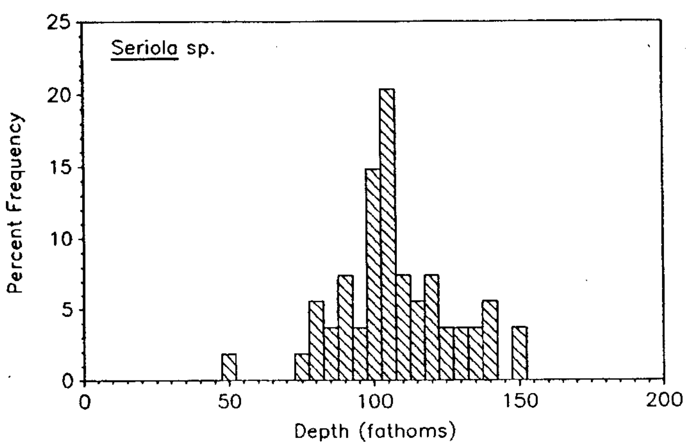
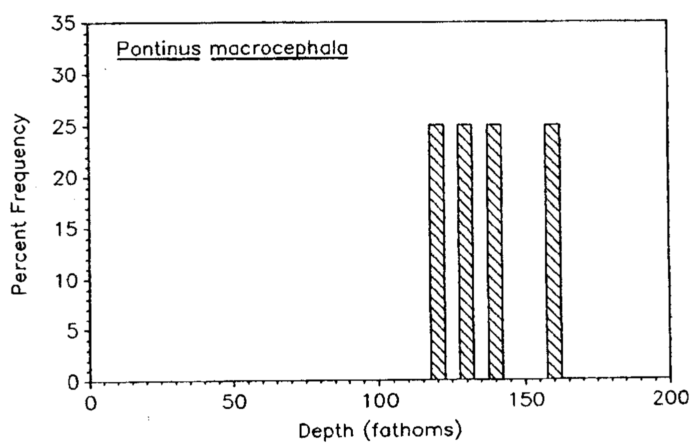




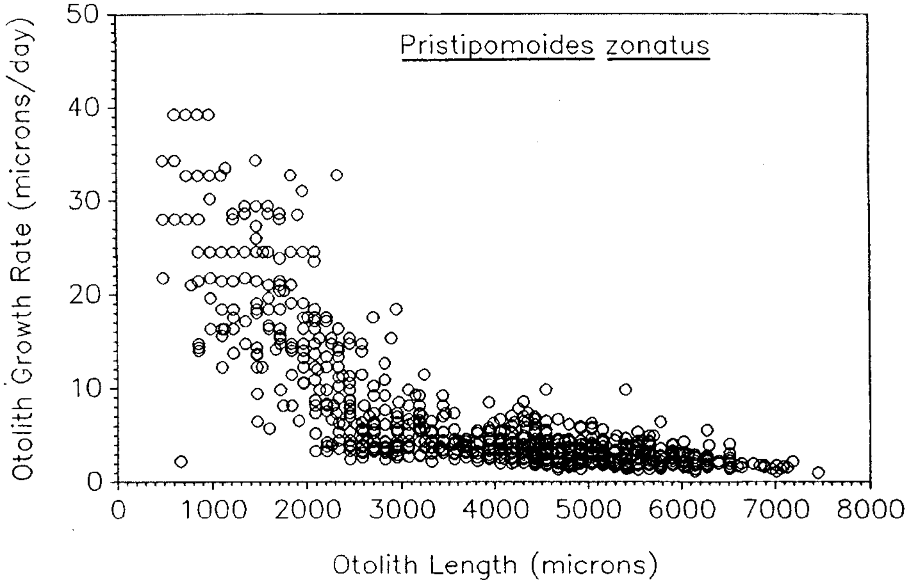


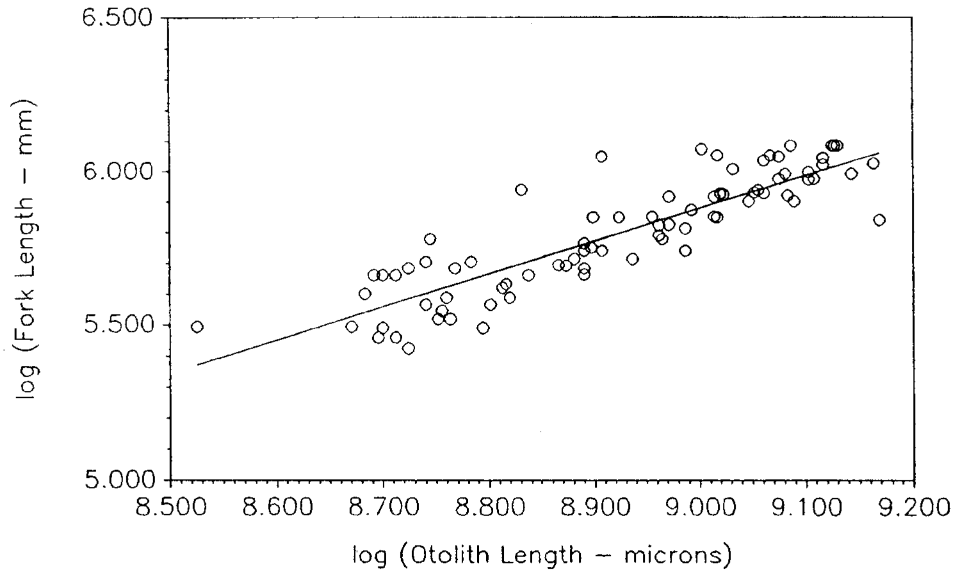


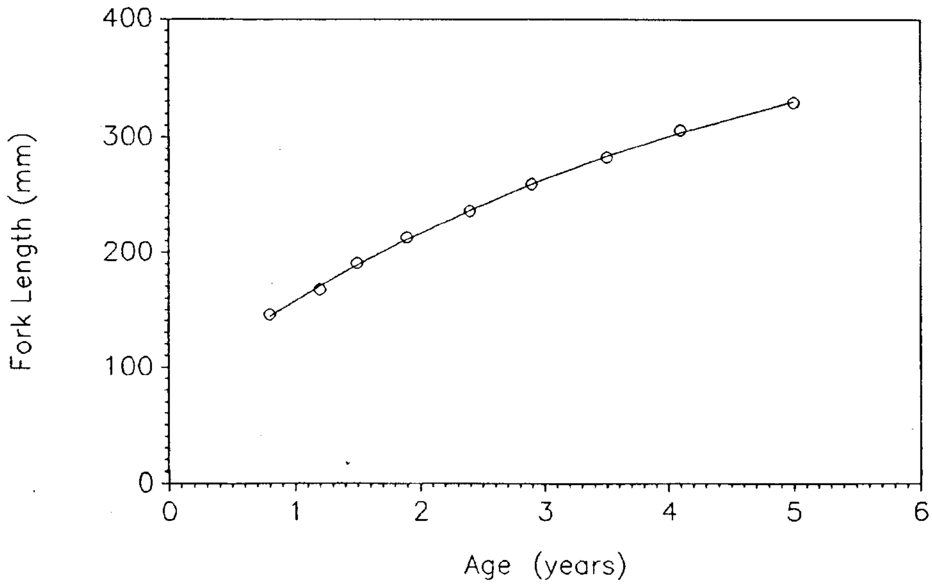




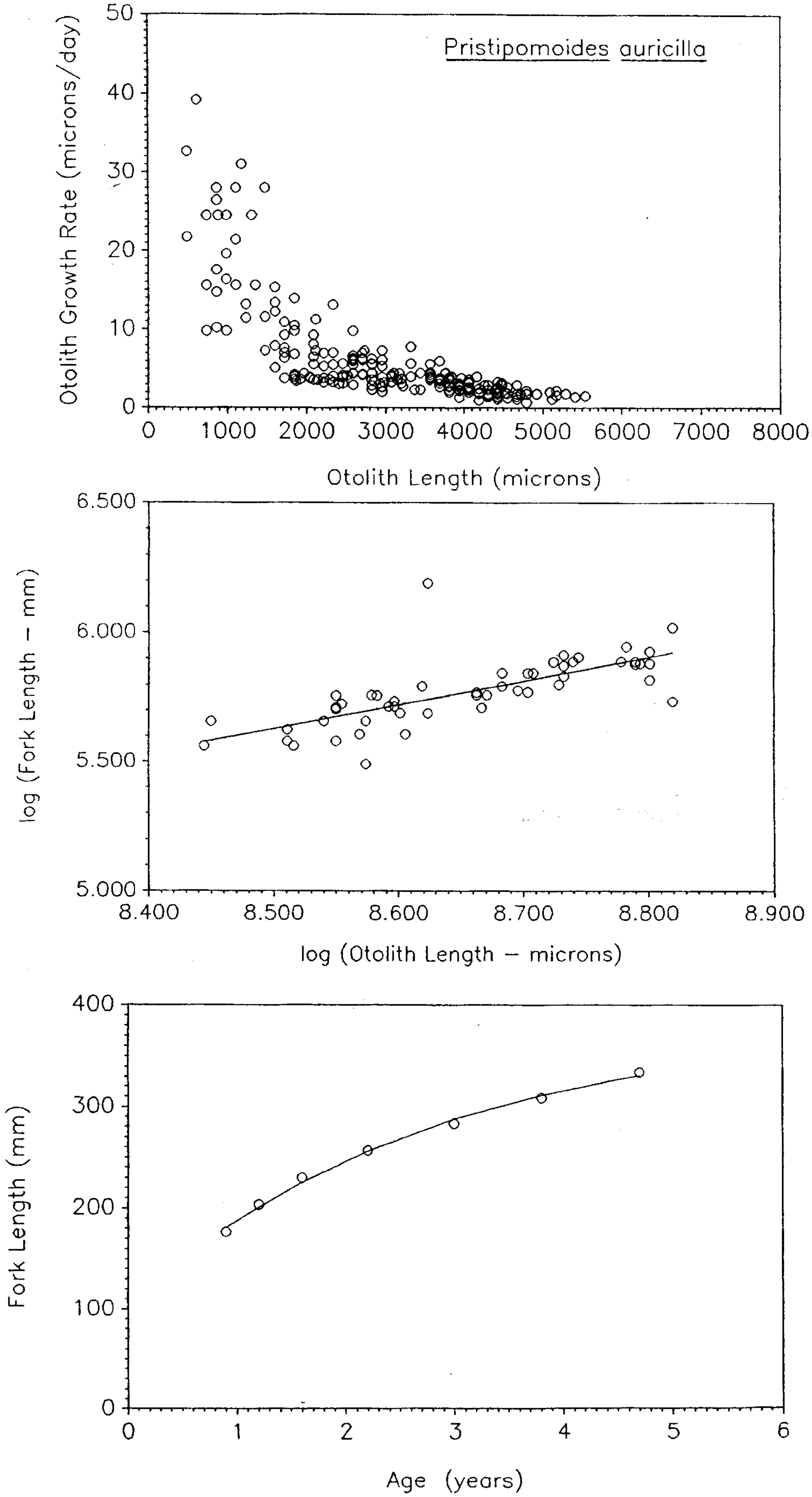
Appendix B.--Analysis of otolith microstructure (increment width) to age 11 species from the Mariana Archipelago. See text for further explanation. (A) Pristipomoides zonatus.



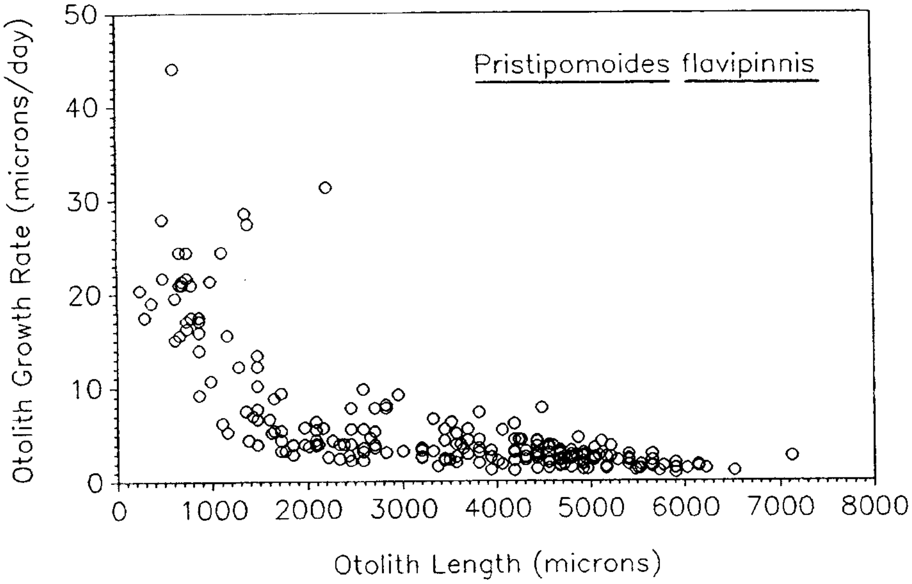


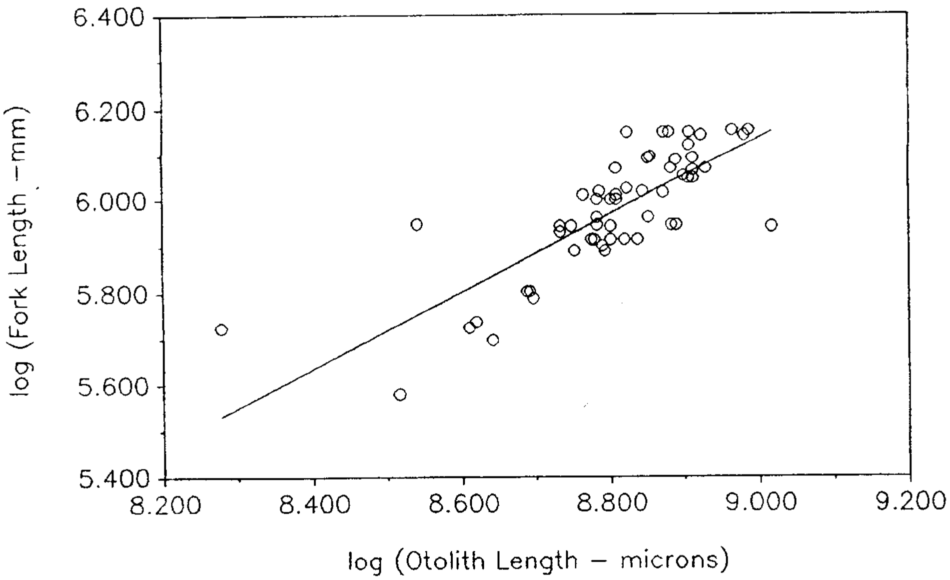


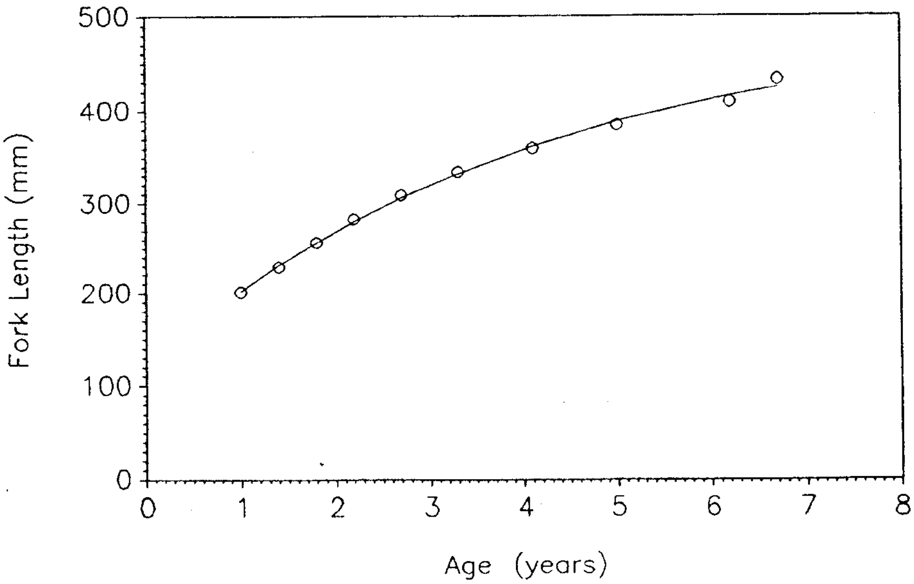
Appendix B.--Continued. (B) Pristipomoides auricilla.



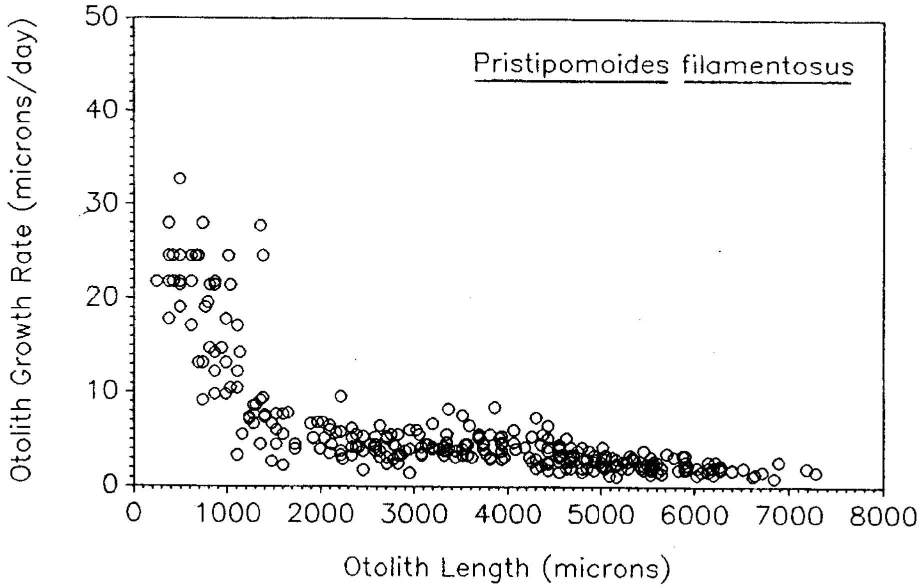
Appendix B.--Continued. (C) __Pristipomoides flavipinnis__.

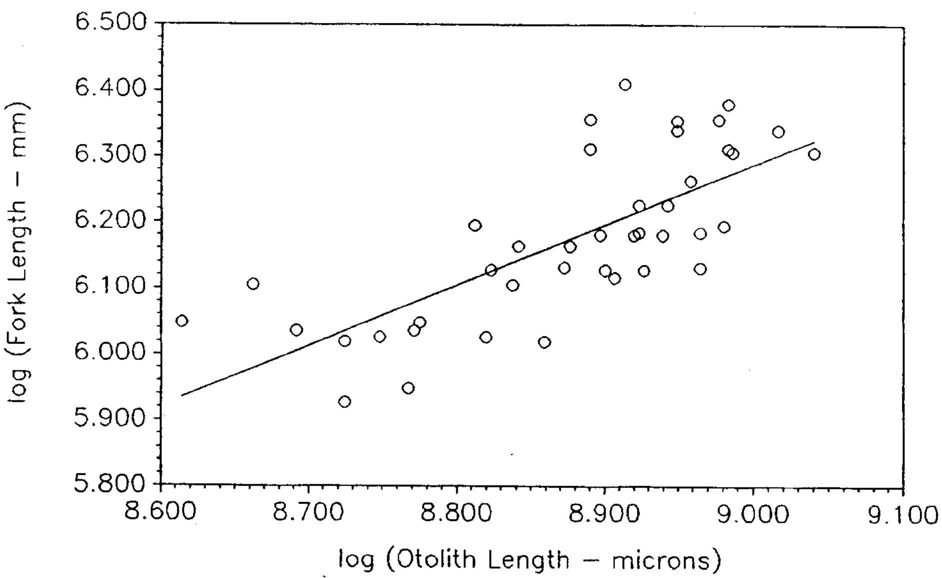


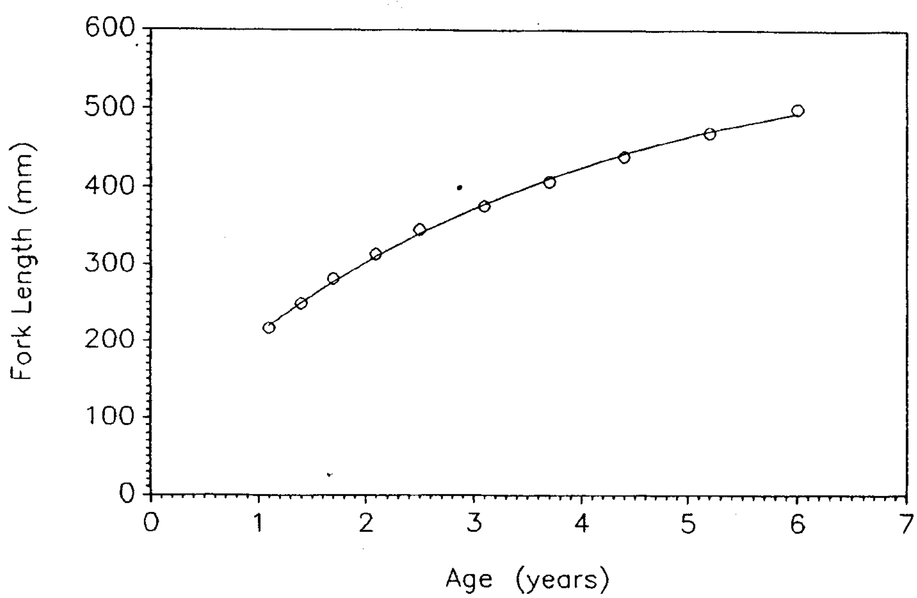




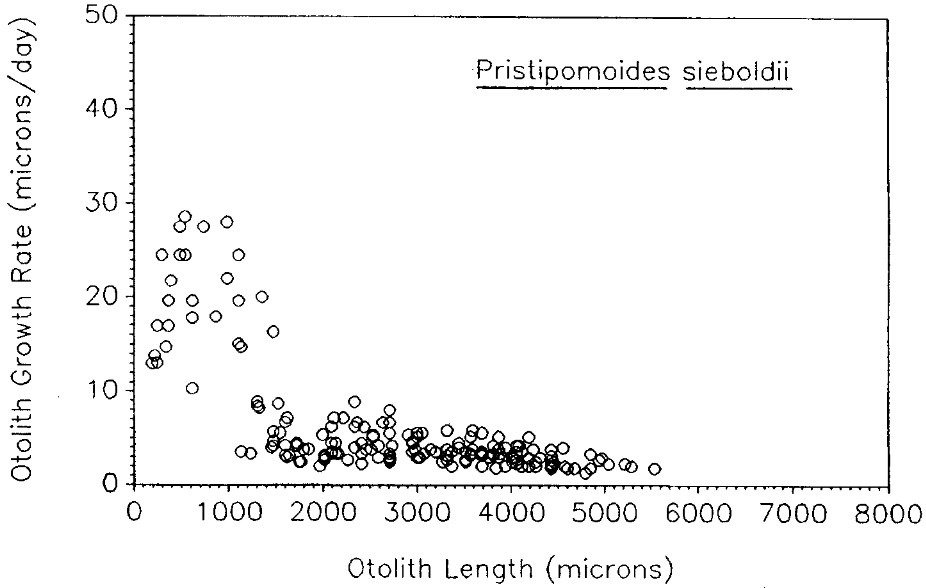
Appendix B.--Continued. (D) Pristipomoides filamentosus.

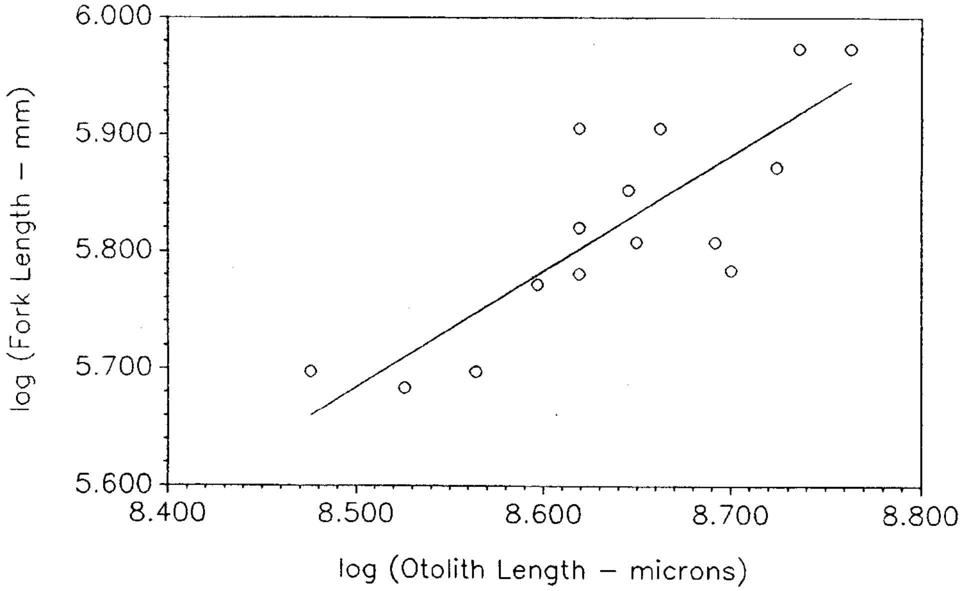


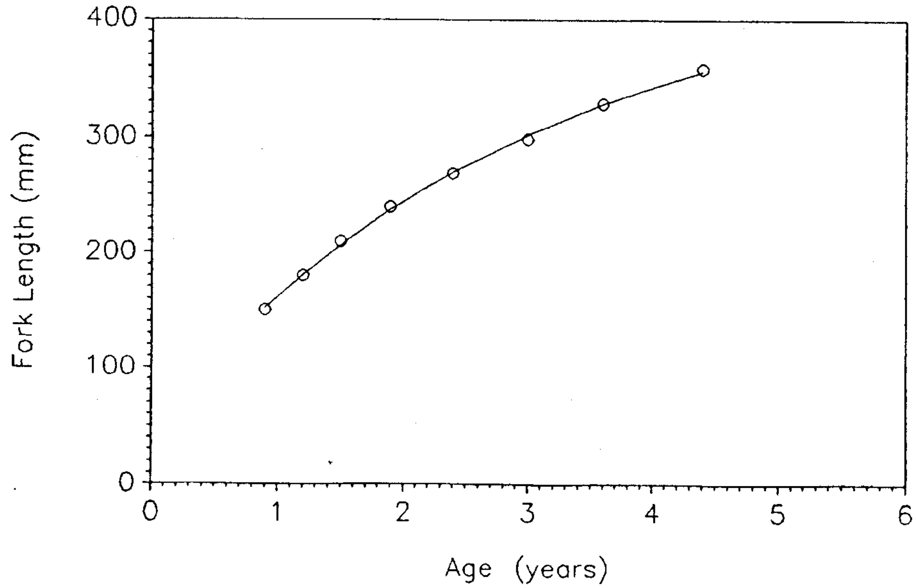




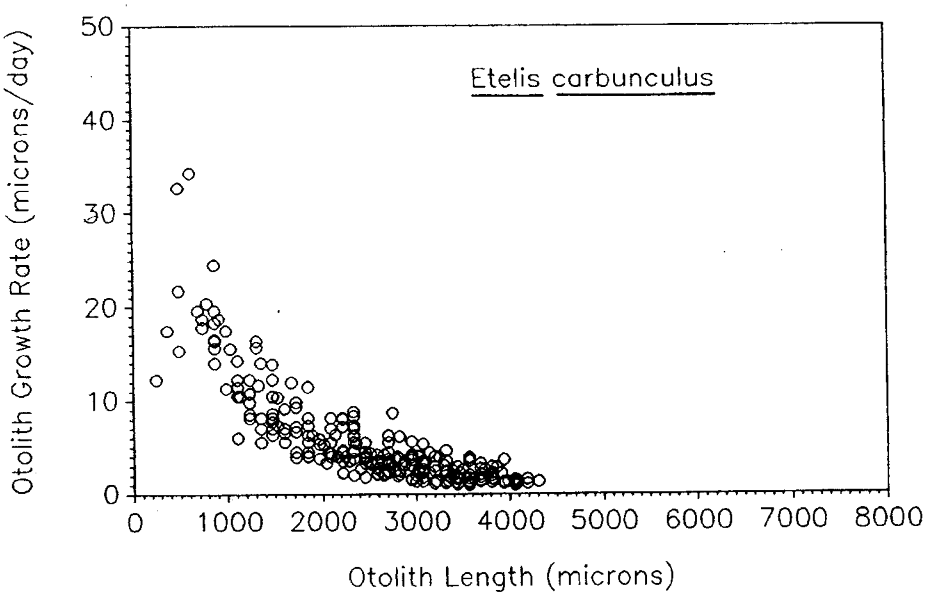
Appendix B.--Continued. (E) *Pristipomoides sieboldii*.

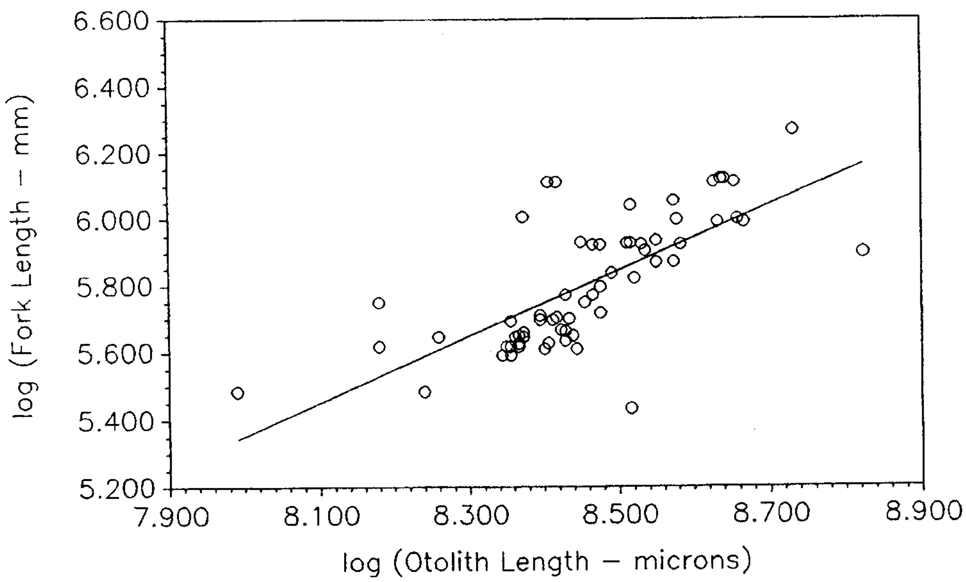


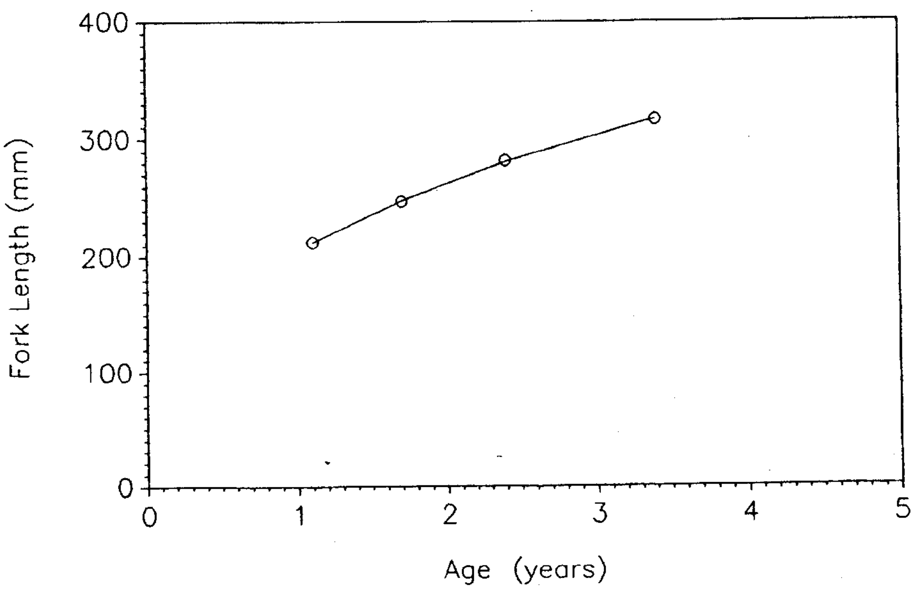




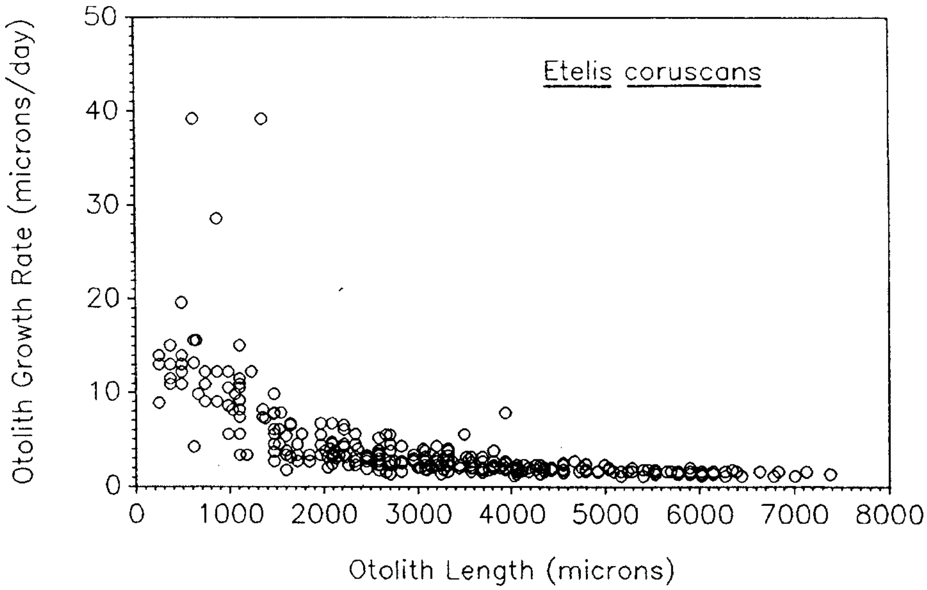
Appendix B.--Continued. (F) _Etelis carbunculus_.

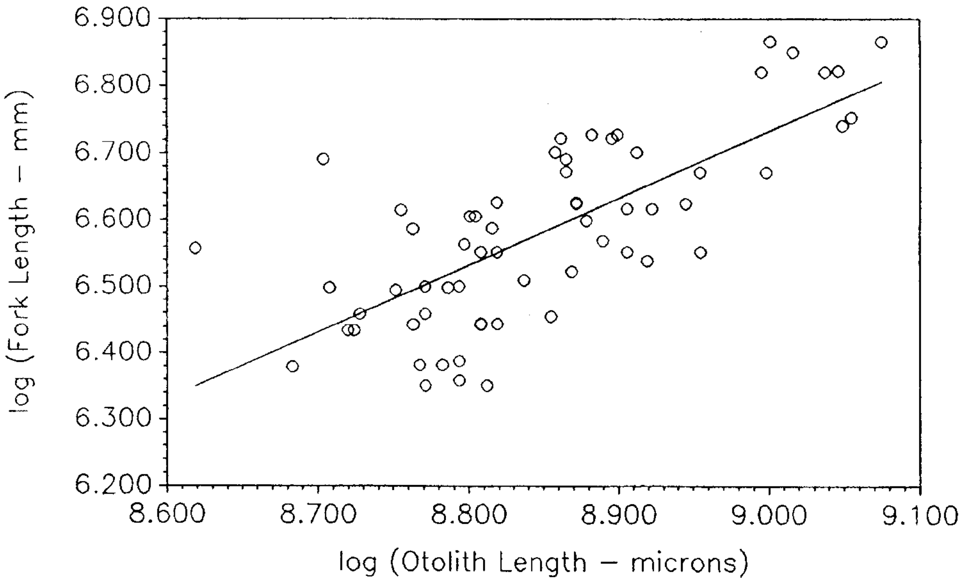


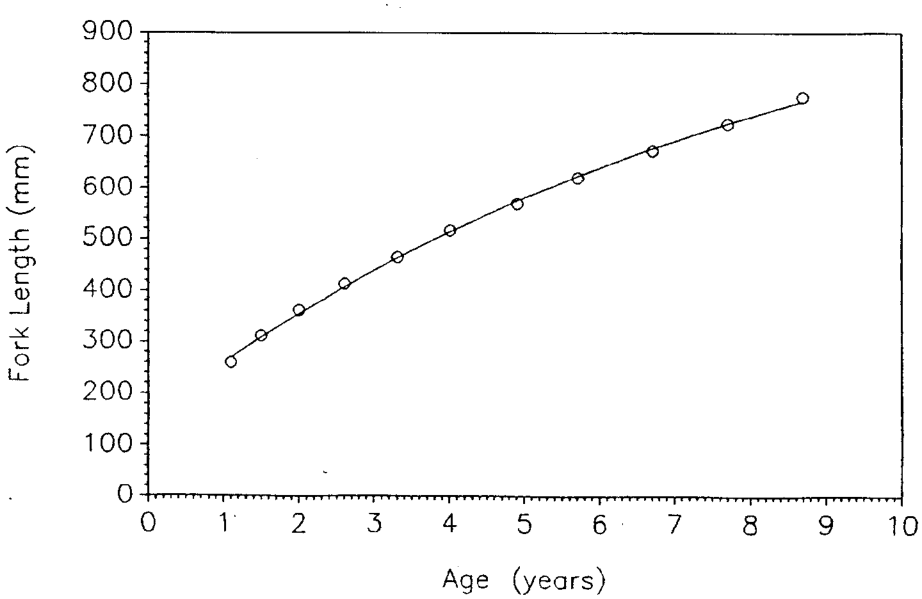




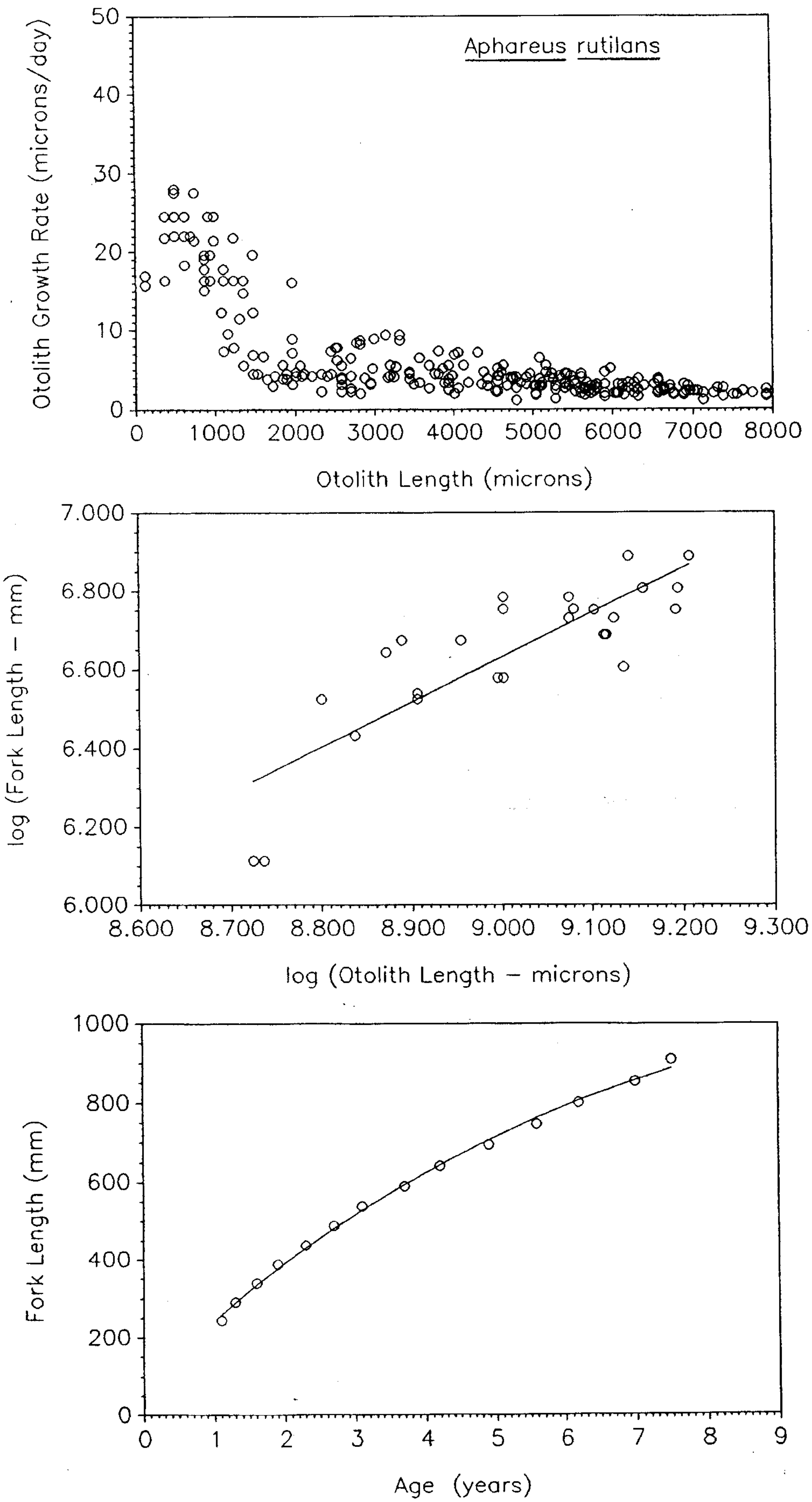
Appendix B.--Continued. **(G) *Etelis coruscans*.**



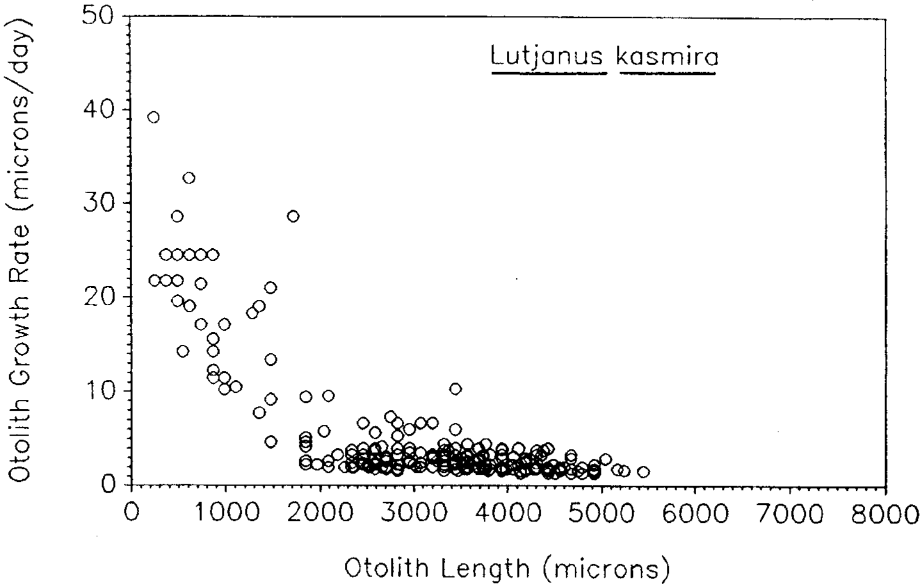


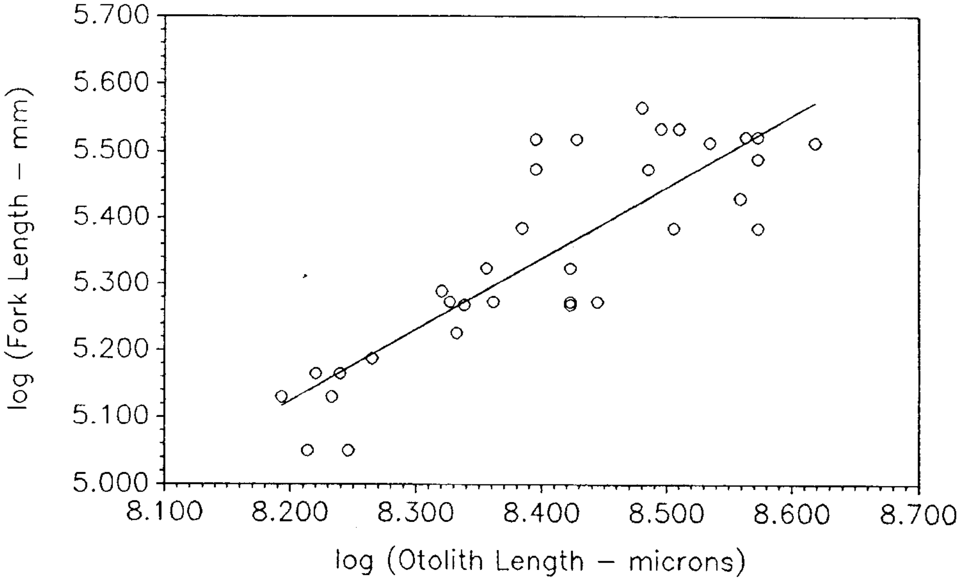


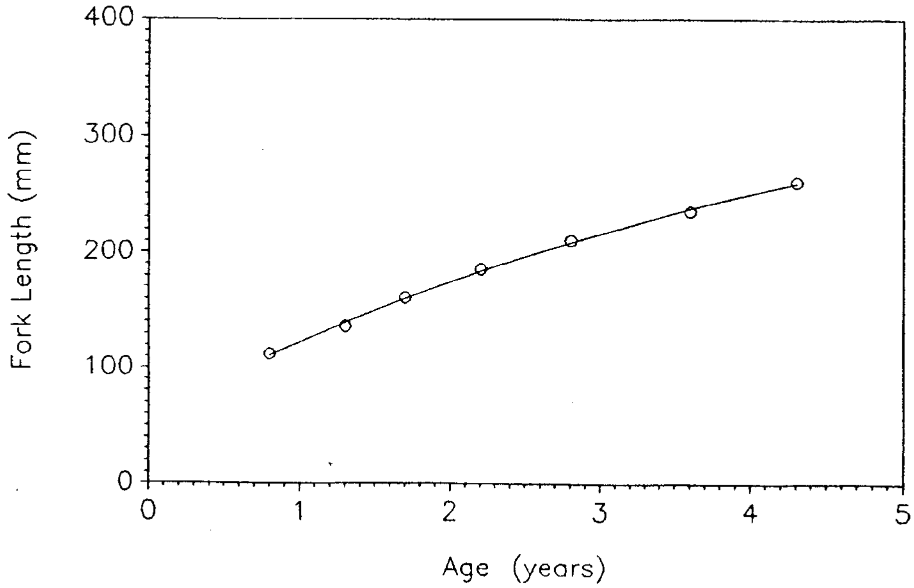
Appendix B.--Continued. **(H) *Aphareus rutilans*.**



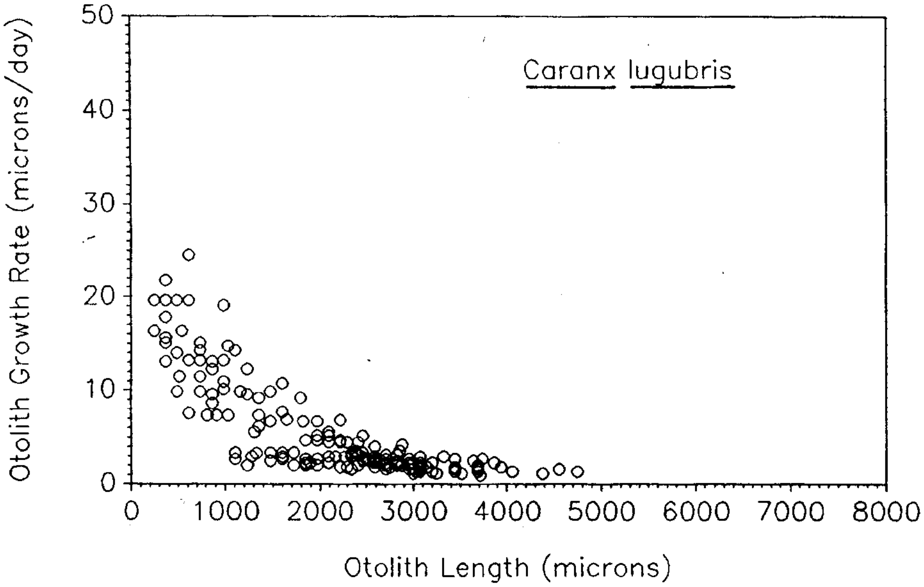
Appendix B.--Continued. (I) *Lutjanus kasmira*.

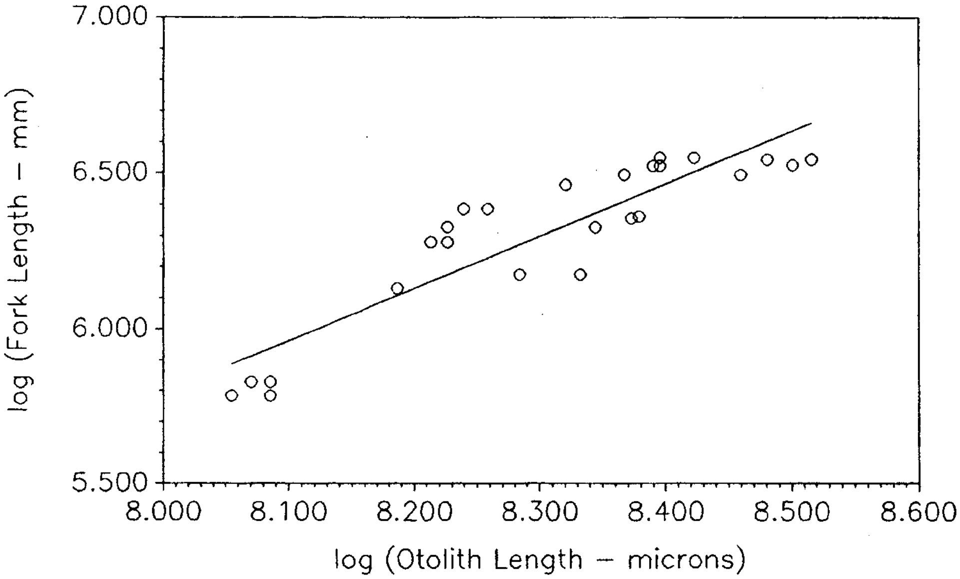


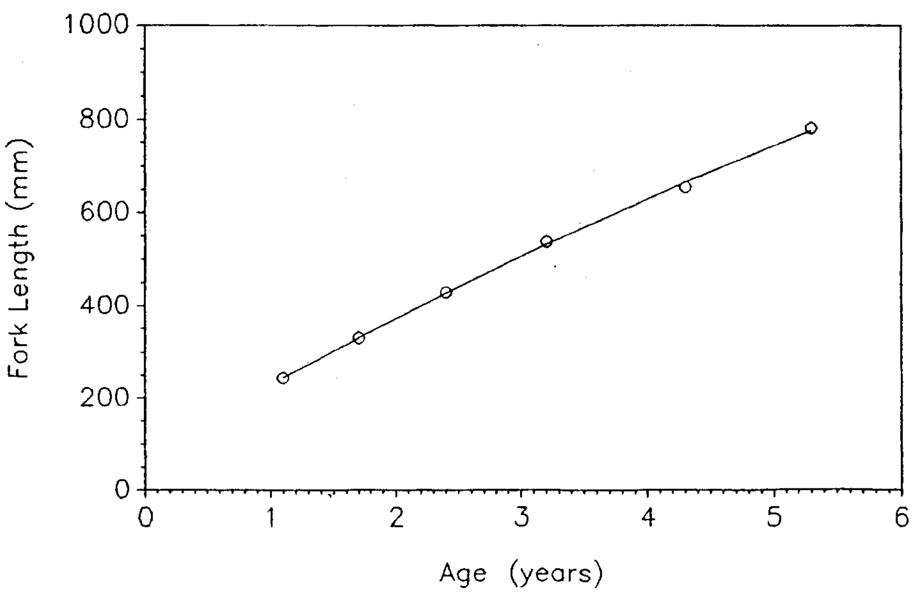




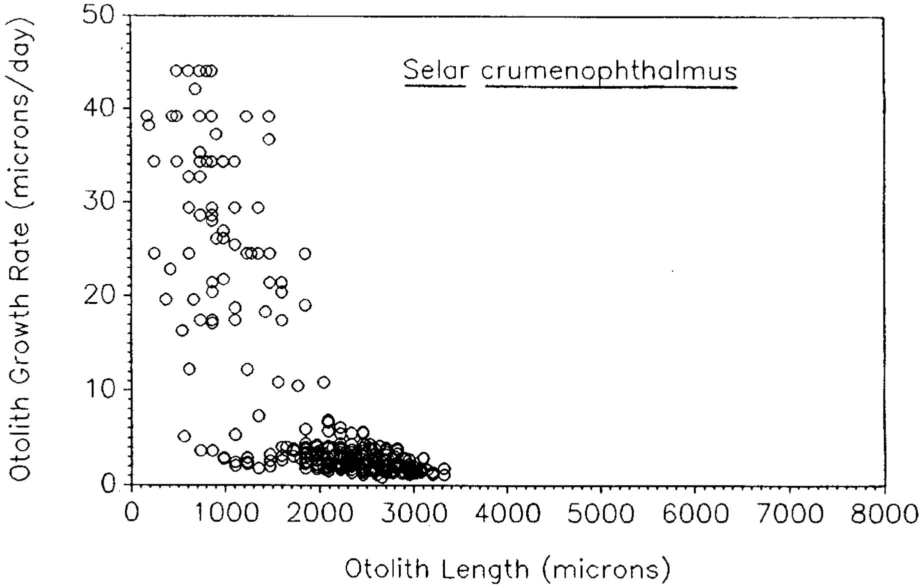
Appendix B.--Continued. (J) *Caranx lugubris*.

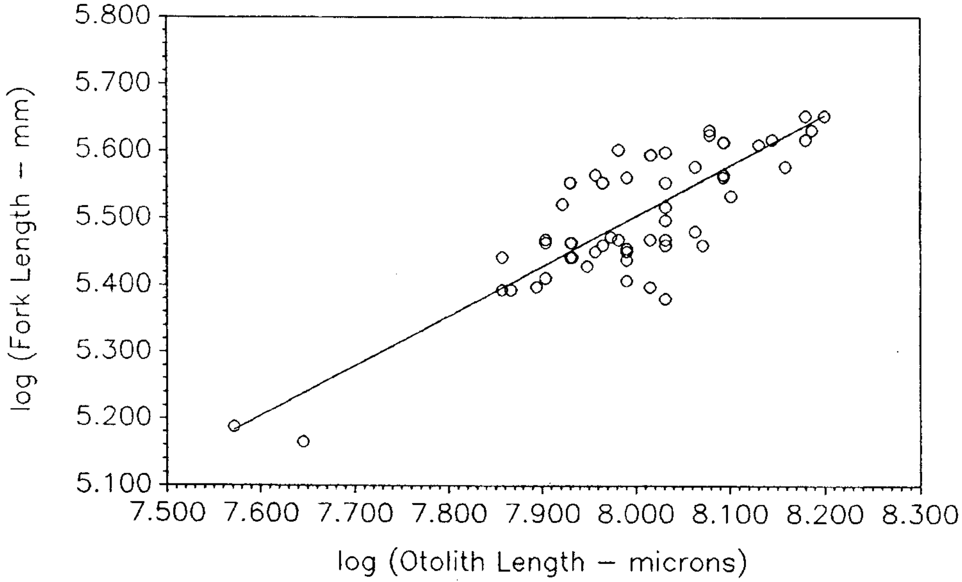


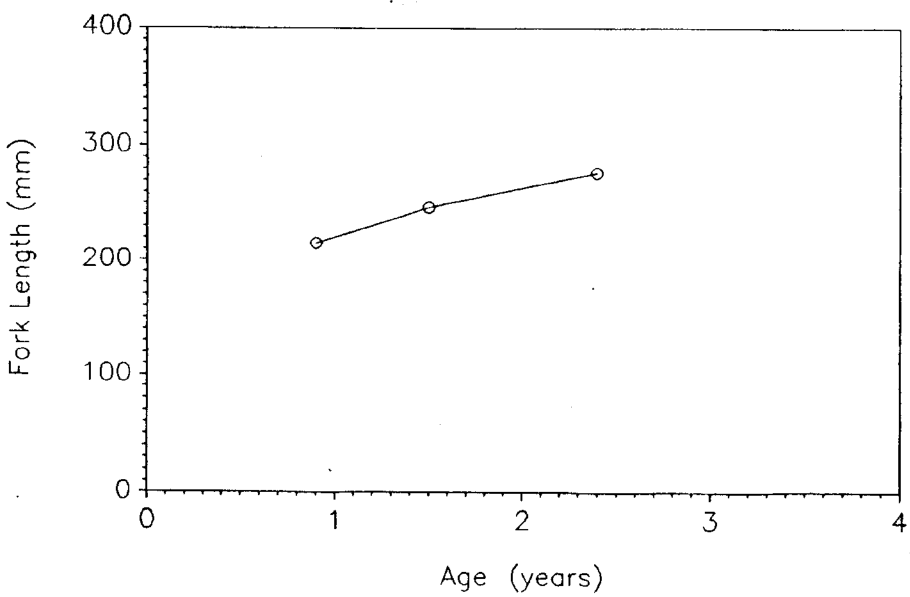




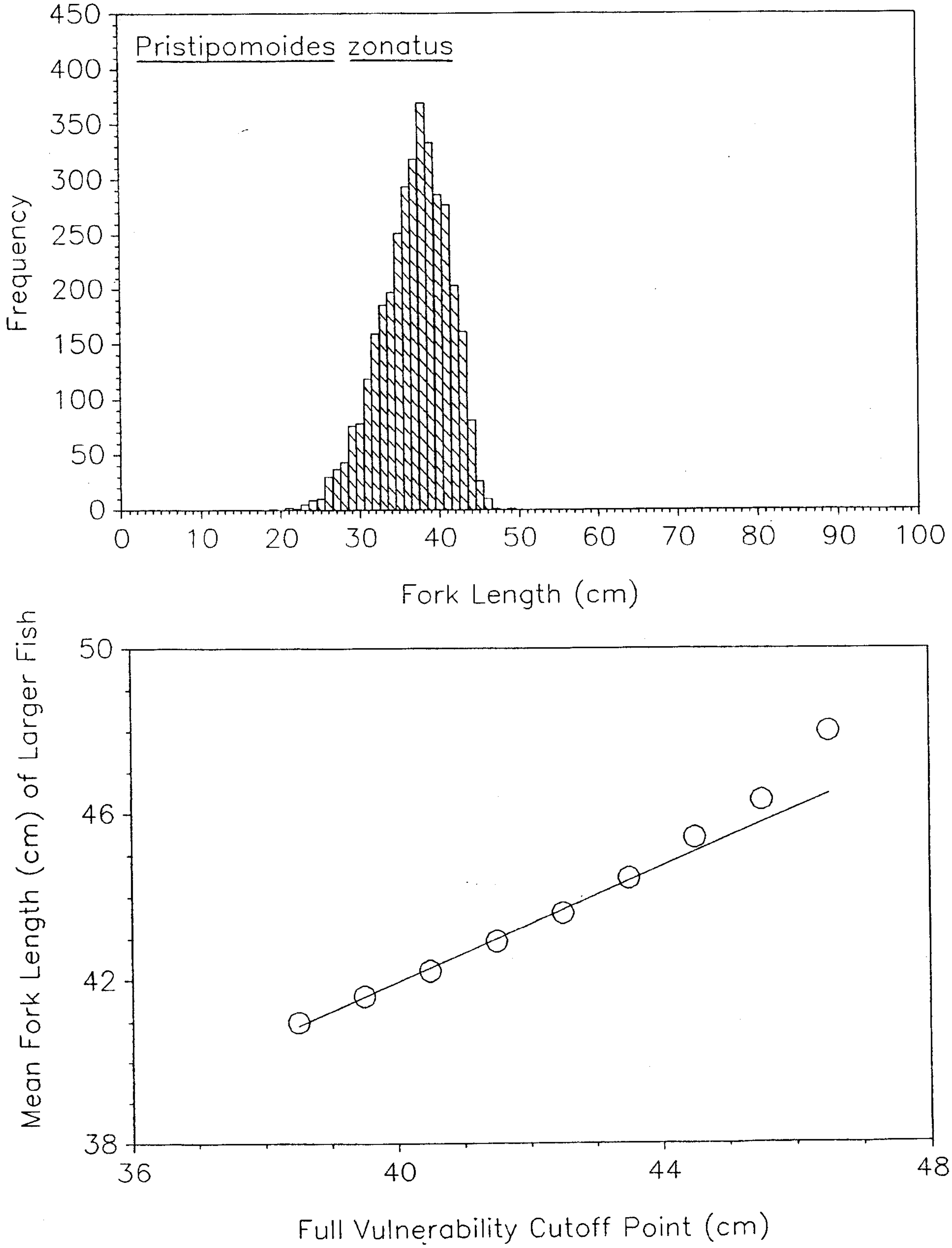
Appendix B.--Continued. (K) <u>Selar crumenophthalmus</u>.



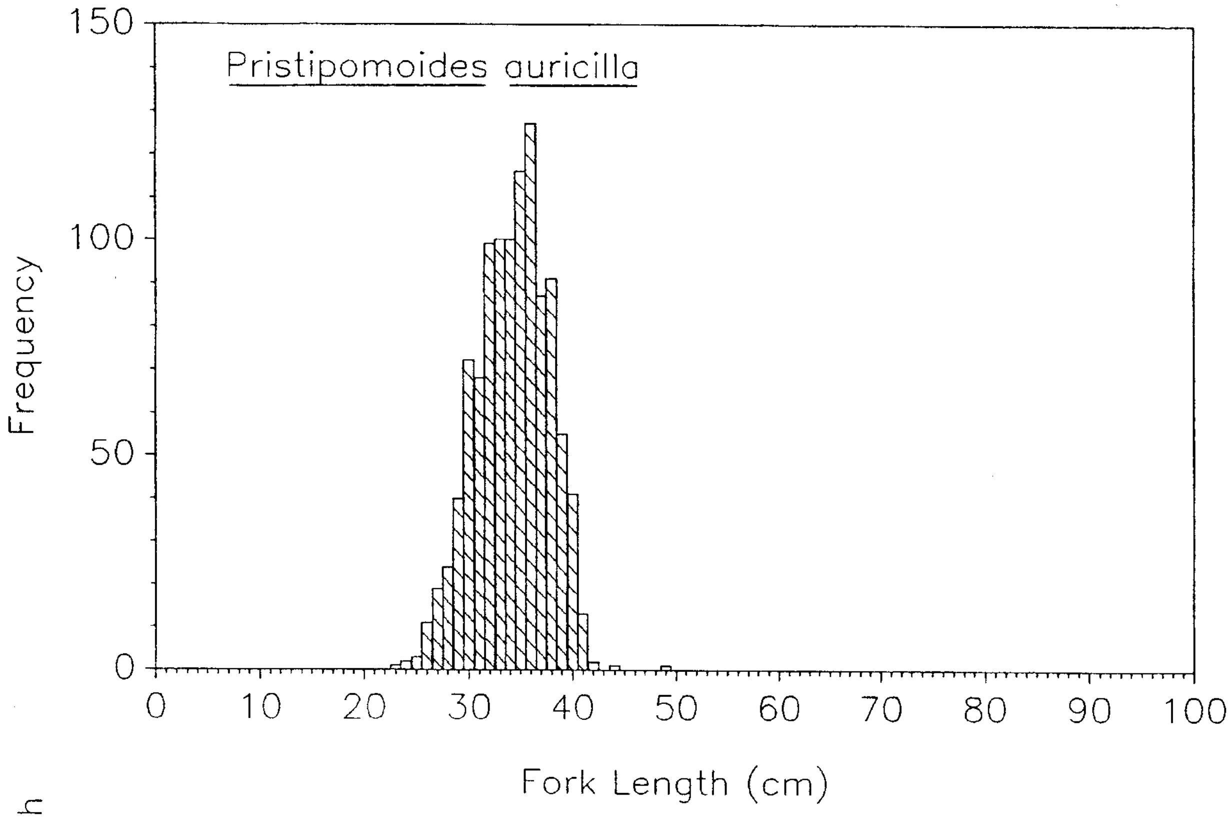


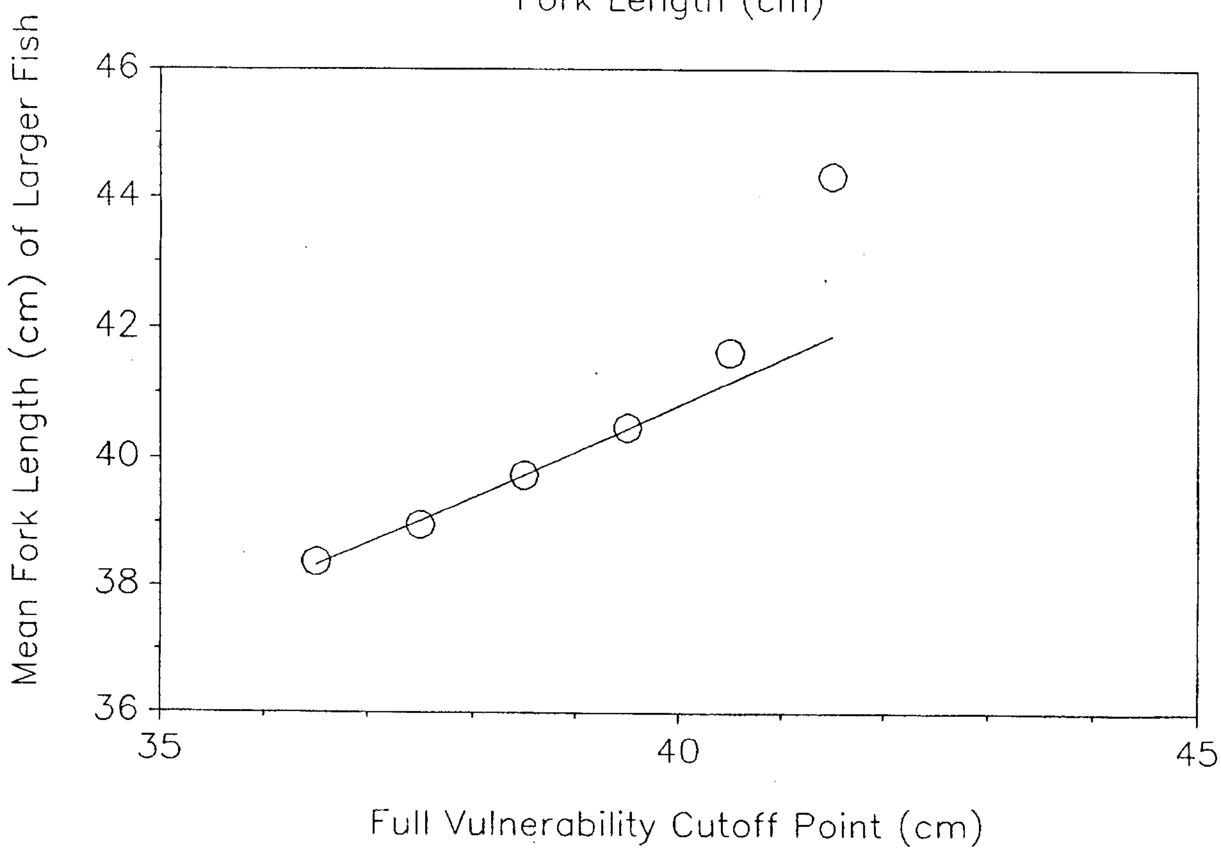


Appendix C.--Length-frequency data for seven bottom fish species from the Mariana Archipelago (upper panel) with the fitted Wetherall et al. (1987) regression (lower panel). See text for further explanation. (A) *Pristipomoides zonatus*.

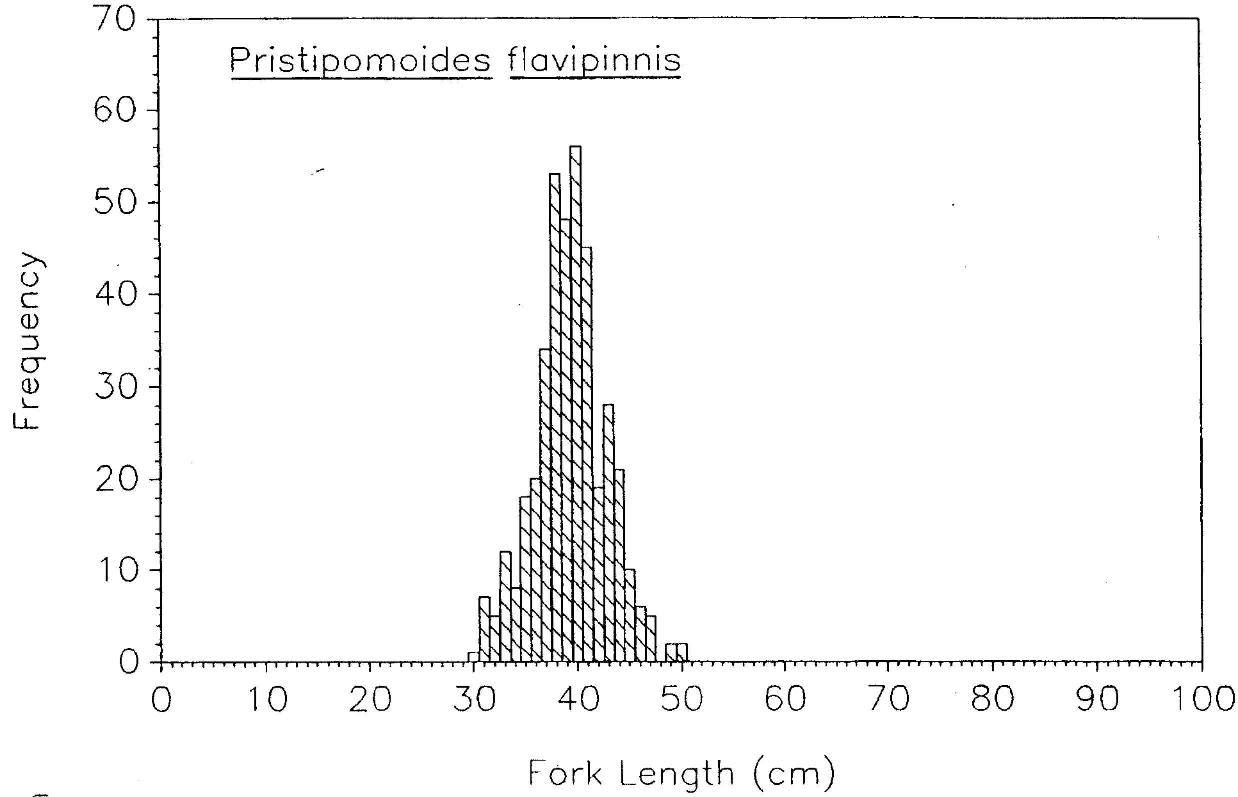


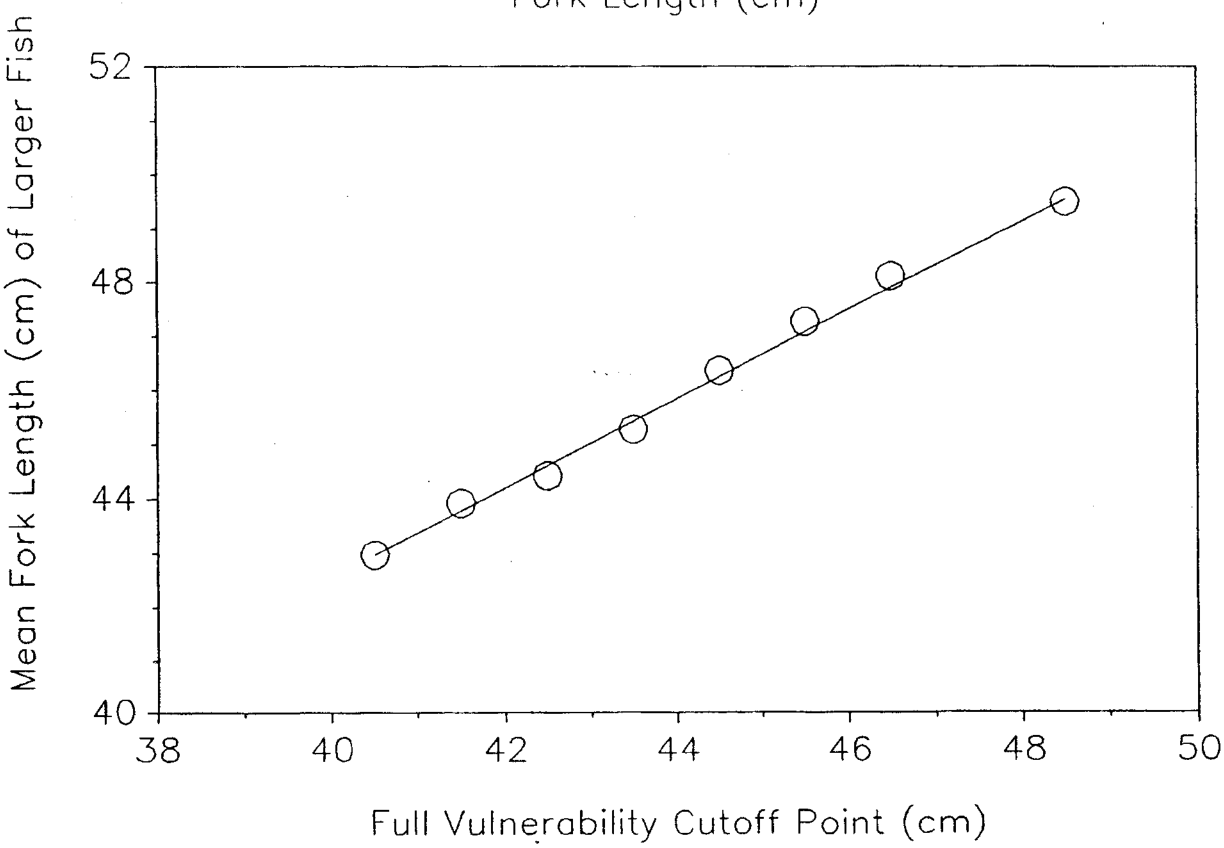
Appendix C.--Continued. (B) <u>Pristipomoides auricilla</u>.



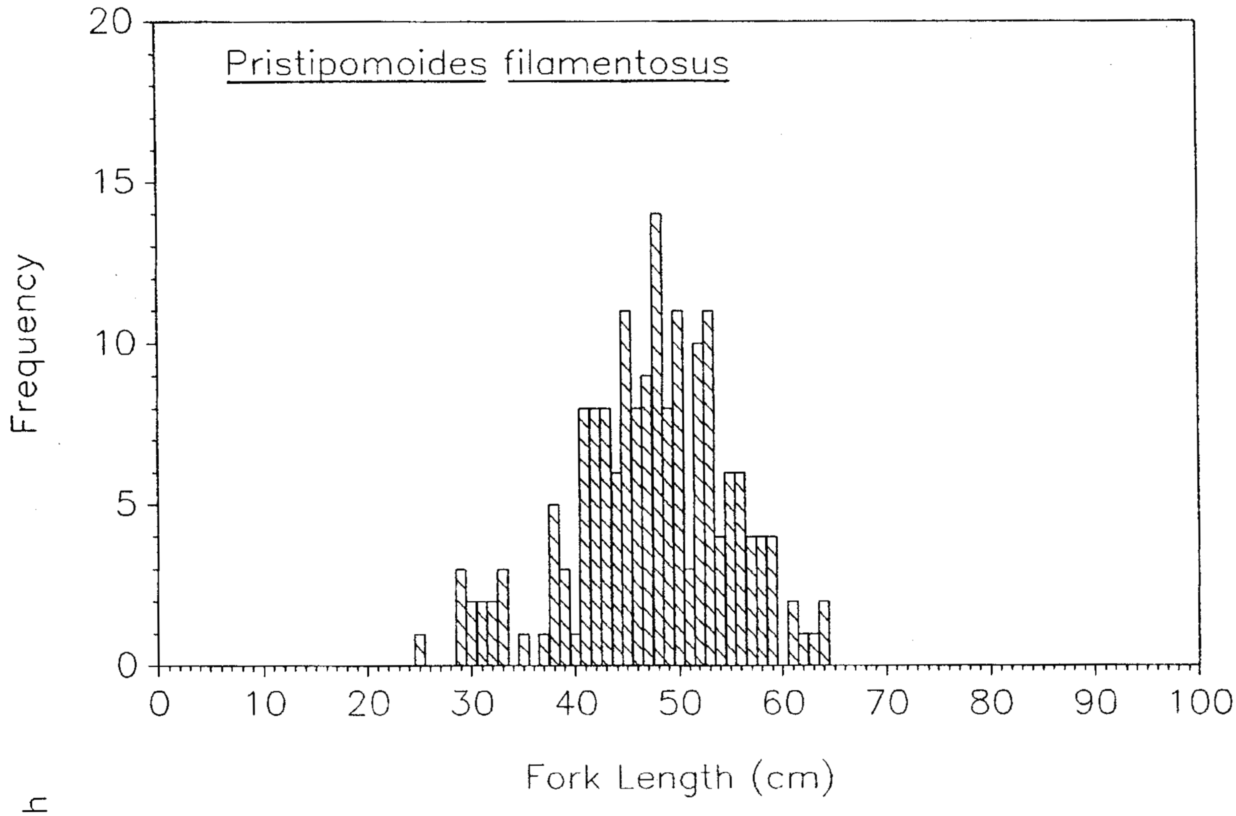


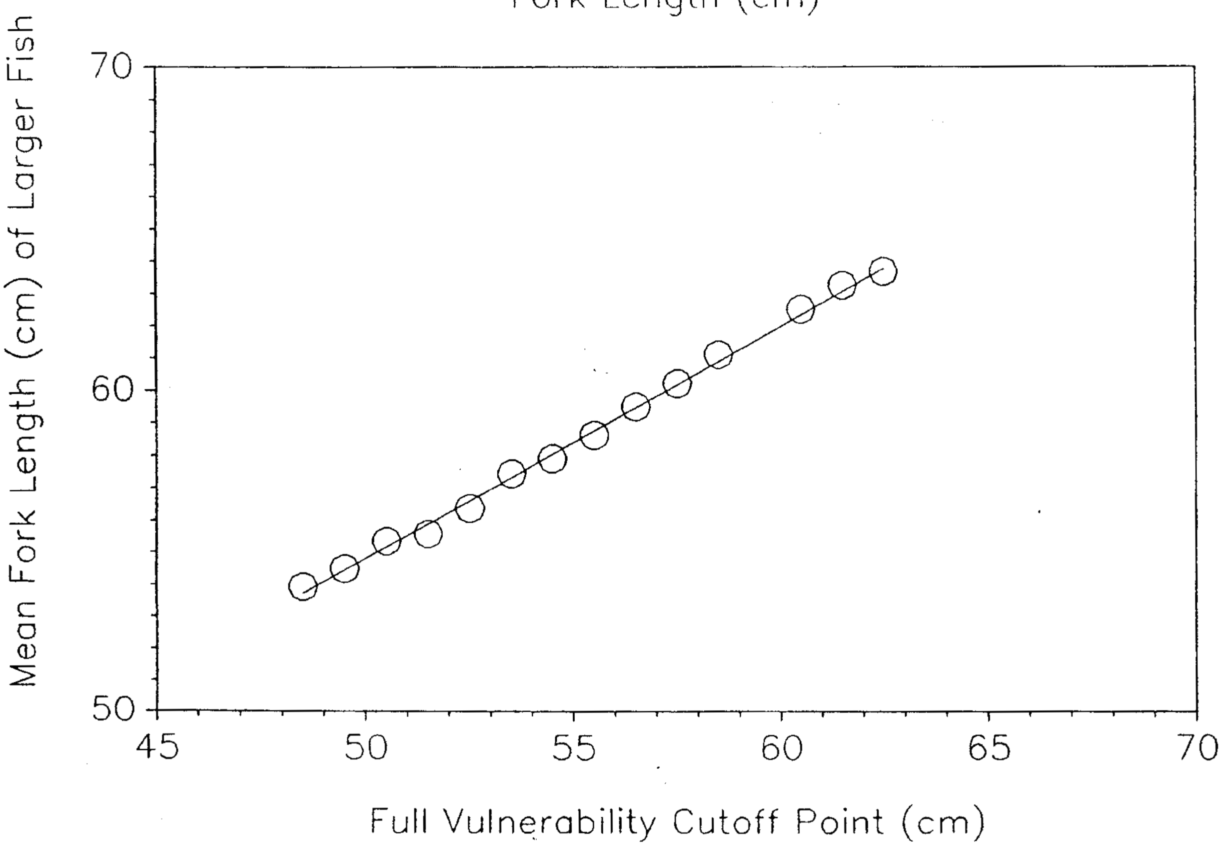
Appendix C.--Continued. **(C)** **<u>Pristipomoides flavipinnis</u>.**



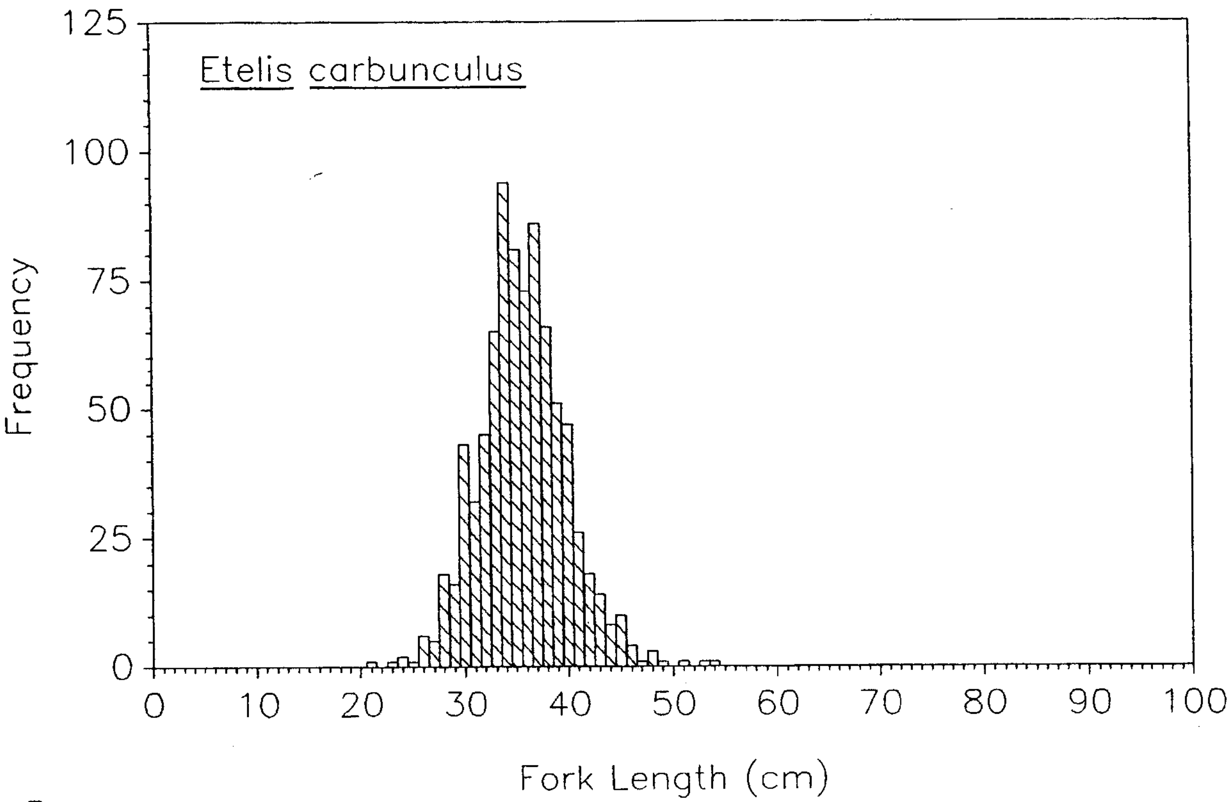


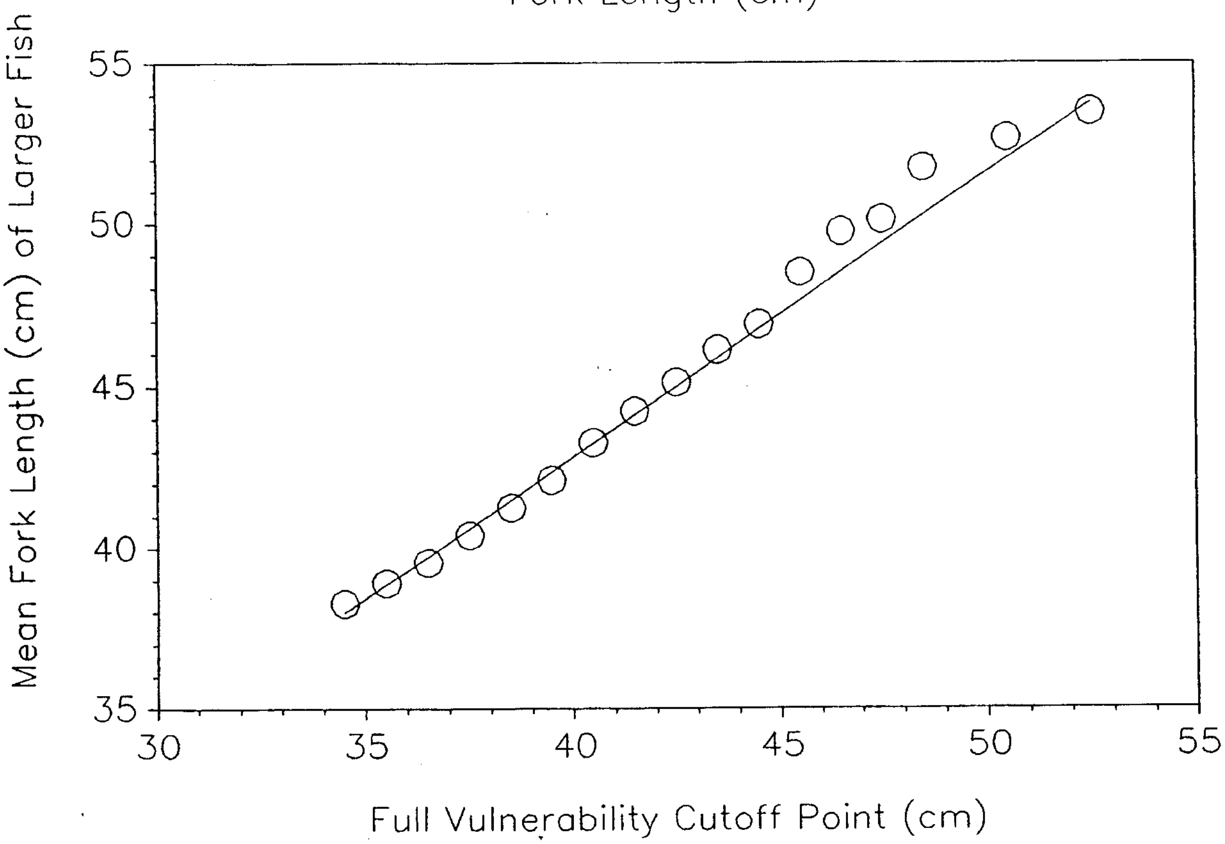
Appendix C.--Continued. (D) *Pristipomoides filamentosus*.



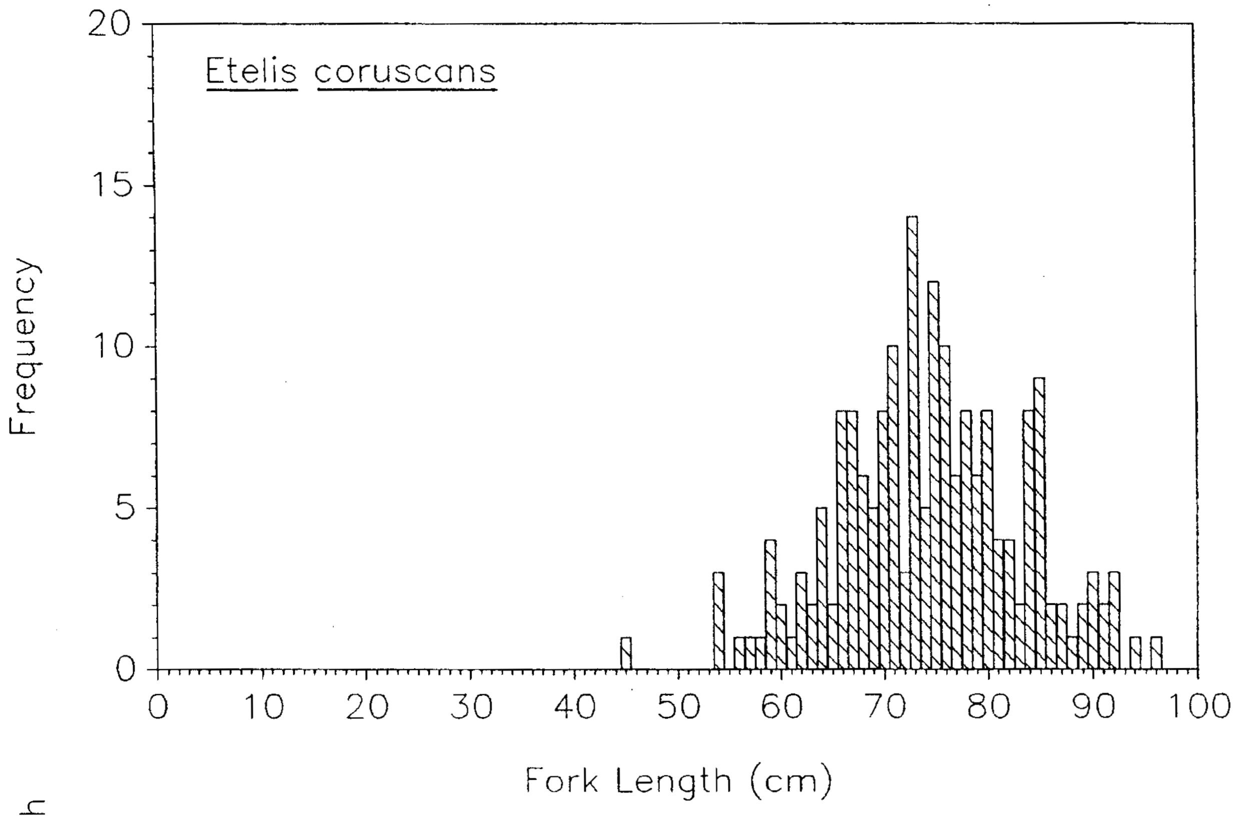


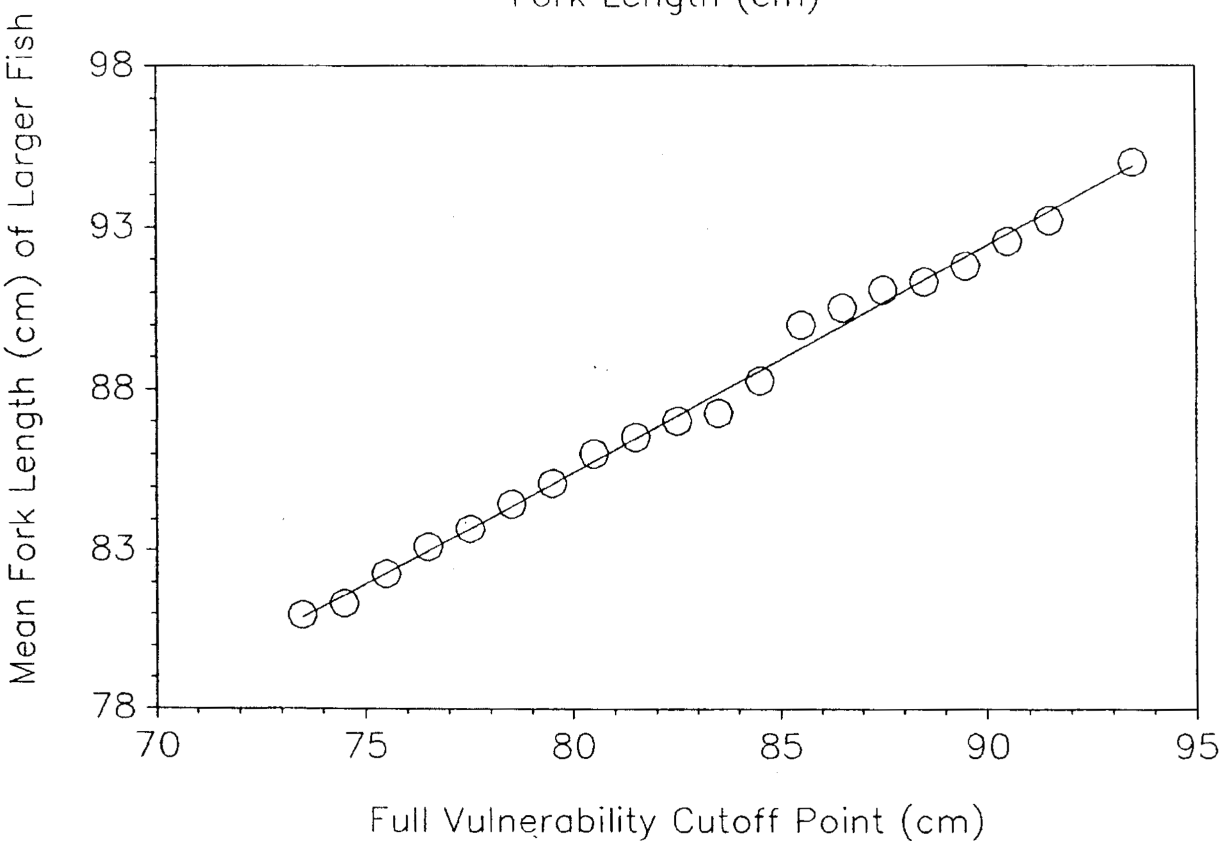
Appendix C.--Continued. (E) <u>Etelis</u> <u>carbunculus</u>.



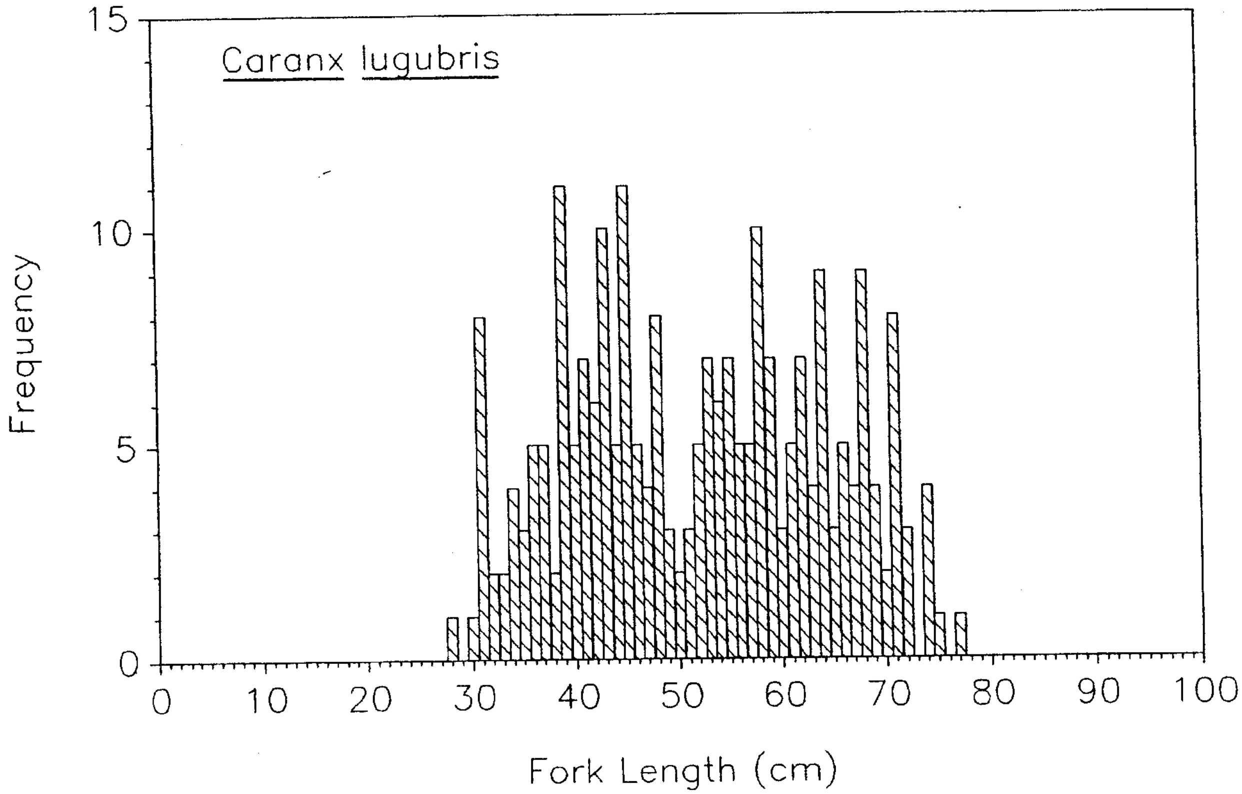


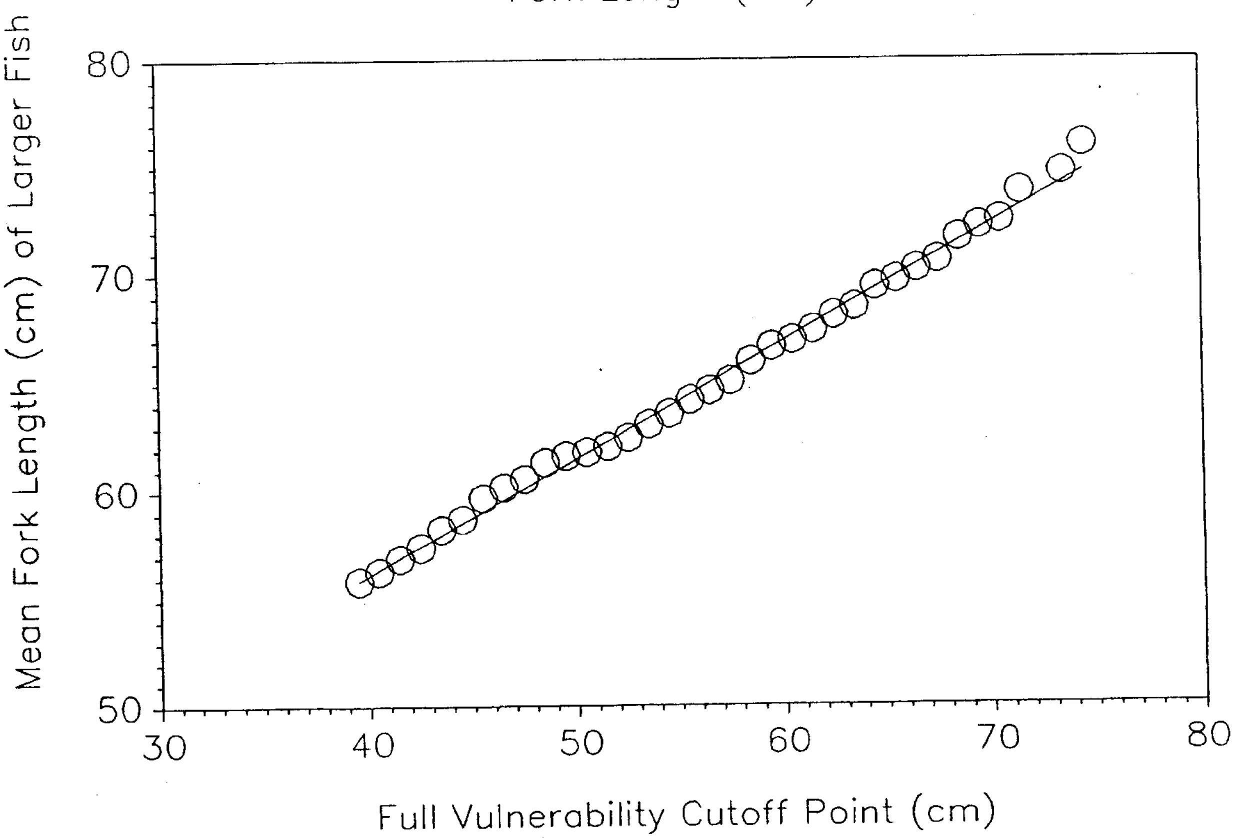
Appendix C.--Continued. (F) *Etelis coruscans*.



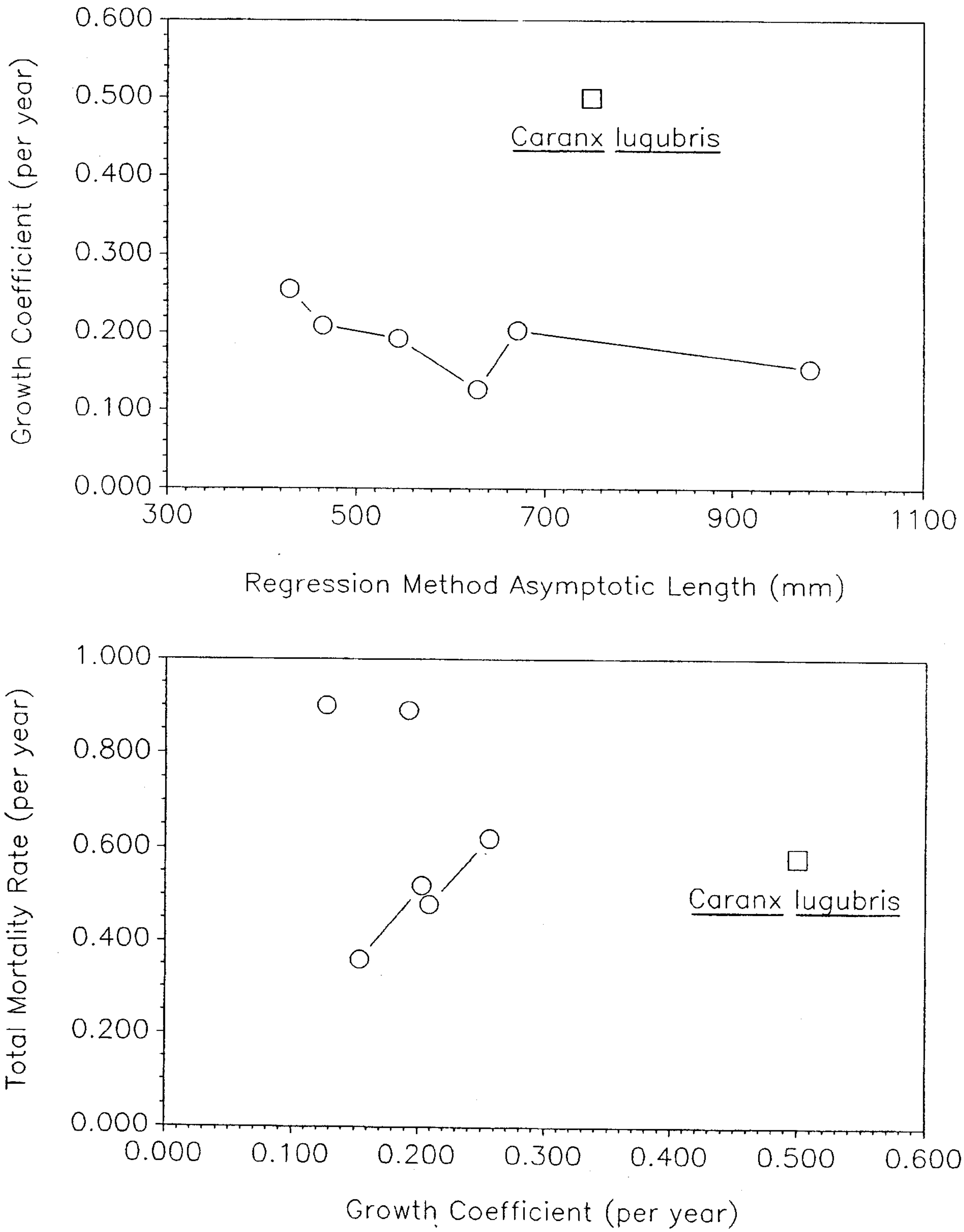


Appendix C.--Continued. (G) <u>Caranx lugubris</u>.





Appendix D.--Relationships among growth and mortality parameters for Marianas bottom fish. The von Bertalanffy $\underline{L}_\infty$ parameter and $\underline{Z}/\underline{K}$ ratio were estimated using the Wetherall et al. (1987) regression technique and the growth coefficient ($\underline{K}$) estimated from otolith age at length data.



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