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VARIATION IN THE GROWTH OF SABLEFISH *(ANOPLOPOMA FIMBRIA)* IN THE NORTHEAST PACIFIC OCEAN

by

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ABSTRACT

What do we mean by variation in fish growth? I take this to mean that estimated growth rates from two sampled populations of the same species are observed to be different. The sampled populations may actually be the same population sampled at different times or locations. These differences may be real, or the artifacts of sampling or quantitative methods used to observe and measure growth. Sablefish appear to exhibit real differences in growth rates through its distribution. Sablefish substocks off Alaska and off the West Coast of the U.S. show marked differences in growth, which appear to be environmentally and genetically derived. Sablefish also move to deeper water as they age; thus, sampling depth will affect length-age collections, as does the selectivity of fishing gear(s) employed at these depths. Analysis of growth rates obtained from tag-recapture data show that sablefish growth off the West Coast is retarded by El Niño Southern Oscillation effects (ENSO). When fitting growth curves from tagging data, inappropriate methodology can bias growth estimates, as compared to results estimated from observed length-at-age data. Additionally, climatic effects can influence migration and mixing of stocks which result in (real) growth differences. I review these factors as they contribute to the observed variation in the growth of sablefish.

Introduction

In studies of fish populations we often observe variations in fish growth. However, we are often confused as to just what these variations mean, and whether they are "real." The term "real growth" itself has different meaning in different contexts. For example, an individual studying the selectivity of fishing gears may consider the observed growth of fish sampled by the gears as showing a "real" difference. While an individual interested in the actual growth characteristics of the underlying population might conclude that these observed differences in growth are just "artifacts" of the selectivity of gears. Thus an observed difference in growth might be considered real or not depending on whether the focus of the study is on the method of sampling or analysis, or on the underlying growth in the sampled population. In this paper we consider real growth as that characterizing a population, not the method of sampling.

Here are some factors we interpret as leading to real differences in fish growth:

1. Real differences in growth often occur due to geographic and bathymetric differences in sampling locations, or the time periods being sampled and compared. These real differences might have both environmental (e.g., broad climate effects) and/or genetic bases, and are sometimes fairly <u>static</u> (i.e., unchanging) through time.

Perhaps the greatest source of real <u>changes</u> in observed fish growth on time scales studied by fishery biologists are climate driven events that affect feeding opportunities, trigger strong year-classes, or cause unusual migrations.

2. Climatic variation can affect portions of a species range differently, causing further observed variations in fish growth.

3. Factors causing migration or mixing of stocks that have different growth characteristics are also a source of variations in growth. Migrations might be seasonal (e.g., along established migration routes), or linked to unusual climatic events.

Other factors can lead to observed variations in fish growth that we interpret as artifacts:

4. Difference in the selectivity of fishing gears sampling the stock (which we mentioned at the start).

5. Statistical methodologies that produce biased results; or a relative bias between methods even though we don't know which method (or both) may be biased.

6. Different ageing methods applied to samples of fish structures (e.g., otoliths) can lead to a variety of apparent differences in growth rates. For example, biases in ageing different samples may cause differences in apparent size at age.

Factors such as these can cause variations in growth, even when the very same population is being sampled or resampled.

Variation in the Growth of Sablefish

Far from being an academic list of possible events, the above list was inspired by our studies of sablefish (*Anoplopoma fimbria*) in the northeast Pacific Ocean. Sablefish are a commercially important species found throughout the northeast Pacific Ocean (Fig. 1) from southern California, through Canada and Alaska, and in the western Pacific down to Japan (Kodolov 1968). Juveniles are not found in Asian waters and the adults are assumed to have recruited from the northeast Pacific.

Sablefish spend their early life history in surface and shallow in-shore waters, but migrate to deep, off-shore, continental slope waters at around age 3 yr (Sasaki 1985). Sablefish are unusual in that they have a propensity to migrate to deeper and deeper waters as time passes (Fig. 2). Adult sablefish (>3yr) are found in deep waters from 100 m to well over 1,000 m, with abundance centered around 400 m. Presumably, it is because of the constancy of the deep ocean environment that sablefish are so widespread.

There is a major stock boundary between Alaska and west coast stocks near Vancouver Island, Canada. Because sablefish is among the most tagged groundfish in the north Pacific, much is known of its stock structure and the separation between Alaska and West Coast substocks fits nicely with the patterns of migration revealed from tagging (Kimura et al., in prep.). Sablefish from the Alaska stock grow to a larger maximum size, and are larger at age than sablefish found off the West Coast of the U.S. (Table 1, Figs. 1 and 3). This difference, which appears genetically based (Gharrett et al. 1983), is also supported by the major circulation gyres in the northeast Pacific Ocean. This stock delineation is the greatest source of variation in sablefish growth rates in the Northeast Pacific and is a static feature of the population.

Sablefish are difficult to age directly from otoliths, so we sought to confirm the observed growth parameters estimated from direct ages, with growth parameters estimated from growth increments between the time of tagging and recovery. The classical statistical procedure for estimating von Bertalanffy growth parameters from tag-recapture data is due to Fabens (1965). Recently, James (1992) provided a new method of estimating von Bertalanffy parameters from tag-recapture data that avoided the well known biases of Fabens' method. Table 1 shows that West Coast von Bertalanffy growth parameters estimated from Fabens' method differ considerably with those estimated from otolith ages. Here, we have another instance of variation in observed growth rates. However, in this case we find that the more robust James' estimates compare quite well with estimates from otolith ages. Therefore, the perceived discrepancy in growth curves between Fabens' estimates and otolith ages is really due to statistical bias.

There is a reason why Fabens' estimates compare well with growth parameters estimated from otolith ages for the Alaska sablefish, but poorly for the West Coast stock. The reason is that migration is predominantly in the southern direction, apparently leading to a mixture of larger Alaskan sablefish, and smaller California sablefish in the West Coast population (Methot 1995). This mixing causes variation in L_∞, something that biases Fabens' estimates, but something James' estimates was designed to accommodate.

When estimating population growth curves, it is useful to remember that fishing gear selectivity can affect the value of parameters being estimated. For example, the most common gears targeting West Coast sablefish are sablefish pots, and trawl gear. We examined growth increments for tagged sablefish that were captured by pot gear and recaptured by either pot or trawl gear (Kimura et al. 1993). We then regressed growth increments against sex, recovery gear, size at release, and time at liberty. This tag recovery analysis showed that fish recovered by pot gear on average had growth increments 3.7 cm larger than fish recovered using trawl gear (α=0.0001 for the two-tailed test) after the other variables were taken into account. This shows that selectivity of fishing gears can influence growth parameters for West Coast sablefish. Notice that the result described here can be simply explained by a greater selectivity for larger sablefish by the pot gear.

We noted that changes in growth are probably brought about by climatic or other transient environmental events. Sablefish off Alaska live in a predominantly downwelling regime, while sablefish off the West Coast live in an upwelling regime. On occasion, and more frequent in recent years (1972, 1982, 1986, 1991), El Niño Southern Oscillation (ENSO) events occur along the West Coast. Environmental conditions during these events contribute to a weakening of coastal upwelling resulting in poor feeding conditions. By modeling growth increments of sablefish that were tagged and released, and then either exposed or not exposed to El Niño events, we were able to statistically detect a slowing of growth due to El Niño. The model used was $S_2 = S_1 + \Delta_t \exp(\beta_{enso} + \beta_1 S_1 + \beta_2 \Delta_t)$ where S_1 was the size of fish at the time of tagging, S_2 was the size of fish at time of recovery, Δ_t was the time elapse between tagging and recovery, and β_{enso} represents an effect from exposure due to ENSO conditions (Table 2). The result shows a significant effect (α=0.05 for the one-tailed test) of El Niño on the growth of West Coast sablefish.

Another way climate can influence the variability of observed growth is by triggering or inhibiting migrations. For sablefish in the northeast Pacific Ocean, migration between major centers of abundance is primarily from the Alaska substock to the West Coast substock. We found that sablefish migrations from Alaska appear to be correlated with upwelling strength off the West Coast. The reason for this is due to phenomena described by Chelton and Davis (1982) and Hollowed and Wooster (1992). Hollowed and Wooster (1992) noted that the climate/circulation in the northeast Pacific oscillates between Type A (i.e., weak Aleutian Low, strong California current, and strong upwelling off the West Coast) and Type B (i.e., strong Aleutian Low, weak California current, weak upwelling off the West Coast) conditions. It is the Type A conditions, with strong California currents and strong upwelling that appears to encourage the migration of sablefish from Alaska to the West Coast (Fig. 4). Therefore, the strength of migration from Alaska to the West Coast would be negatively correlated with El Niño events. Obviously, migration of larger Alaska sablefish will influence the growth characteristics of fish captured off the West Coast.

Conclusions

We have described six factors that can cause observed variability in the growth of fishes. Five of these were illustrated using sablefish found in the Northeast Pacific. It is obvious that the other factor, i.e. differences in ageing methods, can easily lead to differences in observed growth.

One interesting conclusion from this paper is that new knowledge concerning stock structure greatly contributes to our understanding of the reasons for the observed variability in fish growth. What is equally important is that new information flow both ways: observed variability of fish growth provides important clues concerning stock-structure and fish population dynamics.

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References

Chelton, D.B., and R.E. Davis. 1982. Monthly mean sea level variability along the western coast of North America. J. Phys. Oceanogr., 12:757-784.

Dorn, M.W. 1992. Detecting environmenta; covariates of Pacific whiting *Merluccius productus* growth using a growth-increment regression model. U.S. Fish Bull 90:260-275.

Fabens, A.J. 1965. Properties and fitting of the von Bertalanffy growth curve. Growth 29:265-289.

Gharett, A.J., M.A. Thomason, and L.N. Wishard. 1983. Progress in the study of biochemical genetics of sablefish. *In* Proceedings of the international sablefish symposium, Lowell Wakefield Fisheries Symposia Series, Univ. of Alaska, Alaska Sea Grant Report 83-8, p143-146.

Hollowed, A.B., and W.S. Wooster. 1992. Variability of winter ocean conditions and strong year classes opf Northeast Pacific groundfish. ICES Mar. Sci. Symp. 195:433-444.

James, I.R. 1991. Estimation of von Bertalanffy growth curve parameters from recapture data. Biometrics 47:1519-1530.

Kimura, D.K., A.M. Shimada, and S.A. Lowe. 1993. Estimating von Bertalanffy growth parameters of sablefish *Anoplopoma fimbria* and Pacific cod *Gadus macrocephalus* using tag-recapture data. U.S. Fish. Bull. 91:271-280.

Kimura, D.K., A.M. Shimada, and F.R. Shaw. Stock structure and movement of tagged sablefish (*Anoplopoma fimbria*) in northeast Pacific waters and the effects of ENSO on migration and growth. In preparation.

Kodolov, L.S. 1968. Reproduction of Sablefish. (*Anoplopoma fimbria* (PALL.)). Vop. Ikhtiol., 8(4):662-668. (In Russian, transl. in Prob. Ichthy., 8(4):531-555.)

Methot, R.D. 1995. Latitudinal and bathymetric patterns in sablefish growth and maturity off the U.S. west coast. In M. Saunders and M. Wilkins, editors, Proceedings of the international symposium on the biology and management of sablefish, NOAA/NMFS Technical Report, in press.

Sasaki, T. 1985. Studies on sablefish resources in the North Pacific Ocean. Bull. Far Seas Fish. Res. Lab. 22:1-108.

Table 1A. For sablefish in the Gulf of Alaska, comparison of von Bertalanffy growth parameters estimated from tag-recapture and length-at-age data. The tag-recapture sample sizes were for males n = 643, and for females n = 697. The direct ages sample sizes were for males n = 807, and for females n = 1,165.

Males

	L_0	K_0	t_0	SE(L_0)	SE(K_0)	SE(t_0)
Unweighted Fabens	70.2	0.136		0.83	0.013	
Weighted Fabens	83.0	0.049		3.43	0.007	
James	70.7	0.126		2.84	0.044	
Length-at-age	70.2	0.120	-8.06	0.95	0.014	1.17

Females

	L_0	K_0	t_0	SE(L_0)	SE(K_0)	SE(t_0)
Unweighted Fabens	83.4	0.128		1.36	0.011	
Weighted Fabens	102.8	0.055		5.02	0.007	
James	84.7	0.117		3.53	0.024	
Length-at-age	86.7	0.106	-6.15	1.22	0.008	0.62

Table 1B. For sablefish off the west coast of the United States, comparison of von Bertalanffy growth parameters estimated from tag-recapture and length-at-age data. The tag-recapture sample sizes were for males n = 467, and for females n = 616. The direct ages sample sizes were for males n = 714, and for females n = 814.

Males

	L_0	K_0	t_0	SE(L_0)	SE(K_0)	SE(t_0)
Unweighted Fabens	65.4	0.081		2.08	0.014	
Weighted Fabens	144.2	0.009		100.2	0.010	
James	56.6	0.556		0.65	0.108	
Length-at-age	54.7	0.472	-1.82	0.23	0.055	0.51

Females

	L_0	K_0	t_0	SE(L_0)	SE(K_0)	SE(t_0)
Unweighted Fabens	71.5	0.110		1.79	0.013	
Weighted Fabens	130.1	0.020		33.2	0.008	
James	61.4	0.481		0.92	0.085	
Length-at-age	61.0	0.499	-0.81	0.35	0.047	0.32

Table 2. Parameter estimates and their statistical significance for a tag-recovery growth model intended to detect a growth effect due to ENSO events. Data were divided between Alaska and the West Coast and the ENSO parameter included when a particular tagged fish was at liberty during any ENSO event. The model used was $S_2 = S_1 + \Delta_t \exp(\beta_{enso} + \beta_1 S_1 + \beta_2 \Delta_t)$ where S_1 was the size of fish at the time of tagging, S_2 was the size of fish at time of recovery, Δ_t was the time elapse between tagging and recovery, and β_{enso} represents an effect due to any exposure due to ENSO events.

A. Alaska Modeling Results. Degrees of freedom fot t-statistic=6,354.

Parameter	Estimate	Std. Error	t-value
β_{enso}	0.01855	2.1027 e-02	0.882
β_1	-0.08286	4.8233e-04	-171.784
β_2	-0.00030	9.4454e-06	-32.222

B. West Coast Modeling Results. Degrees of freedom for t-statistic=3,834.

Parameter	Estimate	Std. Error	t-value
β_{enso}	-0.06044	3.2514e-02	-1.859
β_1	-0.09791	6.8600e-04	-142.734
β_2	-0.00034	1.2204e-05	-27.728

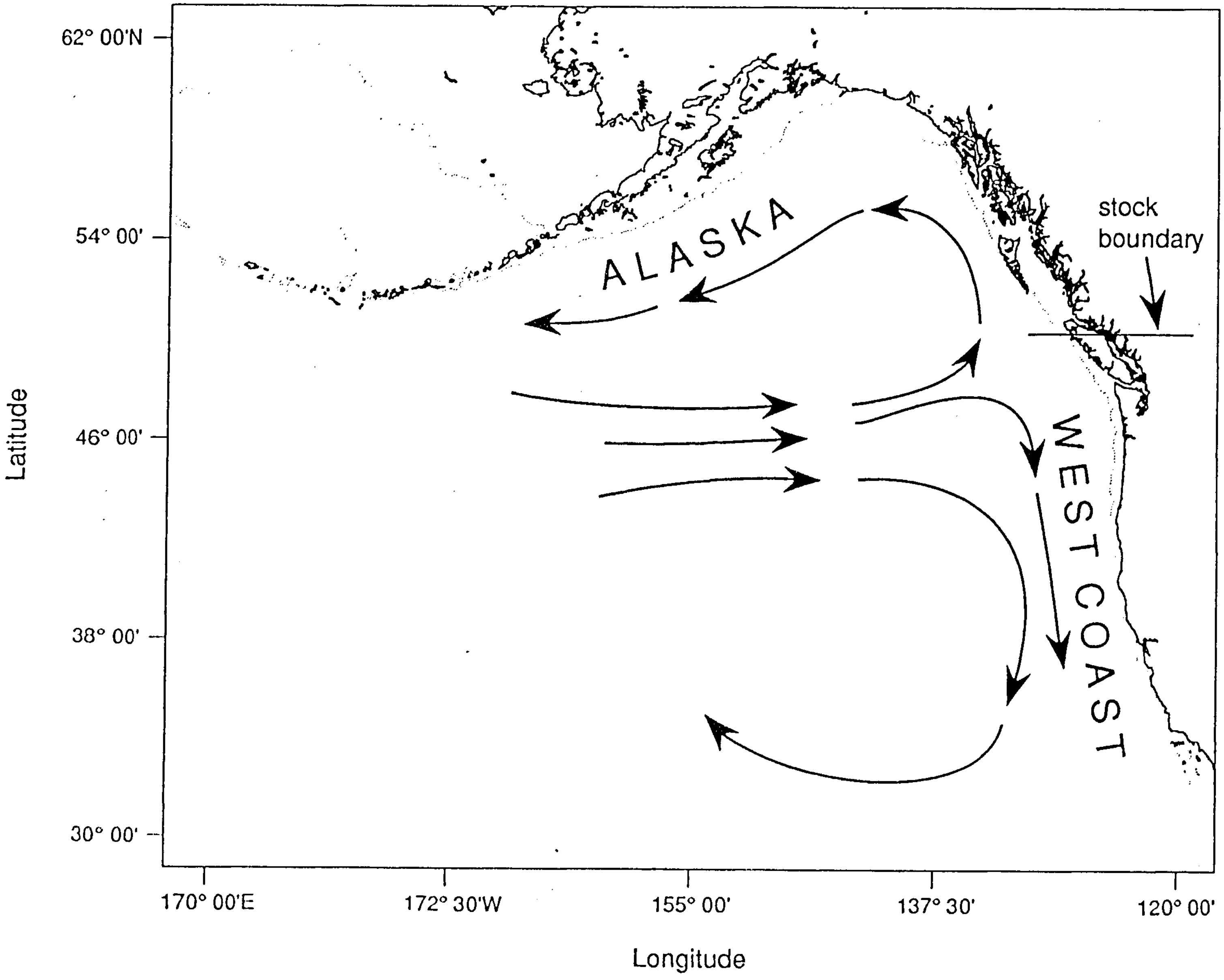
Figures

Fig. 1. Map of the Northeast Pacific Ocean showing the distribution of Alaska and West Coast sablefish. Also shown are the principal circulation gyres in the Northeast Pacific that support this stock dichotomy, and the 400 m depth contour which is the approximate habitat of adult sablefish.

Fig. 2. Plot of depth of tagging versus the change in depth between the time of tagging and recovery. Plots show that sablefish in Alaska and the West Coast continue to move deeper with the passage of time up to 400 m depth.

Fig. 3. (a) Length frequencies plotted by Areas showing the dichotomy between Alaska and West Coast sablefish. The two distributions shifted to the right are from Alaska. (b) The same length frequencies but only for sablefish with length greater than 60 cm. Top distribution are from Alaska, the middle distributions are from the West Coast northern areas, and the lower distributions are from the West Coast southern areas.

Fig. 4. Plot showing correlation of the number of sablefish tagged off Alaska and recovered off the West Coast with the strength of upwelling off the West Coast. The Bakun upwelling indices were mean coastal summer upwellings (April-August) from 42°-48°N latitude (Dorn 1992).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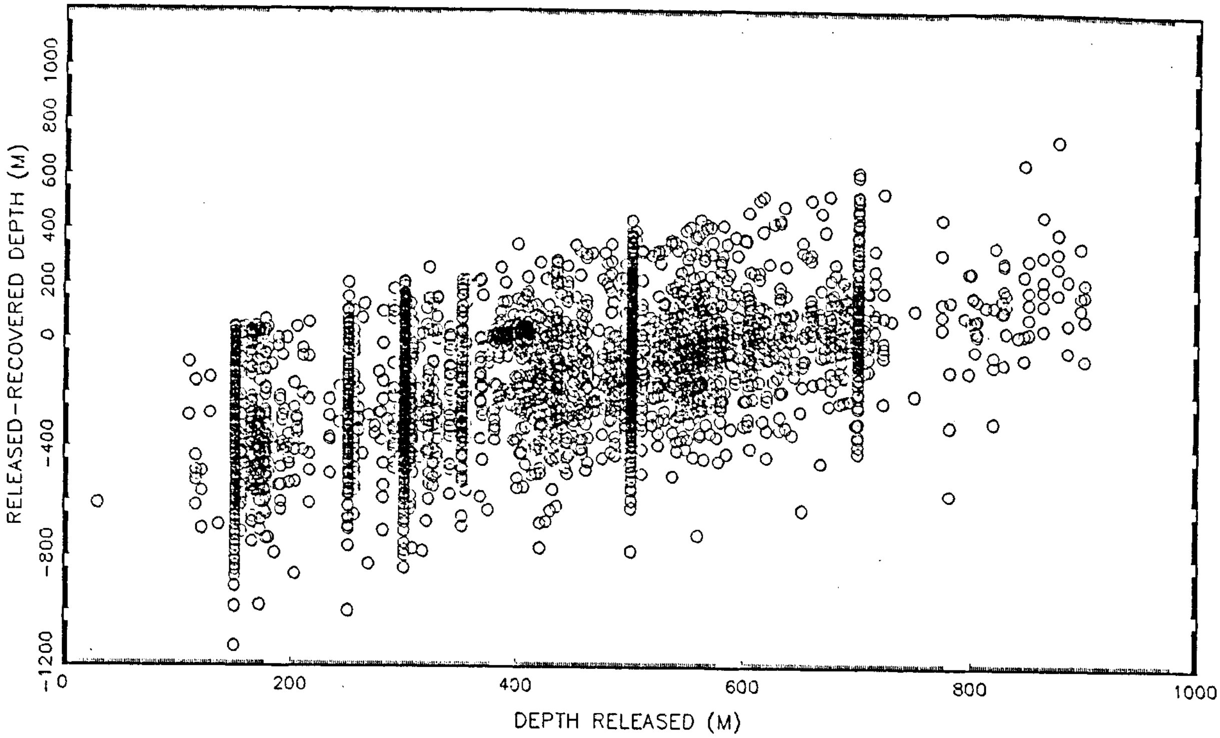
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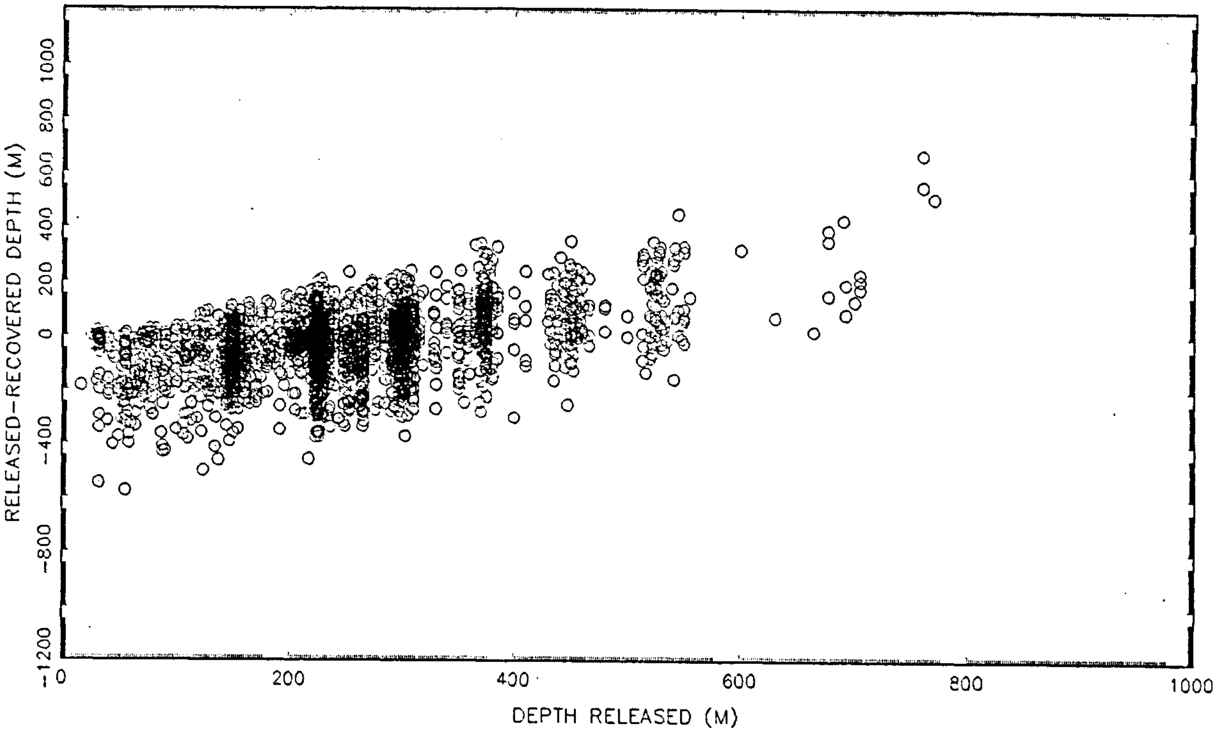
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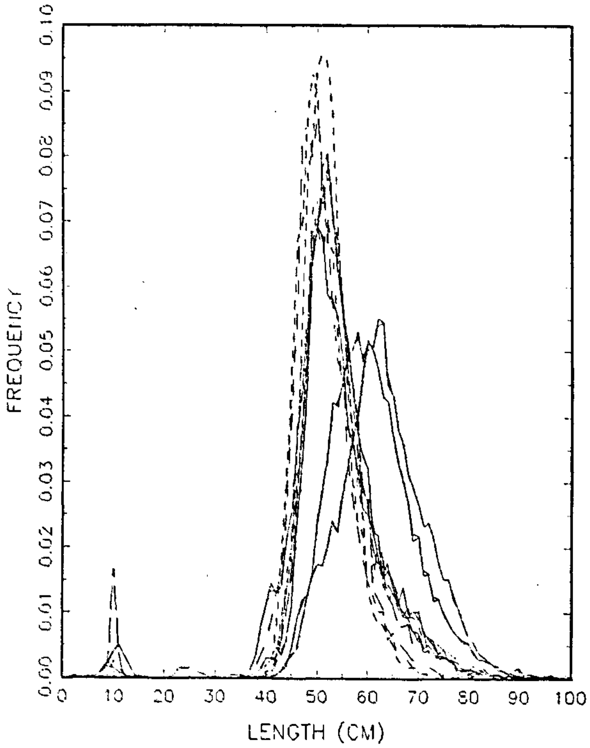
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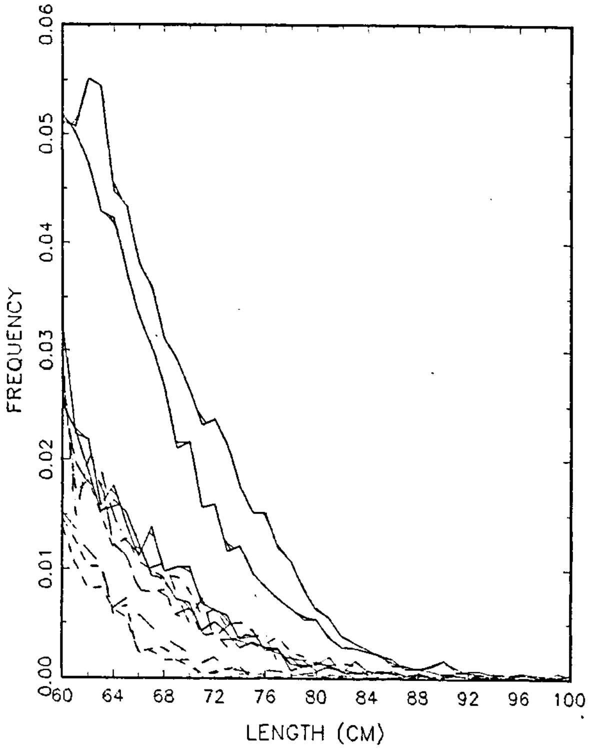
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