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Abstract

Historical CalCOFI data were used with a variety of modeling approaches (log-linear models for larval density, logistic models for presence-absence of larvae, and a hybrid delta distribution approach) to obtain estimates of larval abundance for bocaccio rockfish (*Sebastes paucispinis*) during 1956-1957, 1969-1970, 1972, 1975-1976, 1978, 1981 and 1984. The density and presence-absence models indicate that larval abundance reaches a peak around CalCOFI line 80 and during March. All approaches indicate that bocaccio larvae are most abundant about 100 km offshore. All indices indicate low to moderate larval abundance for bocaccio rockfish during the middle 1950's but indices were not consistent about annual trends during 1969-1984. Precision of larval abundance indices was related to sample size (numbers of tows). Estimated boccacio abundance may have been affected by a change from ring to bongo nets in 1978. Less efficient sampling prior to 1978 would have resulted in underestimation of larval abundance. Results indicate that a useful index of larval abundance for *current* and historical bocaccio larval abundance could be constructed once the CalCOFI database is brought up to date.

Introduction

Following MacCall (1995), we developed indices of historical larval abundance for bocaccio rockfish (*Sebastes paucispinis*) from CalCOFI (California Cooperative Fisheries Investigations) ichthyoplankton (fish egg and larva) data. This work was interesting and important because larval abundance may track changes in spawning biomass and because indices of larval abundance might be included in stock assessment models (e.g. Bence and Rogers 1992) use to manage the fishery for bocaccio rockfish. We focussed on historical trends in larval abundance because recent data were not available (see below). Historically, CalCOFI data were collected prior to the first west coast bottom trawl survey conducted by NMFS on the continental shelf during 1980. Thus, CalCOFI data may provide crucial information about trends in larval abundance and spawning biomass before the groundfish fishery was fully developed. In addition, it may be possible to develop indices based on CalCOFI data that measure recent trends in larval abundance and spawning biomass for bocaccio rockfish (see below).

CalCOFI data are used routinely in stock assessments for pelagic schooling fishes off southern California such as northern anchovy (*Engraulis mordax*, Jacobson et al. 1994) and Pacific sardine (*Sardinops sagax*, Barnes et al. 1992) but have never before been used in a groundfish assessment. Indices of relative abundance for pelagic fish based on CalCOFI data track long term trends in abundance but are imprecise for any one year (Jacobson et al. 1994; Deriso et al., in press). Ability to track trends is probably due to long term (1951-present), consistent (other than changes in gear discussed below), and relatively intense sampling (Hewitt 1988). Imprecision is probably due to the "patchy" and highly variable nature of fish eggs and larvae in the ocean as well as variable effects of weather, climate, location and oceanographic features (e.g. El Niño) on their seasonal and spatial distribution. CalCOFI data track spawning biomass most accurately when the distribution of sampling effort (CalCOFI sampling pattern) and the distribution of the spawning stock coincide, ichthyoplankton is abundant and evenly distributed, and the relationship between fecundity and biomass is constant over time.

CalCOFI data have been collected of a grid of lines and stations off the west coast (mainly central and southern California) since 1951 (Hewitt 1988). CalCOFI cruises are identified by year and principle month. For example, the cruise conducted primarily during January of 1956 was cruise number 5601 although some samples may have been taken late in December 1955 or early in February 1956. For simplicity, the month used for data from each cruise was the last two digits of the cruise number (e.g. January for cruise 5601). "Spawning years" were assigned to CalCOFI data based on the peak spawning season for bocaccio. For example, the 1956 spawning year started on 1 December 1955 and ended on 1 May 1956.

Bocaccio larvae are relatively easy to identify (Moser 1967) and common (among the top 50 species encountered) in CalCOFI samples (Moser et al. 1993). CalCOFI data for bocaccio were standardized counts or densities of larvae per unit area (larvae 0.05 m^{-2}, Stevens et al. 1990) for individual bongo and ring net tows. Larval, rather than egg, densities were used because rockfish are live bearers that give birth to larvae rather than eggs. Bongo and ring nets were used because they are relatively efficient for larval fish. Possible changes in efficiency of sampling gear are discussed below.

Bocaccio larvae have not yet been identified in samples from all CalCOFI cruises and not

all available data were in the CalCOFI database.[1,2] We used all available data, however, to estimate larval abundance indices. Bocaccio data for calendar years 1956 and 1969, originally analyzed by MacGregor (1986), were keypunched from MacGregor's original data sheets (G. Moser, Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA, 92038, pers. comm.) because they were not available in the CalCOFI database. Data for calendar years between 1972 to 1984 were extracted in a routine fashion from the CalCOFI database (R. Charter , Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA, 92038, pers. comm.).

Based on results in Moser et al. (1993) and MacCall (1995), as well as preliminary analyses, we used data for December-April (the peak spawning season), CalCOFI lines 60-93.3 (near San Francisco to the US-Mexican border) and from the most inshore station out to station 90 (bocaccio larvae are rare beyond station 90). Bocaccio larvae may be relatively abundant north of San Francisco (Moser et al. 1993), but sampling was sporadic in northern areas.[3]

Different types of CalCOFI indices were developed for bocaccio to determine how sensitive results were to decisions about statistical methodology. Ideally, different approaches would give similar results. The "MACCALL&PRAGER" index was based on MacCall and Prager (1988) and MacCall (1995). The MACCALL&PRAGER index uses a combined survey and modeling approach, log-linear models, and densities of bocaccio larvae summarized by CalCOFI line. The "GAM" index was based on Smith (1990), Mangel and Smith (1990) and Deriso et al (in press.). The GAM index uses logistic regression and presence-absence of bocaccio larvae in individual CalCOFI tows. The "DELTA" approach was based on delta-lognormal linear models (Pennington 1983; Lo et al. 1992) fit to tow-by-tow data. The DELTA index was intermediate between the MACCALL&PRAGER and GAM approaches because presence-absence information (the GAM index) and information about density of bocaccio larvae in "positive" tows (tows in which larvae were actually captured) were combined. Finally, the "RALSTON" approach was based on a log-linear model fit to tow-by-tow density data stratified spatially and temporally.

Theoretically, presence-absence indices (e.g. GAM) will work best if bocaccio larvae are rare and very patchy while density based indices (MACCALL&PRAGER and RALSTON) will work best if bocaccio larvae are abundant and evenly distributed (Mangel and Smith 1990). The compromise DELTA approach was designed to accommodate highly variable data typical of

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[1] The CalCOFI database is expected to be complete and up to date for bocaccio and other rockfish by 1997.

[2] Cruises with bocaccio identified (parentheses indicate cruises outside of the spawning season): 5601, 5602, 5603, 5604, (5605, 5606, 5607, 5608, 5609, 5610, 5611), 5612, 6901, 6902, 6904, (6905, 6906, 6907, 6908, 690,9 6910), 6912, 7202, 7203, (7205, 7207, 7210), 7412, 7501, 7503, (7505, 7507, 7510, 7511), 7512, 7712, 7801, 7803, 7804, (7805, 7807, 7808), 8012, 8101, 8102, 8104, (8105, 8107, 8108), 8401, 8402, 8403, 8404, (8405, 8407, 8410).

[3] Results using CalCOFI lines 40-133.3 were similar were similar to results for lines 60-90 put precision for areas north of line 60 was poor.

ichthyoplankton surveys. The DELTA index may make more complete use of data than the GAM presence-absence index because DELTA uses both presence-absence and density information.

MACCALL&PRAGER Index

CalCOFI data (figures 1-3) were summarized by line and month using a survey-based "one dimensional Sette-Ahlstrom" method (MacCall and Prager 1988, MacCall 1995). First, standard CalCOFI line and standard CalCOFI station were calculated for each bongo tow (standard lines were lines 60, 63.3, 66.7, 70, etc.; standard stations were stations 30, 35, 40, etc.). Next, the average density of bocaccio larvae was calculated for each cruise (cruises correspond to months, see below), standard line and standard station. Survey weights, based on the area represented, were then calculated for each average density. For example, if data for cruise 5602 and standard line 60 were available for standard stations 35, 40, 50 and 60, then the inshore survey weight for data from standard station 40 would be w_i=(40-35)/2=2.5, the offshore survey weight would be w_o=(50-40)/2=5, and the combined survey weight for standard station 40 would be w=2.5+5=7.5. The inshore weight for stations nearest the coast was w_i=(standard station-coastal station)/2+2.5 and the offshore weight for stations farthest offshore was w_o=(90-standard station)/2+2.5. Finally, the data were summarized by line and cruise:

$$D_{L,c} = \frac{\sum_{s=1}^{N_s} d_{L,c,s}\, w_{L,c,s}}{\sum_{s=1}^{N_s} w_{L,c,s}} \qquad [1]$$

where $D_{L,c}$ was the average density of bocaccio larvae along line L during cruise c, $d_{L,c,s}$ was the average density for standard station s, and $w_{L,c,s}$ was the total (inshore+offshore) survey weight. The time (month) of the survey was implicitly defined by the cruise number (c, see above). In what follows, $D_{L,c}$ is replaced by the notation $D_{L,y,m}$ where y is spawning year and m is month (0-4 for December-April).

The log-linear model used to estimate the MACCALL&PRAGER index was:

$$\ln(D_{L,y,m} + k) = \Lambda_L + \Upsilon_y + \Gamma_m + \epsilon_{L,y,m} \qquad [2]$$

where k was a constant slightly less than the smallest value of $D_{L,y,m}$, Λ_L was a line effect, Υ_y was a year effect, Γ_m was a month effect, and $\epsilon_{L,y,m}$ was a statistical error assumed to be normally distributed with constant variance. The constant k, which may affect results from log-linear models (Berry 1987), was used to avoid taking the log of zero when no bocaccio larvae were taken along a line. For the MACCALL&PRAGER index, k=0.012 (1% smaller than the smallest non-zero observation).

The MACCALL&PRAGER model was fit by least squares (Figure 4) and the index of larval abundance for bocaccio was predicted values of $D_{L,y,m}$ at standard line 80 in March of each year. Likelihood ratio tests indicated that neither more complex (e.g. with interactions between

months and lines) nor simpler models could not be justified on statistical grounds.

MacCall and Prager's Approach—Historical and Statistical Motivation

MacCall and Prager (1988) developed one of the earliest modeling approaches to estimating an annual index of abundance from CalCOFI ichthyoplankton data. When the approach was developed, the standard method for tracking trends in abundance using ichthyoplankton data was the survey based "larval census" (Smith 1972; see Moser et al. 1993 for examples). The original development for MacCall and Prager's approach is best understood in the context of the larval census. Historically, it links between survey based approaches and model based approaches that were developed later. The optimum choice or blend of survey based and modeling techniques is unknown. Simulation analyses will probably be required to determine the best approach for bocaccio larvae.

The larval census approach (Smith 1972) sums monthly and regional abundance of larvae to produce an annual total. Missing observations are a problem in larval census calculations because there is no way to "fill the holes" and account for larvae in unsampled area or time strata. MacCall and Prager's solution was to estimate relationships between areas and times using a general linear model (GLM) and to use the estimated relationships to infer larval abundance in unsampled strata. The approach was similar to the EM algorithm (Haberman 1974).

Although the initial motivation was to fill in missing values for a larval census estimate, it was evident that year effect parameter estimates were themselves an abundance index. There was, however, a logical problem with the year effect estimates in the context of the larval census approach because observations from strata with very low larval abundance had as much effect on the abundance index as observations from strata with high abundance. This logical problem was compounded because most of the data were collected from low abundance strata (areas and seasons when fish were not spawning). To avoid this, MacCall and Prager iteratively re-weighted data in their GLM by the expected abundance in each cell. This produced estimates of GLM year effect parameters that were roughly analogous to a larval census estimate.

Use of data summarized by CalCOFI lines in the MacCall and Prager approach has advantages, particularly with log-linear models with an added constant (k in eq. [2]). Summarizing CalCOFI data by line reduces the number of zero observations and may have reduced potential effects from the added constant. In addition, the size of the data set was reduced by a factor of ten as individual tows were aggregated by standard lines (large data sets were a problem in the days when computer capacity was limited). A disadvantage is that an appropriate statistical distribution for errors ($\epsilon_{L,y,m}$) around the dependent variable $\ln(D_{L,y,m}+k)$ is not available and larval abundance estimates are not maximum likelihood estimates. As described above, results may be affected by choice of the constant k. Information may be lost by pooling data along lines and by month.

MacCall and Prager's (1988) approach reduced reliance on a models by using a survey based larval census approach where possible and statistical models only where necessary. CalCOFI lines were usually sampled completely from the inshore station out to at least station 90 (Figure 2). Further, the stations sampled along a line usually followed a fixed pattern (Figure 2). Because the survey procedure was relatively fixed and because stations were usually sampled

according to a regular pattern, it makes sense to divide the area along a line up into "cells" and to compute the average density for a line as a weighted average of the density in each cell.

Potential effects due to interactions between onshore-offshore position (station) and other factors were reduced in the MacCall and Prager (1988) approach because onshore-offshore position and stations were not modeled. Consider, for example, a short lived environmental change that moved the California current and bocaccio larvae offshore without changing larval abundance. A model including a fixed station effect might be confused by the offshore shift unless a year by station interaction was included. To take another example, the onshore-offshore distribution of bocaccio larvae may be effected by the Channel Islands off southern California. A model with a fixed station effect might be confused by the Channel Islands unless a line by station interaction were included. In contrast, a model fit to data summarized by CalCOFI line would probably not be affected by changes in the onshore-offshore distribution of bocaccio larvae.

As described above, MacCall and Prager (1988) fit a preliminary model and then reweighted the data for each line based on the anti-logged predicted value for each line. In essence, observations with high predicted values from the preliminary model received highest weights in the final model. This was done so that lines with low predicted value would get less weight than those with high predicted value. The log transformation in equation [2] reduces the range of the differences between the highest and lowest positive observations and may tend to make them equally important in fitting a statistical model. MacCall and Prager's (1988) reweighting scheme was not used here in the log-linear index of abundance for bocaccio larvae because it runs contrary to current standard statistical practice. In standard practice with data like larval counts (i.e. with a nominal Poison distribution), observations with highest expected value (and highest variance) are given reduced weight when fitting models and estimating parameters (McCullagh and Nelder 1983). Viewed outside the context of the larval census approach, the MacCall and Prager approach seems to postulate a statistical distribution where the variance of log scale observations decreases with the mean.

GAM Index

The linear predictor for the model used to estimate the GAM index was:

$$\eta_{L,d,y,m,t} = \alpha + \lambda_1 L + \lambda_2 L^2 + \delta_1 d + \delta_2 d^2 + \Upsilon_y + \Gamma_m \qquad [3]$$

where L was the actual (not standard) CalCOFI line for tow t, d was distance from shore, and α, λ_1, λ_2, δ_1, and δ_2 were parameters estimated in the model. Distance from shore was calculated for each bongo net tow based on a list of coastal stations for standard CalCOFI lines with linear interpolation between standard lines where necessary. The GAM model, including linear predictor, was:

$$P_{L,d,y,m} = \frac{e^{\eta_{L,d,y,m,t}}}{1 + e^{\eta_{L,d,y,m,t}}} + \epsilon_{L,d,y,m,t} \qquad [4]$$

where $P_{L,d,y,m}$ was the probability that a bongo tow would be positive for bocaccio larvae and the statistical error $\epsilon_{L,d,y,m}$ was assumed to follow a binomial distribution with expected value $P_{L,d,y,m}$ and variance $P_{L,d,y,m}(1-P_{L,d,y,m})$.

The GAM model was fit to a dummy variable for presence-absence of bocaccio larvae (one if larvae present and zero otherwise) by logistic regression (Figure 5) and the index of larval abundance for bocaccio was predicted values from the model at 72 km from shore along line 80 in March of each year. Likelihood ratio tests indicated that neither more complex nor simpler models could not be justified on statistical grounds. For simplicity, interactions between factors and terms in [3] were not examined.

RALSTON Index

The RALSTON index was fit to tow-by-tow CalCOFI data aggregated by spawning year, spawning month and spatial strata corresponding to distance from shore and CalCOFI line (see below).

Distance Stratum ID	Distance (km) of Station From Shore	Line Stratum ID.	CalCOFI Line
1	$d < 50$	1	$63.3 \le L < 65$
2	$50 \le d < 100$	2	$65 \le L < 70$
3	$100 \le d < 150$	3	$70 \le L < 75$
4	$150 \le d < 200$	4	$75 \le L < 80$
5	$200 \le d < 300$	5	$80 \le L < 85$
6	$300 \le d < 500$	6	$85 \le L < 90$
		7	$90 \le L < 95$

The model for the RALSTON index was:

$$\ln(N_{L,d,y,m,t} + k) = \Lambda_L + \Xi_d + \Upsilon_y + \Gamma_m + \Lambda\Xi_{L,d} + \Lambda\Gamma_{L,m} + \Xi\Gamma_{d,m} + \epsilon_{L,d,y,m,t} \qquad [7]$$

where $N_{L,d,y,m,t}$ the standardized count (density) of larvae per unit area in tow t, Ξ_d was a distance from shore effect, and all two way interactions between distance, line and month effects ($\Lambda\Xi_{L,d}$, $\Lambda\Gamma_{L,m}$ and $\Xi\Gamma_{d,m}$) were included. For the RALSTON index, k=2 (the smallest non-zero observation in the database was 2.09). The RALSTON model was fit by least squares (Figure 6) and the index of larval abundance for bocaccio was predicted values of $D_{L,y,m}$ at standard line 80 in March of each year. Likelihood ratio tests indicated that neither more complex nor simpler models could not be justified on statistical grounds. In particular, the three way interaction between distance, line and month effects ($\Lambda\Xi\Gamma_{L,d,m}$) was not statistically significant.

DELTA Index

The DELTA index predicts the abundance of bocaccio larvae at a particular location and time as the product of the probability that a tow will be positive ($P_{L,d,y,m}$) multiplied by the

expected number of bocaccio larvae in positive tows ($Z_{d,y,m}$). The first term ($P_{L,d,y,m}$) is the same as the GAM index (see above). The second term ($Z_{d,y,m}$) gives the conditional density of bocaccio larvae in positive tows and was modeled:

$$\ln(Z_{d,y,m,t}) = \alpha + \delta_1 d + \delta_2 d^2 + \Upsilon_y + \Gamma_m + \epsilon_{d,y,m,t} \qquad [5]$$

where $Z_{d,y,m,t}$ was the number of larvae in positive tow t, and $\epsilon_{d,y,m,t}$ was a statistical error assumed to be normally distributed with constant variance. The model for density of bocaccio in positive tows was fit by least squares (Figure 7). Likelihood ratio tests indicated that neither more complex (e.g. with line effects) nor simpler models could not be justified on statistical grounds. For simplicity, interactions between factors and terms in [3] were not examined.

The DELTA index of abundance for year y was the product $\Delta_y = P_{L,d,y,m}\, Z_{d,y,m}$ with terms on the right hand side calculated for a tow 72 km from shore along line 80 in March of each year. The variance of the DELTA index (Lo et al. 1992) was approximated:

$$Var(\Delta_y) = P_y^2\, Var(Z_y) + Z_y^2\, Var(P_y) + 2\, P_y\, Z_y\, Cov(Z_y, P_y) \qquad [6]$$

where Var() is a variance and Cov() is a covariance. The covariance of Z_y an P_y was approximated from the correlation of Z_y and P_y *among* years and the *within-year* standard deviation of Z_y and P_y (Appendix 1 in Lo et al. 1992).

Results and Discussion

The MACCALL&PRAGER, GAM and RALSTON models indicate that larval abundance reaches a peak around CalCOFI line 80, at about 100 km from shore and during March (figures 4-6). Results from the model for number of bocaccio larvae in positive tows ($Z_{d,y,m}$, used to compute the DELTA index), also indicate highest abundances about 100 km offshore but show a flat seasonal peak around January (Figure 7).

The RALSTON (CV 16%-22%), GAM (CV's 10%-42%) and DELTA (CV's 18%-63%) indices were much more precise than the MacCall and Prager index (CV's 64%-140%, Table 1). The precision of all indices was related to sample size with lowest sample sizes giving lowest precision and highest CV's. The covariance term in the estimator for the variance of the DELTA index (eqn. [6]) was assumed to be zero because the correlation of Z_y and P_y among years was negative (Table 2).

All indices indicate low to moderate larval abundance for bocaccio rockfish during the middle 1950's (Figure 8). Data for additional years during the 1950's are not available but Figure 14 in Moser (1967) indicates that larval abundance for bocaccio during 1953 was similar or greater than larval abundance during 1956-1957. Thus, the mid-1950's may have been a period of low to moderate larval abundance for bocaccio rockfish.

Indices of larval abundance for bocaccio did not give consistent information about annual trends during 1969-1984 (Figure 9). The MACCALL&PRAGER, GAM and RALSTON indices indicate that bocaccio larval abundance declined during 1969-1984 while the DELTA and GAM indices indicate that larval abundance increased. None of the trends in time were, however, statistically significant (the null hypothesis of no change over time was tested by regression of log abundance on spawning year). Correlations among the various indices (other than with $Z_{d,y,m}$) were positive (Table 2) but correlations among the MACCALL&PRAGER, RALSTON and GAM indices were higher than correlations involving the DELTA index.

The GAM index of larval abundance for bocaccio may have been affected by "saturation" when bocaccio larvae were abundant. Saturation in presence-absence data is a potential problem when larvae are common because almost all tows may become positive (at least one larvae taken) and the index becomes less sensitive to further increase in abundance (Deriso et al., in press.). There was evidence of saturation when the GAM index was plotted against MACCALL&PRAGER but no evidence of saturation when the GAM index was plotted against RALSTON (Figure 10). The apparent nonlinearity and saturation indicated by the plot of the GAM and MACCALL&PRAGER indices may have been due imprecision (high CV's, Table 1) and large positive measurement errors in the two highest values of the MACCALL&PRAGER index.

Simulation studies (Myers and Pepin 1990) indicate that estimates based on the delta log normal distribution may be biased when positive observations do not follow the log normal distribution exactly. It is not clear how the results in Myers and Pepin (1990) apply to estimated trends in the DELTA index for bocaccio larvae, but the distribution of log scale residuals from the model for larval density in positive tows ($Z_{d,y,m}$) was skewed to the right (Figure 11) and not precisely normal. Thus, the DELTA index may have been affected by bias and other statistical problems.

Effects from Changes in Sampling Gear

It is important to determine if changes in sampling gear (Table 3) might have affected estimated trends in abundance of bocaccio larval. Bocaccio larvae were collected during spawning years 1956-1957 with 1 m silk ring nets (mesh size 0.55 mm) towed obliquely from a depth of 140 m. Data for spawning years 1969-1976 were collected with 1 m nylon ring nets (mesh size 0.505 mm) towed obliquely from 210 m. Data for spawning years 1978-1984 were collected with 0.71 m nylon bongo nets (mesh size 0.505 mm) towed obliquely from 210 m.

Changes in the size of the net frame and volume of water filtered when ring nets were replaced with bongo nets in 1978 probably had minimal effects because these factors were included in calculation of the standardized larval counts used in our models (Stevens et al. 1990). Ring nets, however, had a three cable bridle and may have been less efficient (particularly for large, mobile larvae) than bongo nets which were pulled by a single cable (Smith and Richardson 1977). Differences in efficiency exist between bongo and ring nets (with the same mesh size) for northern anchovy (*Engraulis mordax*) eggs but data are not available for anchovy larvae (Lo 1983). Thus, estimated bocaccio abundance may have been effected by the change from ring to bongo nets in 1978. Less efficient sampling prior to 1978 would have resulted in underestimation of larval abundance.

Changes in depth from 140 m to 210 m in 1969 (Table 3) probably had minimal effects because rockfish (Sebastes spp.) larvae are usually found near the thermocline which is shallower than 140 m. Ahlstrom (1959) and Moser and Boehlert (1991) report that rockfish larvae were seldom taken below 120 m.

Changes in net material and mesh size in 1969 (Table 3) probably had little effect on catches of bocaccio larvae and trends in estimated larval abundance. Differences in sampling efficiency between 0.55 mm silk and 0.505 mm nylon mesh were small for northern anchovy (Lo 1983). Length data (Figure 12) were available for bocaccio larvae taken during some months of spawning years 1955 (n=13), 1956 (n=84), 1968 (n=25), 1969 (n=829) and 1975 (n=135). According to Moser (1967), bocaccio larvae are 4-5 mm at parturition (when released from their mothers). Some bocaccio larvae in our analysis were smaller than 4 mm (Figure 10) due, presumably, to shrinkage in formaldehyde and handling (G. Moser, Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA, 92038, pers. comm.). There were no clear differences between the lengths of bocaccio larvae collected using different mesh or gear although larvae collected during January of 1956 were consistently smaller than during other years (Figure 13).

Future Work

Models used to estimate the GAM indices of larval abundance for bocaccio rockfish did not include interaction terms between factors and covariates (e.g. spawning month and distance from shore) that may have been significant although plots in Moser et al. (1993, bottom of p. 92) indicate that interactions exist. MacCall and Prager (1988) fit models with and without interaction terms and found that interactions had little effect on annual abundance indices but interactions remain an area for future improvements.

For comparison, the GAM index was computed again using only data for the relatively small current (1985-present) CalCOFI sampling pattern. The current pattern extends from CalCOFI lines 76.7 (Point Conception) to line 93.3 (US-Mexican border). Results (tables 1-2 and figures 8-9) were similar to results from the original GAM model. This suggests that it will be possible to produce a useful index of larval abundance for *current* and historical bocaccio larval abundance once the CalCOFI database is brought up to date.

Appropriate measures of uncertainty for CalCOFI need to be developed. CV's for abundance indices in Table 1 were computed for the predicted values (fitted lines) at 72 km from shore along line 80 in March of each year (see above). It is also possible to compute CV's for other times and areas or for year effect parameters *per se* (i.e. without adjusting to a specific location or time of year) which are generally smaller than the CV's in Table 1.

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References

Ahlstrom, E. H. 1959. Vertical distribution of pelagic fish eggs and larvae off California and Baja California. Fish. Bull. (U.S.) 60: 103-160.

Barnes, J. T., L. D. Jacobson, A. D. MacCall, and P. Wolf. 1992. Recent population trends and abundance estimates for the Pacific sardine (Sardinops sagax). Calif. Coop. Ocean. Fish. Invest. Rep. 33: 60-75.

Bence, J. R., and J. B. Rogers. 1992. Status of bocaccio in the Conception/Monterey/Eureka areas in 1992 and recommendations for management in 1993. *In:* Pacific Fishery Management Council. Status of the Pacific coast groundfish fishery through 1992 and recommended acceptable biological catches for 1993, Appendix B. Portland, OR.

Berry, D.A. 1987. Logarithmic transformations in log normal linear models. J. Am. Stat. Assoc. 65: 198-211.

Deriso, R. B., J. T. Barnes, L. D. Jacobson, and P. J. Arenas. In press. Catch-at-age analysis for Pacific sardine (Sardinops sagax), 1983-1995. Calif. Coop. Ocean. Fish. Invest. Rep.

Haberman, S. 1974. Log-linear models for frequency tables derived by indirect observation: maximum likelihood equations. Annals of Statistics 2: 911-924.

Hewitt, R. P. 1988. Historical review of the oceanographic approach to fishery research. Calif. Coop. Oceanic Fish. Invest. Rep. 29: 27-41.

Jacobson, L. D., N. C. H. Lo, and J. T. Barnes. 1994. A biomass-based assessment model for northern anchovy, Engraulis mordax. Fish. Bull., U.S. 92: 711-724.

Lo, N.C.H. 1983. Re-estimation of the three parameters associated with anchovy egg and larval abundance: temperature dependent incubation time, yolk-sac growth rate and egg and larval retention in mesh nets. NOAA Tech. Mem. NOAA-TM-NMFS-SWFC-31: 33p.

Lo, N.C.H., L. D. Jacobson, and J. L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49: 2515-2526.

MacCall, A. D., and M. H. Prager. 1988. Historical changes in abundance of six fish species off southern California, based on CalCOFI egg and larva samples. Calif. Coop. Oceanic Fish. Invest. Rep. 29: 81-101.

MacCall, A. 1995. Bocaccio update -- progress report (May 26, 1995). Southwest Fisheries Science Center, Tiburon Laboratory, National Marine Fisheries Service, 3150 Paradise Drive, Tiburon, CA, 94920. Unpublished report.

MacGregor, J. S. 1986. Relative abundance of four species of Sebastes off California and Baja California. Calif. Coop. Oceanic Fish. Invest. Rep. 27: 121-135.

Mangel, M., and P. Smith. 1990. Presence-absence sampling for fisheries management. Can. J. Fish. Aquat. Sci. 47:1875-1887.

McCullagh, P., and J. A. Nelder. 1983. Generalized linear models. Chapman and Hall, New York.

Moser, H. G. 1967. Reproduction and development of *Sebastodes paucispinis* and comparison with other rockfishes off southern California. Copeia 1967(4): 773-797.

Moser, H. G., and G. W. Boehlert. 1991. Ecology of pelagic larvae and juveniles of the genus *Sebastes*. Env. Biol. Fish. 30: 203-224.

Moser, H. G., R. L. Charter, P. E. Smith, D. A. Ambrose, S. R. Charter, C. A. Meyer, E. M. Sandknop, and W. Watson. 1993. Distributional atlas of fish larvae and eggs in the California Current region: Taxa with 1000 or more total larvae, 1951 through 1984. Calif. Coop. Oceanic Fish. Invest. Rep. Atlas 31: 233 p.

Myers, R.A., and P. Pepin. 1990. The robustness of lognormal-based estimators of abundance. Biometrics 46: 1185-1192.

Pennington, M. 1983. Efficient estimators of abundance for fish and plankton surveys. Biometrics 39: 281-286.

Smith, P.E. 1972. The increase in spawning biomass of northern anchovy, *Engraulis mordax*. U.S. Fish. Bull. 70: 849-874.

Smith, P. E. 1990. Monitoring interannual changes in spawning area of Pacific sardine (Sardinops sagax). Calif. Coop. Ocean. Fish. Invest. Rep. 31: 145-151.

Smith, P. S., and S.L. Richardson. 1977. Standard techniques for pelagic fish egg and larva surveys. FAO Fish. Tech. Paper No. 175: 99p.

Stevens, E. G., R. L. Charter, H. G. Moser, and C. A. Meyer. 1990. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1994. NOAA Tech. Mem. NMFS NOAA-TM-NMFS-SWFC-141: 157 p.

Table 1. Indices of larval abundance for bocaccio rockfish from CalCOFI data with coefficients of variation (CV), the number of units (lines or tows) sampled and number of units positive for bocaccio rockfish. The MACCALL&PRAGER, DELTA and RALSTON indices have units of larvae per unit area. The GAM index has units of probability of bocaccio larvae occurring in a bongo net tow. "GAM-Current Grid" is similar to GAM except that it was estimated from data for the relatively small, current CalCOFI sampling grid (see text). $Z_{d,y,m}$ is the conditional density of bocaccio larvae in positive tows and was used to compute the DELTA index (see text). CV's are for predicted larval abundance at 72 km from shore along line 80 in March of each year.

Year	MacCall & Prager	CV	Num. Lines	Num. Pos. Lines	GAM	CV	Num. Tows	Num. Pos. Tows	GAM-Current Grid	CV	Num. Tows	Num. Pos. Tows	$Z_{d,y,m}$	CV	DELTA	CV	RALSTON	CV
1956	2.71	71%	26	17	0.41	23%	157	23	0.39	23%	133	22	9.32	22%	3.81	32%	1.89	17%
1957	2.61	127%	5	4	0.46	42%	35	5	0.40	45%	35	5	4.47	47%	2.08	63%	1.37	22%
1969	46.9	74%	28	27	0.70	10%	274	98	0.68	12%	173	56	11.9	16%	8.30	19%	4.14	17%
1970	0.70	103%	11	4	0.30	47%	95	7	0.40	40%	57	7	4.98	41%	1.50	62%	1.54	19%
1972	16.1	71%	22	22	0.62	11%	219	82	0.58	14%	115	38	9.41	14%	5.87	18%	2.97	17%
1975	4.90	68%	33	26	0.40	15%	392	71	0.35	18%	297	48	15.8	13%	6.29	20%	2.05	16%
1976	63.4	140%	4	4	0.63	23%	50	12	0.57	26%	50	12	11.3	34%	7.09	41%	2.99	21%
1978	2.31	66%	37	22	0.32	20%	327	41	0.31	23%	236	28	14.4	16%	4.64	26%	1.73	16%
1981	6.25	70%	43	27	0.43	19%	390	51	0.44	22%	214	31	14.9	19%	6.39	27%	2.19	17%
1984	1.07	64%	44	18	0.31	23%	254	30	0.32	27%	139	18	12.9	18%	3.98	29%	1.56	17%

Table 2. Correlation between larval abundance indices for bocaccio rockfish listed in Table 1.

	MACCALL &PRAGER	GAM	GAM-Current Grid	$Z_{d,y,m}$	DELTA	RALSTON
MACCALL &PRAGER	1.00	0.82	0.81	0.10	0.69	0.81
GAM		1.00	0.95	-0.03	0.70	0.90
GAM-Current Grid			1.00	-0.12	0.63	0.92
$Z_{d,y,m}$				1.00	0.68	0.23
DELTA					1.00	0.84
RALSTON						1.00

Table 3. Sampling gear and procedures for bocaccio larvae taken during CalCOFI cruises (Moser et al. 1993).

Years	Net Frame	Net Material	Mesh Size (mm)	Target Haul Depth (m)	Mean Volume Filtered / m depth (m^3)
1951-1968	1 m ring	silk bolting cloth	0.55	140	3.6
1969-1975	1 m ring	nylon	0.505	210	3.3
1978-1984	0.71 m bongo	nylon	0.505	210	2.0

Figure 1. CalCOFI line and station plan.

Figure 2. CalCOFI bongo tows used to estimate larval abundance for bocaccio rockfish by cruise, line and station. Lines are plotted from line 60 in the north (top) to line 90 in the south (bottom) but stations are plotted in reverse order with western (inshore) stations on the right.

Figure 3. CalCOFI bongo tows positive for bocaccio rockfish by cruise, line and station. Lines are plotted from line 60 in the north (top) to line 90 in the south (bottom) but stations are plotted in reverse order with western (inshore) stations on the right.

Figure 4. MACCALL&PRAGER (log-linear) model fit to bocaccio data.

Figure 5. GAM (presence-absence) model fit to bocaccio data.

Figure 6. RALSTON (log-linear) model fit to bocaccio data.

Figure 7. Log-linear model fit to the number (density) of bocaccio larvae in positive tows.

Figure 8. Indices of larval abundance for bocaccio rockfish during the 1956-1984 spawning years. Straight lines are from regressions of log(index) on spawning year. None of the regressions were statistically significant.

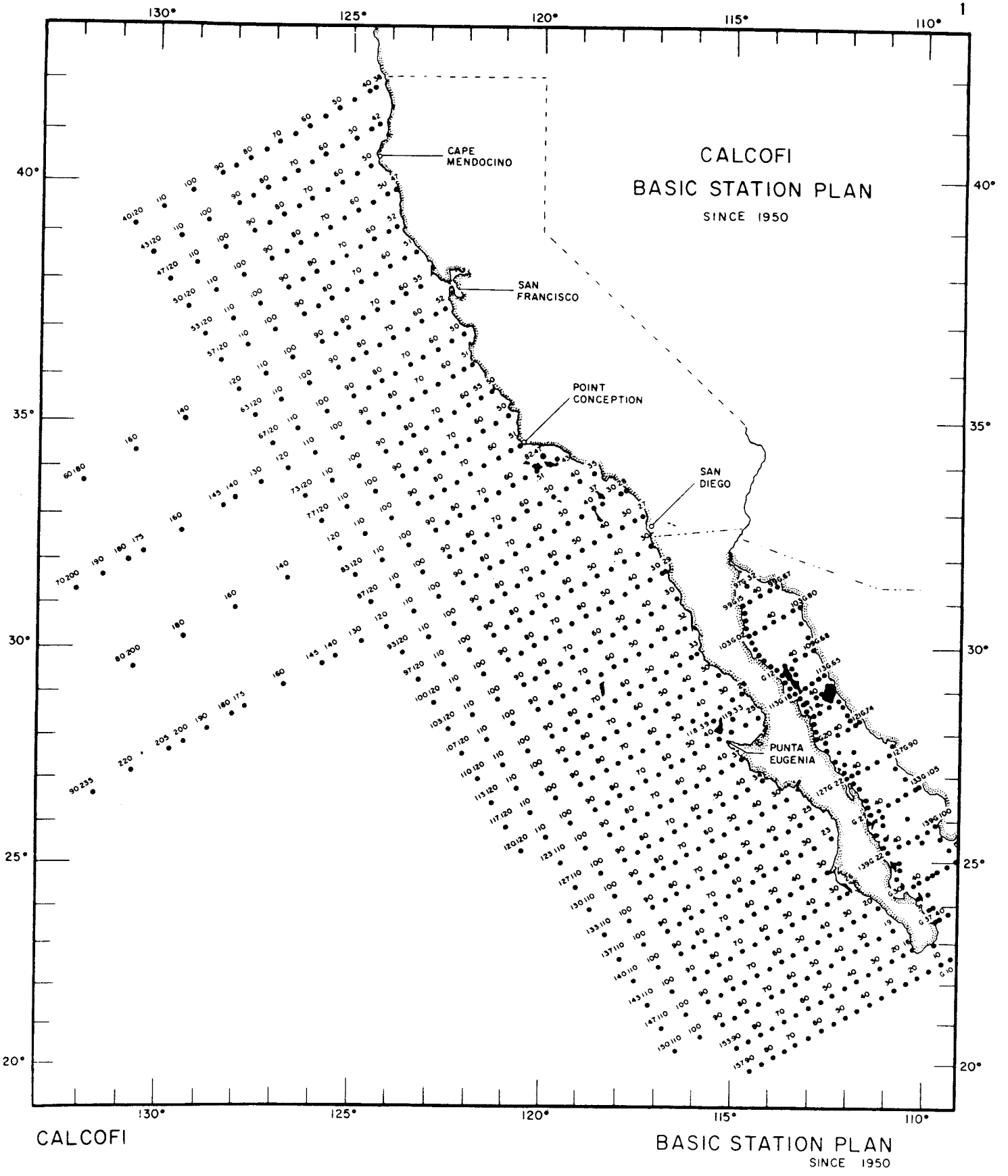
Figure 9. Indices of larval abundance for bocaccio rockfish during the 1969-1984 spawning years. Straight lines are from regressions of log(index) on spawning year. None of the regressions were statistically significant.

Figure 10. GAM abundance index for bocaccio rockfish plotted against the MACCALL&PRAGER index (top) and against the RALSTON index (bottom).

Figure 11. Log scale residuals from the log-linear model fit to positive tows for bocaccio.

Figure 12. Lengths (after preservation) of 1,068 bocaccio larvae collected during spawning years 1955, 1956, 1968, 1969 and 1975 (a few larvae longer than 9.5 mm were omitted from the plot).

Figure 13. Lengths (after preservation) of bocaccio larvae by spawning year and month.



CALCOFI BASIC STATION PLAN SINCE 1950

Figure 1.

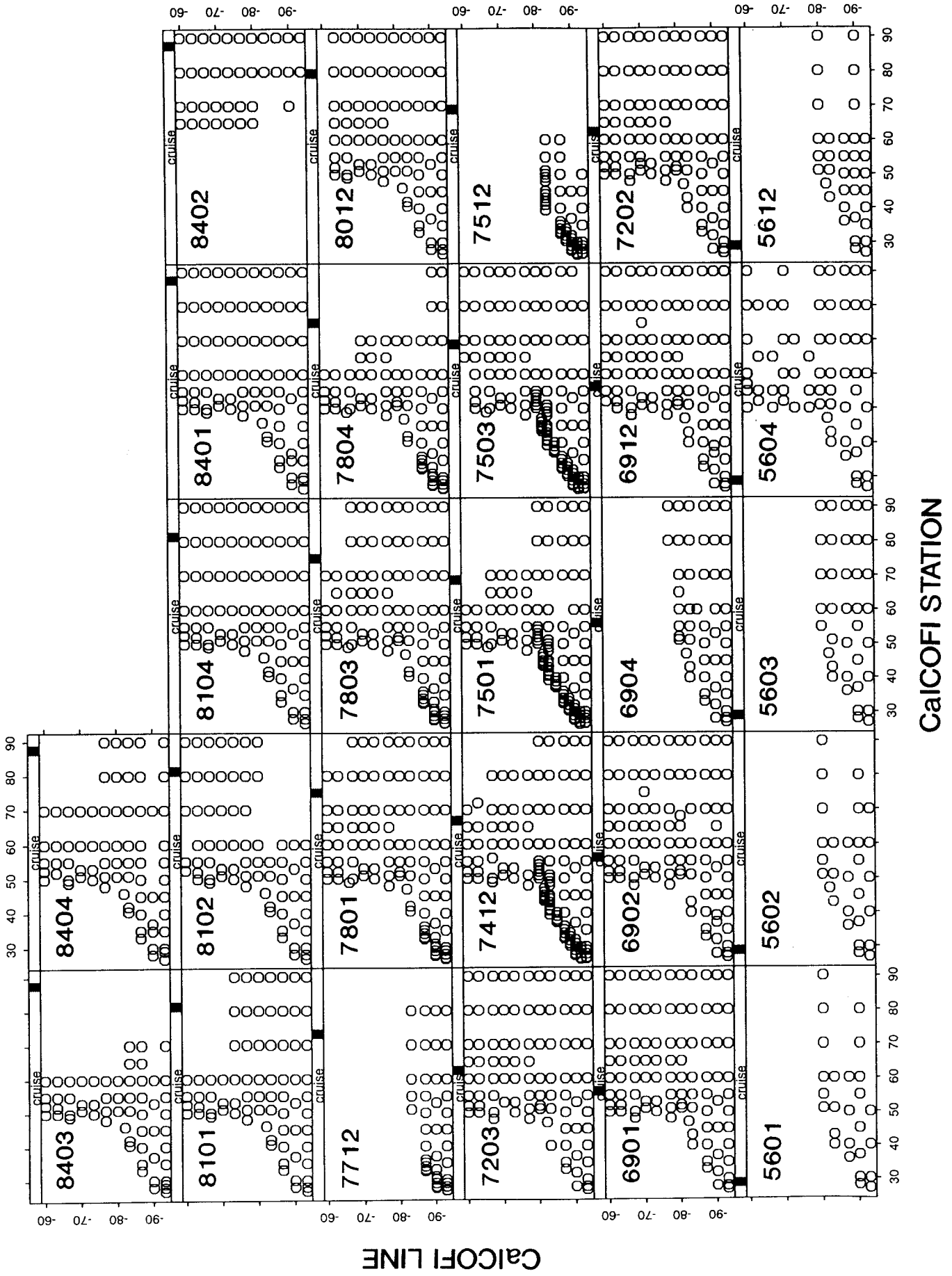

8403
8404
8101
8102
7712
7801
7203
7412
6901
6902
5601
5602
8104
8401
8402
7803
7804
8012
7501
7503
7512
6904
6912
7202
5603
5604
5612
cruise
CalCOFI LINE
CalCOFI STATION

Figure 2.

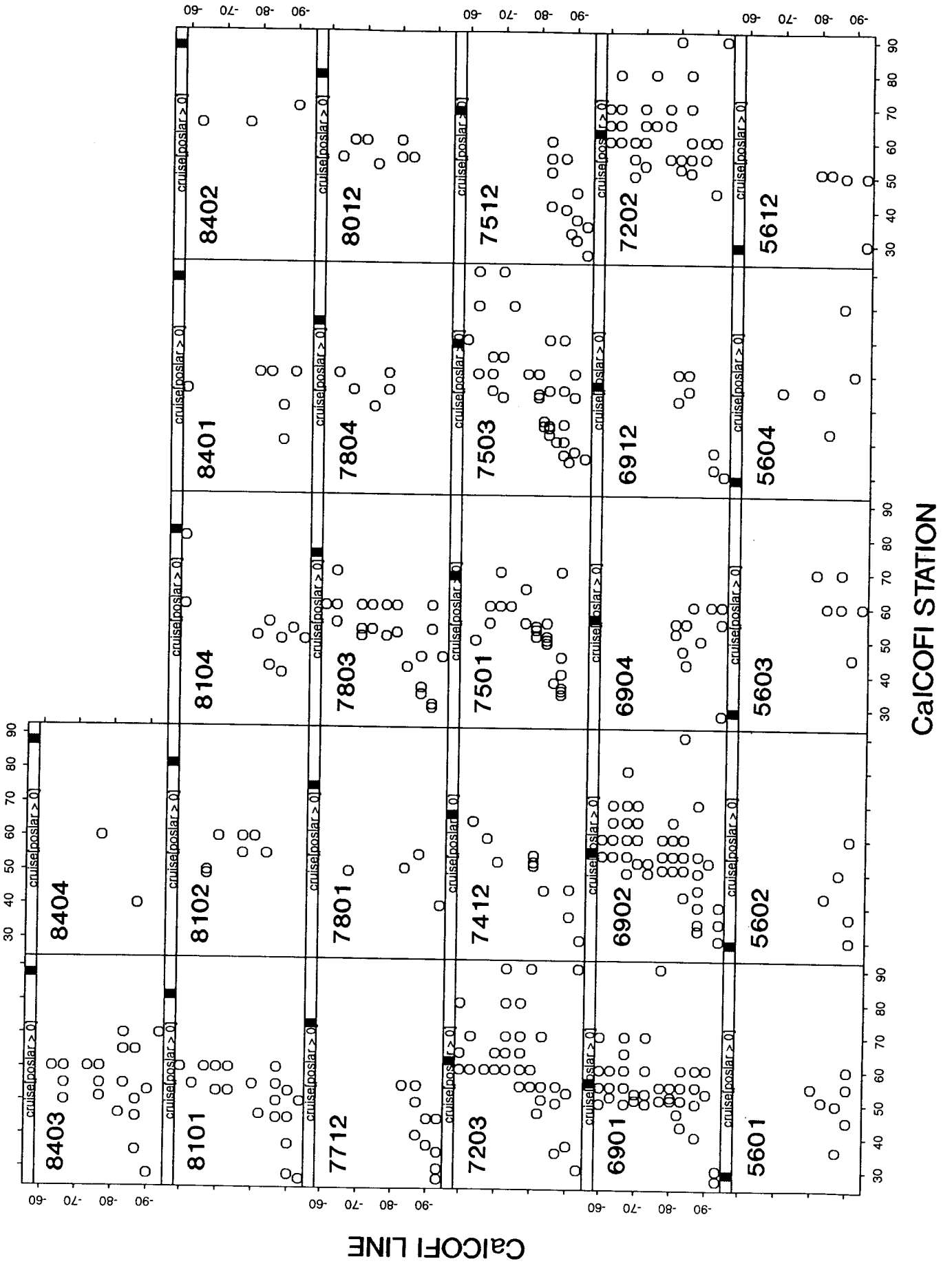

CalCOFI STATION
CalCOFI LINE
8403
8404
8101
8102
8104
8401
8402
7712
7801
7803
7804
8012
7203
7412
7501
7503
7512
6901
6902
6904
6912
7202
5601
5602
5603
5604
5612
cruise[poslar > 0]

Figure 3.

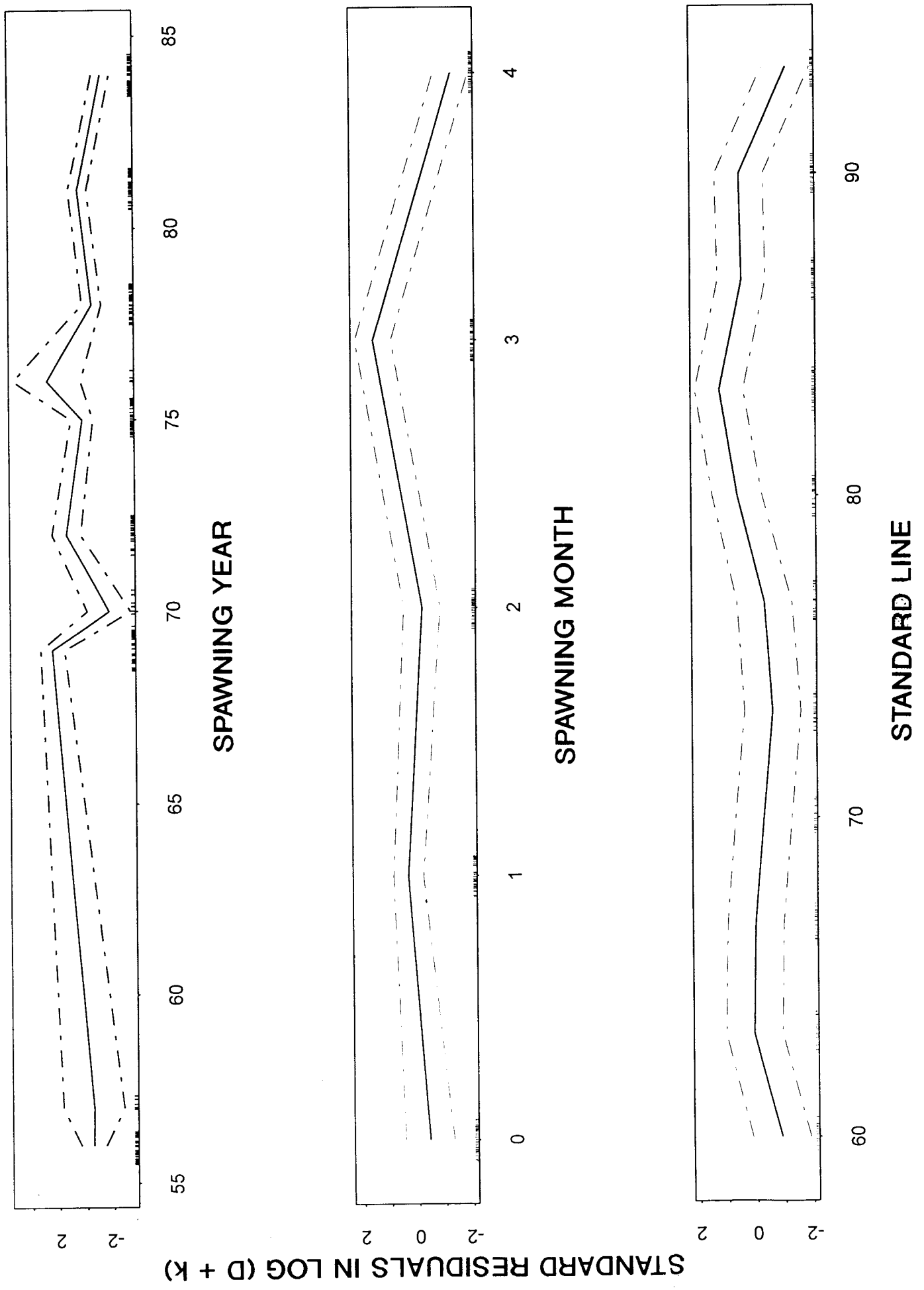

STANDARD RESIDUALS IN LOG (D + K)
2
-2
55
60
65
70
75
80
85
SPAWNING YEAR
0
1
2
3
4
SPAWNING MONTH
60
70
80
90
STANDARD LINE

Figure 4.

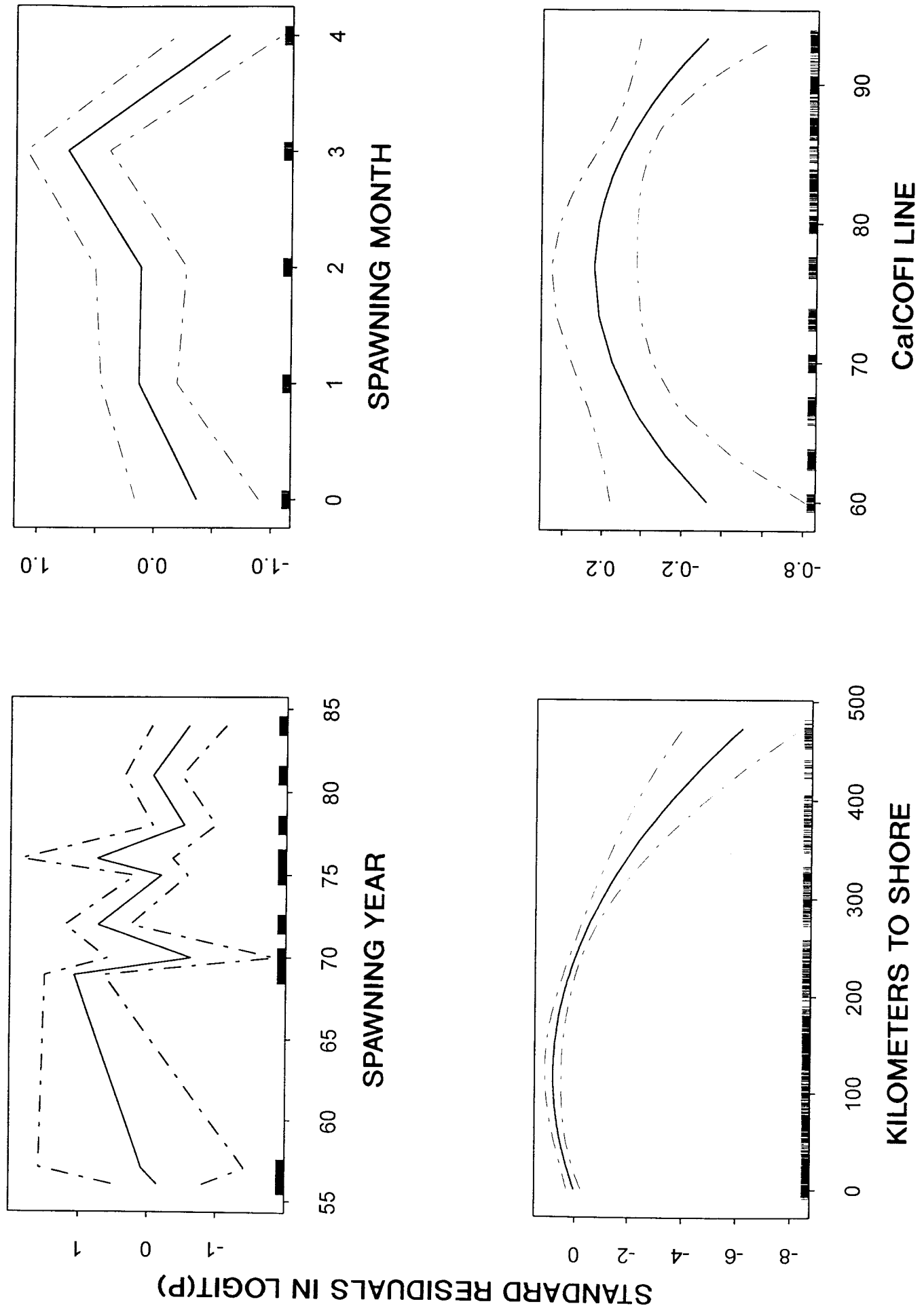

STANDARD RESIDUALS IN LOGIT(P)
SPAWNING YEAR
SPAWNING MONTH
CalCOFI LINE
KILOMETERS TO SHORE

Figure 5.

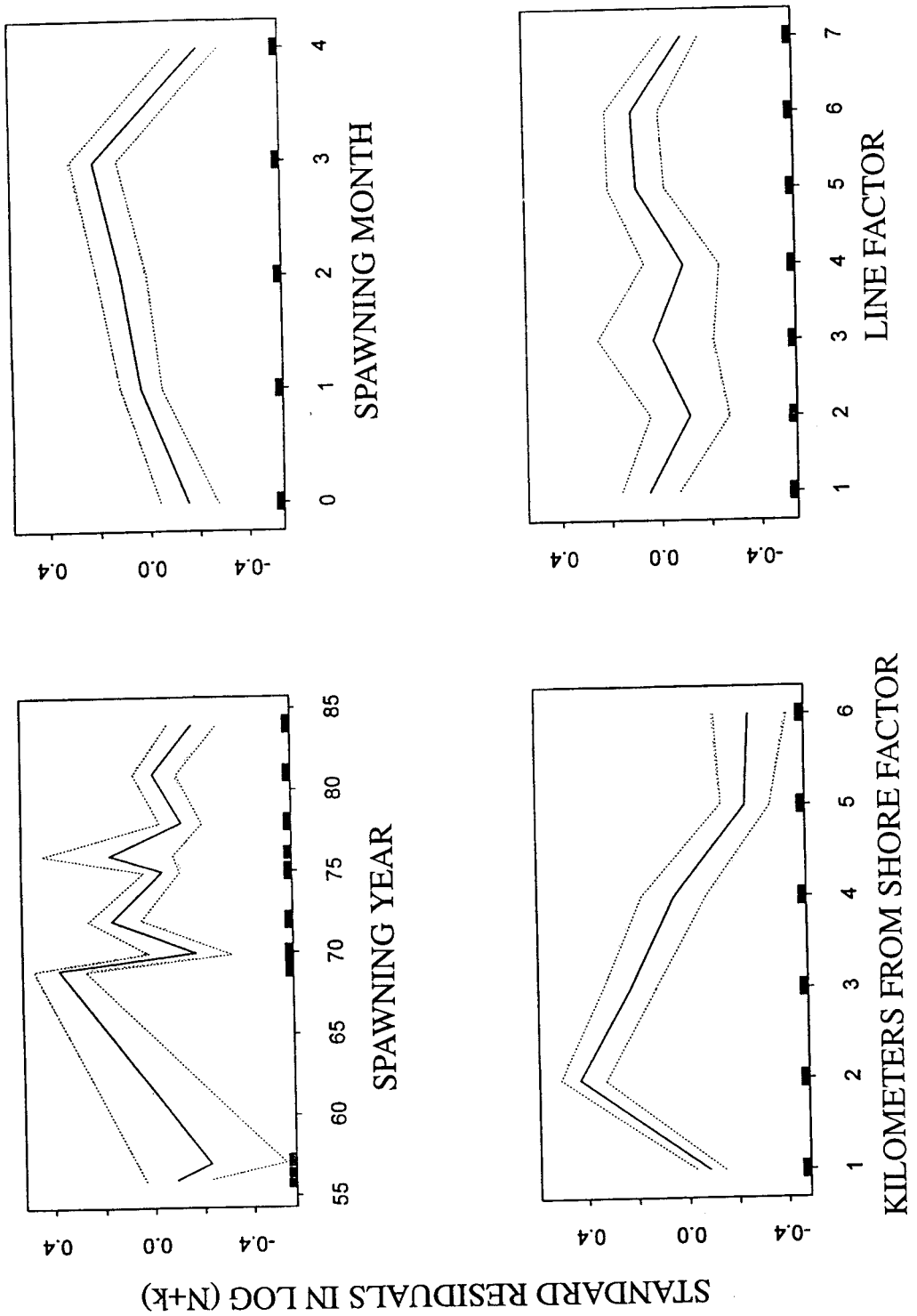

STANDARD RESIDUALS IN LOG (N+k)
0.4
0.0
-0.4
55
60
65
70
75
80
85
SPAWNING YEAR
0
1
2
3
4
SPAWNING MONTH
1
2
3
4
5
6
KILOMETERS FROM SHORE FACTOR
1
2
3
4
5
6
7
LINE FACTOR

Figure 6.

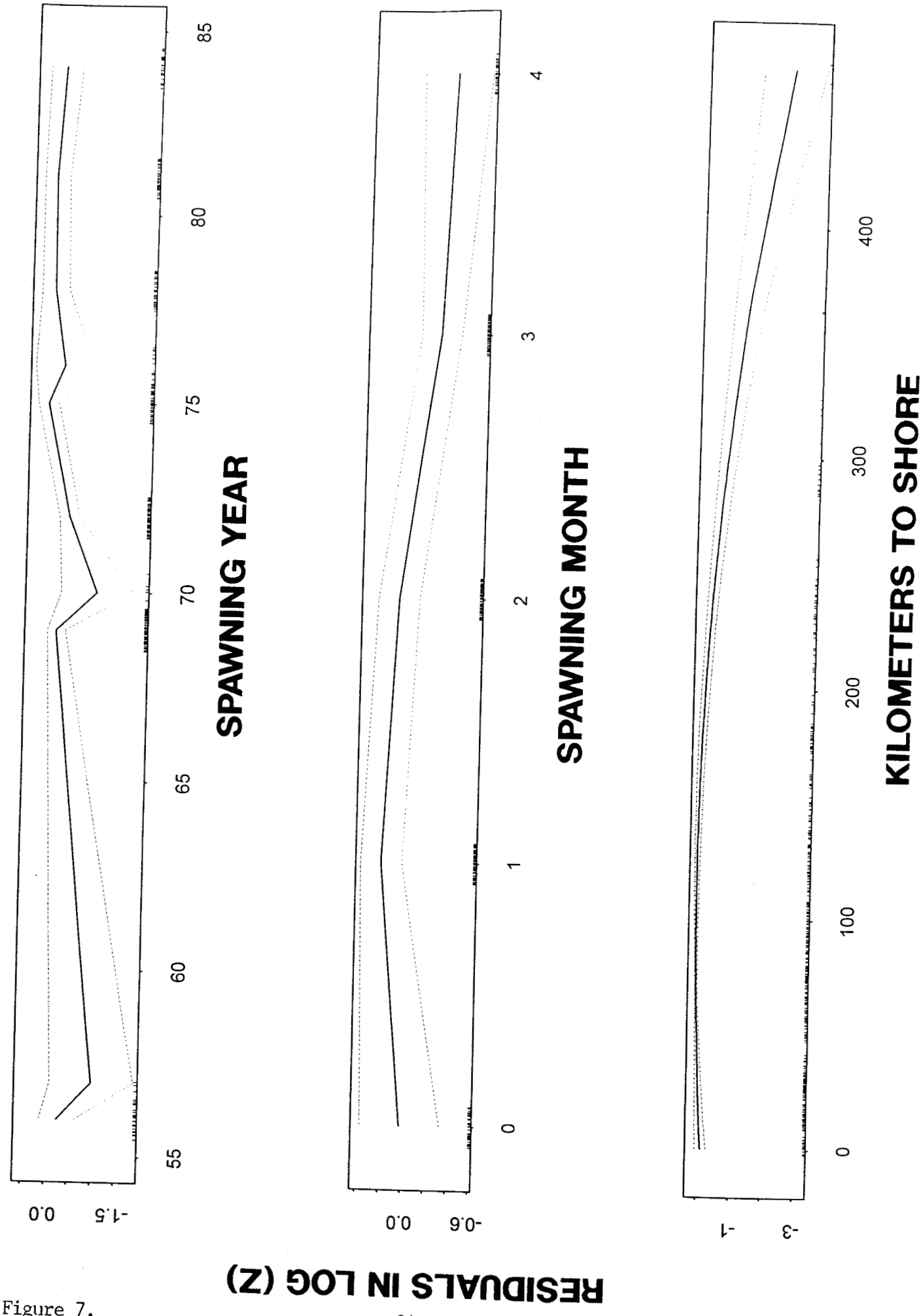

RESIDUALS IN LOG (Z)
-1.5
0.0
55
60
65
70
75
80
85
SPAWNING YEAR
-0.6
0.0
0
1
2
3
4
SPAWNING MONTH
-3
-1
0
100
200
300
400
KILOMETERS TO SHORE

Figure 7.

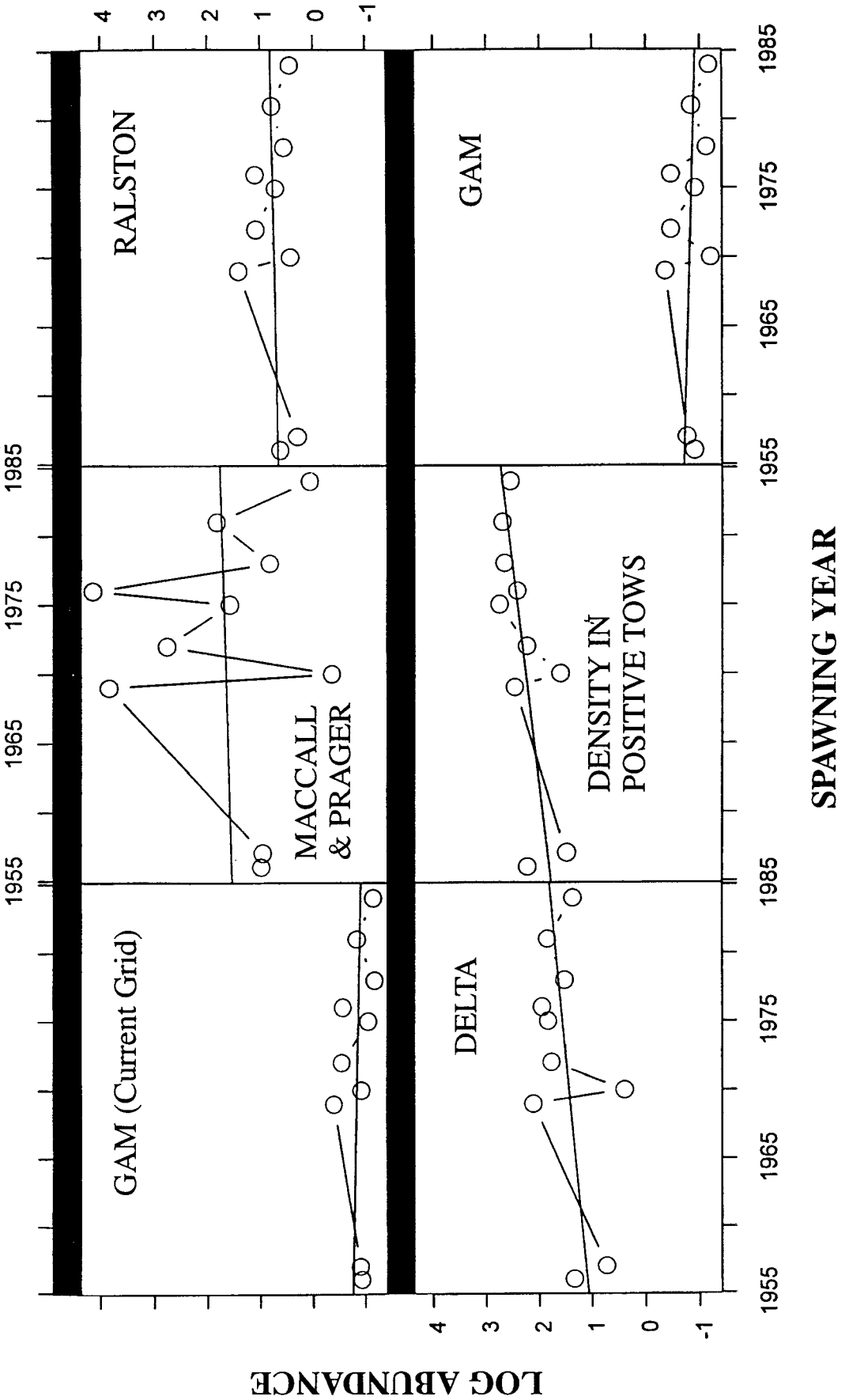

GAM (Current Grid)
MACCALL & PRAGER
RALSTON
DELTA
DENSITY IN POSITIVE TOWS
GAM
LOG ABUNDANCE
SPAWNING YEAR
1955
1965
1975
1985
-1
0
1
2
3
4

Figure 8.

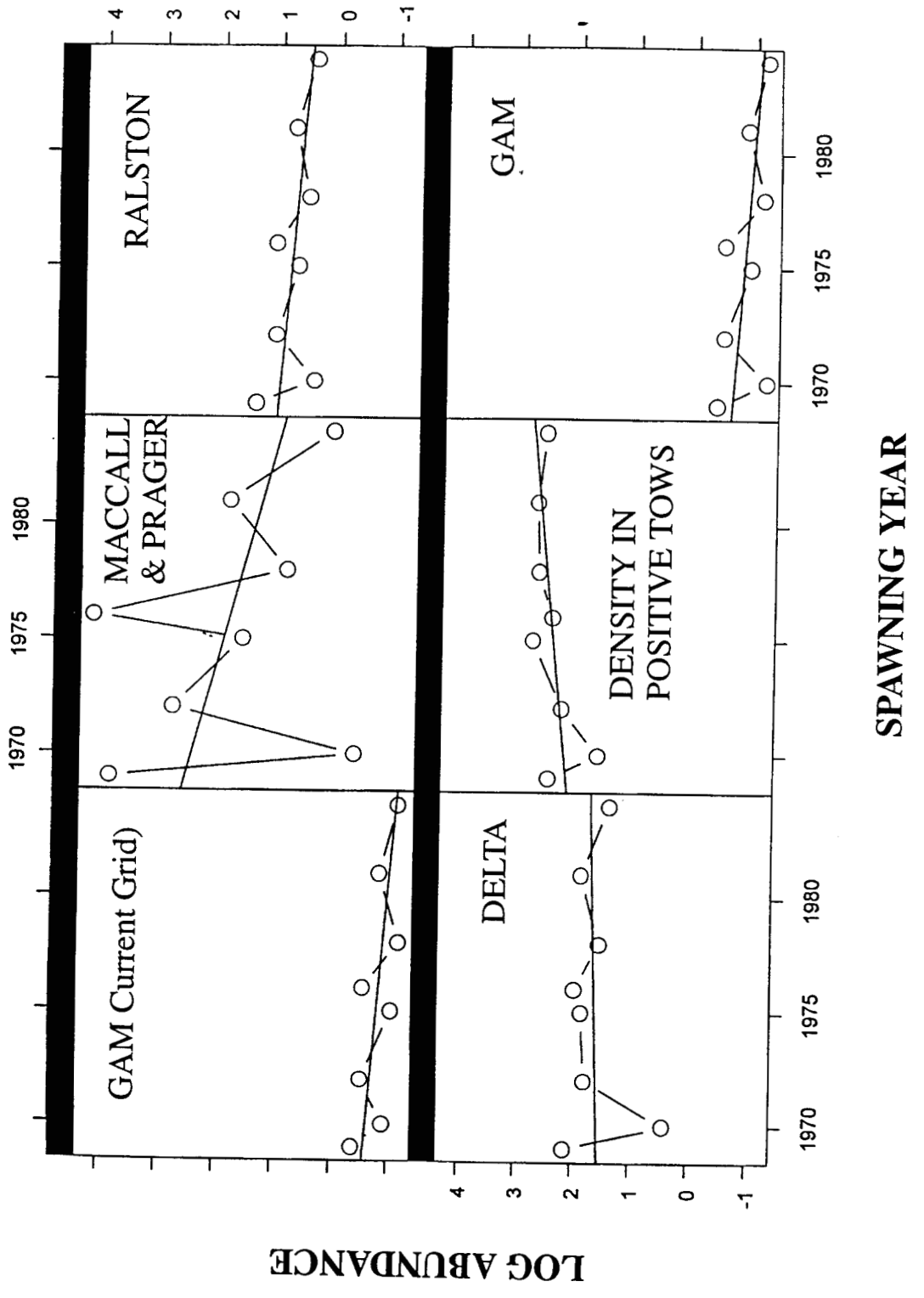

GAM Current Grid)
MACCALL & PRAGER
RALSTON
DELTA
DENSITY IN POSITIVE TOWS
GAM
1970
1975
1980
4
3
2
1
0
-1
LOG ABUNDANCE
SPAWNING YEAR

Figure 9.

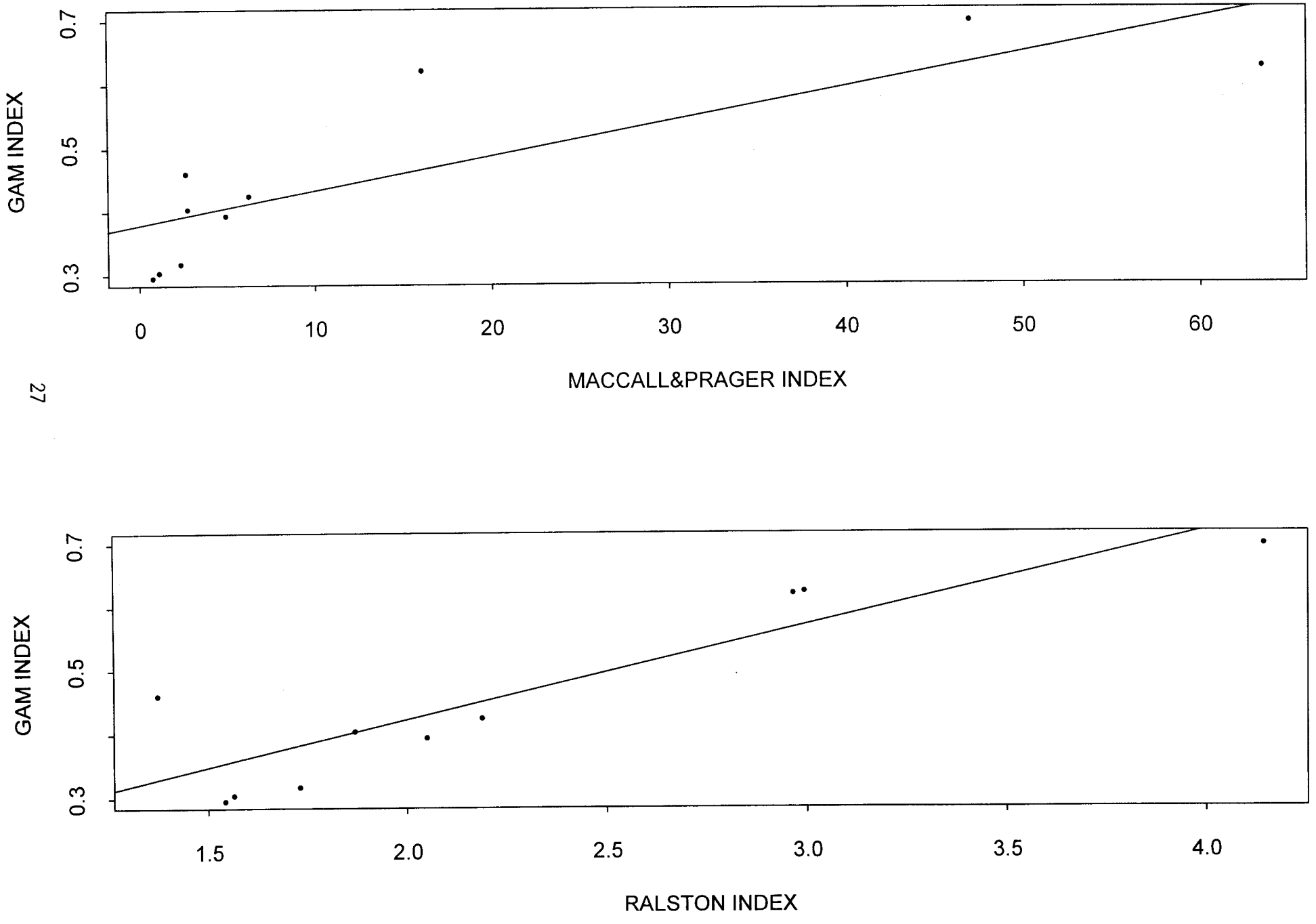

GAM INDEX
0.3
0.5
0.7
0
10
20
30
40
50
60
MACCALL&PRAGER INDEX
GAM INDEX
0.3
0.5
0.7
1.5
2.0
2.5
3.0
3.5
4.0
RALSTON INDEX

Figure 10.

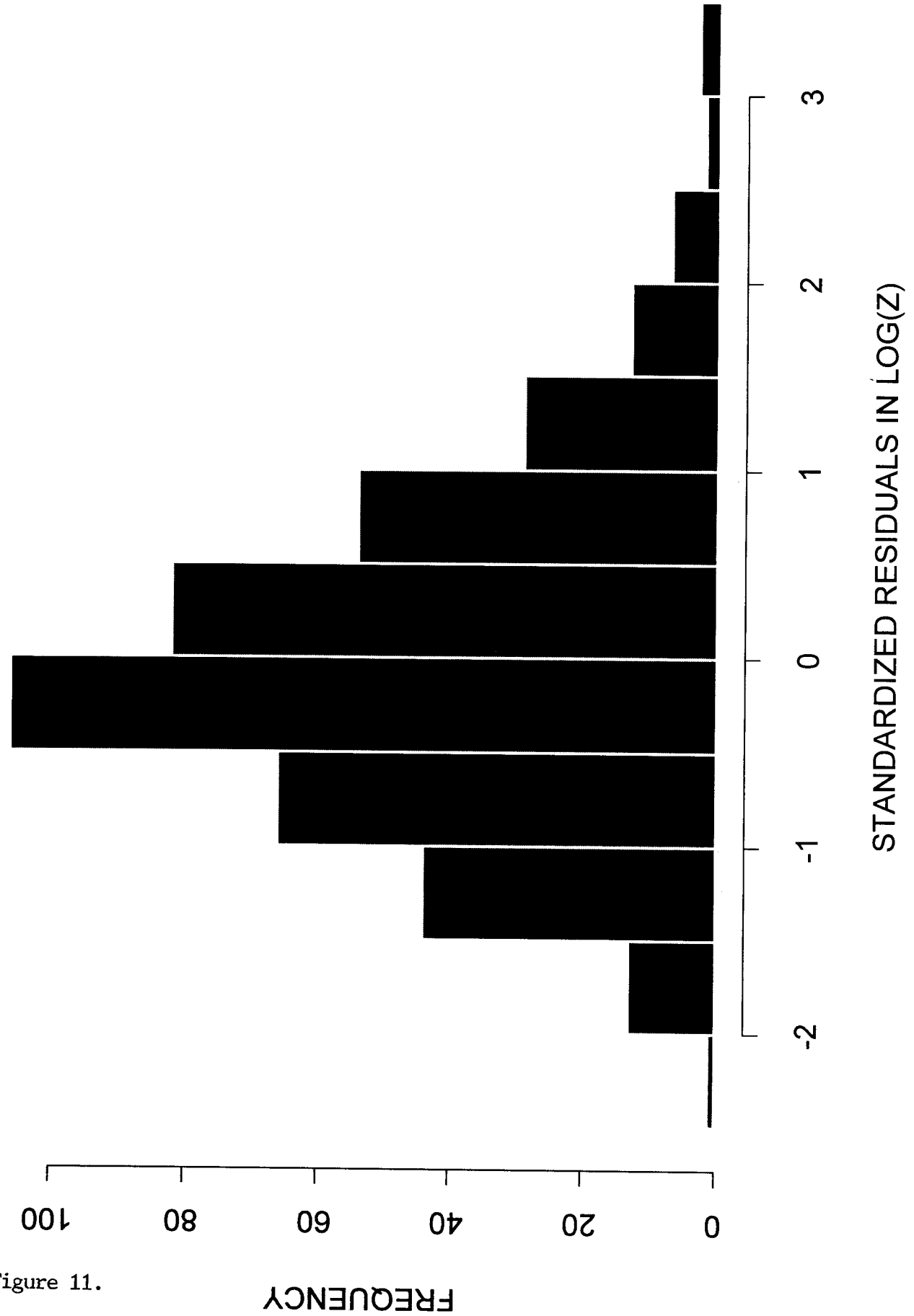

FREQUENCY
0
20
40
60
80
100
-2
-1
0
1
2
3
STANDARDIZED RESIDUALS IN LOG(Z)

Figure 11.

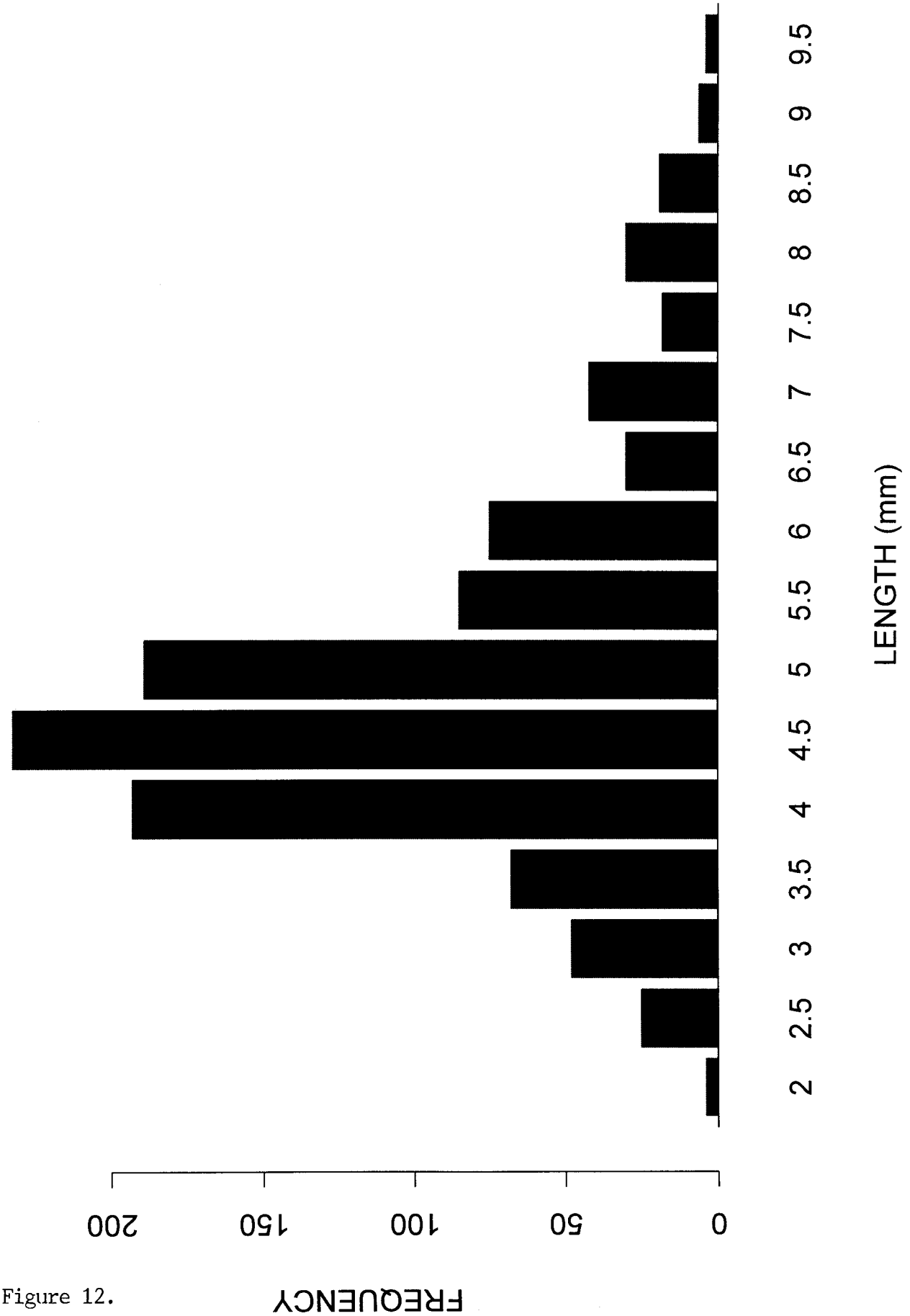

FREQUENCY
0
50
100
150
200
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
LENGTH (mm)

Figure 12.

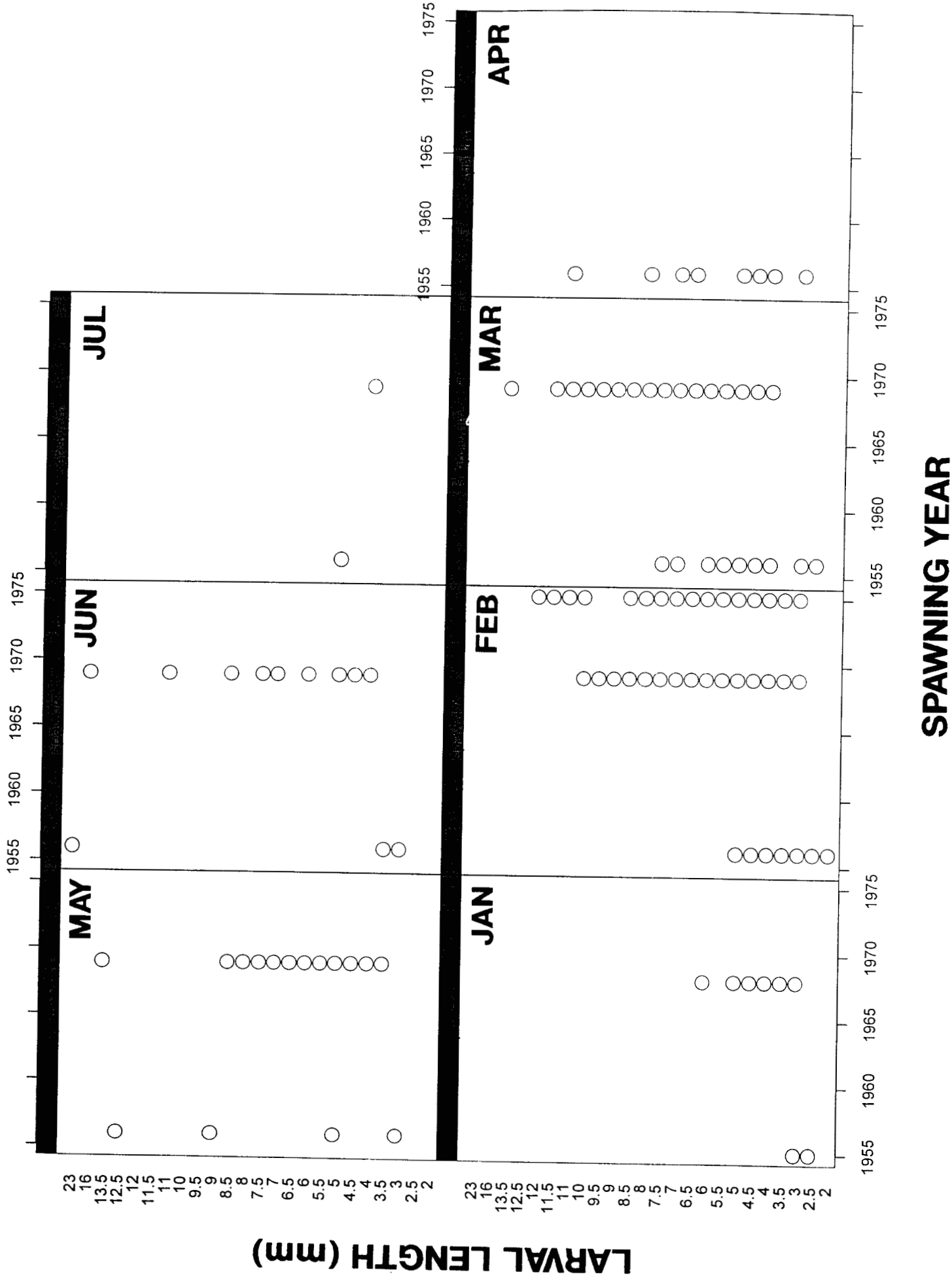

MAY
JUN
JUL
JAN
FEB
MAR
APR
1955
1960
1965
1970
1975
23
16
13.5
12.5
12
11.5
11
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
LARVAL LENGTH (mm)
SPAWNING YEAR

Figure 13.