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Evaluation of spatial/temporal sources of variation in Nekton catch and the efficacy of stratified sampling in the Chesapeake Bay : final report for CBSAC V to Chesapeake Bay Stock Assessment Committee and the National Marine Fisheries Service, NOAA

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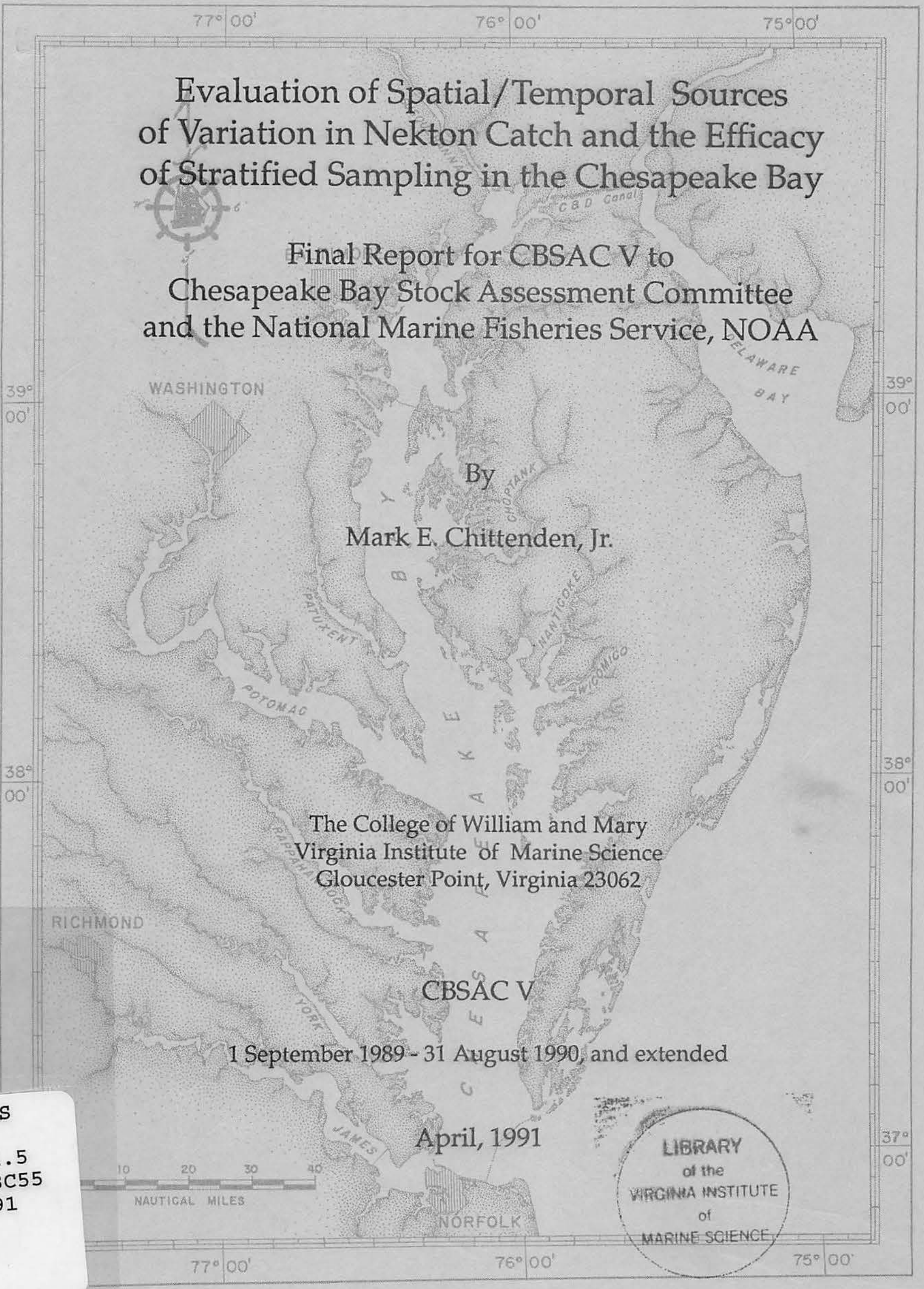

Evaluation of Spatial/Temporal Sources of Variation in Nekton Catch and the Efficacy of Stratified Sampling in the Chesapeake Bay

Final Report for CBSAC V to Chesapeake Bay Stock Assessment Committee and the National Marine Fisheries Service, NOAA

By

Mark E. Chittenden, Jr.

The College of William and Mary
Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

CBSAC V

1 September 1989 - 31 August 1990, and extended

April, 1991

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ABSTRACT/SUMMARY

Collections were made January through December 1988 using a 30' semiballoon trawl at 48 stations randomly selected each month, using equal allocation, from twelve geographical strata superimposed on a sampling frame of 16,730 possible stations uniformly distributed throughout water $\geq$ 12 feet deep in the Virginia mainstem Chesapeake Bay. The twelve geographical strata superimposed on the spatial sampling frame divided it into longitudinally-equal Upper, Middle and Lower Regions, each subdivided into four cross-bay regions, an Eastern Shore Littoral (12-30'), a Western Shore Littoral (12-30'), a Central Plain (30-42'), and Deeps (> 42').

The experimental design was regarded as a 12 x 12 completely randomized factorial arrangement with factors being "Months" with twelve levels, eg. individual months of the year, and "Areas" with twelve levels, eg. the three upbay-downbay regions and four cross-bay regions. Two covariates, temperature and salinity, were included in the model, which was evaluated as an analysis of covariance. The importance of the various sources of variation in the model were quantified as:

$$100\ r^2 = \frac{Component\ SS}{Corrected\ Total\ SS}$$

Where $100r^2$ describes the reduction in the total sum of squares (SS) attributed to the component SS. To supplement the ANOVA/ANCOVA F tests, Tukey's hsd multiple comparisons tests were

used to evaluate significant differences among months. Spatially, differences among the three upbay-downbay regions and the four cross-bay regions were evaluated by pre-planned, individual degree of freedom comparison tests.

Three transformations of the basic counts of abundance data -- log, square root, and no transformation -- were evaluated to choose which one best fit the data. The log transformation was chosen as the best and applied before the various ANOVA/ANCOVA evaluations. Assumptions of the ANOVA/ANCOVA models were evaluated using residual plots, the Kolomogorov D statistic to test for normality, and Cochran's C statistic to test for homogeneity of variance.

The collection scheme may also be regarded as a stratified random sampling design to develop indexes of abundance. The efficacy of the present stratified random sampling design in comparison to completely random sampling was quantified for annual and monthly indexes of abundance using the design effect (deff) statistic.

The analyses described above were each applied to five important species of fishes which collectively made up some 96% of the total catch of fishes. These included the bay anchovy (Anchoa mitchilli), spot (Leiostomus xanthurus), northern searobin (Prionotus carolinus), weakfish (Cynoscion regalis), and Atlantic croaker (Micropogonias undulatus). Analyses were also applied to the blue crab (Callinectes sapidus), the most important of the invertebrate nekton. Details of the analyses and findings are described for each individual species. An overview of the results follows.

For each species, the chosen log transformation was superior to the square root or no transformation. The log transformation generally provided the smallest standard error, the best model fit as judged by $100r^2$ values, the greatest number of effective degrees of freedom, reasonable normality, and reasonable or the most nearly reasonable homogeneity of variance. For each species, the assumptions of ANOVA/ANCOVA were at least reasonably well met using the log transformation.

For each species, the fitted models explained much of the total variation observed in the counts of abundance data. For three species, the ANOVA model finally accepted explained nearly 70% or more of the total variation -- northern searobin (75%), spot (74%), and blue crab (67%). The model explained some 60% of the total variation in weakfish (63%) and Atlantic croaker (59%). The model had the least explanatory power in the bay anchovy (53%), a year-round resident of the Chesapeake Bay. The other species either migrate from the Chesapeake Bay to overwinter in the ocean (the fishes), or burrow in the bottom sediments and are not then available to trawls (the blue crab). As a result, counts of abundance in these species go to zero for several months of the year.

The Months main effect was always significant and was usually the single most important factor in the model. It explained almost half the total variation in catches for blue crabs, spot, and northern searobin (some 47% in each case). It was much less important for weakfish (28%), Atlantic croaker (16%), and, especially, the resident bay anchovy (13%). The Interaction term was always significant and was usually second in explanatory power to the Months main effect. Interaction explained some 17-35% of the total variation in catches. It implies that the Months and Areas main effects are not constant; rather the Areas effect, for example, varies from month to month. The significant Interaction reflects in each species life history attributes like migrations, movements, recruitment, and "decruitment", whose effects vary from month to month in the course of the year. The Areas main effect was always significant, but it was generally the least important factor in the model and explained but little of the total variation in catch. The Areas main effect explained only 2-6% of the total variation in blue crabs, spot, northern searobin, and Atlantic croaker. It explained only 11% of the total in weakfish. It was most important in the bay anchovy, for which it explained only 16%. The implication of the general unimportance of the Areas main effect is that, for practical purposes, the sampling frame is quite homogeneous in its physical, chemical, and biological characteristics at any point in time.

For each species, the temperature and salinity covariates in the model were often non-significant, and they both always had negligible explanatory power, eg. -- they explained less than 1% of the total variation in each species. As a result, they were deleted from the accepted model to simplify further analyses. Their lack of importance probably reflects the fact that their effects overlap with the Months and Areas factors, and that the latter factors successfully capture the effects of temperature and salinity in the sampling frame.

Most species exhibited a general low in the abundance of trawl-vulnerable stages during the winter and the early spring or late fall months. This was the case in spot, weakfish, blue crabs, northern searobin, and Atlantic croaker. Peak abundance in these species generally occurs in late spring, summer, and fall. The bay anchovy exhibited a more complex annual pattern than the other species. It showed two peaks and troughs in abundance. There was an initial trough in abundance in February followed by a gradual increase in abundance through the spring to an initial peak in abundance in June. Abundance declined after June to form a second trough from August through October. Abundance then abruptly rose to a second annual peak in December and January. Length frequency analysis was used to indicate intra-annual patterns of movements, recruitment, and/or "decruitment" in each species.

For each species, there was one common property in their cross-bay spatial distributions: there was no significant difference in their abundance in any month in the deeper waters of the sampling frame, eg. they were equally abundant in the Central Plain and Deeps waters within months. For most species, there were two other common properties in their cross-bay spatial distributions: 1) in months when they were not abundant there was no significant difference between the combined littoral waters of the Eastern and Western Shores and the combined deeper waters of the Central Plain and Deeps; this was true for spot, northern searobin, weakfish, Atlantic croaker, and blue crab, and 2) in months when they were abundant, they were generally significantly more abundant in the combined deeper waters of the Central Plain and Deeps than in the combined littoral waters of the Eastern and Western Shores; this was true in spot, weakfish, Atlantic croaker, and less regularly, in the bay anchovy. It was not true in the blue crab or northern searobin.

Comparative patterns of abundance in the Eastern Shore and Western Shore Littoral waters varied from species to species. Details are given for each species.

For most species, there was one common property in their upbay-downbay distributions: there was no significant difference between their abundance in the Upper, Middle, and Lower Bay regions during months when they were not abundant. This was true for blue crabs, spot, weakfish, northern searobin, and Atlantic croaker. For all species, there were distinct intra-annual patterns in their upbay-downbay distributions, patterns that largely reflect recruitment, nurseries, and movements into and from the Chesapeake. The general pattern is that abundance shift towards the Lower Bay in the fall as water temperatures drop and most species leave the bay. Abundance shifts towards the Upper Bay in the late spring and summer as recruitment occurs and nurseries form. Details of the intra-annual pattern are specific to each species and are given.

The present stratification scheme in time and space appears to have had success in substantially reducing the variance of the overall, annual indexes of abundance in comparison to completely random sampling. The degree of effectiveness varied from species to species. Deff values of 0.36-0.49 indicate that stratification reduced the variance of the annual indexes to about a third to half their values for completely random sampling in northern searobin, spot, and blue crabs. Much less reduction in the variance was achieved for bay anchovy, weakfish, and Atlantic croaker, deff values of 0.65-0.76 indicating that stratification reduced the variance only to about two-thirds to three-quarters of that for completely random sampling. In large part, the success for the annual indexes reflects the minimization or removal of the effects of time on catches. The importance of time (Months) was illustrated earlier in evaluations of the sources of variation in the ANOVA model.

The present stratification scheme appears to have not been very effective in reducing the variance of the monthly indexes of abundance. The variance of the mean for stratified random sampling often exceeded that for completely random sampling or the variance was reduced by only 15% or less. The reason for this is that stratification sacrifices many degrees of freedom; it is worth while only if it removes important sources of variation in the catch. The unimportance of spatial factors

(Areas) the primary ones affecting the monthly indexes, was illustrated earlier in the evaluation of sources of variation in the ANOVA model. The non-effectiveness of the present stratified random sampling design with monthly indexes apparently reflects a largely homogeneous sampling frame within months.

The present ANOVA model was generally successful in explaining some one-half to three-quarters of the variation in catch, depending on species. As a result, there seems to be limited opportunity for further variance reduction through experimental design alone. Suggestions are made for improvement in future sampling designs, and theoretical options are briefly explored for variance reduction and confidence limit improvement.

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INTRODUCTION

The Chesapeake Bay, the largest estuary in the U.S. and third largest in North America behind Hudson and James Bays, has historically supported valuable fisheries that have been exploited for both recreational and commercial purposes. In recent years, their perceived decline has become the focus of much concern and research. The present work, a continuation of earlier work and recommendations (Chittenden, 1987, 1989) is a part of that research to develop a trawling program to help describe and monitor Chesapeake Bay fishery resources.

Much work has been conducted and published to describe the composition, distribution, and seasonality of fishes in the Chesapeake Bay Region. Lippson and Lippson (1984) have summarized much of this in a recent, excellent, popularized account of the Chesapeake fauna. The Chesapeake Bay proper has received little emphasis in more scientifically oriented publications. Primary emphasis in that literature has been on the tributary estuarine rivers (for examples, McHugh 1967; Markle 1976; Merriner, Kriete, and Grant 1976; Chao and Musick 1977), the continental shelf and seaside bays (for examples, Schwartz 1961, 1964; Richards 1965; Richards and Castagna 1970; Colvocoresses and Musick 1984), and recreational catches and/or very shallow waters of the Bay (for examples, Richards 1965; Orth and Heck 1980). The deeper open waters of the mainstem Chesapeake Bay, the greatest water area, have been largely unaddressed.

The species that make up the Chesapeake Region fauna have generally been well described in lists and generalized annotated accounts of species (Hildebrand and Schroeder 1928; Massmann 1962; Musick 1972; Musick and Wiley 1972). McHugh (1967), Birdsong and Musick (1972), and Musick and Wiley (1972) concluded that Hildebrand and Schroeder (1928) remains the best general reference to the bay fauna. However, much still remains to be learned about the basic biology of the fauna and their spatial/temporal distributions in the mainstem Chesapeake Bay, things essential to wise management. Descriptions of temporal distributions of fishes in the Chesapeake Region have largely emphasized its riverine tributaries (Markle 1976; Merriner et al. 1976) and general descriptions for the bay proper, in some cases from commercial fishery statistics (Hildebrand and Schroeder 1928). No published work describes the spatial distributions of fishes in the Chesapeake Bay proper, other than in general terms. Since the earlier works, as part of the present research, Chittenden (1989) has described the overall and spatial/temporal percentage compositions of the trawl-vulnerable fauna in the deeper, open waters of the mainstem Chesapeake Bay in Virginia, their abundances, and their size compositions. The present study statistically analyzes and describes spatial/temporal distributions of the more important fish species and blue crabs. It also evaluates sources of variation in trawl catches and the efficacy of stratified random sampling to describe Chesapeake Bay fishery resources.

METHODS

Methods follow under the headings "Data Collection" and "Data Analysis". The first section follows and elaborates on descriptions in Chittenden (1989).

Data Collection:

Collections were made monthly January-December 1988 with a 30' semi-balloon trawl, having a 1-1/2 inch bag mesh, a 1/2-inch bag liner, a tickler chain, and a 60' bridle. This design was used in many previous collections in the estuarine tributaries and bay by the Virginia Institute of Marine Science (VIMS) in the period 1956-1987 (Wojcik and Van Engel 1988, Gear Code 70). One vessel, the R/V Captain John Smith, was used to make each collection in the present studies. Single trawl tows of 5 min duration bottom time were successfully made at a pre-planned total of 48 randomly-selected stations each month, stations being located in the field using Loran C. Chittenden (1987) describes the rationale for the sample size selection and sampling design employed. Stations were computer-selected, using a stratified random sampling design with equal allocation, from a sampling frame of 16,730 possible stations, located about 0.25 mm (15 seconds) apart in depths $\geq$ 12' in Virginia waters of the Chesapeake Bay proper. Figure 1 illustrates the spatial stratification scheme, and Table 1 describes the number of possible stations in each stratum.

Each station in the sampling frame was the locus of

Figure 1. Spatial stratification scheme and sampling frame used in mainstem Chesapeake Bay trawling. Depths below 12' are included to illustrate their area. Table 1 defines strata and their code numbers.

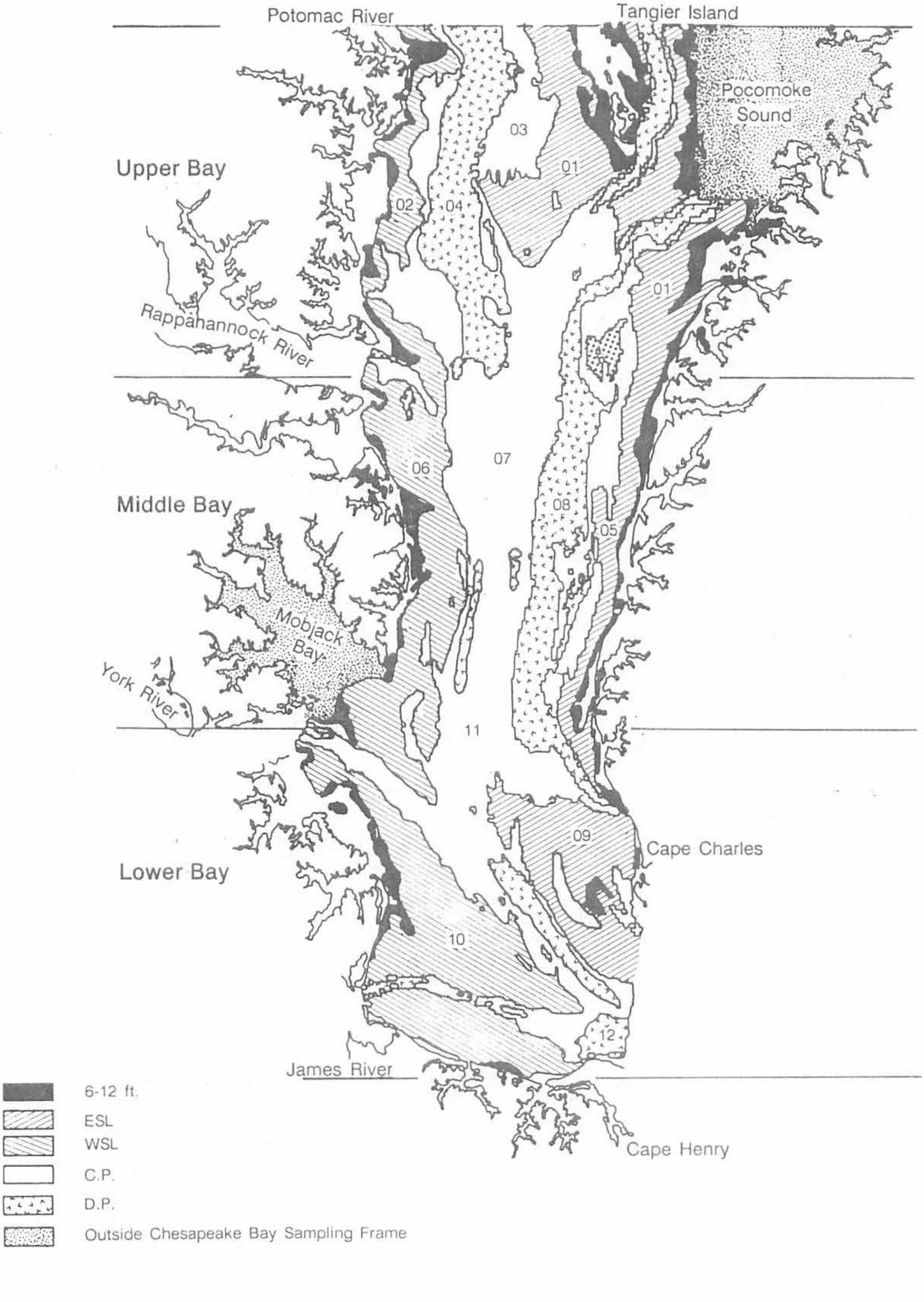

Potomac River
Tangier Island
Pocomoke Sound
Upper Bay
03
01
02
04
01
Rappahannock River
07
06
Middle Bay
08
05
Mobjack Bay
York River
11
09
Cape Charles
Lower Bay
10
12
James River
Cape Henry
6-12 ft.
ESL
WSL
C.P.
D.P.
Outside Chesapeake Bay Sampling Frame

Table 1. Number of possible stations and geographical area (nm^2) by stratum in the Virginia waters of the Chesapeake Bay.

Stratum and Stratum Code Number	Possible Stations	Area
Upper Eastern Shore Littoral (12-30'): 01	1883	121.6
Upper Western Shore Littoral (12-30'): 02	565	36.5
Upper Central Plain (30-42'): 03	2146	138.6
Upper Deeps (>42'): 04	1613	104.1
	6207	400.8
Middle Eastern Shore Littoral (12-30'): 05	469	30.3
Middle Western Shore Littoral (12-30'): 06	1255	81.0
Middle Central Plain (30-42'): 07	2313	149.3
Middle Deeps (>42'): 08	1055	68.1
	5092	328.7
Lower Eastern Shore Littoral (12-30'): 09	1074	69.3
Lower Western Shore Littoral (12-30'): 10	2119	136.8
Lower Central Plain (30-42'): 11	1719	111.0
Lower Deeps (>42'): 12	519	33.5
	5431	350.6
Grand Totals	16,730	1080.1

intersecting latitude and longitude lines and had assigned to it a depth, determined from National Ocean Survey records, used to help stratify the sampling frame into twelve geographical strata which were sampled each month of the year. These twelve spatial strata formed the "Areas" component of the analysis of variance (ANOVA) and analysis of covariance (ANCOVA) models later referred to, and months of the year formed the "Months" component. These twelve spatial strata=Areas included longitudinally-equal upbay-downbay portions of the Virginia waters of the Bay proper, which I refer to hereafter as Upper, Middle, and Lower Regions. The exact dividing lines between these three regions were drawn, in part, for programming convenience. Each of the three regions was then subdivided into cross-bay regions that I refer to hereafter as an Eastern Shore Littoral (12-30':ESL), a Western Shore Littoral (12-30':WSL), a Central Plain (30-42':CP) and a Deeps (>42':D) Region. The three upbay-downbay regions and the four cross-bay regions form the basis for the pre-planned individual degree of freedom comparison tests referred to later.

Four trawl tows were made at the pre-selected stations in each stratum each month, with few exceptions. In those few exceptions, which occurred when the trawl became hung on the bottom, first or second alternate stations were occupied in the same depths 0.1 nm away from the original target using pre-planned back-up positions for each station. Accomplished cruise tracks are presented in Chittenden (1989, Appendix Figures) and station positions are available on computer file.

Cruise tracks each month were established between stations prior to each cruise and consisted, basically, of a circle that formed the shortest overall distance from the initial station to the last one occupied. The initial station to be occupied each month was randomly selected, and subsequent stations followed in sequence along the cruise track. The direction of travel along the cruise track -- upbay or downbay along the circle -- was randomly selected before each cruise started. This scheme was successfully accomplished in most cruises. Windy weather prevented following the pre-planned cruise track on a few dates. At those times, a new starting station was randomly selected from amongst stations in areas where work could be accomplished, and the original cruise track was then followed from that new starting point.

Hydrographic data were successfully taken at each station occupied, with three exceptions which occurred when the Kemmerer bottle was lost. These data included surface and bottom records of temperature determined using a stem thermometer, salinity determined using a refractometer, and dissolved oxygen determined using a YSI meter.

Collections were generally sorted to species in the field, placed on ice, and returned to the lab for further processing in which lengths were measured on all specimens, when feasible, and species lots were weighed. Entries of length data, from which counts of abundance were tabulated, were made using computer-interfaced measuring boards developed with CBSAC support for the author in previous years. When it was not feasible in abundant species to measure and count all specimens for length in a given tow, an adaptation of Lahiri's method of systematic sampling (Cochran 1977, but see also Paloheimo and Dickie 1963; and May and Hodder 1966) was used to give roughly 500-1000 specimen lots each tow. This lot was weighed and counted, the total lot was weighed, and the total count was derived by ratio estimate.

Data Analysis:

The collections scheme used may be reasonably regarded in several ways including: 1) as an analysis of variance-type experimental design from which to evaluate sources of variation in catches, and 2) as a stratified random sampling design which can be compared to a completely random sampling design to evaluate the efficacy and benefits of stratification. Both viewpoints were used in the present study.

From the former perspective, the experimental design was a fixed effects 12 x 12 completely randomized factorial arrangement with factors being "Months" with 12 levels, eg. individual months of the year, and "Areas" with 12 levels, eg. Eastern Shore Littoral, Western Shore Littoral, Central Plain and Deeps, each in the Upper, Middle, and Lower Regions of the bay. Two covariates were included in the ANCOVA model, temperature, whose effects overlap with the Months factor, and salinity, whose effects overlap with Area.

Months and Areas main effects, Interaction, and the covariates were tested against the residual mean square. After establishing significance, or non-significance, the importance of the various sources of variation in the model were evaluated by using a relation similar to the coefficient of determination , $100r^2$:

$$100\ r^2 = \frac{Component\ SS}{Corrected\ Total\ SS}$$

Where $100r^2$ describes the reduction in the total sum of squares (SS) attributed to the component SS. This quantified how much of the total variation was associated with the complete model and with its individual components. Sources of variation that did not explain at least 1% of the total variation, even if significant, were deleted from the final ANOVA as being unimportant: in particular, the covariates were so deleted. Justification for that approach is that: 1) it simplified further analyses with little loss of explanatory power, and 2) significance was established using a very large sample size (generally n = 576, 430 df for the residual mean square), so that even unimportant factors could be declared statistically significant. Using that approach, in effect, the minor variation due to the covariates is pooled with the residual mean square.

The data on abundance used in analyses were expressed as counts of abundance per trawl tow (a standard 5-minute tow), an expression that often requires transformation. Three standard transformations (Steel and Torrie 1960) were compared to evaluate which provided the best fit to the model and best met the assumptions of ANOVA-ANCOVA: none, y + 0.5, and log (y + 1). These will be referred to hereafter as "no transformation", "square root transformation", and "log transformation". The latter most often provides the best fit to counts of abundance data. Transformations were evaluated on the basis of: 1) smallest standard error, 2) largest $100r^2$ value for the complete model, 3) smallest coefficient of variation, 4) best achievement of homogeneity of within-cell variance as measured by Cochran's C statistic (Winer 1972), and 5) provision of the greatest value for effective degrees of freedom (Satterthwaite 1946; Cochran 1977) in calculating confidence limits. The transformation with the smallest standard error often best fits the data (Winer 1972). In accomplished fact, the log transformation usually best met all the criteria, so most data presentation was based on the log transformation. This was supplemented with a geometric mean (GM) back transformation.

Assumptions of the ANOVA-ANCOVA models (Steel and Torrie 1960) were evaluated. The ANCOVA assumption of within-Months x Areas cell homogeneity of slopes was evaluated by calculating residuals from the ANOVA model (eg., no covariates formally recognized in the model) and plotting them (four residuals per cell, eg., in one plot) against temperature and salinity to detect the nature of the regression relation. The assumption of independence of the residuals was assumed to be met by the random selection each month of stations to be occupied. The assumption of normality was evaluated in the spirit of reasonably normal, because ANOVA/ANCOVA is generally robust to at least minor departure from normality (Winer 1972). Residuals from the ANOVA model were plotted as one overall frequency distribution to judge "reasonably normal". This was supplemented by a Kolomogorov D statistic to test goodness of fit, generally with n = 576. The plots (for logs) generally indicated a reasonable approximation to normality, but the D test indicated non-normality. Being generally based on n = 576, the test was extremely sensitive and able to detect very small departures from normality -- a situation much like the unimportant ($100r^2 < 1\%$), but significant, covariates deleted from the model. Homogeneity of within-cell variances, to which ANOVA is also robust, was evaluated by Cochran's C statistic (Winer 1972).

Residuals from the ANOVA model were plotted against months and areas to detect variation not extracted by a simple relation, and against bottom dissolved oxygen levels to detect other variation not recognized in the model.

Interpretation of the spatial/temporal distributions, eg. Areas and Months, tested by ANOVA and ANCOVA was colored by the always-significant Interaction term in the model. A significant interaction implies that the effects of months and areas on abundance are complex and not consistent, eg. the simple effects of Areas vary from Month to Month, and vice versa; they are not constant as they would be if Interaction were not significant.

The most satisfactory analysis in such a situation is generally to interpret the simple effects, an approach made complex in the present case because there are twelve levels of each factor. In the present case, the Months factor generally explained much more variation than the Areas factor, reflecting, in part, seasonal recruitment, "decruitment", and migrations into and out of the Chesapeake. That fact suggested the most appropriate approach to follow, and the one used, would be: 1) to make an initial interpretation of the Months effect -- and set a background -- using Tukey's hsd multiple comparisons test; although insensitive, this would be sufficient to establish "en-masse"-type presences and absences that reflect major recruitment and migration patterns, 2) to next use length frequency analysis to describe the periodicity of recruitment, "decruitment", movements, and age groups involved, and then 3) to evaluate within months any Areas effects on abundance using the pre-planned, orthogonal, individual degree-of-freedom F tests alluded to earlier under data collection. The spatial aspects of the sampling design lead to several logical hypotheses that compare abundances in both a cross-sectional and an upbay-downbay view of the Chesapeake:

1. Littoral Areas (pooled Eastern Shore and Western Shore Littoral areas of the Chesapeake) vs. Deeper Waters (pooled Central Plains and Deeps areas),
2. the Eastern Shore Littoral vs. the Western Shore Littoral, each pooled over the Upper, Middle and Lower

bay waters,

3. Central Plain deep waters vs. Deeps deep waters, each pooled over the Upper, Middle and Lower bay waters,
4. Middle bay waters vs. the average of the Upper and Lower bay waters, and
5. Upper bay waters (those near Maryland) vs. Lower bay waters (those near the ocean).

Within each month of the year, these five comparisons were tested against the residual mean square of the ANOVA table to evaluate the Interaction and Areas main effect terms. Overall contrast tests (all months pooled in the one test) have questionable validity and are not presented because of the significant Interaction term.

Confidence intervals presented were calculated using the error mean square from the ANOVA model, unless indicated otherwise.

In several cases, data on temperature or salinity were missing (the three cases noted earlier in which the collecting device was lost) or obviously in error (for example, a 22° C temperature value in winter when all other values were some 2-5° C). In these few cases, the Months x Areas cell mean temperature or salinity was substituted to maintain the simplicity and balance of the design. Little error should be introduced thereby. Temperature and salinity are very conservative properties of water and generally varied little within cells.

The efficacy of the present stratified random sampling design in comparison to completely random sampling was quantified for monthly and annual estimates of mean abundance using the design effect (deff) statistic after estimating the variances of the mean for completely random sampling (v_{ran}) and for the present stratified random sampling design ($s^2_{y(st)}$) following Cochran (1977). Estimates of the monthly and annual indices of abundance are presented for stratified random sampling with 95% confidence limits calculated using the effective number of degrees of freedom (Satterthwaite 1946; Cochran 1977).

Analyses described above were applied to six species found important in the collections, five fishes and one invertebrate. The five fishes included the bay anchovy (Anchoa mitchilli), spot (Leiostomus xanthurus), northern searobin (Prionotus carolinus), weakfish (Cynoscion regalis), and Atlantic croaker (Micropogonias undulatus). The first four fishes made up > 95% of the total catch of fishes in these studies (Chittenden 1989). The Atlantic croaker, which supports important fisheries, brings the total to some 96%. The one invertebrate, the blue crab (Callinectes sapidus) supports important fisheries in the bay region and was exceeded in abundance only by the first three fishes named. Blue crab data were not fully recorded in May, so that month was deleted in the blue crab analyses. Other than that exception, one analysis in common was generally followed for each species and one format in common was used to present results on each species. That approach facilitates among-species comparisons and analysis of comparative patterns.

Analyses were performed using SAS procedures or data steps on a 386 microcomputer or mainframe (SAS Institute Inc. 1988a, b).

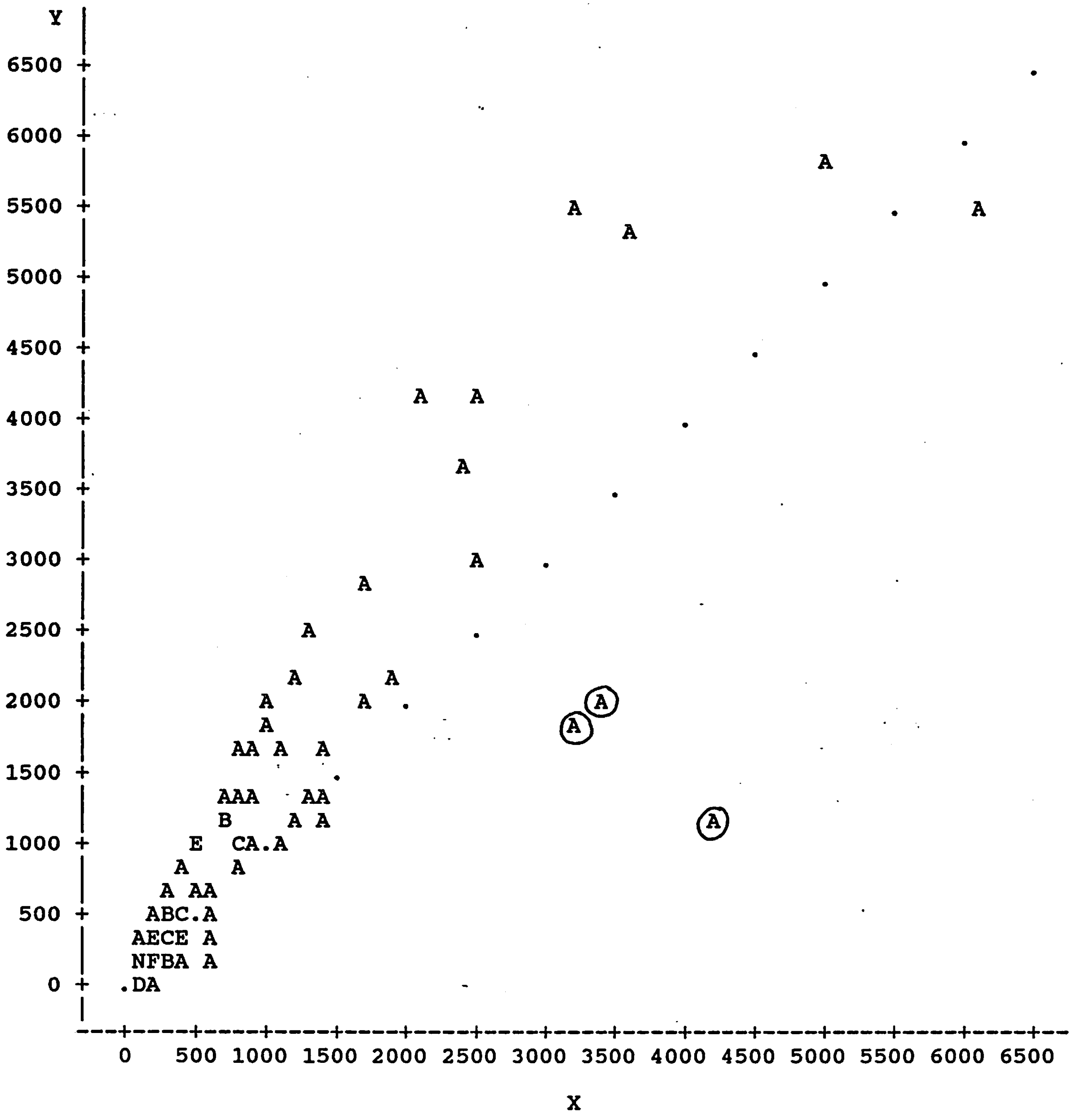
SPECIES RESULTS AND DISCUSSION

Bay Anchovy

Choosing an Appropriate Transformation:

The log transformation appears reasonably appropriate for the present counts of abundance data on bay anchovy. Plots of the untransformed standard deviation on the untransformed arithmetic mean within Months x Areas cells, with the exception of three circled data points (Figure 2), indicate a quadratic relationship, or that most data points are scattered above the 45 degree diagonal. The calculated slope ($b = 1.044$) of the regression of the untransformed standard deviation on the untransformed arithmetic mean, however, is not significantly different from a hypothesized $\beta = 1$ ($t = 0.99$; 142 df). Non-significance may simply indicate great influence by the circled data points, because the data points are just not scattered along the diagonal. Plots of the variance on the arithmetic mean (not shown) are even less satisfactory than the preceding plots. They found nearly all data points above or well above the diagonal. The calculated slope ($b = 4640.19$) of the regression of the variance on the mean is significantly greater than a hypothesized $\beta = 1$ ($t = 17.59$; 142 df). These conditions indicate neither transformation is adequate, but evidence on homogeneity of variance and normality given later suggests the log transformation is fairly reasonable.

Figure 2. Relationship between standard deviation (y) and untransformed arithmetic mean counts of abundance (x) for bay anchovy. The 45° diagonal has slope b = 1, so y = x along it. A = 1 observation, B = 2 observations, etc.


Y
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
X

The log transformation had the smallest standard error (0.97), the smallest coefficient of variation (CV = 63.68), provided the best fit for the postulated model ($100r^2 = 53.02$), and, as noted later, provided homogeneity of variance and normality, and the greatest number of effective degrees of freedom (Table 2). Using these criteria, the square root transformation had less desirable properties than the log transformation and untransformed data had the least desirable properties of all. In comparison to the other species, the log transformation in the bay anchovy was much less superior to the other transformations evaluated.

General Data Description:

Bay anchovy were the most abundant fish in the sampling frame. They were one of two predominant species and made up 65.0% of the overall catch (Chittenden 1989).

The overall geometric mean catch was 32.41 bay anchovy, with 95% confidence limits about the mean being 26.79-39.18 (Table 3). The overall mean log catch was 1.52, with 95% confidence limits being 1.44-1.60. The standard error of the mean log catch was 0.97, and the coefficient of variation was 63.68 (Table 3). The maximum catch was 14,052 bay anchovy and the minimum was 0.

Bay anchovy are resident year-round in the Chesapeake Bay. They were ubiquitous and were captured essentially year-round in each area (Table 4). None were captured on only a few occasions: in one stratum in August and November and in four strata in

Table 2. Summary of the comparative properties of listed transformations on bay anchovy abundance counts.

	Transformation		
Property	log	none	Square Root
Mean	1.52	584.26	14.15
Std. error	0.97	1358.76	16.50
$100r^2$	53.02	41.19	46.88
CV	63.68	232.56	116.57
Independence of Residuals	yes	yes	yes
Homogeneity of Variance Using Cochran's C.	yes	no	no
Normality	reasonable	did not examine	did not examine
Homogeneity of Slopes		did not examine	did not examine

Table 3. Summary statistics on overall log bay anchovy abundance, with a geometric mean (GM) back-transformation. No transformation was applied to the sample size (n) and the minimum-maximum counts.

	LOG	GM
n	576	--
Min-Max	0-14,052	--
Mean	1.52	32.41
95% Confidence Limits	1.44-1.60	26.79-39.18

Table 4. Summary of Bay anchovy presence or absence in the Month-Area Cells. X = Present; - = Absent.

	UPPER BAY				MIDDLE BAY				LOWER BAY				TOTAL PRESENT
Month	ESL (01)	WSL (02)	CP (03)	DP (04)	ESL (05)	WSL (06)	CP (07)	DP (08)	ESL (09)	WSL (10)	CP (11)	DP (12)	
Jan	X	X	X	X	X	X	X	X	X	X	X	X	12
Feb	X	X	X	X	X	X	X	X	X	X	X	X	12
Mar	X	X	X	X	X	X	X	X	X	X	X	X	12
Apr	X	X	X	X	X	X	X	X	X	X	X	X	12
May	X	X	X	X	X	X	X	X	X	X	X	X	12
Jun	X	X	X	X	X	X	X	X	X	X	X	X	12
Jul	X	X	X	X	X	X	X	X	X	X	X	X	12
Aug	-	X	X	X	X	X	X	X	X	X	X	X	11
Sep	X	X	X	X	-	X	X	X	-	-	X	-	8
Oct	X	X	X	X	X	X	X	X	X	X	X	X	12
Nov	X	X	X	X	X	X	X	X	-	X	X	X	11
Dec	X	X	X	X	X	X	X	X	X	X	X	X	12
Total Present	11	12	12	12	11	12	12	12	10	11	12	11	138

September (of 144 Areas x Months cells).

Overview of the ANOVA-ANCOVA:

The postulated models explain much of the total variation in bay anchovy catches. A log transformation explained about 54% of the total variation (Table 5). Somewhat less is explained (Table 2) using a square root transformation (46.88%) and only a little less with no transformation (41.19%).

The overall log ANCOVA (or ANOVA) model was significant at $\alpha = 0.01$ (Table 5). The Months and Areas main effects were both highly significant. The Areas main effect was a little more important than the Months effect in explaining variation in bay anchovy catches, $100r^2$ values being 16.22% for Areas and only 12.73% for Months. Interaction was significant and explained more variation (24.07%) than either main effect. The significant Interaction implies that spatial and temporal factors have a complex effect on the distribution of bay anchovy, eg. -- the simple effects of Areas, for example, are not constant; rather they vary from month to month.

Neither the salinity nor temperature covariate explained much variation in bay anchovy catches (0.25 and 0.37%, respectively) beyond that associated with the Areas and Months effects, and neither covariate was significant (Table 5). Therefore, the covariates were deleted from the model, and further analyses were made using only the ANOVA model with its main effects and interactions.

Table 5. Summary of the ANCOVA on bay anchovy, log transformation, with $100r^2$ values.

Source of Variation	df	SS	MS	F	$100r^2$
Corr. Tot.	575	866.17	--	--	100.00
Model	145	464.64	3.20	3.43 **	53.64
Months (M)	11	110.30	10.03	10.74 **	12.73
Areas (A)	11	140.48	12.77	13.68 **	16.22
M x A	121	208.52	1.72	1.85 **	24.07
Sal	1	2.15	2.15	2.30 NS	0.25
Temp	1	3.20	3.20	3.42 NS	0.37
Error	430	401.52	0.93	--	46.36

The overall log ANOVA model explained 53.03% of the variation in bay anchovy catches (Table 2). Its most important component was the Interaction, and the Areas main effect was next in importance (Table 5). The Months main effect was comparatively unimportant, especially in comparison to other species. Random variation, or variation not recognized and not included in the model, accounted for about 47% of the total variation.

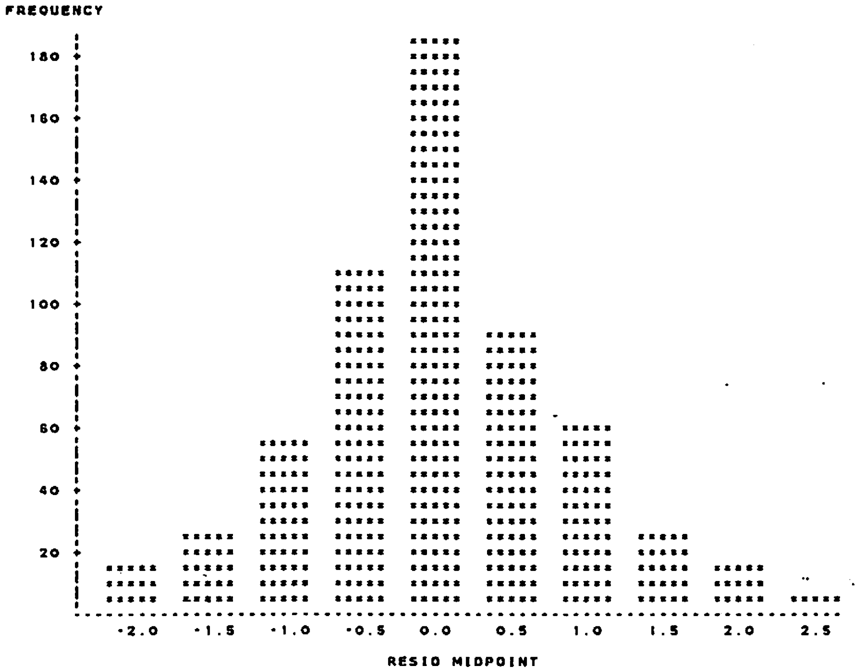
Validity of the Assumptions of the ANCOVA-ANOVA models:

The assumptions of the ANOVA-ANCOVA models appear to be reasonable, if not exactly fulfilled, when a log transformation is used on the bay anchovy catch data.

The assumption of normality of the residuals is a fairly reasonable approximation, though not true. The frequency distribution of the residuals from the log ANOVA model (Figure 3) appears to be fairly <u>reasonably</u> normal, though possibly slightly skewed. The Kolomogorov D statistic is significant ($D = 0.062$; $n = 576$) at $\alpha = .01$, which indicates the distribution of the residuals is not truly normal. The significant D statistic, however, in part reflects an exceptionally large sample size which can detect even small departures from normality.

The assumption of homogeneity of within-cell variance is reasonable using a log transformation on the catch data. Cochran's C statistic ($C = 0.0332$; 3 df; $n = 144$) is not significant at $\alpha = .05$. In contrast, Cochran's C statistic ($C =$

Figure 3. Frequency distribution of the residuals to evaluate the assumption of normality in bay anchovy.


FREQUENCY
180
160
140
120
100
80
60
40
20
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
RESID MIDPOINT

0.0750) is significant at $\alpha = .01$ using a square root transformation; similarly, Cochran's C (C = 0.126) is also significant at $\alpha = .01$ with no transformation.

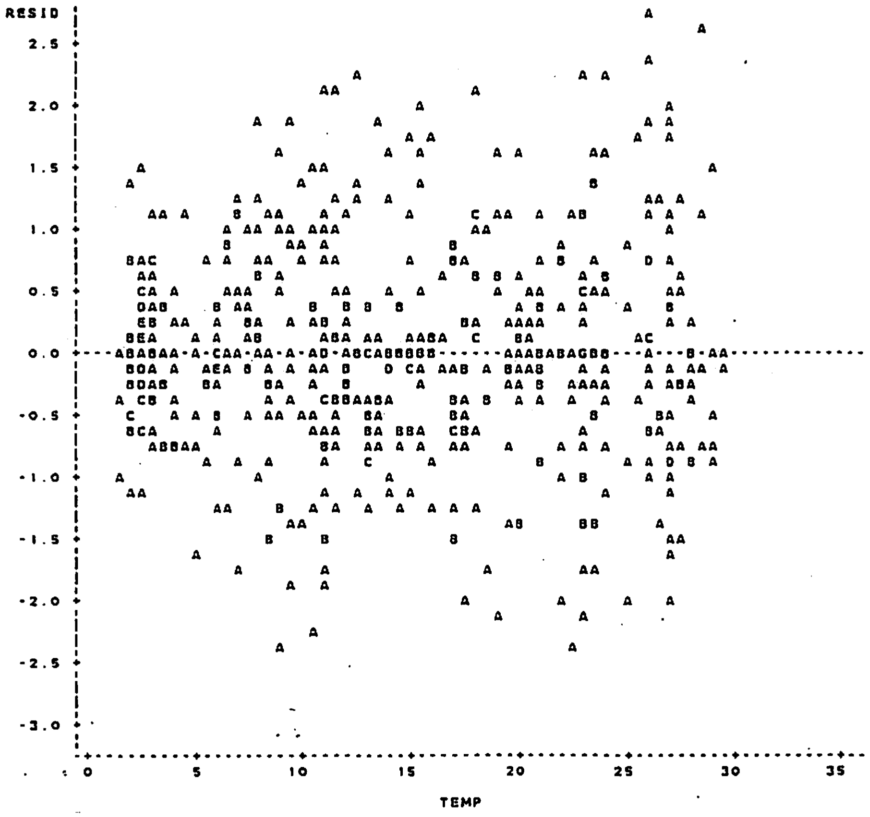
The assumption of homogeneous, linear regression on the covariates within cells also appears reasonable, or there was no regression. The residuals from the ANOVA model were plotted (not shown) on temperatures within Months x Areas cells and on salinity. A relationship between the residuals and temperature or between the residuals and salinity was apparent in only a few cells (of 144).

These conclusions of little or no within-cell relation between residuals and temperature or salinity are illustrated by overall plots (all data) of the relationships between temperature and residuals and salinity and residuals (Figures 4, 5).

Interpretation of Interaction and Main Effects to Evaluate Spatial/Temporal Distributions:

Bay anchovy catches show great variation between months that forms a clear, but complex, intra-annual pattern of change which includes two major peaks in abundance. Monthly catches formed an initial trough in the mid winter month of February and then gradually increased through the spring to an initial peak in the early summer month of June (Figure 6; Table 6). Catches subsequently declined after June to form a second, but seemingly more prolonged, trough from August through September and October. Catches then rose somewhat abruptly to a second annual peak in the winter months of December and January. Tukey's multiple

Figure 4. The overall relationship (all data) between residuals from log bay anchovy catches and bottom temperature (C^0). A = 1 observation, B = 2 observations, etc.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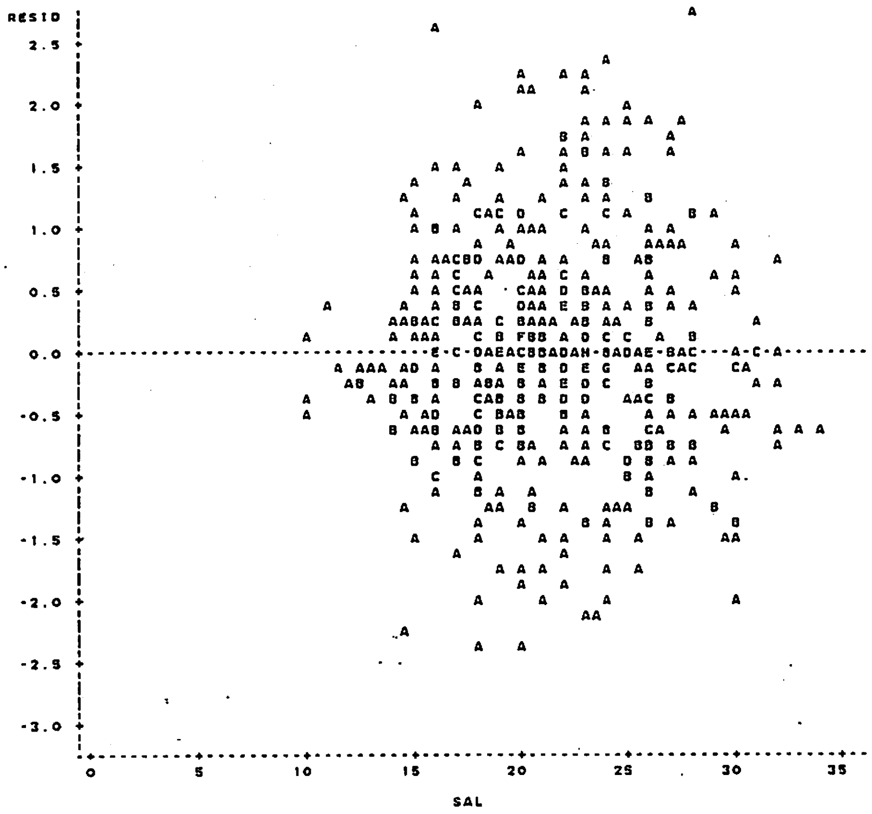
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0
5
10
15
20
25
30
35
TEMP

Figure 5. The overall relationship (all data) between residuals from log bay anchovy catches and bottom salinity (parts per thousand). A = 1 observation, B = 2 observations, etc.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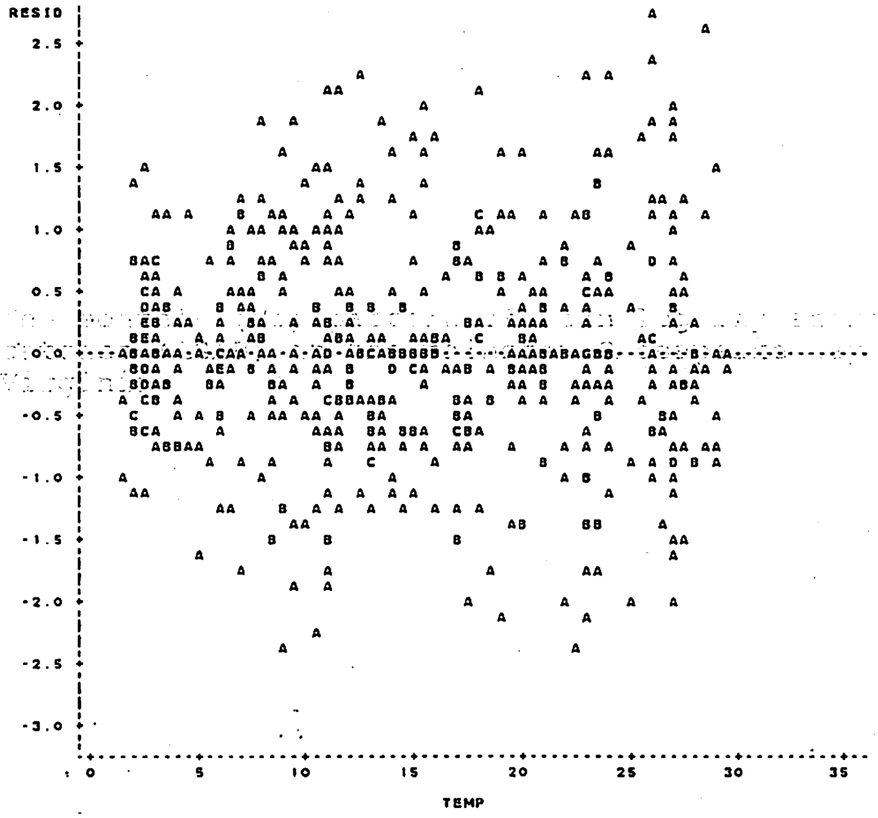
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0
5
10
15
20
25
30
35
SAL

Figure 6. The monthly (Mo) pattern of mean log bay anchovy catches (LGAB) in the mainstem Chesapeake Bay, Virginia.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0.5
0.0
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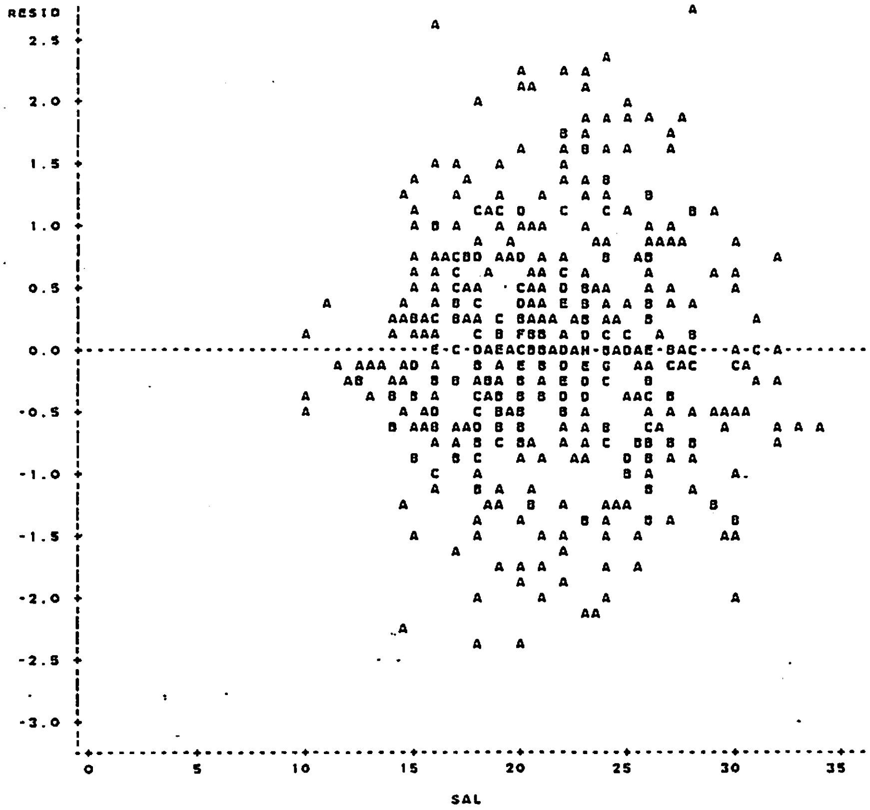
-1.0
-1.5
-2.0
-2.5
-3.0
0
5
10
15
20
25
30
35
TEMP

Figure 5. The overall relationship (all data) between residuals from log bay anchovy catches and bottom salinity (parts per thousand). A = 1 observation, B = 2 observations, etc.


RESID
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1.5
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0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0
5
10
15
20
25
30
35
SAL

Figure 6. The monthly (Mo) pattern of mean log bay anchovy catches (LGAB) in the mainstem Chesapeake Bay, Virginia.

```
LGAB
 3.0 +
     |
     |
 2.5 +
     |
     |      +                                                                 +
 2.0 +                                    +
     |                              +
     |                        +
 1.5 +                                          +
     |                                                                  +
     |                  +                                   +     +
 1.0 +            +                                   +
     |
     |
 0.5 +
     |
     |
 0.0 +
     -+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-
      0     1     2     3     4     5     6     7     8     9    10    11    12

                                           MO
```

Table 6. Summary of 95% confidence limits (CL) about monthly mean log abundance of bay anchovy with a geometric mean (GM) back-transformation.

Month	log	CL	GM	CL
Jan	2.14	1.86-2.42	137.17	71.21-263.36
Feb	0.94	0.66-1.22	7.65	3.52- 15.55
Mar	1.13	0.85-1.41	12.51	6.06- 24.86
Apr	1.65	1.37-1.93	43.50	22.25- 84.14
May	1.90	1.62-2.18	78.88	40.75-151.84
Jun	2.04	1.75-2.32	107.46	55.69-206.53
Jul	1.51	1.23-1.80	31.71	16.10- 61.59
Aug	1.00	0.71-1.28	8.92	4.19- 17.99
Sep	1.19	0.90-1.47	14.35	7.02- 28.37
Oct	1.21	0.93-1.49	15.28	7.51- 30.15
Nov	1.36	1.08-1.65	22.15	11.10- 43.29
Dec	2.22	1.94-2.50	164.67	85.59-316.00

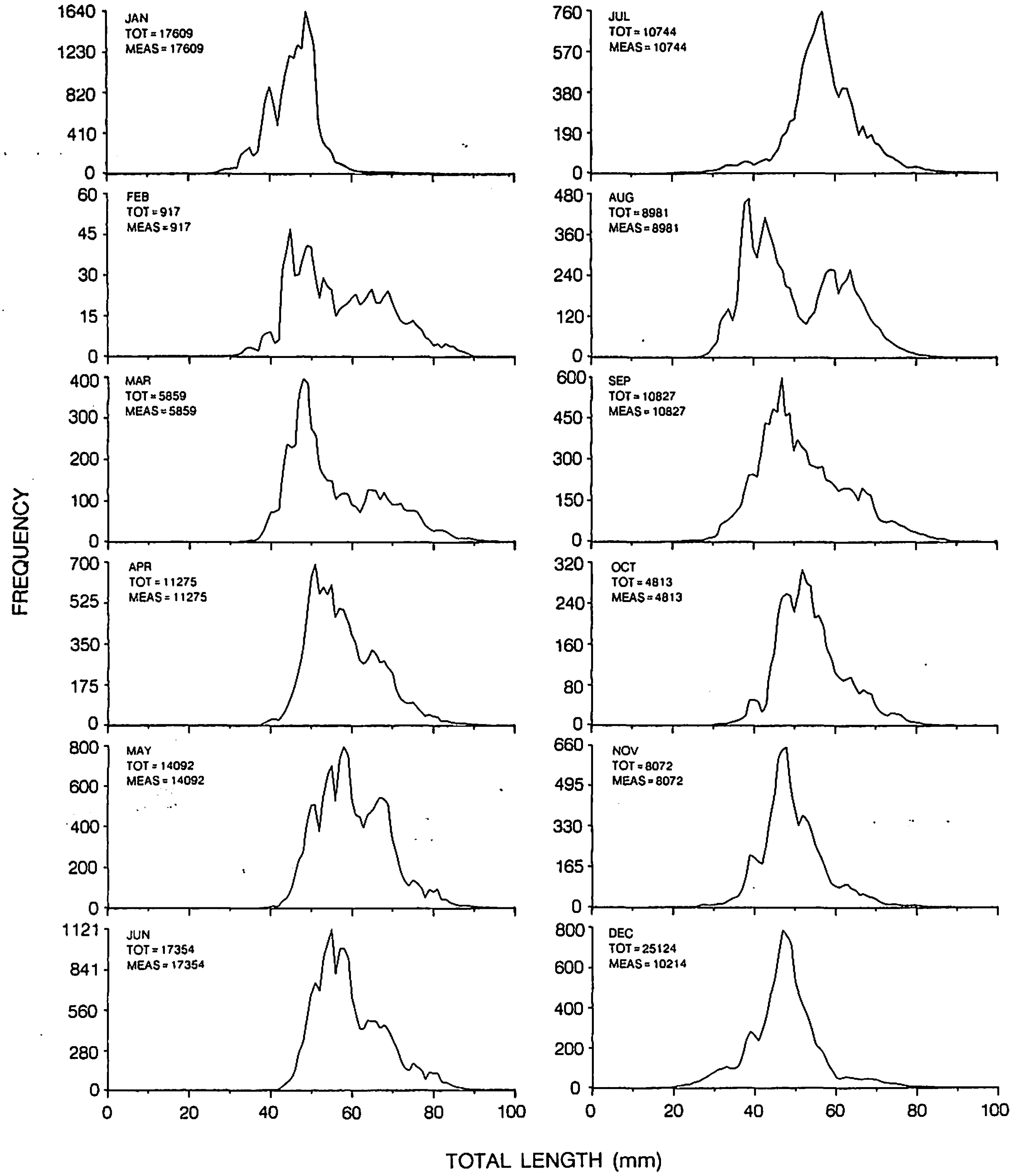
comparisons tests (Table 7), which elaborate on the significant F tests for Months, show, in general, significantly more anchovies were caught in December and January, when one peak of abundance formed, and in May and June, when the second peak formed. Significance is generally in comparison to February and March, when one trough in abundance formed, and to August, September and October, when the second trough formed. Intermediate size catches in April and November were, variously, significantly different or not from the peak and trough months.

The annual pattern of bay anchovy catches reflects an unclear combination of recruitment, movements, and survivorship of, apparently, two intra-annual or annual cohorts. Analyses of hard parts is needed to properly evaluate the age structure and explain its patterns (Chittenden, 1989). However, some initial analyses are possible. Two cohorts seem to predominate in the length frequencies in March and in August (Figure 7). The cohort of large fish present in March seems clearly linked to a similar cohort in February, but there is no clear linkage to a cohort in January. Presumably, the appearance of the cohort of large fish in February represents an influx from outside the sampling frame, since growth of the individuals in the one clear cohort in January does not seem to explain it. As they grow in size, the cohort of large fish in March can be subsequently followed in the length frequencies with less and less success through June as it blends more and more with the cohort of smaller fish. The right tail of the frequency distribution of the cohort of large fish

Table 7. Summary of Tukey's hsd multiple comparisons tests on log bay anchovy abundance. Means with different letters are significantly different.

		MEAN		
Month	n	log	GM	Significance
Dec	48	2.22	164.58	a
Jan	48	2.14	137.04	a b
Jun	48	2.04	107.39	a b
May	48	1.90	78.80	a b c
Apr	48	1.65	43.46	a b c d
Jul	48	1.51	31.73	b c d e
Nov	48	1.36	22.12	c d e
Oct	48	1.21	15.29	d e
Sep	48	1.19	14.35	d e
Mar	48	1.13	12.52	d e
Aug	48	1.00	8.93	e
Feb	48	0.94	7.65	e

Figure 7. Monthly length frequencies of bay anchovy. Frequencies are moving averages of three.



FREQUENCY
TOTAL LENGTH (mm)
JAN
TOT = 17609
MEAS = 17609
1640
1230
820
410
0
FEB
TOT = 917
MEAS = 917
60
45
30
15
0
MAR
TOT = 5859
MEAS = 5859
400
300
200
100
0
APR
TOT = 11275
MEAS = 11275
700
525
350
175
0
MAY
TOT = 14092
MEAS = 14092
800
600
400
200
0
JUN
TOT = 17354
MEAS = 17354
1121
841
560
280
0
JUL
TOT = 10744
MEAS = 10744
760
570
380
190
0
AUG
TOT = 8981
MEAS = 8981
480
360
240
120
0
SEP
TOT = 10827
MEAS = 10827
600
450
300
150
0
OCT
TOT = 4813
MEAS = 4813
320
240
160
80
0
NOV
TOT = 8072
MEAS = 8072
660
495
330
165
0
DEC
TOT = 25124
MEAS = 10214
800
600
400
200
0
0
20
40
60
80
100
0
20
40
60
80
100

seems to remain constant at about 90 mm TL through the winter and spring, implying that: 1) growth ceases at about 90 mm, 2) the large fish leave the sampling frame, or 3) the life span comes to end when the individuals reach 90 mm. The cohort of small fish in March seems clearly linked to a similar cohort in February and to an even earlier cohort in January. As they grow in size, the cohort of small fish in March can be subsequently followed in the length frequencies, despite a gradual blending with the larger fish, through August. In August, this cohort apparently forms the cohort of large fish clearly visible then. The cohort of large fish in August rapidly blends with the cohort of small fish in September, and it seems to gradually disappear thereafter. The cohort of small fish in August can be readily followed through December. Individuals in that cohort seem to reach a peak in size in October. Then the length frequency of that cohort seems to gradually shift to the left as sizes decrease through December, a pattern that would imply movement (?) of the larger members of the cohort from the sampling frame after October at least. The size composition in December is very similar to that in the preceding January. Young anchovies seem to recruit to the sampling frame primarily from about November or December through January and from July through August or September. Fish about 20-30 mm TL appear to be most common at those times fish about 20-30 mm TL appear to be most common.

There was large, inconstant, variation in bay anchovy abundance across the Chesapeake Bay and along an upbay-downbay axis. The inconstancy explains the significant F test for interaction.

Across-bay patterns of bay anchovy abundance showed large changes during the year. In most months (11 of 12), observed catches were higher in the combined deeper waters of the Central Plain and Deeps than they were in the combined littoral waters of the Eastern and Western Shores (Figure 8; Table 8). Catches in the deeper waters were some three times larger, on average, than those in the littoral waters (overall GM = 18.38, littoral waters; overall GM = 56.61, deeper waters). However, the observed differences between the littoral and deeper waters were significant in only seven months. In each case of significance, abundance was greater in the deeper waters. There was no obvious pattern to whether or not differences were significant. During months of peak abundance, differences were significant in some months (January) but not in others (December and June). Similarly, during months of low abundance, differences were significant in some months (March and August) but not in others (February). Differences between littoral and deeper waters were significant in each of the summer and fall months from July through November. Differences were not significant in many winter and spring months (December, February, and April through June).

The comparative pattern of bay anchovy abundance remained the same year-round in the deeper waters. There was little or no difference, or regular pattern, in observed abundance between the

Figure 8. The monthly (Mo) pattern of mean log bay anchovy catches (LGAB) in the mainstem Chesapeake Bay, Virginia by Across-Bay Region. Regions are Eastern Shore Littoral (1), Western Shore Littoral (2), Central Plain (3), and Deeps (4). When the number for a region is not indicated, the data value is the same as for the indicated region number.

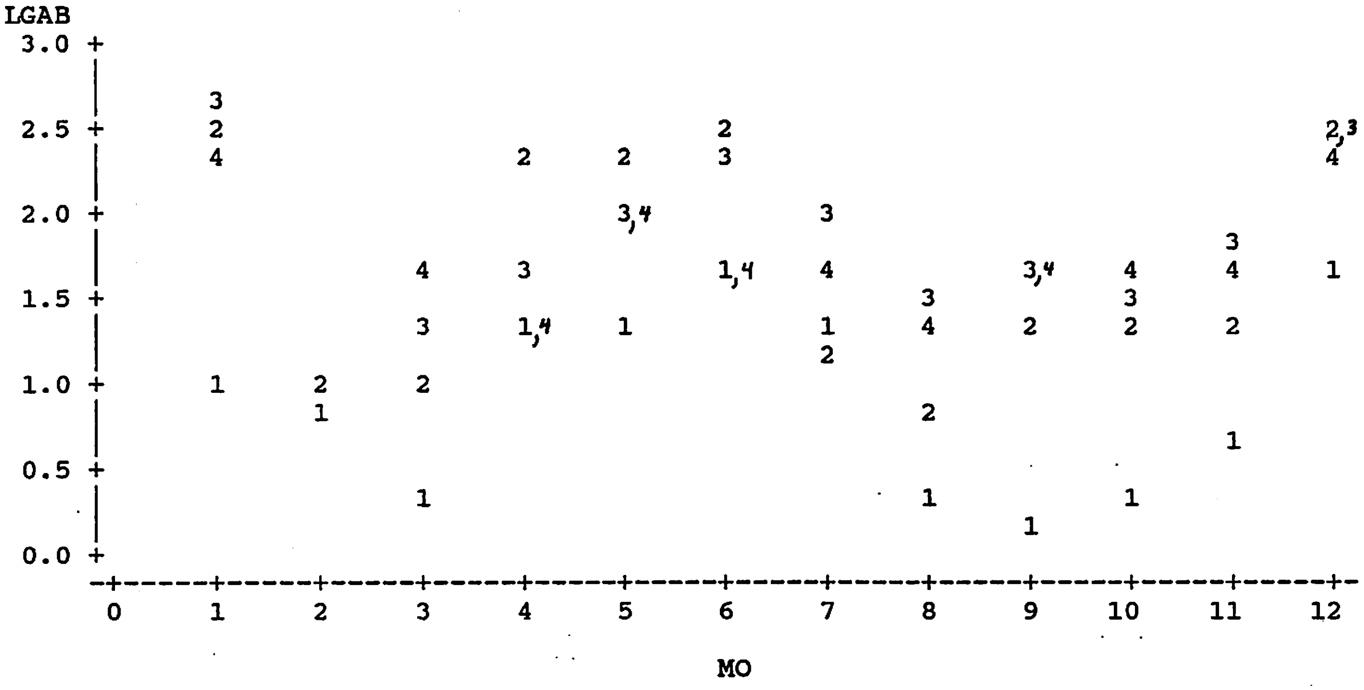

LGAB
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
MO

Table 8. Summary of individual degree of freedom contrast tests to evaluate differences in log bay anchovy abundance between Littoral waters (ESL and WSL) and the deeper Central Plain - Deeps waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig.	log	GM
Jan	7.43	7.89	**	1.75-2.53	54.86-340.75
Feb	0.12	0.13	ns	0.89-0.99	6.71- 8.71
Mar	7.62	8.09	**	0.73-1.53	4.40- 32.82
Apr	1.27	1.35	ns	1.81-1.49	63.72- 29.59
May	0.25	0.27	ns	1.83-1.98	66.55- 93.46
Jun	0.01	0.01	ns	2.02-2.05	103.95-111.09
Jul	5.56	5.91	*	1.17-1.86	13.93- 70.64
Aug	7.33	7.78	**	0.61-1.39	3.04- 24.41
Sep	8.29	8.80	**	0.77-1.60	4.90- 38.96
Oct	7.89	8.37	**	0.81-1.62	5.40- 40.40
Nov	7.19	7.63	**	0.98-1.75	8.49- 55.42
Dec	0.86	0.91	ns	2.09-2.35	120.82-224.32

Central Plain and Deeps waters, and there were no significant differences in abundance between these regions in any months (Figure 8; Table 9). The overall geometric mean catch was 66.01 in the Central Plain waters and 48.53 in the Deeps.

The comparative pattern of bay anchovy abundance varied during the year in the littoral waters. In nearly all months (11 of 12) observed catches were higher in the Western Shore Littoral waters than in the Eastern Shore Littoral (Figure 8; Table 10). Catches in the Western Shore Littoral were nearly seven times higher, on average, than those in the Eastern Shore Littoral (overall GM = 6.86, ESL; overall GM = 46.75, WSL). However, observed differences between the Eastern Shore and Western Shore were significant in only seven months. Differences between the Eastern Shore and Western Shore waters were significant in the late fall and winter months of peak abundance (December and January) and in most of the late spring-early summer months of peak abundance (April through June). Differences between regions were not significant in the winter trough months of low abundance (February and March) nor in the summer trough month of lowest abundance (August).

Upbay-downbay patterns of bay anchovy abundance showed much change during the year, largely reflecting a general pattern of greatest abundance towards the Lower Bay in the coldest months of the year and greatest abundance towards the Upper Bay in other months. Observed catches were significantly greater in the Lower Bay than in the Upper Bay during January and March, two of the

Table 9. Summary of individual degree of freedom contrast tests to evaluate differences in log bay anchovy abundance between the Eastern Shore Littoral and Western Shore Littoral waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	11.24	11.94	**	1.06-2.43	10.55-269.10
Feb	0.32	0.34	ns	0.77-1.00	4.91- 9.05
Mar	2.95	3.14	ns	0.38-1.08	1.41- 11.11
Apr	7.54	8.01	**	1.25-2.37	16.80-234.27
May	4.69	4.98	*	1.39-2.27	23.40-185.99
Jun	4.42	4.70	*	1.59-2.45	38.06-281.01
Jul	0.15	0.16	ns	1.25-1.10	16.89- 11.47
Aug	1.90	2.01	ns	0.32-0.89	1.11- 6.71
Sep	9.25	9.82	**	0.15-1.39	0.41- 23.63
Oct	6.37	6.77	**	0.29-1.32	0.95- 19.97
Nov	3.32	3.52	ns	0.61-1.35	3.03- 21.35
Dec	3.97	4.22	*	1.68-2.49	46.73-309.92

Table 10. Summary of individual degree of freedom contrast tests to evaluate differences in log bay anchovy abundance between Central Plain and Deeps waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.65	0.70	ns	2.70-2.37	498.90-232.64
Feb	0.10	0.10	ns	0.92-1.05	7.39- 10.24
Mar	0.53	0.56	ns	1.38-1.68	23.01- 46.65
Apr	0.38	0.40	ns	1.61-1.36	39.81- 21.94
May	0.00	0.00	ns	1.98-1.97	94.83- 92.11
Jun	2.43	2.58	ns	2.37-1.73	232.26- 52.85
Jul	0.89	0.94	ns	2.05-1.66	110.55- 45.01
Aug	0.18	0.20	ns	1.48-1.30	28.86- 18.93
Sep	0.00	0.01	ns	1.59-1.62	37.68- 40.28
Oct	0.10	0.10	ns	1.55-1.68	34.75- 46.93
Nov	0.29	0.31	ns	1.86-1.64	71.64- 42.81
Dec	0.13	0.14	ns	2.43-2.28	265.77-189.28

coldest months of the year (Figure 9; Tables 11, 12). Catches in the Lower Bay were about seven times greater than in the Upper Bay, on average, from January through March (mean of the mean GM = 19.83, Upper Bay; mean of the mean GM = 141.01, Lower Bay). There was no significant difference between Upper, Middle, or Lower Bay waters in February when catches were very low. Catches in the Middle Bay waters were intermediate between, and not significantly different from the average in, the other two regions in January. In March, highest catches were in the Middle Bay, implying they were significantly higher than in the Upper Bay, because there was no significant difference between the Upper and Lower Bays. There was no significant difference between regions in April as catches and temperatures began to increase. In all later months, with the exception of August when catches were low and there were no significant upbay-downbay difference, observed catches were higher in the Upper Bay waters than in the Lower Bay; the differences between these two regions were significant in each month except October and December. Catches in the Upper Bay from May through November were almost nine times higher, on average, than those in the Lower Bay (mean of the mean GM = 100.31, Upper Bay; mean of the mean GM = 11.77, Lower Bay). Observed Lower Bay catches were smaller than in either the Upper or Middle Bay waters from May through December. Except for August, as noted above, observed catches in the Middle Bay waters were higher than in either the Upper or Lower Bay waters from June through December. That implies Middle Bay

Figure 9. The monthly pattern (Mo) of mean log bay anchovy catches (LGAB) in the mainstem Chesapeake Bay, Virginia by Up-Down Bay Region. Regions are Upper Bay (1), Middle Bay (2), and Lower Bay (3). When the number for a region is not indicated, the data value is the same as for the indicated region number.

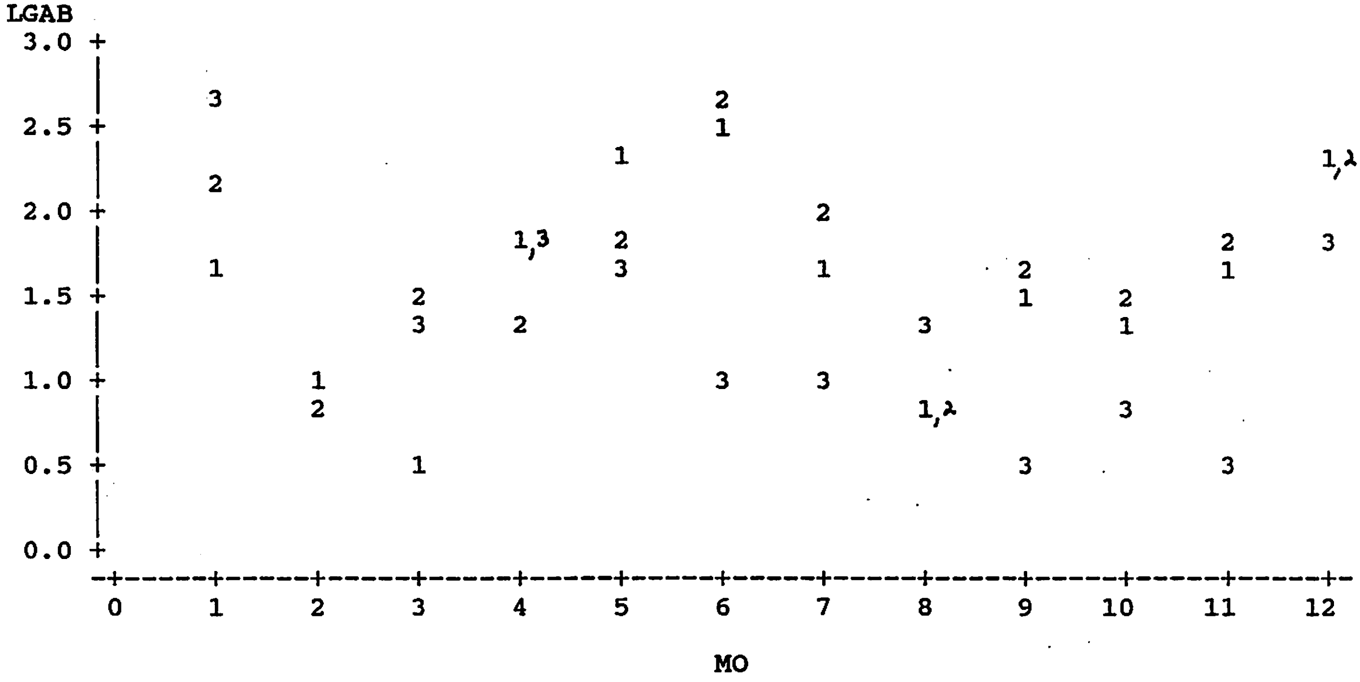

LGAB
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
MO

Table 11. Summary of individual degree of freedom contrast tests to evaluate differences in log bay anchovy abundance between the Upper and Lower Bay waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	6.72	7.14	**	1.68-2.60	46.81-393.53
Feb	0.14	0.15	ns	1.04-0.90	9.85-7.00
Mar	4.97	5.28	*	0.59-1.37	2.83-22.49
Apr	0.19	0.02	ns	1.86-1.81	71.83-64.02
May	4.42	4.70	*	2.34-1.60	220.31-38.94
Jun	19.95	21.19	**	2.52-0.94	328.91-7.69
Jul	4.54	4.82	*	1.68-0.92	46.57-7.39
Aug	1.69	1.79	ns	0.84-1.30	5.92-18.92
Sep	7.07	7.50	**	1.45-0.51	26.94-2.21
Oct	3.26	3.46	ns	1.39-0.75	23.67-4.67
Nov	10.61	11.27	**	1.71-0.55	49.83-2.58
Dec	2.14	2.27	ns	2.41-1.90	257.78-77.72

Table 12. Summary of individual degree of freedom contrast tests to evaluate differences in log bay anchovy abundance between the Middle Bay and the average in the Upper and Lower Bay waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

Contrast	SS	F	Sig	MEANS log	MEANS GM
Jan	0.00	0.00	ns	2.14-2.14	138.83-136.34
Feb	0.10	0.11	ns	0.87-0.97	6.45-8.32
Mar	2.27	2.41	ns	1.44-0.98	26.45-8.48
Apr	3.44	3.66	ns	1.27-1.84	17.60-67.82
May	0.48	0.51	ns	1.76-1.97	56.66-93.02
Jun	9.02	9.58	**	2.65-1.73	443.97-52.55
Jul	4.40	4.67	*	1.94-1.30	86.69-18.98
Aug	0.51	0.54	ns	0.85-1.07	6.09-10.74
Sep	4.22	4.48	*	1.61-0.98	39.33-8.47
Oct	1.85	1.97	ns	1.49-1.07	29.86-10.82
Nov	5.26	5.59	*	1.83-1.13	67.04-12.50
Dec	0.40	0.43	ns	2.35-2.15	222.23-141.73

catches were significantly greater than in the Lower Bay in those months, because Upper Bay catches were usually significantly higher than Lower Bay ones.

Other Sources of Variation in Bay Anchovy Catches:

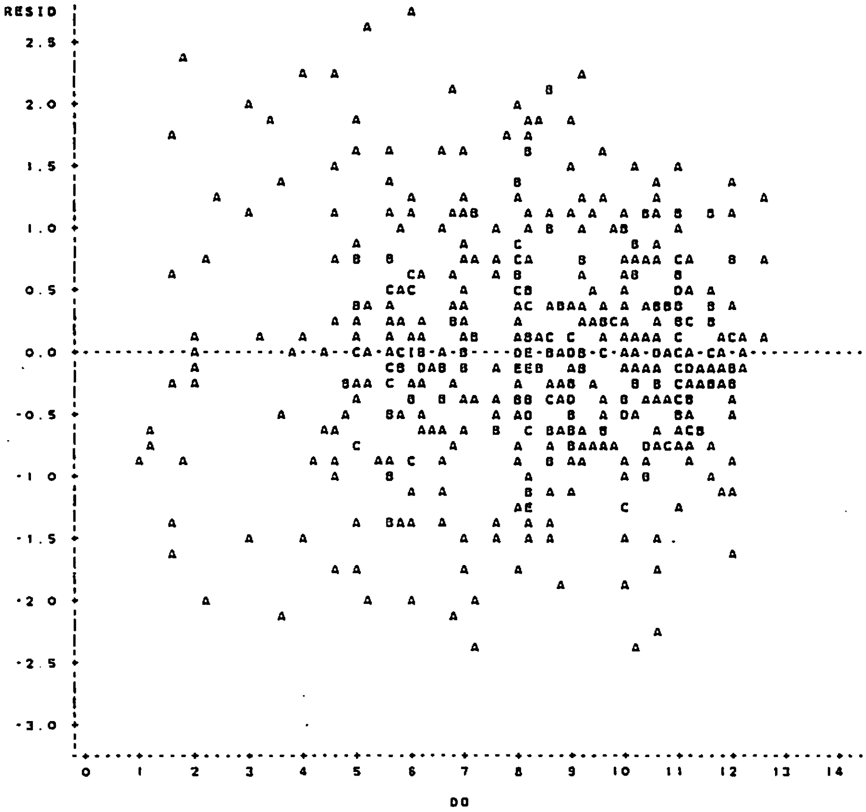
Overall plots of residuals against bottom D.O. indicate no strong relationship (Figure 10). The two variables are independent over much of the D.O. range. Even at low D.O. (D.O < 2 mg/l), there seems to be little pattern though many residuals seem to be negative. There is little suggestion of lower abundance in, or avoidance of, low D.O. areas. However, the pattern is not completely clear, possibly because not many collections were made when D.O. was low.

Overall plots of residuals against temperature indicate no regression or other relations not already postulated in the model (Figure 4). Variation in residuals generally appears quite constant within temperatures though it may be low at temperatures below about 8° C.

Overall plots of residuals against salinity indicate no regression or other effects not already postulated in the model (Figure 5). The pattern of the residuals seems to form a circle, the smallest residuals occurring at the lowest and highest salinity values.

Overall plots of residuals against Areas (not shown) indicate no regression or other relations not already included in the model. Variation in residuals appears constant within Areas.

Figure 10. The overall relationship (all data) between residuals from log bay anchovy catches and bottom dissolved oxygen (mg/l). A = 1 observation, B = 2 observation, etc.


RESID
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DO

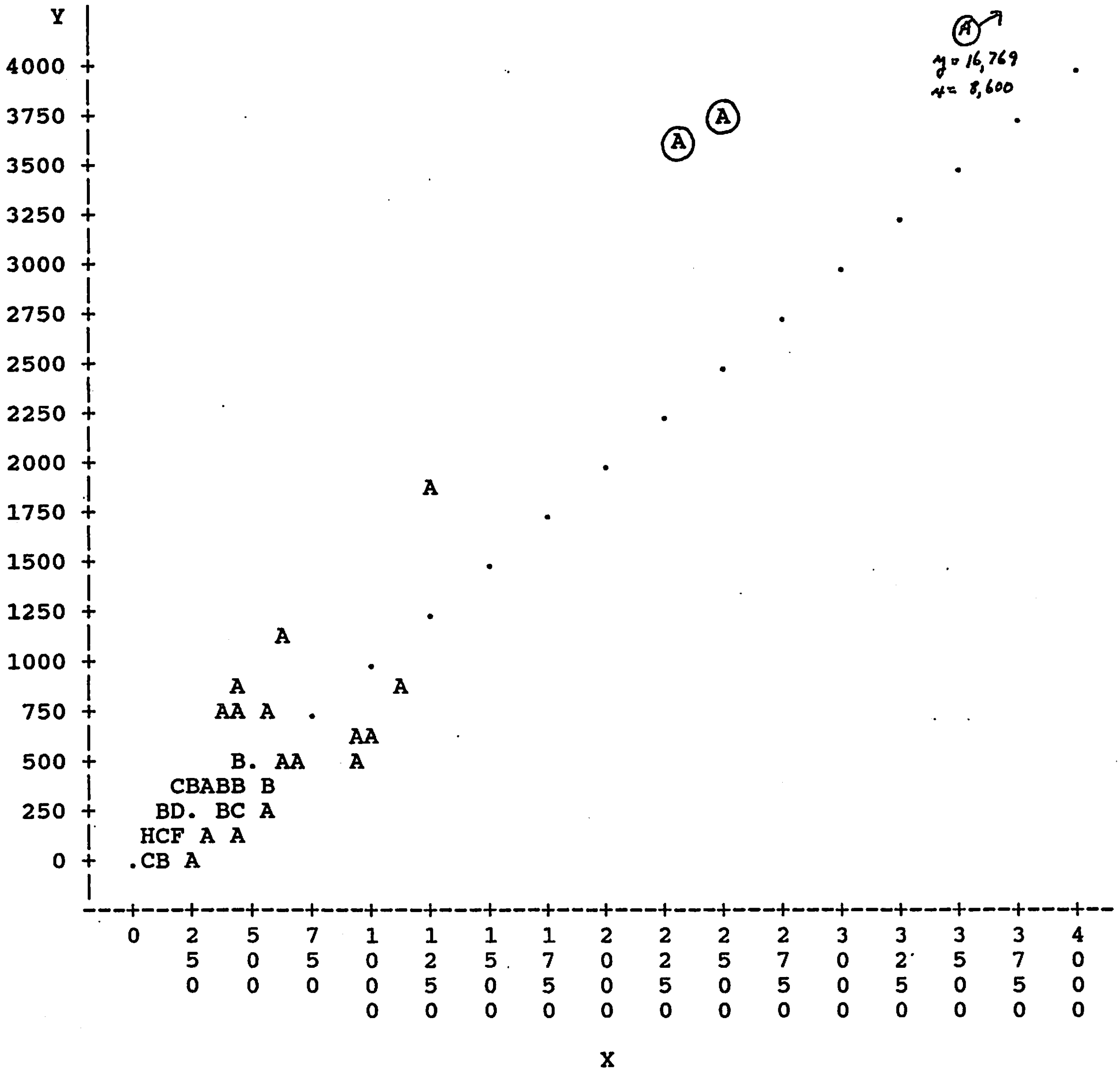
Overall plots of residuals against Months (not shown) indicate no regression or other relations not already included in the model. Variation in residuals appears quite constant within Months.

Spot

Choosing an Appropriate Transformation:

The log transformation appears appropriate for the present counts of abundance data on spot. Plots of the untransformed standard deviation on the untransformed arithmetic mean within Months x Areas cells indicate these variables are reasonably equal for mean catches below some 1300 spot (Figure 11), because those data points are scattered along the 45 degree diagonal. With mean catches larger than 2000, the standard deviation lies above the diagonal indicating the log transformation is not fully appropriate for larger catches. The calculated slope ($b = 1.821$) of the regression of the untransformed standard deviation on the untransformed arithmetic mean is significantly higher than a hypothesized $\beta = 1$ ($t = 27.01$; 142 df) when all data points are included. However, deleting three data points (circled in Figure 11) whose mean is greater than 2000, and which probably act as influential observations, gives a calculated slope ($b = 0.917$) that is only marginally significant but below a hypothesized $\beta = 1$ ($t = -1.98$; 139 df; $\alpha = .05$). In contrast, plots of the variance on the mean (not shown) found nearly all data points above or well above the diagonal. The calculated slope ($b = 27{,}136.03$) of the regression of the variance on the mean is significantly greater than a hypothesized $\beta = 1$ ($t = 26.51$; 142 df) when all data points are included. These conditions indicate the square root transformation is not sufficient to normalize the

Figure 11. Relationship between standard deviation (y) and untransformed arithmetic mean counts of abundance (x) for spot. The 45° diagonal has slope b = 1, so y = x along it. A = 1 observation, B = 2 observations, etc.


Y
4000
3750
3500
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
3250
3500
3750
4000
X
A
B
C
D
F
H
y = 16,769
x = 8,600

counts of abundance, but the log transformation is reasonable.

The log transformation had the smallest standard error (0.70), the smallest coefficient of variation (CV = 68.61), provided the best fit for the postulated model ($100r^2 = 73.71$), and as noted later, provided reasonable homogeneity of variance and normality, and the greatest number of effective degrees of freedom (Table 13). Using these criteria, the square root transformation had properties much less desirable than the log transformation and analysis with no transformation was even worse.

General Data Description:

Spot were the second most abundant fish in the sampling frame. They were one of two predominant species and made up 27.67% of the overall catch (Chittenden 1989).

The overall geometric mean catch was 9.32 spot, with 95% confidence limits about the mean being 8.04-10.77 (Table 14). The overall mean log catch was 1.01, with 95% confidence limits being 0.96-1.07. The standard error of the mean log catch was 0.70, and the coefficient of variation was 68.61 (Table 13). The maximum catch was 33,749 spot and the minimum was 0.

Spot are not resident year-round in the Chesapeake Bay. None were captured January-February (Table 15). They were not frequently captured in March or April, being absent in most strata then (11 of 12 in March; 9 of 12 in April).

Table 13. Summary of the comparative properties of listed transformations on spot abundance counts.

	Transformation		
Property	log	none	Square Root
Mean	1.01	248.64	8.13
Std. error	0.70	1493.78	11.11
$100r^2$	73.71	26.96	49.46
CV	68.61	600.77	136.65
Independence of Residuals	yes	yes	yes
Homogeneity of Variance Using Cochran's C.	reasonable	no	no
Normality	reasonable	did not examine	did not examine
Homogeneity of Slopes	reasonable	did not examine	did not examine

Table 14. Summary statistics on overall log spot abundance, with a geometric mean (GM) back-transformation. No transformation was applied to the sample size (n) and the minimum-maximum counts.

	LOG	GM
n	576	--
Min-Max	0-33,749	--
Mean	1.01	9.32
95% Confidence Limits	0.96-1.07	8.04-10.77

Table 15. Summary of spot presence or absence in the Month-Area Cells. X = Present; - = Absent.

	UPPER BAY				MIDDLE BAY				LOWER BAY				TOTAL PRESENT
Month	ESL (01)	WSL (02)	CP (03)	DP (04)	ESL (05)	WSL (06)	CP (07)	DP (08)	ESL (09)	WSL (10)	CP (11)	DP (12)	
Jan	-	-	-	-	-	-	-	-	-	-	-	-	0
Feb	-	-	-	-	-	-	-	-	-	-	-	-	0
Mar	-	-	-	-	-	-	-	-	-	X	-	-	1
Apr	-	-	X	X	-	-	-	-	-	-	-	X	3
May	X	X	X	X	-	X	X	-	-	X	X	-	8
Jun	X	X	X	X	X	X	X	X	X	X	X	X	12
Jul	X	X	X	X	X	X	X	X	X	X	X	X	12
Aug	X	X	X	X	X	X	X	X	X	X	X	X	12
Sep	X	X	X	X	X	X	X	X	X	X	X	X	12
Oct	X	X	X	X	X	X	X	X	X	X	X	X	12
Nov	X	X	X	X	X	X	X	X	X	X	X	X	12
Dec	X	X	X	X	X	X	X	X	X	X	X	X	12
Total Present	8	8	9	9	7	8	8	7	7	8	8	8	95

Overview of the ANOVA-ANCOVA:

The postulated models explain much of the total variation in spot catches. A log transformation explained about 74% of the total variation (Table 16). Much less is explained (Table 13) using a square root transformation (49.46%) and comparatively little is explained with no transformation (26.96%).

The overall log ANCOVA (or ANOVA) model was significant at $\alpha = .01$ (Table 16). The Months and Areas main effects were both highly significant. The Months main effect was far more important than the Areas effect -- some ten times as important -- in explaining variation in spot catches, $100r^2$ values being 47.60% for Months and only 4.81% for Areas. Interaction was significant and explained 21.30% of the total variation. The significant interaction implies that spatial and temporal factors have a complex effect on the distribution of spot, eg. -- the simple effects of Areas, for example, are not constant; rather they vary from month to month.

The temperature covariate was not significant, though the salinity covariate was. Neither covariate explained much variation in spot catches (0.01%, temperature; 0.73%, salinity) beyond that associated with the Months and Areas effects, whether significant or not. Therefore, the covariates were deleted from the model, and further analyses were made using only the ANOVA model with its main effects and interactions.

The overall log ANOVA finally accepted explained 73.71% of the variation in spot catches (Table 13). Its most important

Table 16. Summary of the ANCOVA on spot, log transformation, with $100r^2$ values.

Source of Variation	df	SS	MS	F	$100r^2$
Corr. Tot.	575	794.52	--	--	100.00
Model	145	591.46	4.08	8.64 **	74.44
Months (M)	11	378.23	34.38	72.81 **	47.60
Areas (A)	11	38.19	3.47	7.35 **	4.81
M x A	121	169.21	1.40	2.96 **	21.30
Sal	1	5.79	5.79	12.26 **	0.73
Temp	1	0.04	0.04	0.09 ns	<0.01
Error	430	203.06	0.47	--	25.56

component by far was the Months main effect, and Interaction was next in importance (Table 16). The Areas main effect had comparatively little importance. Random variation, or variation not recognized and not included in the model, accounted for only 26% of the total variation in spot catches.

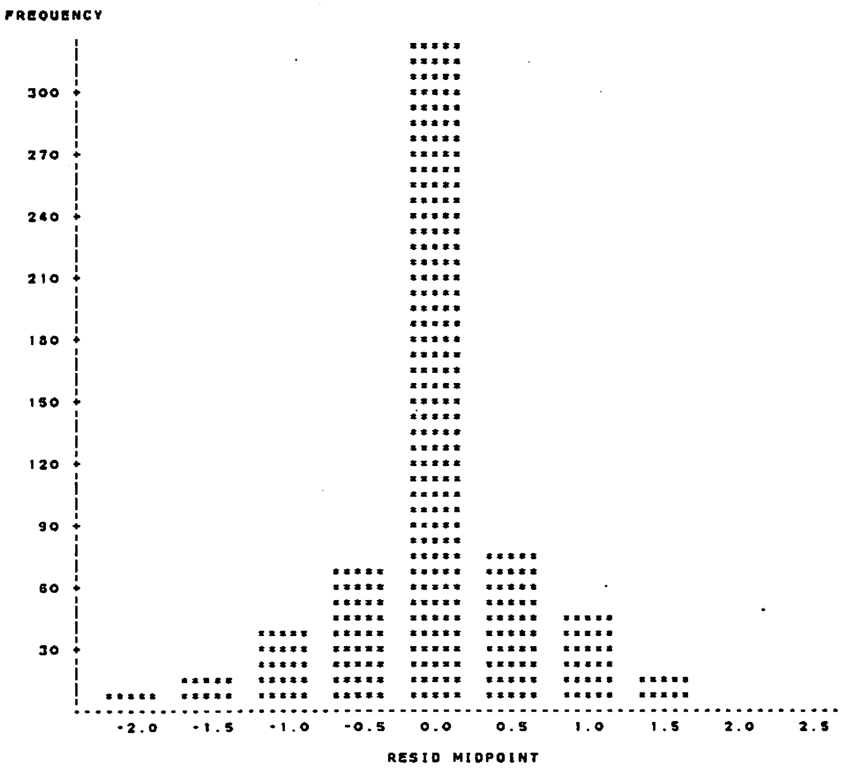
Validity of the Assumptions of the ANOVA-ANCOVA models:

The assumptions of the ANOVA-ANCOVA models appear to be reasonably well-fulfilled, if not exactly fulfilled, when a log transformation is used on the spot catch data.

The assumption of normality of the residuals is a reasonable approximation, though not true. The frequency distribution of the residuals from the log ANOVA model (Figure 12) appears to be reasonably normal, with zero mean and reasonable symmetry about the mean. The Kolomogorov D statistic, however, is significant ($D = 0.174$; $n = 576$) at $\alpha = .01$, which indicates the distribution of the residuals is not truly normal. The significant D statistic, in part, reflects an exceptionally large sample size which can detect even very small departures from normality. The small departure from normality should not contradict the basic conclusion indicated by the residual plot: the assumption is reasonable albeit not exact.

The assumption of homogeneity of within-cell variance is reasonable using a log transformation on the catch data. Cochran's C statistic ($C = 0.715$; 3 df; $n = 144$ df) is significant at $\alpha = .01$. However, significance reflects the

Figure 12. Frequency distribution of the residuals to evaluate the assumption of normality in spot.


FREQUENCY
300
270
240
210
180
150
120
90
60
30
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
RESID MIDPOINT

inclusion of one Month x Areas cell whose variance (4.98) was double that of the next largest variance (2.40), because it included two zero catches along with one enormously large catch (33,749 spot, the greatest catch made). Deleting that cell, Cochran's C statistic ($C = 0.037$, 3 df; $n = 143$) is not significant. The cell was retained in further ANOVA tests, however, because an r_{10} test (Dixon and Massey, 1969) did not declare the enormous catch an outlier ($r_{10} = 0.38$). In contrast to the log transformation, Cochran's C statistic ($C = 0.135$; 3 df; $n = 143$) remains significant at $\alpha = .01$ using a square root transformation; similarly, Cochran's C ($C = 0.357$; 3 df; $n = 143$) also remains significant at $\alpha = .01$ with no transformation.

The assumption of homogeneous, linear regression on the covariates within Months x Areas cells also appears reasonable, or there was no regression. The residuals from the ANOVA model were plotted (not shown) on temperatures within cells and on salinity. Only one cell (of 144) indicated a relationship (linear) between the residuals and temperature and three cells did so for salinity. These conclusions of little or no within-cell relation between residuals and temperature or salinity are illustrated by overall plots (all data) of the relationships between temperature and residuals and salinity and residuals (Figures 13, 14).

Interpretation of Interaction and Main Effects to Evaluate Spatial/Temporal Distributions:

Spot catches show great variation between months that forms

Figure 13. The overall relationship (all data) between residuals from log spot catches and bottom temperature (C°). A = 1 observation, B = 2 observations, etc.

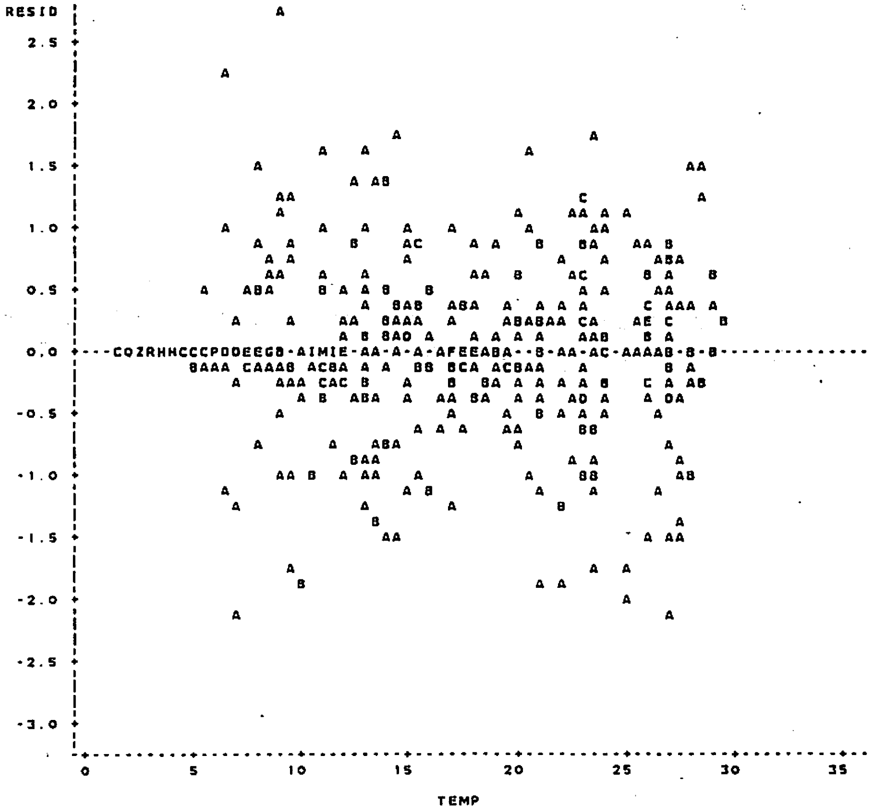
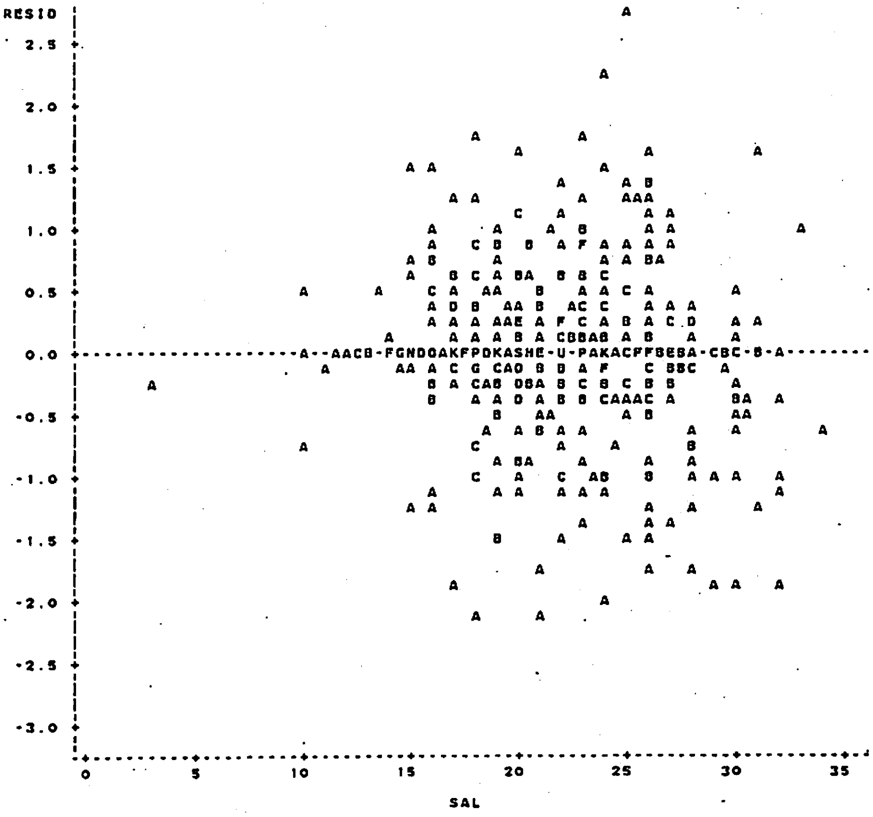

RESID
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0
5
10
15
20
25
30
35
TEMP

Figure 14. The overall relationship (all data) between residuals from log spot catches and bottom salinity (parts per thousand). A = 1 observation, B = 2 observations, etc.


RESID
2.5
2.0
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1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0
5
10
15
20
25
30
35
SAL

a clear annual pattern of change from a winter low to a summer-fall peak. No spot were captured in the winter and early spring months of January through March (Figure 15; Table 17). Monthly catches generally rose after March to reach a peak in the summer and early fall months of August through October. Catches then gradually declined in November and December towards their winter lows. Tukey's multiple comparisons tests (Table 18), which elaborate on the significant F test for Months, show significantly more spot were caught in the summer and early fall months of June through October than in the winter and early spring months of January through May. Intermediate size catches in November and December were, variously, significantly different or not from the peak summer-early fall catches and the negligible winter-early spring ones. Small early spring catches in March through May were, variously, significantly different or not from the larger summer-fall catches and the January-February months when no spot were caught.

The annual pattern of catches reflects migratory movements of spot into and out of the Chesapeake Bay and their recruitment to and decruitment from the sampling frame and gear. With few exceptions, only two age groups of spot were captured by the sampling gear as indicated in length frequencies, particularly in April (Figure 16). These age groups consist of the small, recently-recruited young-of-the-year, which were some 15-30 mm TL in April, and fish presumably of age I, which were some 150-210 mm TL in April. Neither age group occurs in the Chesapeake Bay

Figure 15. The monthly (Mo) pattern of mean log spot catches (LGAB) in the mainstem Chesapeake Bay, Virginia.

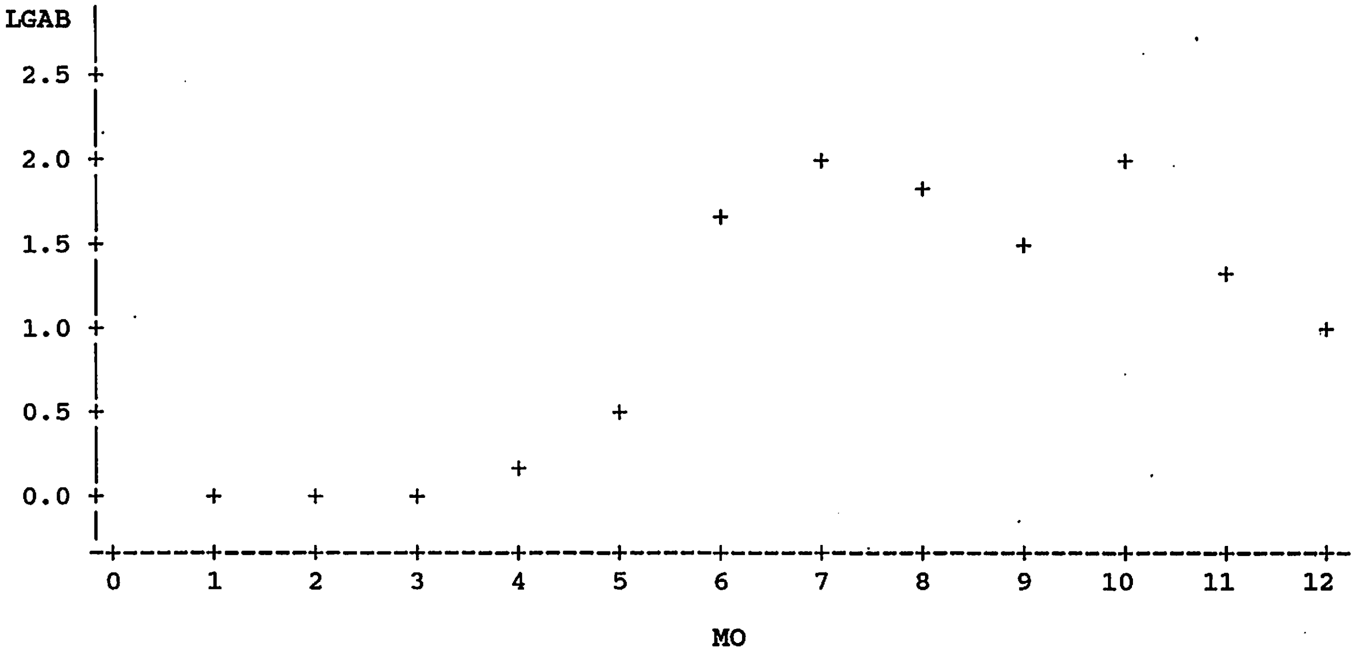

LGAB
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
MO

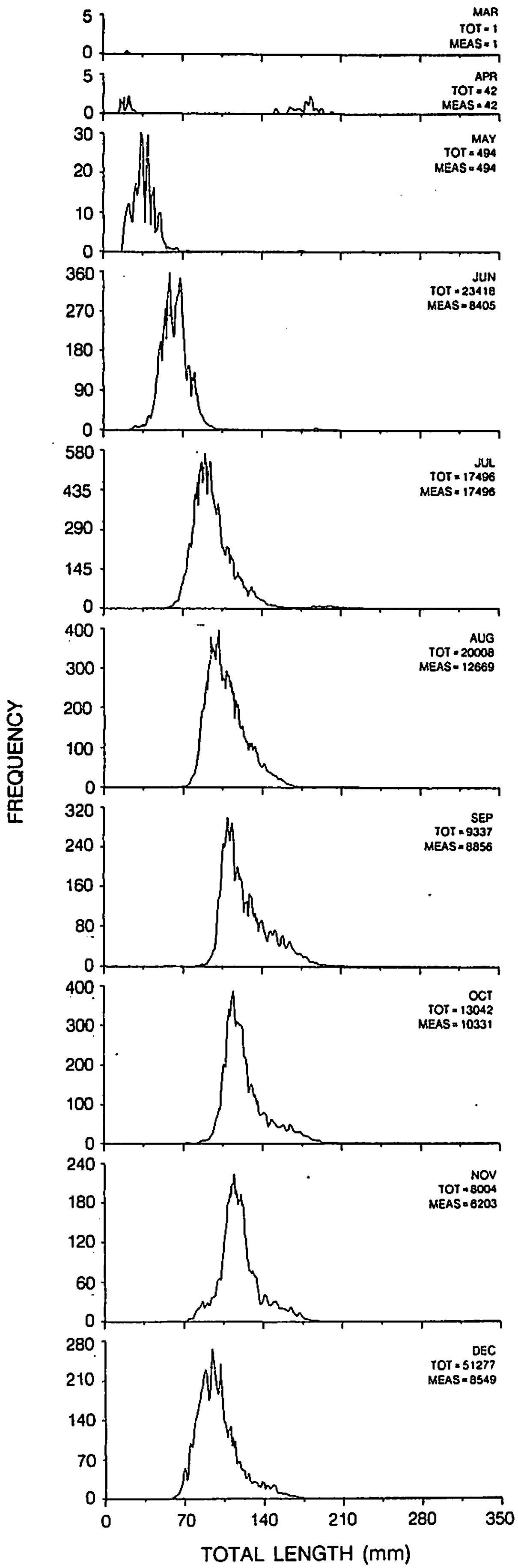
Table 17. Summary of 95% confidence limits (CL) about monthly mean log abundance of spot, with a geometric mean (GM) back-transformation.

Month	log	CL	GM	CL
Jan	0.00	-0.20-0.20	0.00	-0.37- 0.59
Feb	0.00	-0.20-0.20	0.00	-0.37- 0.59
Mar	0.01	-0.20-0.21	0.02	-0.36- 0.62
Apr	0.08	-0.12-0.29	0.21	-0.24- 0.93
May	0.47	0.27-0.67	1.96	0.86- 3.71
Jun	1.69	1.49-1.90	48.39	30.03- 77.63
Jul	2.01	1.80-2.21	100.38	62.68-160.38
Aug	1.89	1.69-2.09	76.82	47.89-122.89
Sep	1.51	1.31-1.71	31.28	19.28- 50.39
Oct	2.03	1.83-2.24	107.01	66.85-170.94
Nov	1.40	1.19-1.60	23.87	14.62- 38.58
Dec	1.07	0.87-1.27	10.81	6.42- 17.80

Table 18. Summary of Tukey's hsd multiple comparisons tests on log spot abundance. Means with different letters are significantly different.

		MEAN		
Month	n	log	GM	Significance
Oct	48	2.03	106.89	a
Jul	48	2.01	100.39	a
Aug	48	1.89	76.80	a b
Jun	48	1.69	48.43	a b c
Sep	48	1.51	31.28	b c d
Nov	48	1.40	23.89	c d
Dec	48	1.07	10.80	d
May	48	0.47	1.96	e
Apr	48	0.08	0.21	e f
Mar	48	0.01	0.01	e f
Jan	48	0.00	0.00	f
Feb	48	0.00	0.00	f

Figure 16. Monthly length frequencies of spot. Frequencies are moving averages of three.


MAR
TOT = 1
MEAS = 1
APR
TOT = 42
MEAS = 42
MAY
TOT = 494
MEAS = 494
JUN
TOT = 23418
MEAS = 8405
JUL
TOT = 17496
MEAS = 17496
AUG
TOT = 20008
MEAS = 12669
SEP
TOT = 9337
MEAS = 8856
OCT
TOT = 13042
MEAS = 10331
NOV
TOT = 8004
MEAS = 6203
DEC
TOT = 51277
MEAS = 8549
5
0
5
0
30
20
10
0
360
270
180
90
0
580
435
290
145
0
400
300
200
100
0
320
240
160
80
0
400
300
200
100
0
240
180
120
60
0
280
210
140
70
0
FREQUENCY
0
70
140
210
280
350
TOTAL LENGTH (mm)

in the winter and early spring months of January through March, as evidenced by the almost complete absence of any spot in the catch then. Few age I spot were captured after April following their migration into the Chesapeake Bay after overwintering in the ocean. Young-of-the-year spot begin to recruit to the sampling frame primarily in April and May, though one was captured in March. If this recruitment reflects descent to the bottom from pelagic early stages, it apparently occurs in a short time period, because few fish < 30 mm were captured other than in April and May. Except for April, catches of spot in the mainstem Chesapeake were primarily composed of the young-of-the-year in all months when spot were present. Growth of the young-of-the-year can be readily followed in the length frequencies through August and September when a peak is reached. Thereafter, sizes of spot in the catch begin to decrease through December, a pattern which indicates the larger, presumably older spot migrate to the ocean first to overwinter, leaving behind the smaller, presumably younger members of the cohort. This downbay movement must begin by September when lengths of the spot reach their maximum in the sampling frame. The period September through December, therefore, represents a period when young spot are moving through the Chesapeake Bay on their first annual movement to overwinter in the ocean.

Spot are widely distributed throughout the sampling frame in the summer and fall months of June through December. They occur in the Eastern Shore Littoral, Western Shore Littoral, Central

Plains, and Deeps waters and in the Upper, Middle and Lower bay portions of the sampling frame (Table 15; Figures 17, 18).

There were large intra-annual changes in patterns of spot abundance, not a constancy, across the Chesapeake Bay and along an upbay-downbay axis. These changes in patterns explain the significant F test for interaction.

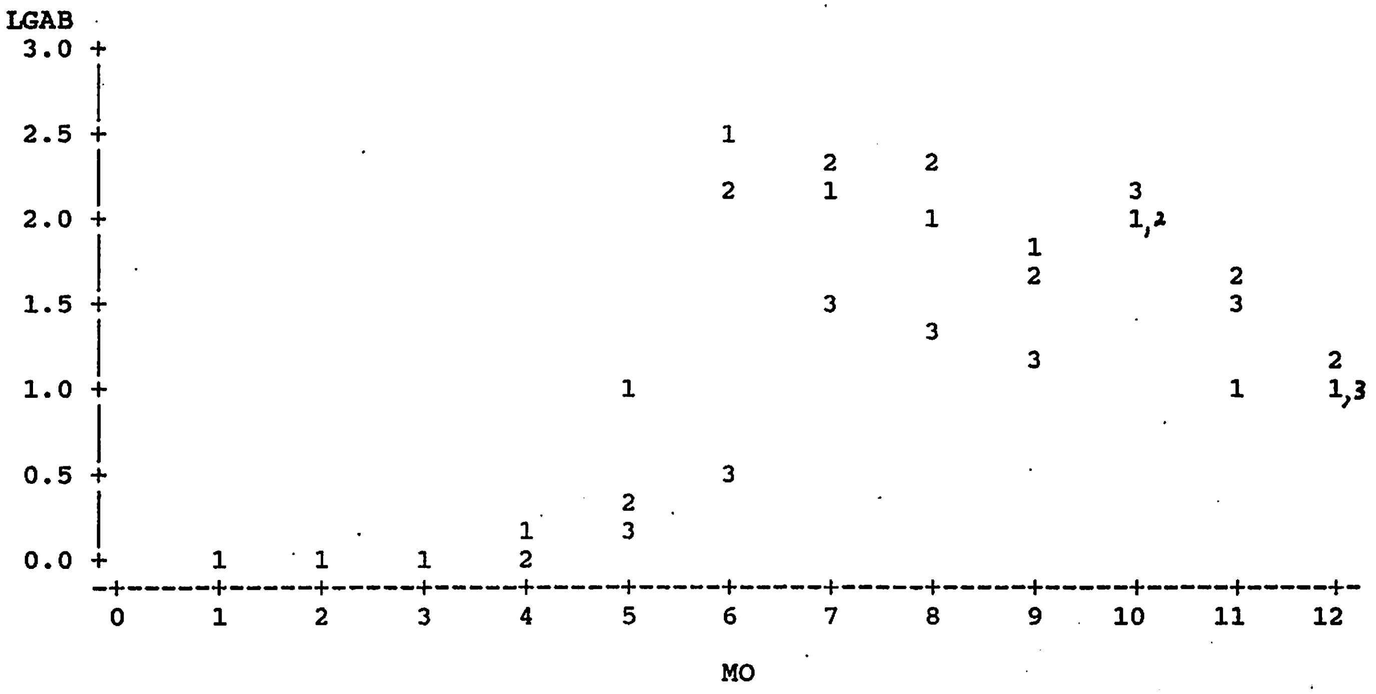
Across-bay patterns of spot abundance showed large changes during the year. There was little or no difference in abundance between the combined littoral waters of the Eastern and Western Shores and combined deeper waters of the Central Plain and Deeps, and no significant difference, in the winter and spring months of January through April when spot were absent, or not abundant, in the Chesapeake (Figure 17; Table 19). Thereafter, this pattern changed. In May, as they began to become more abundant, spot were significantly more abundant in the littoral waters than in the deeper waters. However, the difference in May really reflects only a significantly greater abundance in the Western Shore Littoral waters. There was little or no difference between the Eastern Shore Littoral and the two deeper regions. In June, as they approached peak abundance, spot were homogeneously distributed across the Chesapeake Bay. There was no significant difference in abundance then between the combined littoral waters and the combined deeper waters (Table 19), between the Central Plain and Deeps waters (Table 20), or between the Eastern Shore Littoral and Western Shore Littoral waters (Table 21). From July through September, however, spot were more abundant each month,

Figure 17. The monthly (Mo) pattern of mean log spot catches (LGAB) in the mainstem Chesapeake Bay, Virginia by Across-Bay Region. Regions are Eastern Shore Littoral (1), Western Shore Littoral (2), Central Plain (3), and Deeps (4). When the number for a region is not indicated, the data value is the same as for the indicated region number.

```
LGAB
3.0 +
    |
    |
2.5 +
    |                                          3,4   4
    |                                                            2,3,4
2.0 +                                                1,3   3
    |                                    2,3   2                       4     3
    |                                    1                       1           4
1.5 +                                    4     1           2,4         2,3
    |
    |                                                2
1.0 +                              2
    |                                                      1           1
    |
0.5 +                                                                        2
    |                              3,4
    |                        3     1                                         1
0.0 +      1     1     1     1
   --+------+------+------+------+------+------+------+------+------+------+------+------+-
     0      1      2      3      4      5      6      7      8      9     10     11     12

                                         MO
```

Figure 18. The monthly pattern (Mo) of mean log spot catches (LGAB) in the mainstem Chesapeake Bay, Virginia by Up-Down Bay Region. Regions are Upper Bay (1), Middle Bay (2), and Lower Bay (3). When the number for a region is not indicated, the data value is the same as for the indicated region number.


LGAB
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9
10
11
12
MO
1,2
1,3

Table 19. Summary of individual degree of freedom contrast tests to evaluate differences in log spot abundance between Littoral waters (ESL and WSL) and the deeper Central Plain - Deeps waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.00	ns	0.30-0.00	0.03- 0.00
Apr	0.34	0.70	ns	0.00-0.17	0.00- 0.47
May	1.54	3.19	ns	0.65-0.29	3.47- 0.96
Jun	81.30	0.00	ns	1.69-1.69	48.28- 48.51
Jul	7.20	14.89	**	1.62-2.39	40.55-246.34
Aug	3.53	7.30	**	1.62-2.16	40.69-144.29
Sep	3.27	6.77	*	1.25-1.77	16.69- 57.91
Oct	0.90	1.85	ns	1.90-2.17	77.86-146.93
Nov	3.29	6.81	*	1.13-1.66	12.60- 44.44
Dec	23.09	47.75	**	0.38-1.77	1.39- 58.31

Table 20. Summary of individual degree of freedom contrast tests to evaluate differences in log spot abundance between Central Plain and Deeps waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Apr	0.04	0.09	ns	0.13-0.21	0.34- 0.62
May	0.03	0.68	ns	0.26-0.33	0.80- 1.14
Jun	0.46	0.94	ns	1.83-1.56	67.02- 35.04
Jul	0.00	0.00	ns	2.39-2.40	244.54-248.15
Aug	0.26	0.54	ns	2.06-2.27	113.14-183.93
Sep	0.99	2.05	ns	1.97-1.57	93.08- 35.89
Oct	0.02	0.03	ns	2.14-2.20	138.60-155.77
Nov	0.63	1.30	ns	1.50-1.82	30.30- 64.97
Dec	0.45	0.94	ns	1.90-1.63	79.01- 41.49

Table 21. Summary of individual degree of freedom contrast tests to evaluate differences in log spot abundance between the Eastern Shore Littoral and Western Shore Littoral waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00-0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00-0.00
Mar	0.00	0.01	ns	0.00-0.25	0.00-0.06
Apr	0.00	0.00	ns	0.00-0.00	0.00-0.00
May	4.46	9.22	**	0.22-1.08	0.66-11.07
Jun	0.17	0.34	ns	1.61-1.78	39.70-58.67
Jul	0.42	0.87	ns	1.49-1.75	29.65-55.33
Aug	3.30	6.83	*	1.99-1.25	96.94-16.74
Sep	2.68	5.53	*	0.91-1.58	7.20-37.17
Oct	0.88	1.82	ns	1.71-2.09	49.73-121.58
Nov	2.41	4.98	*	0.82-1.45	5.56-27.22
Dec	0.85	1.76	ns	0.19-0.57	0.55-2.69

generally much more abundant, in the deeper Central Plain and Deeps waters than in the littoral waters of the Eastern and Western Shores. The differences between the littoral and deeper areas are significant in each of these months except October. Spot were almost four times more abundant, on average, in the deeper waters than in the littoral waters over the July through December period, the mean of the geometric means being 116.37 and 31.63 for these respective regions.

The comparative pattern of spot abundance remained the same year-round in the deeper waters. There was no significant difference in abundance between the Central Plain and Deeps waters within any month, and there was no pattern to the observed differences in abundance (Figure 17; Table 20).

The comparative patterns of spot abundance varied during the year in the littoral waters, though the meaning of this is not fully clear. There was little or no difference in abundance, and no significant differences, between the Eastern and Western Shore Littoral zones during the winter and early spring months of January through April when spot are not abundant or absent from the Chesapeake (Figure 17; Table 21). In May, as their abundance began to increase, spot were significantly more abundant in the Western Shore Littoral than in the Eastern Shore Littoral. Thereafter, the pattern varied, though spot were usually most abundant in the Western Shore Littoral. There was no significant difference between the two littoral regions in June and July, in October, and in December. In August, September and November, differences between the two littoral regions were significant. Abundance was much greater in the Eastern Shore Littoral in August but greater in the Western Shore Littoral in September and November.

Upbay-downbay patterns of spot abundance showed large changes during the year. There was little or no difference in abundance, and no significant differences, between the Upper, Middle, and Lower Bay regions in the winter and early spring months of January through April when spot are absent or not abundant in the Chesapeake Bay (Figure 18; Tables 22, 23). This pattern changed in May as spot began to increase in abundance. From May through September, spot were more abundant each month, generally much more abundant, in the Upper Bay than in the Lower Bay. The differences between these two areas are significant in each of these months. Spot were almost ten times more abundant, on average, in the Upper Bay waters than in the Lower Bay over the May through September period, the mean of the geometric means being 138.36 and 14.15 for these respective regions. Similarly, spot abundance in the Middle Bay was significantly higher than in the Lower Bay over much of the June through September period. In those months, observed abundance was highest in the Middle Bay (July and August, Figure 18) or was significantly higher than the average in the combined Upper and Lower Bay region (August, Table 22). Abundance patterns changed again after September as spot were leaving the Chesapeake Bay. There was no significant difference in abundance between the Upper, Middle and Lower Bay

Figure 19. The overall relationship (all data) between residuals from log spot catches and bottom dissolved oxygen (mg/l). A = 1 observation, B = 2 observation, etc.

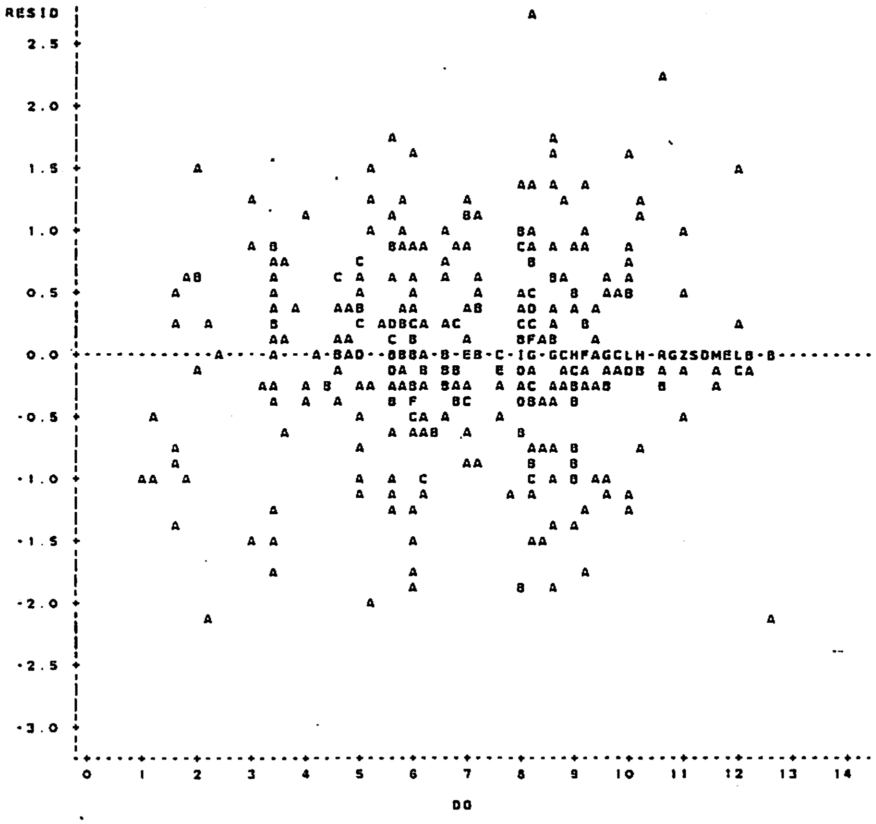
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Table 22. Summary of individual degree of freedom contrast tests to evaluate differences in log spot abundance between the Upper and Lower Bay waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.01	ns	0.00-0.02	0.00- 0.04
Apr	0.01	0.02	ns	0.14-0.11	0.39- 0.29
May	4.49	9.29	**	0.92-0.17	7.29- 0.48
Jun	36.41	75.29	**	2.56-0.42	358.33- 1.64
Jul	2.96	6.12	*	2.19-1.58	153.03- 36.97
Aug	4.96	10.26	**	2.07-1.28	115.98- 18.09
Sep	2.89	5.99	*	1.76-1.16	57.18- 13.56
Oct	0.37	0.76	ns	1.95-2.17	88.88-146.05
Nov	1.40	2.89	ns	1.06-1.48	10.48- 29.03
Dec	0.00	0.01	ns	1.01-1.03	9.19- 9.67

Table 23. Summary of individual degree of freedom contrast tests to evaluate differences in log spot abundance between the Middle Bay and the average in the Upper and Lower Bay waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.00	ns	0.00-0.01	0.00- 0.02
Apr	0.17	0.35	ns	0.00-0.13	0.00- 0.33
May	0.50	1.04	ns	0.33-0.54	1.12- 2.50
Jun	4.03	8.33	**	2.10-1.49	125.86- 29.82
Jul	1.44	2.98	ns	2.25-1.88	177.15- 75.48
Aug	4.51	9.32	**	2.32-1.67	210.09- 46.25
Sep	0.19	0.40	ns	1.60-1.46	38.71- 28.11
Oct	0.07	0.15	ns	1.98-2.06	94.33-113.96
Nov	1.55	3.20	ns	1.65-1.27	43.60- 17.57
Dec	0.28	0.58	ns	1.18-1.02	14.15- 9.42

regions from October through December.

Other Sources of Variation in Spot Catches:

Overall plots of residuals against bottom D.O. indicate no strong relationship (Figure 19). The two variables are independent over much of the D.O. range. At low D.O. (D.O. < 2 mg/l), many residuals seem to be negative or to have small positive values, but the pattern is not clear.

Overall plots of residuals against temperature indicate no regression or other relations not already postulated in the model (Figure 13). Variation in residuals generally appears low at low temperatures when spot are absent from the Chesapeake Bay. There also appears to be a constriction in the magnitude of the residuals: the magnitude of the residuals appears to be smaller at temperatures of about 17-20° than at higher or lower temperatures.

Overall plots of residuals against salinity indicate no regression or other effects not already postulated in the model (Figure 14). Variation in residuals appears low at salinities below 15 0/00 but constant at higher values.

Overall plots of residuals against Areas (not shown) indicate no regression or other relations not already included in the model. Variation in residuals appears constant within Areas.

Overall plots of residuals against Months (not shown) indicate no regression or other relations not already included in the model. Variation in residuals generally appears low or comparatively low in the winter or early spring months when spot catches are low, high when spot catches are high.

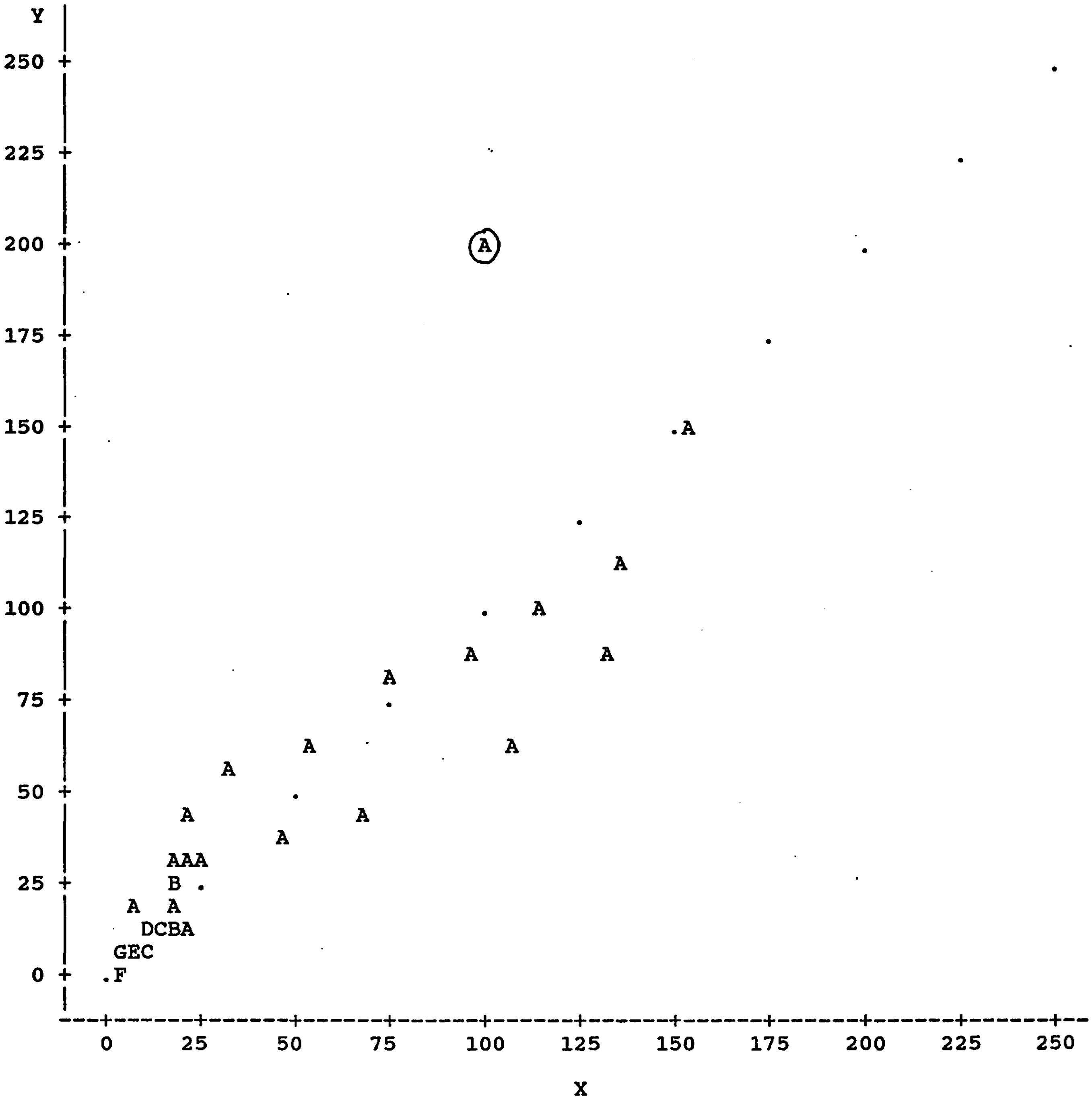
Northern Searobin

Choosing an Appropriate Transformation:

The log transformation appears reasonably appropriate for the present counts of abundance data on northern searobins. Plots of the untransformed standard deviation on the untransformed arithmetic mean within Months x Areas cells indicate these variables are reasonably equal for mean catches up to about 75 searobins (Figure 20). Up to that catch size, data points are scattered along the 45 degree diagonal. Above 75 searobins, data points are generally below the diagonal with the exception of one data point (circled in Figure 20), and the relationship becomes somewhat curved. The calculated slope (b = 1.01) of the regression of the untransformed standard deviation on the untransformed arithmetic mean is significantly below a hypothesized $\beta = 1$ ($t = -2.08$; 142 df; $\alpha = .05$). In contrast, plots of the untransformed variance on the untransformed arithmetic mean (not shown) found nearly all data points above or well above the diagonal. The calculated slope (b = 111.64) of the regression of the variance on the mean is significantly greater than a hypothesized $\beta = 1$ ($t = 13.15$; 142 df). These conditions indicate the square root transformation is not sufficient to normalize the counts of abundance. The log transformation is reasonable though a bit strong at high counts of abundance.

The log transformation had the smallest standard error

Figure 20. Relationship between standard deviation (y) and untransformed arithmetic mean counts of abundance (x) for northern searobin. The 45° diagonal has slope b = 1, so y = x along it. A = 1 observation, B = 2 observations, etc.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150
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200
225
250
X

(0.35), had the second-smallest coefficient of variation (CV = 93.52), provided the best fit for the postulated model ($100r^2$ = 75.41), and, as noted later, provided reasonable homogeneity of variance and normality, and the greatest number of effective degrees of freedom (Table 24). The square root transformation was superior to the log only in having a slightly smaller CV; it was less desirable in all other properties. Untransformed data had the least desirable properties of all.

General Data Descriptions:

Northern searobins were the third most abundant fish in the sampling frame. They made up 1.4% of the overall catch (Chittenden 1989).

The overall geometric mean catch was 1.35 northern searobins, with 95% confidence limits about the mean being 1.20-1.51 (Table 25). The overall mean log catch was 0.37, with 95% confidence limits being 0.34-0.40. The standard error of the mean log catch was 0.35 and the coefficient of variation was 93.52 (Table 24). The maximum catch was 403 searobins and the minimum was 0.

Northern searobins are not resident year-round in the Chesapeake Bay. None were captured in January or February (Table 26). They were not frequently captured in March or December, being absent in most strata then (8 of 12 in March; 9 of 12 in December).

Table 24. Summary of the comparative properties of listed transformations on northern searobin abundance counts.

	Transformation		
Property	log	none	Square Root
Mean	0.37	10.69	1.94
Std. error	0.35	30.01	1.77
$100r^2$	75.41	53.20	68.37
CV	93.52	280.78	90.94
Independence of Residuals	yes	yes	yes
Homogeneity of Variance Using Cochran's C.	reasonable	no	no
Normality	reasonable	did not examine	did not examine
Homogeneity of Slopes	reasonable	did not examine	did not examine

Table 25. Summary statistics on overall log northern searobin abundance, with a geometric mean (GM) back-transformation. No transformation was applied to the sample size (n) and the minimum-maximum counts.

	LOG	GM
n	576	--
Min-Max	0-403	--
Mean	0.37	1.35
95% Confidence Limits	0.34-0.40	1.20-1.51

Table 26. Summary of Northern searobin presence or absence in the Month-Area Cells. X = Present; - = Absent.

	UPPER BAY				MIDDLE BAY				LOWER BAY				TOTAL PRESENT
Month	ESL (01)	WSL (02)	CP (03)	DP (04)	ESL (05)	WSL (06)	CP (07)	DP (08)	ESL (09)	WSL (10)	CP (11)	DP (12)	
Jan	-	-	-	-	-	-	-	-	-	-	-	-	0
Feb	-	-	-	-	-	-	-	-	-	-	-	-	0
Mar	-	-	-	X	-	-	X	-	-	X	-	X	4
Apr	X	X	X	X	X	X	X	X	X	X	X	X	12
May	X	X	X	X	X	X	X	X	X	X	X	X	12
Jun	X	X	X	X	X	X	X	X	X	X	X	X	12
Jul	X	-	X	X	X	X	X	X	X	X	X	X	11
Aug	X	-	-	-	-	X	-	X	X	X	X	X	7
Sep	X	X	X	X	X	-	X	X	X	X	X	X	11
Oct	X	-	X	X	X	X	X	-	X	X	X	-	9
Nov	-	-	-	-	X	X	-	X	X	-	X	X	6
Dec	-	-	-	X	-	-	X	-	X	-	-	-	3
Total Present	7	4	6	8	7	7	8	7	9	8	8	8	87

Overview of the ANOVA-ANCOVA:

The postulated models explain much of the total variation in northern searobin catches. A log transformation explained about 75% of the total variation (Table 27). Somewhat less is explained (Table 24) using a square root transformation (68.37%) and much less with no transformation (53.20%).

The overall log ANCOVA (or ANOVA) model was significant at $\alpha = 0.01$ (Table 27). The Months and Areas main effects were both highly significant. The Months main effect was far more important than the Areas effect -- almost ten times as important -- in explaining variation in searobin catches, $100r^2$ values being 47.10% for Months and only 5.27% for Areas. Interaction was significant and explained 23.03% of the total variation. The significant Interaction implies that spatial and temporal factors have a complex effect on the distribution of searobins, eg. -- the simple effects of Areas, for example, are not constant; rather they vary from month to month.

The temperature covariate was not significant, though the salinity covariate was (Table 27). Neither covariate explained much variation in searobin catches (0.38%, salinity; <0.01%, temperature) beyond that associated with the Areas and Months effects, whether significant or not. Therefore, the covariates were deleted from the model, and further analyses were made using only the ANOVA model with its main effects and interactions.

The overall log ANOVA model finally accepted explained 75.41% of the variation in northern searobin catches (Table 24).

Table 27. Summary of the ANCOVA on northern searobin, log transformation, with $100r^2$ values.

Source of Variation	df	SS	MS	F	$100r^2$
Corr. Tot.	575	212.03	--	--	100.00
Model	145	160.69	1.11	9.28 **	75.79
Months (M)	11	99.86	9.08	76.04 **	47.10
Areas (A)	11	11.18	1.02	8.52 **	5.27
M x A	121	48.84	0.40	3.38 **	23.03
Sal	1	0.80	0.80	6.73 **	0.38
Temp	1	<0.01	<0.01	0.02 NS	<0.01
Error	430	51.34	0.12	--	24.21

Its most important component by far was the Months main effect, and Interaction was next in importance. The Areas main effect had comparatively little importance. Random variation, or variation not recognized and not included in the model, accounted for only about 25% of the total variation in searobin catches.

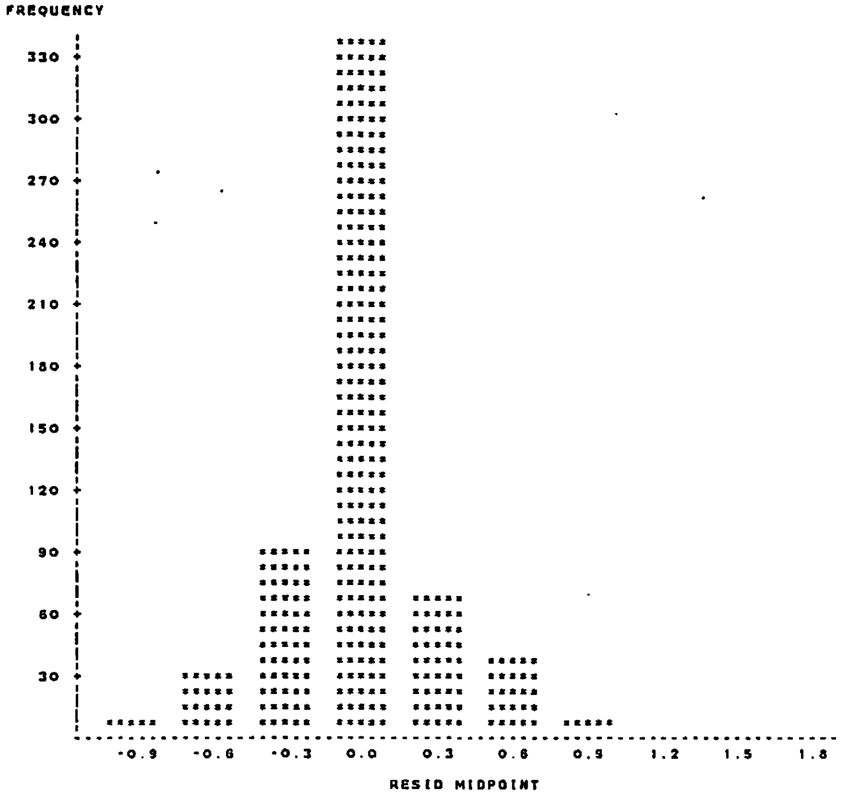
Validity of the Assumptions of the ANCOVA-ANOVA models:

The assumptions of the ANOVA-ANCOVA models appear to be reasonably fulfilled, if not exactly fulfilled, when a log transformation is used on the northern searobin catch data.

The assumption of normality of the residuals is a reasonable approximation, though not true. The frequency distribution of the residuals from the log ANOVA model (Figure 21) appears to be reasonably normal, with zero mean and reasonable symmetry about the mean. The Kolomogorov D statistic, however, is significant ($D = 0.257$; $n = 576$) at $\alpha = .01$, which indicates the distribution of the residuals is not truly normal. The significant D statistic, in part, reflects an exceptionally large sample size which can detect even very small departures from normality. The small departure from normality should not contradict the basic conclusion indicated by the residual plot: the assumption is reasonable albeit not exact.

The assumption of homogeneity of within-cell variance is reasonable using a log transformation on the catch data. Cochran's C statistic ($C = 0.0977$; 3 df; $n = 144$) is significant at $\alpha = .01$ using logs. However, significance reflects the

Figure 21. Frequency distribution of the residuals to evaluate the assumption of normality in northern searobin.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0.9
1.2
1.5
1.8
RESID MIDPOINT

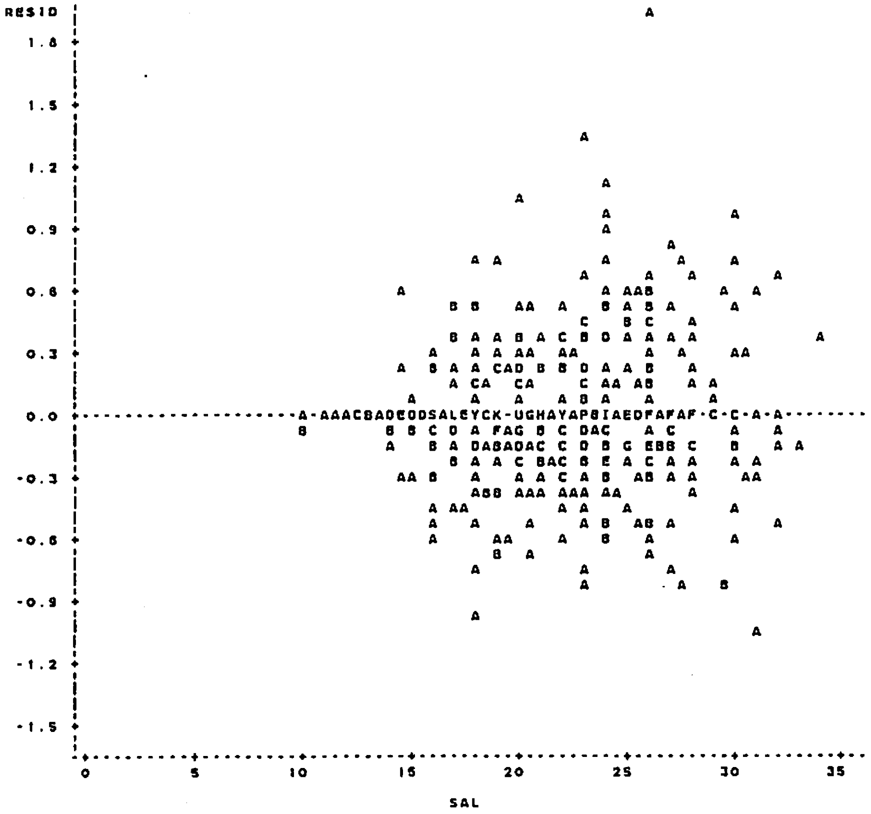
inclusion of one Months X Areas cell whose variance (1.70) was double that of the next largest variance (0.85). Deleting that cell, Cochran's C statistic (C=0.0540) is much improved and not significant at $\alpha = .01$. The cell was retained in further ANOVA tests, however; the general consequence is to make the residual mean square larger and the F tests less sensitive than they would be otherwise. In contrast to the log transformation, Cochran's C statistic (C = 0.0938) remains significant at $\alpha = .01$ using a square root transformation; similarly, Cochran's C (C = 0.25) also remains significant at $\alpha = .01$ with no transformation.

The assumption of homogeneous, linear regression on the covariates within Months x Areas cells also appears reasonable, or there was no regression. The residuals from the ANOVA model were plotted (not shown) on temperatures within cells and on salinity. A relationship between the residuals and temperature or between the residuals and salinity was apparent in only a few cells (of 144). These conclusions of little or no within-cell relation between residuals and temperature or saliity are illustrated by overall plots (all data) of the relationships between temperature and residuals and salinity and residuals (Figures 22, 23).

Interpretation of Interaction and Main Effects to Evaluate Spatial/Temporal Distributions:

Northern searobin catches show great variation between months that forms a clear annual pattern of change from a late fall-winter low to a mid spring-mid summer peak. No searobins

Figure 22. The overall relationship (all data) between residuals from log northern searobin catches and bottom temperature (C°). A = 1 observation, B = 2 observations, etc.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were captured in the winter months of January and February, and few were captured in December or March (Figure 24; Table 28). Monthly catches abruptly rose after March to reach a general peak in the mid spring through mid summer months of April through July. Greatest catches by far were in June. Catches abruptly declined in August and remained low through November as they headed towards their winter lows. Tukey's multiple comparisons tests (Table 29), which elaborate on the significant F test for Months, show significantly more searobins were caught in June than in any other month. Catches in the mid spring-mid summer months of April, May, and July were significantly higher than in all other months except June. Catches in the later summer through early spring months of August through March were generally not significantly different from each other, though catches in September were significantly higher than those from November through March.

The annual pattern of catches reflects migratory movements of northern searobins into and out of the Chesapeake Bay and their recruitment to and decruitment from the sampling frame. With few exceptions only two age groups of searobins occur in the sampling frame as indicated in length frequencies, particularly in October and November (Figure 25). These age groups consist of the recently-recruited young-of-the-year, presumably, which were some 30-60 mm TL or more in October and November, and fish of age I and just approaching that age, which were some 60-165 mm TL in August when they showed a broader size range than later in the

Figure 24. The monthly (Mo) pattern of mean log northern searobin catches (LGAB) in the mainstem Chesapeake Bay, Virginia.

```
LGAB |
     |
 1.4 +
     |                                    +
 1.2 +
     |
 1.0 +
     |
 0.8 +                       +     +           +
     |
 0.6 +
     |
 0.4 +
     |                                                      +
 0.2 +
     |                                                +           +     +
 0.0 +     +     +     +                                                     +
     |
     -+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-
      0     1     2     3     4     5     6     7     8     9    10    11    12

                                          MO
```

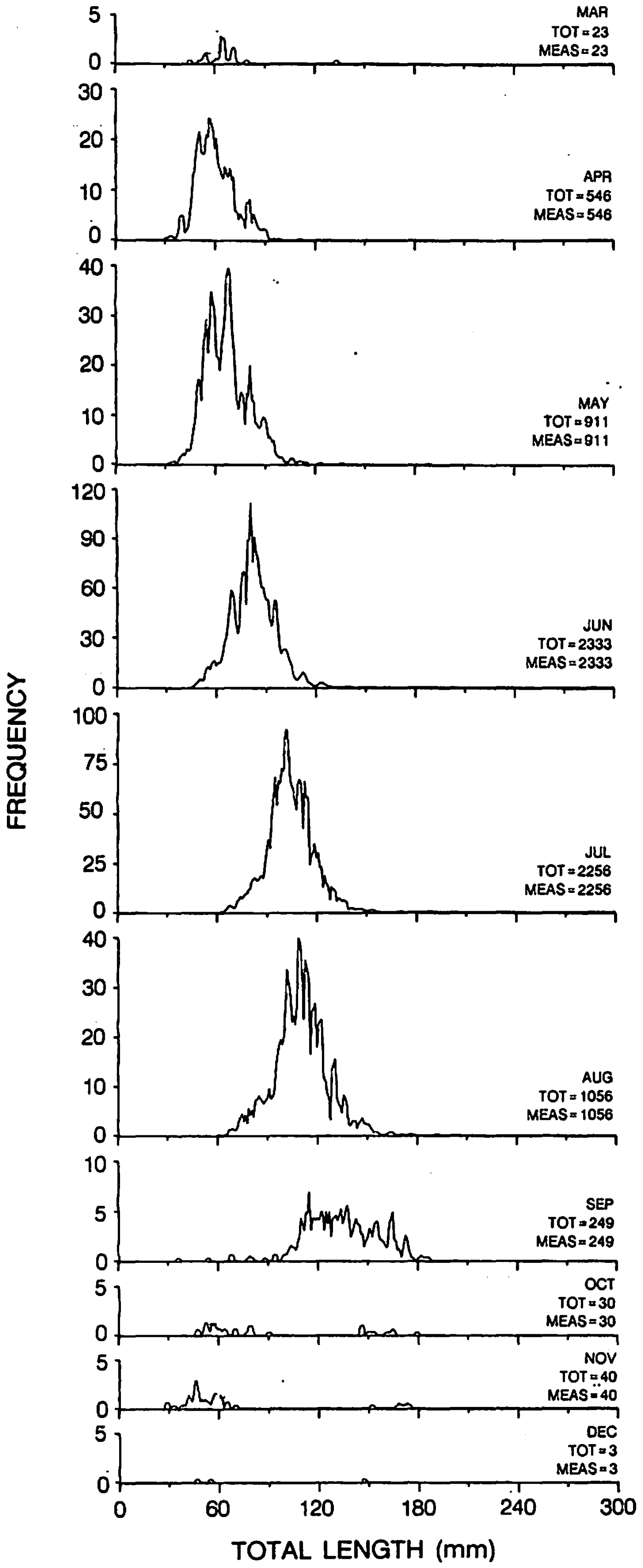
Table 28. Summary of 95% confidence limits (CL) about monthly mean log abundance of northern searobin, with a geometric mean (GM) back-transformation.

Month	log	CL	GM	CL
Jan	0.00	-0.10-0.10	0.00	-0.21- 0.26
Feb	0.00	-0.10-0.10	0.00	-0.21- 0.26
Mar	0.04	-0.06-0.15	0.11	-0.12- 0.40
Apr	0.80	0.70-0.90	5.32	4.01- 6.98
May	0.82	0.72-0.92	5.61	4.24- 7.34
Jun	1.29	1.19-1.39	18.60	14.54-23.72
Jul	0.76	0.66-0.86	4.80	3.60- 6.32
Aug	0.14	0.04-0.24	0.39	0.10- 0.75
Sep	0.35	0.25-0.45	1.22	0.77- 1.81
Oct	0.12	0.02-0.22	0.32	0.04- 0.66
Nov	0.11	0.01-0.21	0.28	0.02- 0.62
Dec	0.02	-0.08-0.12	0.04	-0.17- 0.32

Table 29. Summary of Tukey's hsd multiple comparisons tests on log northern searobin abundance. Means with different letters are significantly different.

		MEAN		
Month	n	log	GM	Significance
Jun	48	1.29	18.60	a
May	48	0.82	5.61	b
Apr	48	0.80	5.32	b
Jul	48	0.76	4.80	b
Sep	48	0.35	1.23	c
Aug	48	0.14	0.39	c d
Oct	48	0.12	0.32	c d
Nov	48	0.11	0.28	d
Mar	48	0.04	0.11	d
Dec	48	0.02	0.04	d
Jan	48	0.00	0.00	d
Feb	48	0.00	0.00	d

Figure 25. Monthly length frequencies of northern searobin. Frequencies are moving averages of three.

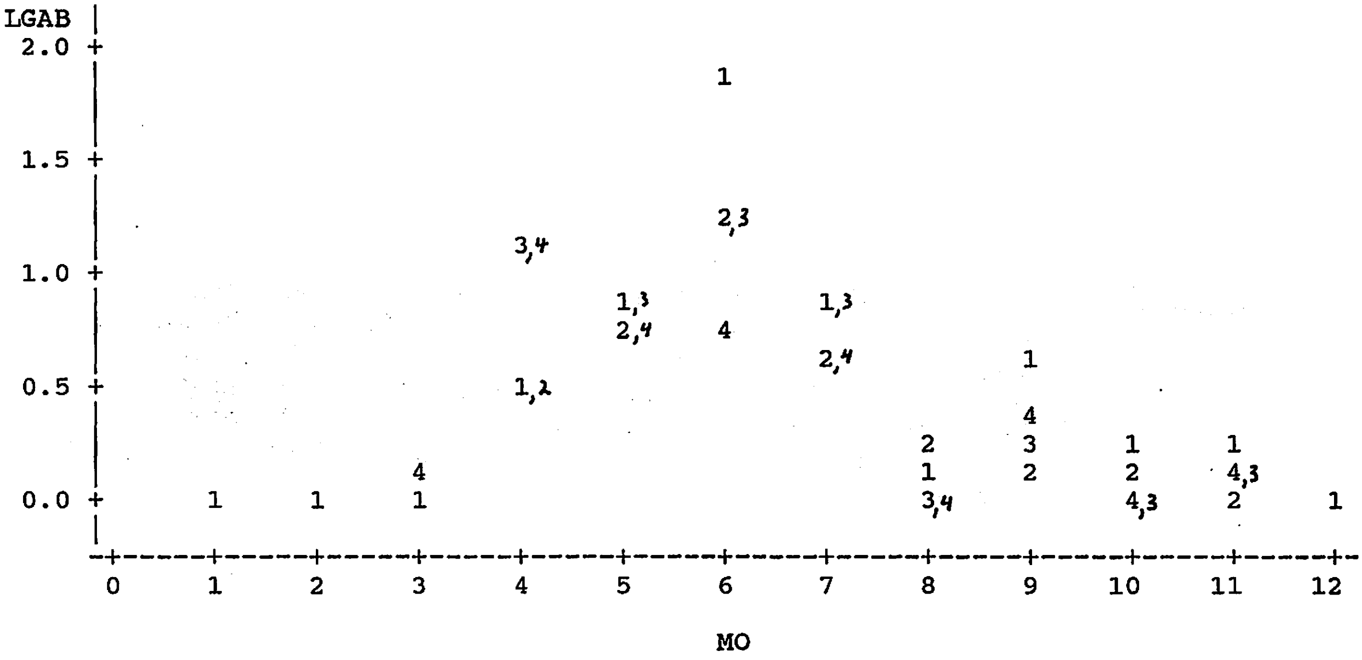

FREQUENCY
5
0
MAR
TOT=23
MEAS=23
30
20
10
0
APR
TOT=546
MEAS=546
40
30
20
10
0
MAY
TOT=911
MEAS=911
120
90
60
30
0
JUN
TOT=2333
MEAS=2333
100
75
50
25
0
JUL
TOT=2256
MEAS=2256
40
30
20
10
0
AUG
TOT=1056
MEAS=1056
10
5
0
SEP
TOT=249
MEAS=249
5
0
OCT
TOT=30
MEAS=30
5
0
NOV
TOT=40
MEAS=40
5
0
DEC
TOT=3
MEAS=3
0
60
120
180
240
300
TOTAL LENGTH (mm)

fall. Neither age group occurs in the Chesapeake Bay in the winter and early spring months as evidenced by the absence of any searobins in the catch. Recruitment of the young resumed in March after a winter hiatus. Only the young searobins occur in the spring and in the summer months as they begin to approach age I. This age group can be followed readily in the length frequencies until September after which it largely leaves the sampling frame and never again is available. It is primarily this group which made up the entire searobin catch. Sizes of the young searobins increase from March through a peak in September or October. Presumably, they leave en-masse after September, because, unlike in spot and weakfish, there is no clear evidence of any decline in sizes after then to indicate the larger, presumably older young move to sea first and leave behind the smaller, presumably younger members. The period September through October, therefore, represents a period when just age I searobins move permanently and en masse from the Chesapeake Bay. This seems to agree well with the abrupt decline in monthly catches in August.

Northern searobins are widely distributed throughout the sampling frame in the late spring through mid summer months of April through July. They occur in the Eastern Shore Littoral, Western Shore Littoral, Central Plain, and Deeps waters and in the Upper, Middle and Lower bay portions of the sampling frame (Table 26; Figures 26, 27).

There were intra-annual changes in patterns of northern

Figure 26. The monthly (Mo) pattern of mean log northern searobin catches (LGAB) in the mainstem Chesapeake Bay, Virginia by Across-Bay Region. Regions are Eastern Shore Littoral (1), Western Shore Littoral (2), Central Plain (3), and Deeps (4). When the number for a region is not indicated, the data value is the same as for the indicated region number.



LGAB
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
MO
1
2,3
3,4
1,3
2,4
4
1,3
2,4
1
1,2
4
2
3
1
1
2
1
4
1
1
1
3,4
2
4,3
4,3
2
1

Figure 27. The monthly pattern (Mo) of mean log northern searobin catches (LGAB) in the mainstem Chesapeake Bay, Virginia by Up-Down Bay Region. Regions are Upper Bay (1), Middle Bay (2), and Lower Bay (3). When the number for a region is not indicated, the data value is the same as for the indicated region number.

```
LGAB |
 2.0 +
     |
     |                                                 3
     |                                          3
 1.5 +
     |
     |
     |                                          1
 1.0 +                                   3
     |                            2      2
     |                            1
     |                                   1
 0.5 +                                                 2             3
     |                                                               2
     |                                                        3      1
     |                     3                           1      2             1      2
 0.0 +       1      1      1                                  1                    1      1
     |
     -+------+------+------+------+------+------+------+------+------+------+------+------+-
      0      1      2      3      4      5      6      7      8      9     10     11     12

                                                MO
```

searobin abundance, not a constancy, across the Chesapeake Bay and along an upbay-downbay axis. These changes in patterns explain the significant F test for interaction.

Across-bay patterns of northern searobin abundance showed changes during the year, but not large ones in comparison to other species. There was little or no difference in abundance between the combined littoral waters of the Eastern and Western Shores and the combined deeper waters of the Central Plain and Deeps, and no significant difference, in most months of the year, especially when searobins were absent, or not abundant, in the Chesapeake (Figure 26; Table 30). This pattern changed in two months when searobins were abundant, April and June, but the change was not consistent. In April they were much more abundant in the deeper Central Plain and Deeps waters than in the littoral waters of the Eastern and Western Shores. In June they were much more abundant in the Littoral waters. The differences between areas are significant in each of the months. The pattern in June, however, largely reflects significantly more searobins in the Central Plain waters than in the Deeps (Table 31) and significantly more searobins in the Eastern Shore Littoral than in the Western Shore Littoral (Table 32). There was little or no difference between the Western Shore Littoral and the Central Plain (Figure 25).

The comparative pattern of northern searobin abundance largely remained the same year-round in the deeper waters. There was no significant difference in abundance between the Central

Table 30. Summary of individual degree of freedom contrast tests to evaluate differences in log northern searobin abundance between Littoral waters (ESL and WSL) and the deeper Central Plain - Deeps waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.05	0.42	ns	0.01-0.08	0.03- 0.20
Apr	4.28	35.48	**	0.50-1.10	2.18-11.58
May	0.00	0.00	ns	0.82-0.82	5.59- 5.62
Jun	3.86	31.99	**	1.58-1.01	36.66- 9.20
Jul	0.00	0.03	ns	0.77-0.75	4.93- 4.68
Aug	0.11	0.93	ns	0.19-0.09	0.55- 0.24
Sep	0.00	0.04	ns	0.36-0.34	1.28- 1.18
Oct	0.04	0.34	ns	0.15-0.09	0.41- 0.23
Nov	0.12	1.01	ns	0.16-0.06	0.44- 0.14
Dec	0.00	0.02	ns	0.01-0.03	0.03- 0.06

Table 31. Summary of individual degree of freedom contrast tests to evaluate differences in log northern searobin abundance between Central Plain and Deeps waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.02	0.15	ns	0.05-0.10	0.12- 0.27
Apr	0.00	0.04	ns	1.11-1.09	11.99-11.18
May	0.21	1.70	ns	0.91-0.73	7.19- 4.35
Jun	1.58	13.09	**	1.27-0.75	17.42- 4.65
Jul	0.47	3.88	ns	0.89-0.61	6.84- 3.12
Aug	0.03	0.25	ns	0.06-0.13	0.14- 1.35
Sep	0.15	1.24	ns	0.26-0.42	0.82- 1.61
Oct	0.06	0.50	ns	0.14-0.04	0.38- 0.10
Nov	0.00	0.01	ns	0.05-0.06	0.12- 0.16
Dec	0.00	0.00	ns	0.03-0.03	0.06- 0.06

Table 32. Summary of individual degree of freedom contrast tests to evaluate differences in log northern searobin abundance between the Eastern Shore Littoral and Western Shore Littoral waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00-0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00-0.00
Mar	0.00	0.03	ns	0.00-0.03	0.00-0.06
Apr	0.04	0.33	ns	0.54-0.46	2.49-1.89
May	0.29	2.42	ns	0.93-0.71	7.50-4.12
Jun	2.79	23.08	**	1.92-1.24	81.52-16.18
Jul	0.30	2.51	ns	0.89-0.66	6.68-3.58
Aug	0.30	2.45	ns	0.08-0.30	0.20-1.00
Sep	2.06	17.03	**	0.65-0.06	3.47-0.16
Oct	0.17	1.38	ns	0.23-0.06	0.70-0.16
Nov	0.43	3.54	ns	0.29-0.03	0.96-0.06
Dec	0.00	0.03	ns	0.03-0.00	0.06-0.00

Plain and the Deeps waters within any month except in June when searobins were significantly more abundant in the Central Plain waters (Figure 26; Table 31).

The comparative patterns of northern searobin abundance varied during the year, but only a little, in the Littoral waters. Observed abundance was generally greater in the Eastern Shore Littoral than in the Western Shore Littoral (Figure 26; Table 32). However, there were no significant differences between the Eastern and Western Shore Littoral zones during much of the year. Searobins were significantly more abundant in June and September in the Eastern Shore Littoral than in the Western Shore Littoral.

Upbay-downbay patterns of searobin abundance showed large changes during the year. There was little or no difference in abundance, and no significant differences, between the Upper, Middle, and Lower Bay regions in the mid fall through mid spring months of October through March when northern searobins are absent or not abundant in the Chesapeake Bay (Figure 27; Tables 33, 34). Similarly in April as searobins became abundant. However, this pattern changed during the May-July months when searobins were very abundant in the Chesapeake Bay. In these months searobins were significantly more abundant in the Lower Bay waters than in the Upper Bay. There was little difference in searobin abundance between the Upper and Lower Bay in the late summer - early winter months, except September when Lower Bay catches were significantly higher.

Table 33. Summary of individual degree of freedom contrast tests to evaluate differences in log northern searobin abundance between the Upper and Lower Bay waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.03	0.24	ns	0.02-0.08	0.04- 0.20
Apr	0.04	0.29	ns	0.74-0.81	4.54- 5.46
May	1.73	14.34	**	0.59-1.05	2.85-10.25
Jun	1.76	14.60	**	1.11-1.58	11.90-37.01
Jul	22.31	184.83	**	0.08-1.75	0.21-55.39
Aug	0.36	2.99	ns	0.03-0.24	0.07- 0.75
Sep	0.81	6.73	*	0.19-0.51	0.55- 2.24
Oct	0.04	0.30	ns	0.09-0.16	0.24- 0.44
Nov	0.18	1.49	ns	0.00-0.15	0.00- 0.41
Dec	0.00	0.00	ns	0.02-0.02	0.04- 0.04

Table 34. Summary of individual degree of freedom contrast tests to evaluate differences in log northern searobin abundance between the Middle Bay and the average in the Upper and Lower Bay waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.01	ns	0.04-0.05	0.09- 0.11
Apr	0.05	0.45	ns	0.85-0.78	6.05- 4.99
May	0.00	0.00	ns	0.82-0.82	5.66- 5.58
Jun	0.27	2.23	ns	1.19-1.35	14.36-21.14
Jul	2.24	18.53	**	0.46-0.92	1.87- 7.25
Aug	0.00	0.03	ns	0.15-0.14	0.42- 0.37
Sep	0.00	0.01	ns	0.34-0.35	1.20- 1.24
Oct	0.00	0.04	ns	0.11-0.13	0.27- 0.34
Nov	0.10	0.87	ns	0.17-0.08	0.49- 0.19
Dec	0.00	0.00	ns	0.02-0.02	0.04- 0.04

Other Sources of Variation in Northern Searobin Catches:

Overall plots of residuals against bottom D.O. indicate no relationship (Figure 28) over the entire D.O. range. Residuals were small at low D.O. (D.O < 2 mg/l), but there was no pattern to suggest largely negative residuals in that range.

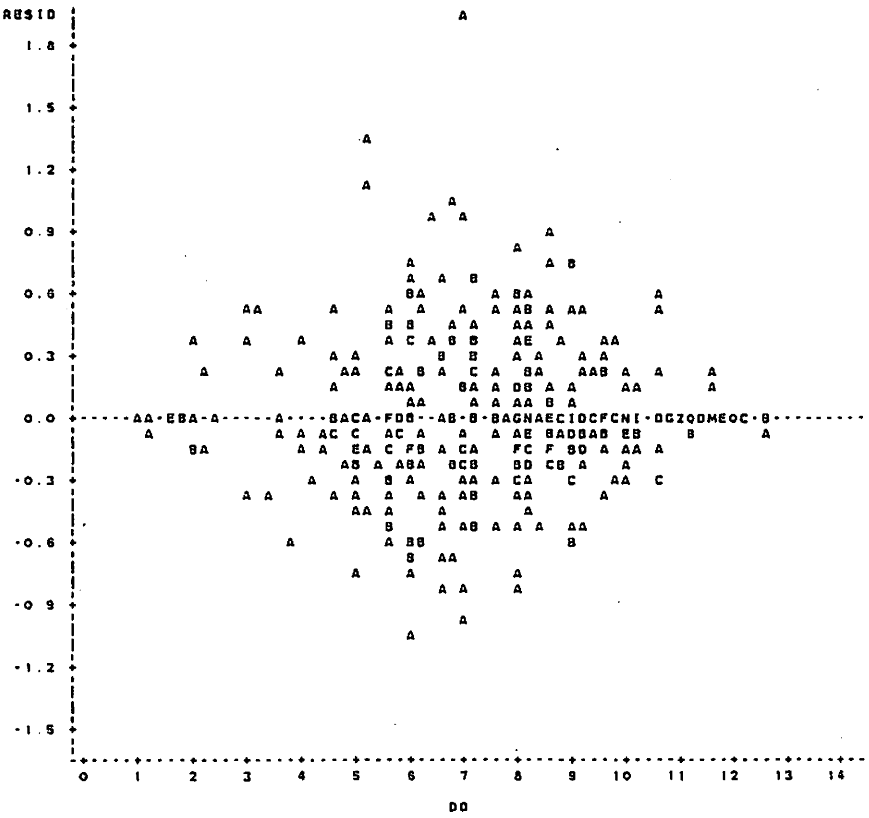
Overall plots of residuals against temperature indicate no regression or other relations not already postulated in the model (Figure 22). Variation in residuals generally appears low at low temperatures when searobins are absent from, or not abundant in, the Chesapeake Bay.

Overall plots of residuals against salinity indicate no regression or other effects not already postulated in the model (Figure 23). The smallest residuals seem to occur at the lowest and highest salinity values.

Overall plots of residuals against Area (not shown) indicate no regression or other relations not already included in the model. Variation in residuals appears constant within Areas.

Overall plots of residuals against Months (not shown) indicate no regression or other relations not already included in the model. Variation in residuals generally appears low in the winter months when searobin catches are low, high when catches are high or intermediate.

Figure 28. The overall relationship (all data) between residuals from log northern searobin catches and bottom dissolved oxygen (mg/l). A = 1 observation, B = 2 observation, etc.


RESID
1.8
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DO

Weakfish

Choosing an Appropriate Transformation:

The log transformation appears appropriate for the present counts of abundance data on weakfish. Plots of the untransformed standard deviation on the untransformed arithmetic mean within Months x Areas cells indicate these variables are reasonably equal (Figure 29), because data points are scattered along the 45 degree diagonal. The calculated slope (b = 1.008) of the regression of the untransformed standard deviation on the untransformed arithmetic mean, moreover, is not significantly different from a hypothesized $\beta = 1$ (t = 0.19; 142 df). In contrast, plots of the variance on the arithmetic mean (not shown) found nearly all data points above or well above the diagonal. The calculated slope (b = 125.91) of the regression of the variance on the mean is significantly greater than a hypothesized $\beta = 1$ (t = 15.43; 142 df). These conditions indicate the square root transformation is not sufficient to normalize the counts of abundance, but the log transformation is.

The log transformation had the smallest standard error (0.32), had the second-smallest coefficient of variation (CV = 138.52), provided the best fit for the postulated model ($100r^2$ = 62.21), and, as noted later, provided homogeneity of variance and normality, and the greatest number of effective degrees of freedom (Table 35). The square root transformation was superior to the log only in having a smaller CV; it was much less

Figure 29. Relationship between standard deviation (y) and untransformed arithmetic mean counts of abundance (x) for weakfish. The 45° diagonal has slope b = 1, so y = x along it. A = 1 observation, B = 2 observations, etc.

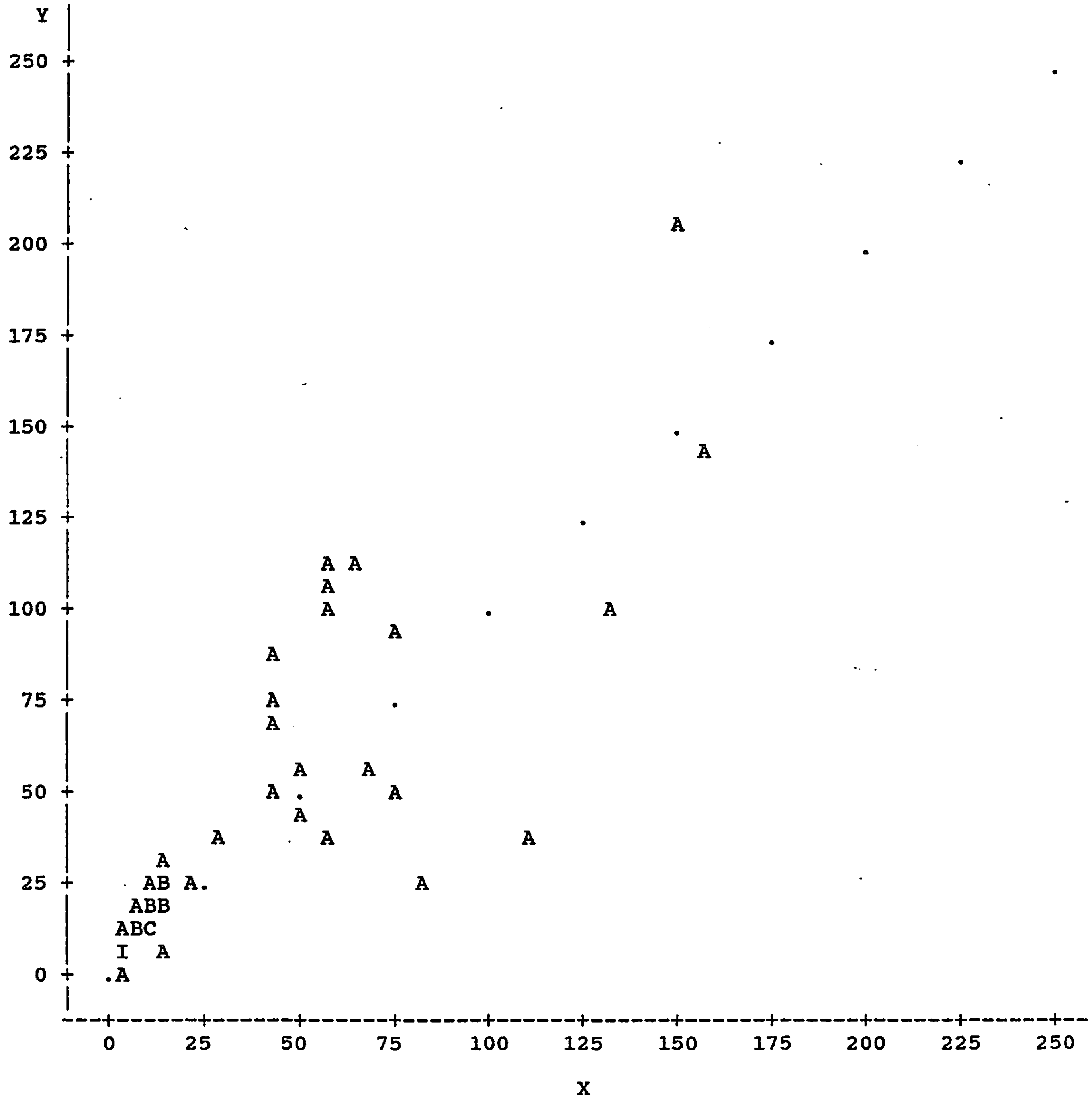

Y
250
225
200
175
150
125
100
75
50
25
0
0
25
50
75
100
125
150
175
200
225
250
X

Table 35. Summary of the comparative properties of listed transformations on weakfish abundance counts.

	Transformation		
Property	log	none	Square Root
Mean	0.32	11.81	1.90
Std. error	0.44	34.40	2.24
$100r^2$	62.21	47.01	56.60
CV	138.52	291.36	117.87
Independence of Residuals	yes	yes	yes
Homogeneity of Variance Using Cochran's C.	yes	no	no
Normality	reasonable	did not examine	did not examine
Homogeneity of Slopes	reasonable	did not examine	did not examine

desirable in all these other properties. Untransformed data had the least desirable properties of all.

General Data Description:

Weakfish were the fourth most abundant fish in the sampling frame. They made up 1.3% of the overall catch (Chittenden 1989).

The overall geometric mean catch was 1.09 weakfish, with 95% confidence limits about the mean being 0.92-1.27 (Table 36). The overall mean log catch was 0.32, with 95% confidence limits being 0.28-0.36. The standard error of the mean log catch was 0.44, and the coefficient of variation was 138.52 (Table 35). The maximum catch was 443 weakfish and the minimum was 0.

Weakfish are not resident year-round in the Chesapeake Bay, and they are not ubiquitous in their distribution. None were captured January-April (Table 37). They were not frequently captured in May, being absent in most strata then (9 of 12). They were also not frequently captured in the Eastern Shore Littoral of the Middle and Lower Bay Regions, being present there only in the months of October, and September through November, respectively, as weakfish move towards the ocean.

Overview of the ANOVA-ANCOVA:

The postulated models explain much of the total variation in weakfish catches. A log transformation explained about 62% of the total variation (Table 38). Somewhat less is explained (Table 35) using a square root transformation (56.74%) and much

Table 36. Summary statistics on overall log weakfish abundance, with a geometric mean (GM) back-transformation. No transformation was applied to the sample size (n) and the minimum-maximum counts.

	LOG	GM
n	576	--
Min-Max	0-144	--
Mean	0.32	1.09
95% Confidence Limits	0.28-0.36	0.92-1.27

Table 37. Summary of weakfish presence or absence in the Month-Area Cells. X = Present; - = Absent.

	UPPER BAY				MIDDLE BAY				LOWER BAY				TOTAL PRESENT
Month	ESL (01)	WSL (02)	CP (03)	DP (04)	ESL (05)	WSL (06)	CP (07)	DP (08)	ESL (09)	WSL (10)	CP (11)	DP (12)	
Jan	-	-	-	-	-	-	-	-	-	-	-	-	0
Feb	-	-	-	-	-	-	-	-	-	-	-	-	0
Mar	-	-	-	-	-	-	-	-	-	-	-	-	0
Apr	-	-	-	-	-	-	-	-	-	-	-	-	0
May	-	X	-	X	-	-	-	-	-	-	-	X	3
Jun	-	-	X	X	-	-	X	X	-	-	X	X	6
Jul	X	X	X	X	-	X	X	X	-	-	X	X	8
Aug	X	-	X	X	-	X	X	X	-	X	X	X	9
Sep	X	X	X	X	-	X	X	X	X	X	X	X	11
Oct	X	X	X	X	X	X	X	X	X	X	X	X	12
Nov	X	X	X	X	-	X	X	X	X	X	X	X	11
Dec	X	-	X	X	-	-	X	X	-	X	X	X	8
Total Present	6	5	7	8	1	5	7	7	3	5	7	8	69

Table 38. Summary of the ANCOVA on weakfish, log transformation, with $100r^2$ values.

Source of Variation	df	SS	MS	F	$100r^2$
Corr. Tot.	575	244.19	--		100.00
Model	145	140.08	0.97	4.94 **	62.48
Months (M)	11	62.71	5.70	29.14 **	27.97
Areas (A)	11	24.28	2.21	11.28 **	10.83
M x A	121	52.49	0.43	2.22 **	23.41
Sal	1	0.23	0.23	1.20 NS	0.10
Temp	1	0.37	0.37	1.89 NS	0.17
Error	430	84.11	0.20	--	37.52

less with no transformation (47.08%).

The overall log ANCOVA (or ANOVA) model was significant at α = 0.01 (Table 38). The Months and Areas main effects were both highly significant. The Months main effect was much more important than the Areas effect -- almost three times as important -- in explaining variation in weakfish catches, $100r^2$ values being 27.94% for Months and 10.83% for Areas. Interaction was significant and explained almost as much variation (23.41%) as the Months main effect. The significant Interaction implies that spatial and temporal factors have a complex effect on the distribution of weakfish, eg. -- the simple effects of Areas, for example, are not constant; rather they vary from month to month.

Neither the salinity nor temperature covariate explained much variation in weakfish catches (0.10 and 0.17%, respectively) beyond that associated with the Areas and Months effects, and neither covariate was significant (Table 38). Therefore, the covariates were deleted from the model, and further analyses were made using only the ANOVA model finally accepted with its main effects and interactions.

The overall log ANOVA model explained 62.21% of the variation in weakfish catches (Table 35). Its most important component was the Months main effect, and Interaction was next in importance (Table 38). The Areas main effect was comparatively unimportant. Random variation, or variation not recognized and not included in the model, accounted for 38% of the total variation in weakfish catches.

Validity of the Assumptions of the ANCOVA-ANOVA models:

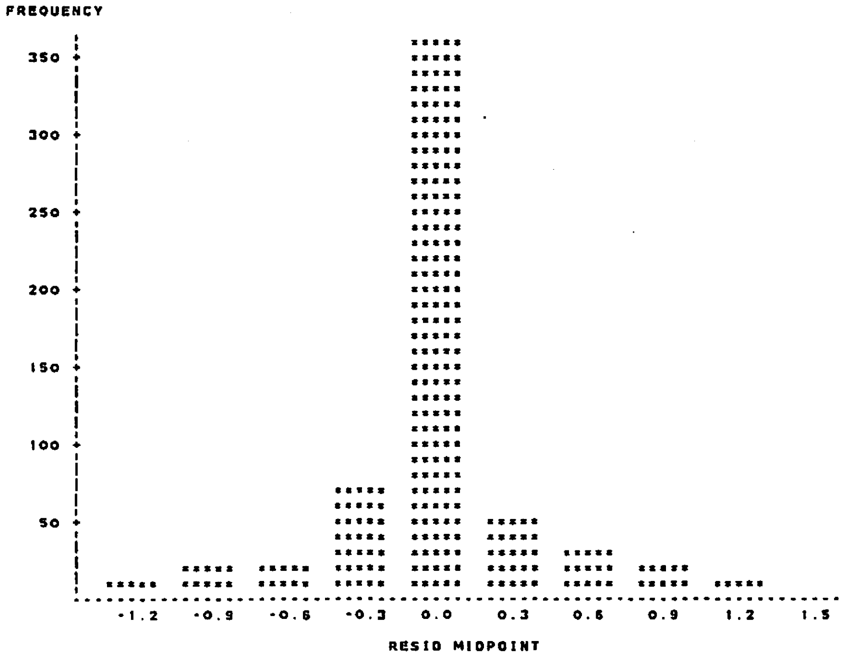
The assumptions of the ANOVA-ANCOVA models appear to be well-fulfilled, if not exactly fulfilled, when a log transformation is used on the weakfish catch data.

The assumption of normality of the residuals is a reasonable approximation, though not true. The frequency distribution of the residuals from the log ANOVA model (Figure 30) appears to be reasonably normal, with zero mean and reasonable symmetry about the mean. The Kolomogorov D statistic, however, is significant ($D = 0.293$; $n = 576$) at $\alpha = .01$, which indicates the distribution of the residuals is not truly normal. The significant D statistic, in part, reflects an exceptionally large sample size which can detect even very small departures from normality. The small departure from normality should not contradict the basic conclusion indicated by the residual plot: the assumption is reasonable albeit not exact.

The assumption of homogeneity of within-cell variance is reasonable using a log transformation on the catch data. Cochran's C statistic ($C = 0.0489$; 3 df; $n = 144$) is not significant at $\alpha = .01$, though it approaches significance at $\alpha = .05$. In contrast, Cochran's C statistic ($C = 0.1089$) is significant at $\alpha = .01$ using a square root transformation; similarly, Cochran's C ($C = 0.243$) is also significant at $\alpha = .01$ with no transformation.

The assumption of homogeneous, linear regression on the covariates within cells also appears reasonable, or there was no

Figure 30. Frequency distribution of the residuals to evaluate the assumption of normality in weakfish.


FREQUENCY
350
300
250
200
150
100
50
-1.2
-0.9
-0.6
-0.3
0.0
0.3
0.6
0.9
1.2
1.5
RESID MIDPOINT

regression. The residuals from the ANOVA model were plotted (not shown) on temperatures within cells and on salinity. No relationship between the residuals and temperatures was apparent in any cell and only one cell (of 144) indicated a relation (linear) for salinity. These conclusions of little or no within-cell relation between residuals and temperature or salinity are illustrated by overall plots (all data) of the relationships between temperature and residuals and salinity and residuals (Figures 31, 32).

Interpretation of Interaction and Main Effects to Evaluate Spatial/Temporal Distributions:

Weakfish catches show great variation between months that forms a clear annual pattern of change from a winter-spring low to a summer-fall peak. No weakfish were captured in the winter and early spring months of January through April (Figure 33; Table 39). Monthly catches gradually rose after April to reach a peak in the late summer and fall months of August through November. Catches then sharply declined in December towards their winter lows. Tukey's multiple comparisons tests (Table 40), which elaborate on the significant F test for Months, show significantly more weakfish were caught in the summer and fall months of August through November than in the winter, spring, and early summer months of January through June. Intermediate size catches in July and December were, variously, significantly different or not from the large summer-fall catches and the negligible winter-spring ones.

Figure 31. The overall relationship (all data) between residuals from log weakfish catches and bottom temperature (C°). A = 1 observation, B = 2 observations, etc.

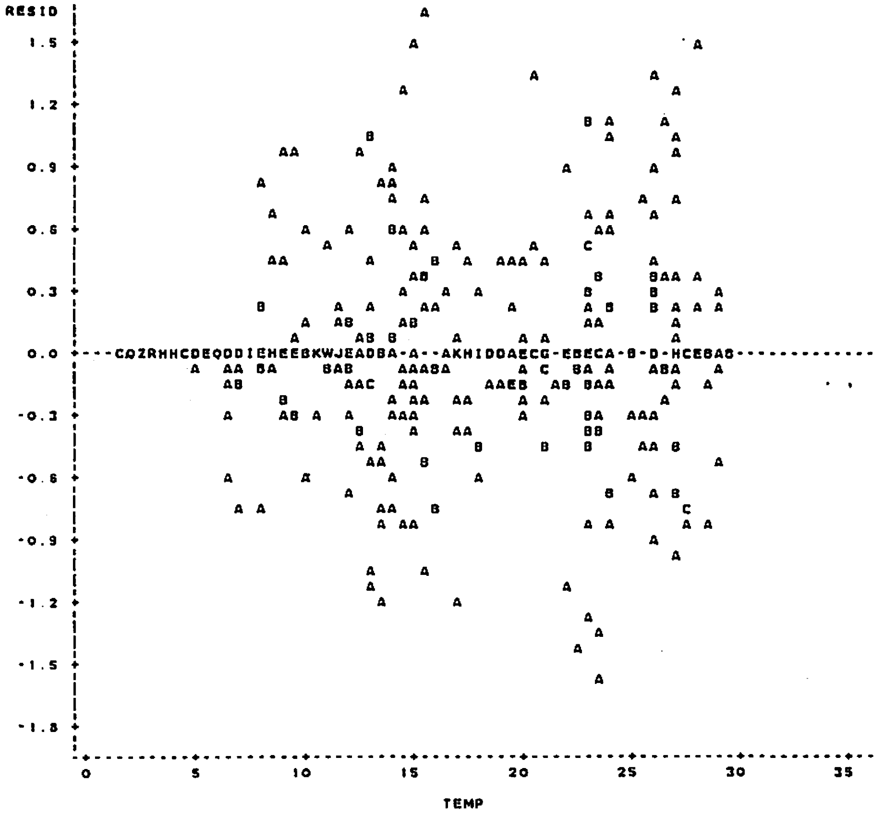

RESID
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
0
5
10
15
20
25
30
35
TEMP

Figure 32. The overall relationship (all data) between residuals from log weakfish catches and bottom salinity (parts per thousand). A = 1 observation, B = 2 observations, etc.

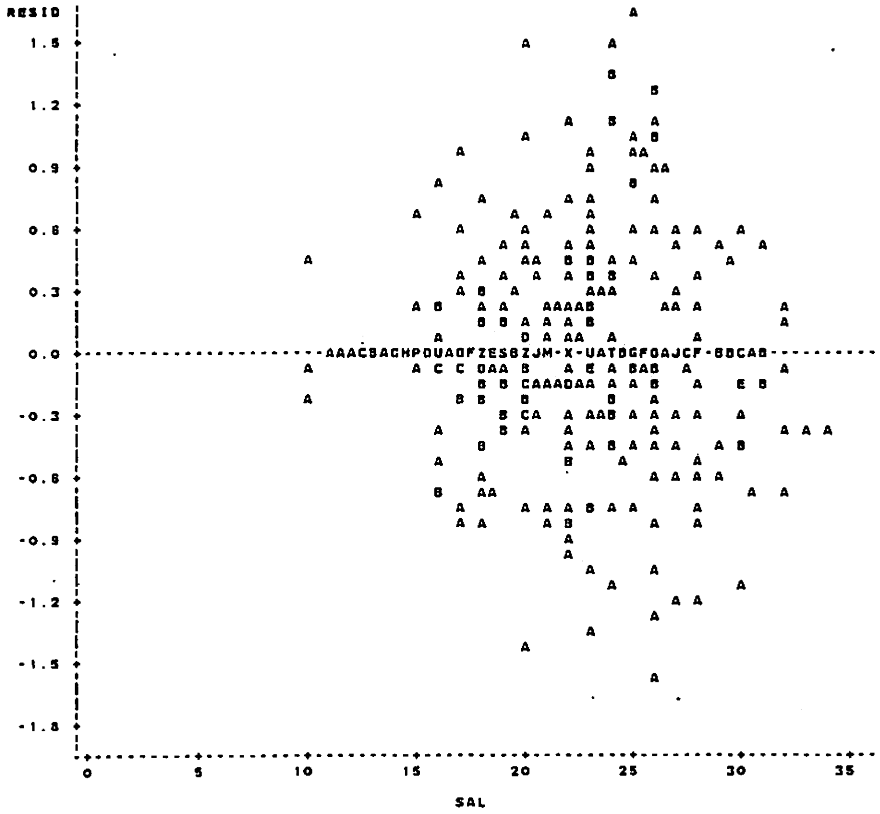

RESID
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
0
5
10
15
20
25
30
35
SAL

Figure 33. The monthly (Mo) pattern of mean log weakfish catches (LGAB) in the mainstem Chesapeake Bay, Virginia.

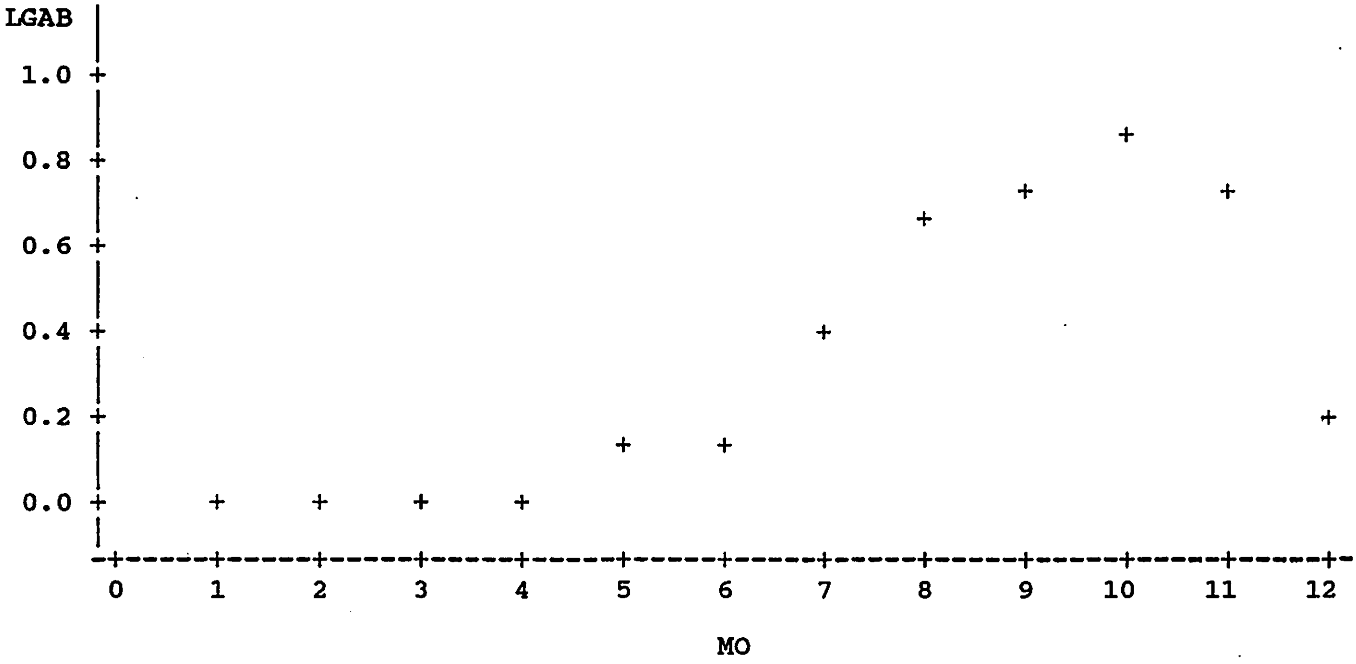

LGAB
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
MO

Table 39. Summary of 95% confidence limits (CL) about monthly mean log abundance of weakfish, with a geometric mean (GM) back-transformation.

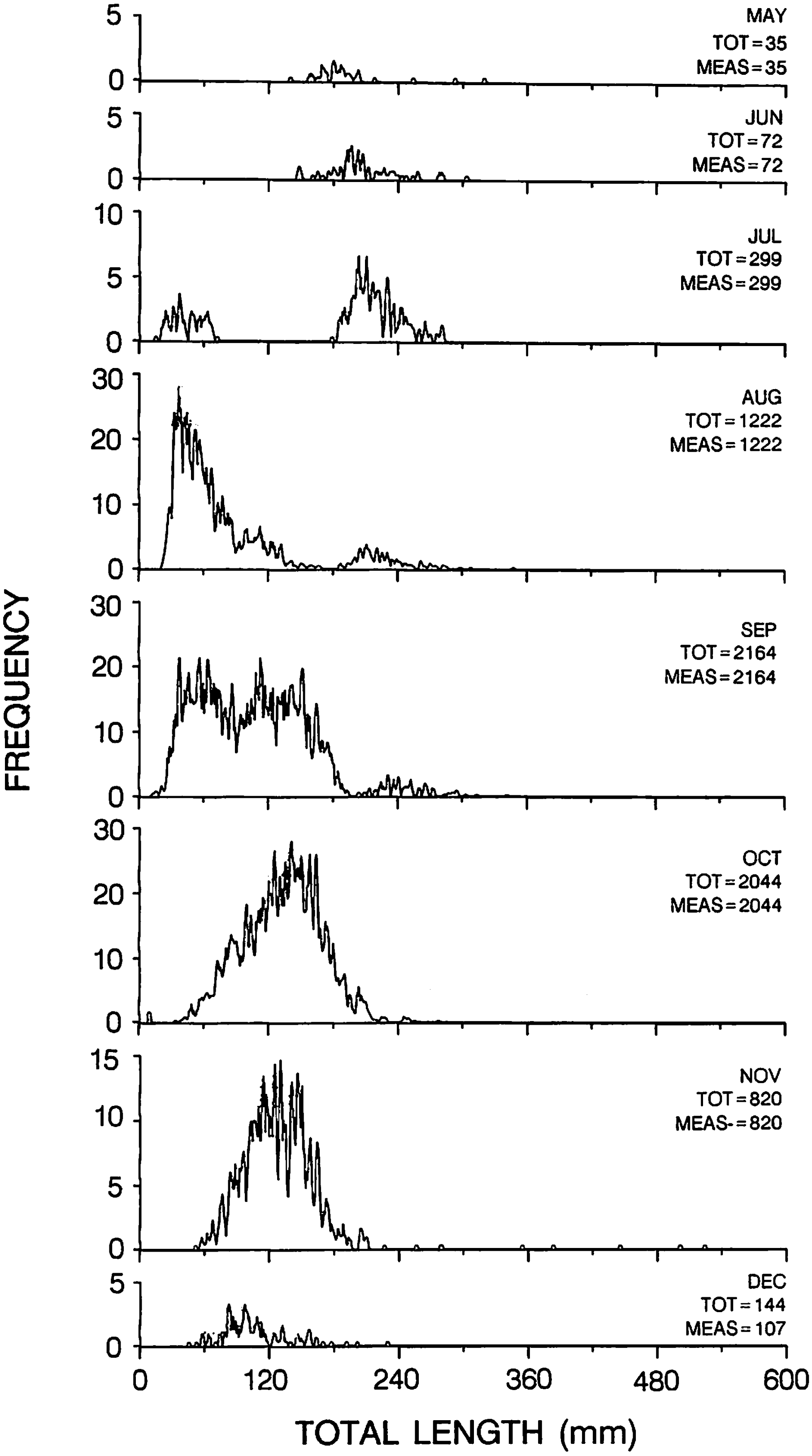
Month	log	CL	GM	CL
Jan	0.00	-0.13-0.13	0.00	-0.26-0.34
Feb	0.00	-0.13-0.13	0.00	-0.26-0.34
Mar	0.00	-0.13-0.13	0.00	-0.26-0.34
Apr	0.00	-0.13-0.13	0.00	-0.26-0.34
May	0.10	-0.03-0.23	0.27	-0.06-0.71
Jun	0.10	-0.03-0.23	0.26	-0.06-0.70
Jul	0.40	0.28-0.53	1.54	0.89-2.41
Aug	0.66	0.53-0.79	3.60	2.41-5.16
Sep	0.74	0.61-0.87	4.53	3.11-7.44
Oct	0.89	0.76-1.02	7.82	4.82-10.52
Nov	0.72	0.59-0.85	5.24	2.90-6.04
Dec	0.21	0.08-0.34	0.63	0.21-1.19

Table 40. Summary of Tukey's hsd multiple comparisons tests on log weakfish abundance. Means with different letters are significantly different.

Month	n	MEAN log	MEAN GM	Significance
Oct	48	0.89	6.82	a
Sep	48	0.74	4.53	a
Nov	48	0.72	4.24	a
Aug	48	0.66	3.58	a b
Jul	48	0.40	1.54	b c
Dec	48	0.21	0.63	c d
May	48	0.10	0.27	d
Jun	48	0.10	0.26	d
Jan	48	0.00	0.00	d
Feb	48	0.00	0.00	d
Mar	48	0.00	0.00	d
Apr	48	0.00	0.00	d

The annual pattern of catches reflects migratory movements of weakfish into and out of the Chesapeake Bay and their recruitment to and decruitment from the sampling frame and gear. With few exceptions only two age groups of weakfish are captured by the sampling gear as indicated in length frequencies, particularly in July (Figure 34). These age groups consist of the recently-recruited young-of-the-year, which were some 25-75 mm TL in July, and fish of age I and just approaching that age, which were some 180-330 mm TL in July. Neither age group occurs in the Chesapeake Bay in the winter and early spring months as evidenced by the absence of any weakfish in the catch. Only approaching-age I weakfish occur in the low catches of May and June which follow their migration into the Chesapeake Bay after overwintering in the ocean. This age group can be followed readily in the length frequencies until September or October after which it "decruits" from, or is no longer available to, the sampling gear. Young-of-the-year weakfish begin to recruit to the sampling frame in July and apparently continue to do so through at least September, because the minimum size and left tail of the frequency distribution remains constant from July through September. Recruitment seemingly ocurs in waves given the biomodal length frequency in September. It is primarily this group which made up the large weakfish catches from August through November. Sizes of the young-of-the-year weakfish increase from July through a peak in October. Sizes decline from October through December, indicating the larger, presumably older

Figure 34. Monthly length frequencies of weakfish. Frequencies are moving averages of three.


MAY
TOT=35
MEAS=35
JUN
TOT=72
MEAS=72
JUL
TOT=299
MEAS=299
AUG
TOT=1222
MEAS=1222
SEP
TOT=2164
MEAS=2164
OCT
TOT=2044
MEAS=2044
NOV
TOT=820
MEAS-=820
DEC
TOT=144
MEAS=107
FREQUENCY
TOTAL LENGTH (mm)
0
120
240
360
480
600
5
10
15
20
30

young move to sea first leaving behind the smaller, presumably younger members. The period October through December, therefore, represents a period when young weakfish are moving through the Chesapeake Bay on their first annual movement to overwinter in the ocean.

There were large intra-annual changes in patterns of weakfish abundance, not a constancy, across the Chesapeake Bay and along an upbay-downbay axis. These changes in patterns explain the significant F test for interaction.

Across-bay patterns of weakfish abundance show large changes during the year. There was little or no difference in abundance between the combined littoral waters of the Eastern and Western Shores and the combined deeper waters of the Central Plain and Deeps, and no significant difference, in the winter and spring months of January through June when weakfish were absent, or not abundant, in the Chesapeake (Figure 35; Table 41). However, this pattern changed so that in all months when weakfish were at all abundant -- July through December -- they were much more abundant in the deeper Central Plain and Deeps waters than in the littoral waters of the Eastern and Western Shores. The differences between Littoral and Deeper areas are significant in each of these months. Weakfish were some 5-8 times more abundant in the deeper waters than in the Littoral in that period depending on whether the overall means (Littoral GM = 0.43; Deeper Waters GM = 2.05) or the means of the means (Littoral mean GM =1.17; Deeper Waters mean GM =8.92) are compared.

Figure 35. The monthly (Mo) pattern of mean log weakfish catches (LGAB) in the mainstem Chesapeake Bay, Virginia by Across-Bay Region. Regions are Eastern Shore Littoral (1), Western Shore Littoral (2), Central Plain (3), and Deeps (4). When the number for a region is not indicated, the data value is the same as for the indicated region number.

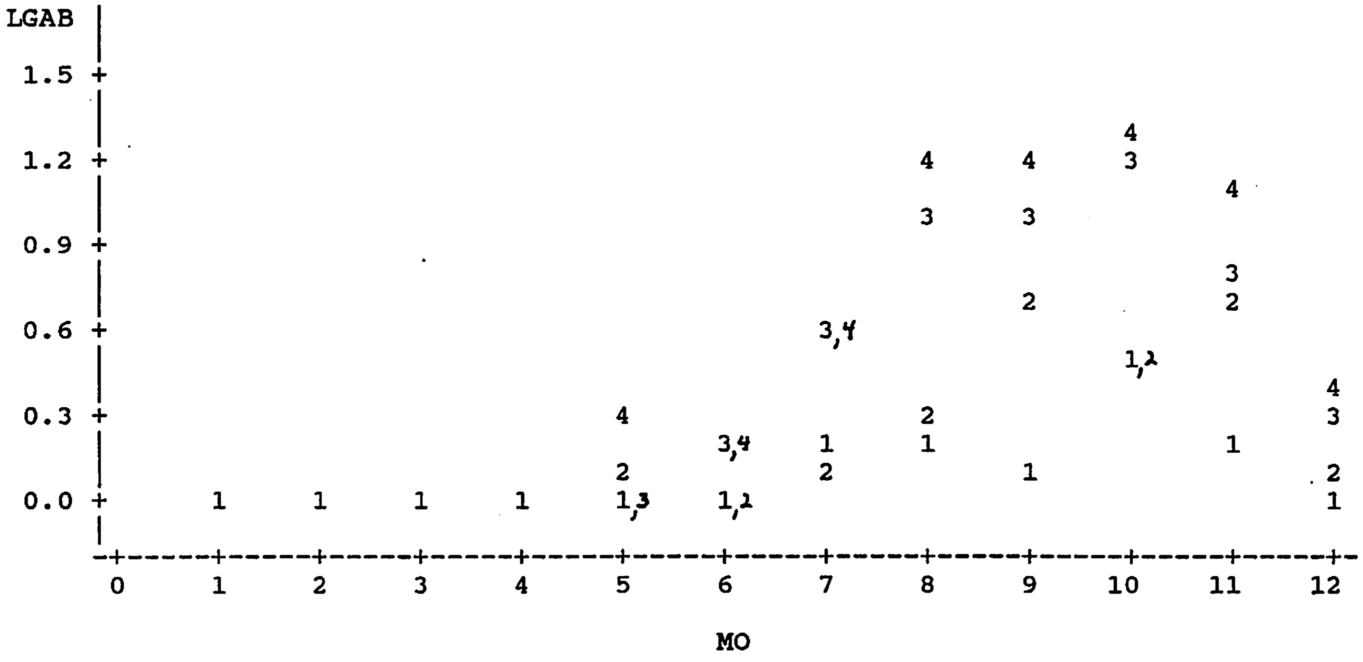

LGAB
1.5
1.2
0.9
0.6
0.3
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
MO
1
1
1
1
4
2
1,3
3,4
1,2
3,4
1
2
4
3
2
1
4
3
2
1
4
3
1,2
4
3
2
1
4
3
2
1

Table 41. Summary of individual degree of freedom contrast tests to evaluate differences in log weakfish abundance between Littoral waters (ESL and WSL) and the deeper Central Plain - Deeps waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	P_r>F	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Apr	0.00	0.00	ns	0.00-0.00	0.00- 0.00
May	0.24	1.23	ns	0.03-0.17	0.08- 0.49
Jun	0.49	2.52	ns	0.00-0.20	0.00- 0.60
Jul	2.69	13.70	**	0.17-0.64	0.47- 3.37
Aug	9.15	46.64	**	0.22-1.10	0.68-11.51
Sep	6.14	31.30	**	0.39-1.10	1.43-11.60
Oct	6.75	34.44	**	0.52-1.27	2.30-17.55
Nov	2.92	14.89	**	0.47-0.97	1.97- 8.24
Dec	0.97	4.97	*	0.07-0.35	0.17- 1.26

The comparative pattern of weakfish abundance remains the same year-round in the deeper waters. There was no significant difference in abundance between the Central Plain and Deeps waters within any month, though weakfish were generally more abundant each month in the Deeps (Figure 35; Table 42).

The comparative pattern of weakfish abundance varied during the year in the Littoral waters. There was little or no difference in abundance, and no significant differences, between the Eastern and Western Shore Littoral zones during much of the year (Figure 35; Table 43). However, weakfish were significantly more abundant in September and November in the Western Shore Littoral than in the Eastern Shore Littoral as they migrate from the Chesapeake to the ocean to overwinter. They were also more abundant, though not significantly so, in the Western Shore Littoral in October, the only other month when catches were at all high in the littoral zones.

Upbay-downbay patterns of weakfish abundance showed large changes during the year. There was little or no difference in abundance, and no significant differences, between the Upper, Middle and Lower Bay regions in the winter, spring, and early summer months of January through July when weakfish are absent or not abundant in the Chesapeake Bay (Figure 36; Tables 44, 45). However, this pattern changed during the August-November months when weakfish were most abundant in the Chesapeake Bay. In the late summer and early fall months of August through October weakfish were more abundant in the Middle region waters than the

Table 42. Summary of individual degree of freedom contrast tests to evaluate differences in log weakfish abundance between Central Plain and Deeps waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Apr	0.00	0.00	ns	0.00-0.00	0.00- 0.00
May	0.73	3.71	ns	0.00-0.35	0.00- 1.23
Jun	0.05	0.24	ns	0.16-0.25	0.44- 0.77
Jul	0.00	0.00	ns	0.64-0.64	3.38- 3.37
Aug	0.10	0.51	ns	1.03-1.16	9.79-13.51
Sep	0.21	1.07	ns	1.00-1.19	9.16-14.64
Oct	0.10	0.52	ns	1.20-1.33	14.98-20.54
Nov	0.34	1.75	ns	0.85-1.09	6.02-11.17
Dec	0.05	0.28	ns	0.31-0.40	1.02-1.52

Table 43. Summary of individual degree of freedom contrast tests to evaluate differences in log weakfish abundance between the Eastern Shore Littoral and Western Shore Littoral waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00-0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00-0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00-0.00
Apr	0.00	0.00	ns	0.00-0.00	0.00-0.00
May	0.03	0.13	ns	0.00-0.06	0.00-0.16
Jun	0.00	0.00	ns	0.00-0.00	0.00-0.00
Jul	0.07	0.34	ns	0.22-0.12	0.66-0.30
Aug	0.07	0.38	ns	0.17-0.28	0.47-0.91
Sep	2.31	11.76	**	0.08-0.70	0.19-3.96
Oct	0.02	0.11	ns	0.49-0.55	2.08-2.53
Nov	1.46	7.46	*	0.23-0.72	0.68-4.24
Dec	0.05	0.23	ns	0.03-0.11	0.06-0.29

Figure 36. The monthly pattern (Mo) of mean log weakfish catches (LGAB) in the mainstem Chesapeake Bay, Virginia by Up-Down Bay Region. Regions are Upper Bay (1), Middle Bay (2), and Lower Bay (3). When the number for a region is not indicated, the data value is the same as for the indicated region number.

```
LGAB  |
      |
  1.5 +
      |
      |
  1.2 +                                                                      3
      |                                                               2      2
      |                                                                             3
  0.9 +                                                        2
      |                                                                             2
      |                                                               1
  0.6 +                                                        1
      |                                                 2      3
      |                                                 1             3      1      1
  0.3 +                                                 3                                  3
      |                                   1                                                1
      |                                   3      1                                         2
  0.0 +       1      1      1      1      2
      |
      -+------+------+------+------+------+------+------+------+------+------+------+------+-
       0      1      2      3      4      5      6      7      8      9     10     11     12

                                                  MO
```

Table 44. Summary of individual degree of freedom contrast tests to evaluate differences in log weakfish abundance between the Upper and Lower Bay waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Apr	0.00	0.00	ns	0.00-0.00	0.00- 0.00
May	0.05	0.25	ns	0.19-0.12	0.56- 0.31
Jun	0.00	0.03	ns	0.10-0.08	0.26- 0.19
Jul	0.25	1.26	ns	0.45-0.27	1.80- 0.87
Aug	0.21	1.07	ns	0.65-0.48	3.43- 2.05
Sep	0.46	2.34	ns	0.66-0.42	3.61- 1.66
Oct	4.79	24.40	**	0.41-1.18	1.58-14.30
Nov	2.66	13.54	**	0.39-0.97	1.47- 8.31
Dec	0.05	0.27	ns	0.23-0.31	0.68- 1.03

Table 45. Summary of individual degree of freedom contrast tests to evaluate differences in log weakfish abundance between the Middle Bay and the average in the Upper and Lower Bay waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00-0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00-0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00-0.00
Apr	0.00	0.00	ns	0.00-0.00	0.00-0.00
May	0.26	1.31	ns	0.00-0.13	0.00-0.43
Jun	0.02	0.09	ns	0.13-0.09	0.35-0.22
Jul	0.19	0.99	ns	0.49-0.36	2.12-1.29
Aug	0.87	4.42	*	0.85-0.57	6.09-2.68
Sep	3.80	19.39	**	1.14-0.54	12.83-2.50
Oct	0.87	4.45	*	1.08-0.80	11.13-5.28
Nov	0.14	0.72	ns	0.80-0.68	5.25-3.80
Dec	0.29	1.50	ns	0.10-0.27	0.25-0.85

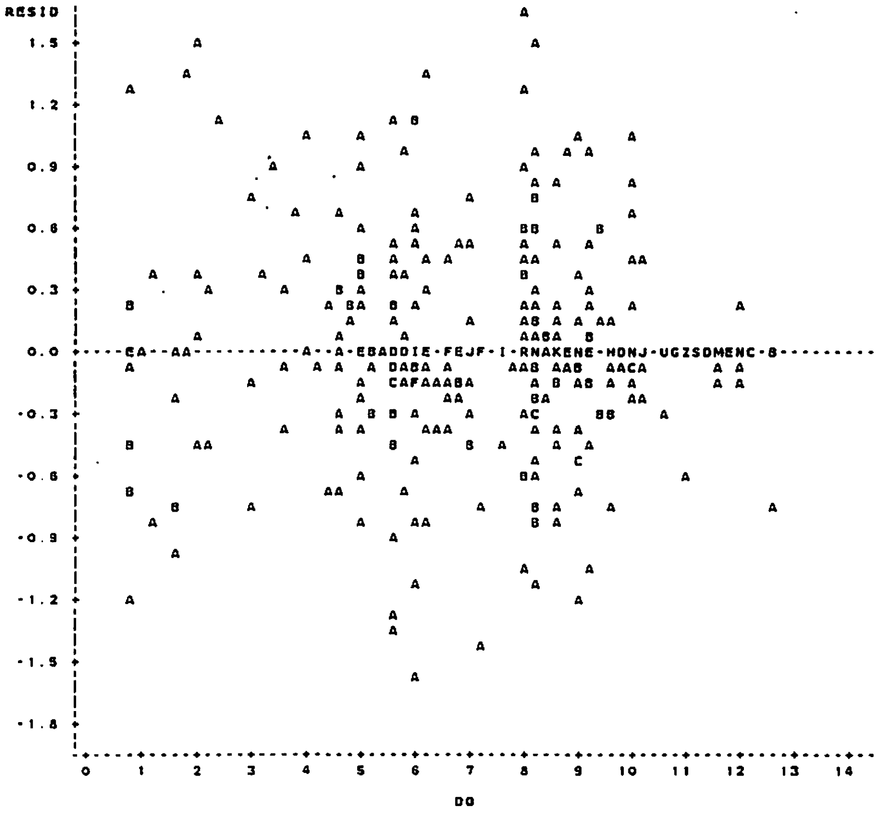
average of their abundance in the Upper and Lower Bay. These differences were significant. During August and September, they reflect greater weakfish abundance in the Middle Bay than in either the Upper or Lower Bay. As weakfish moved out of the Chesapeake Bay in the mid to late fall months of October and November, they became significantly more abundant in the Middle and Lower regions than in the Upper Region. In this period, weakfish were more abundant, though not sigificantly so, in the Lower Bay than in the Middle Bay. There was little difference between the three regions in December, none significant, when abundance was again low everywhere, though the last weakfish had not yet disappeared for the winter.

Other Sources of Variation in Weakfish Catches:

Overall plots of residuals against bottom D.O. indicate no strong relationship (Figure 37). The two variables are independent over much of the D.O. range. At low D.O. (D.O < 2 mg/l), most residuals seem to be negative or to have small positive values. This would suggest lower abundance in, or avoidance of, low D.O. areas. However, the pattern is not completely clear, because one large positive residual occurred at 1.0 mg/l D.O.

Overall plots of residuals against temperature indicate no regression or other relations not already postulated in the model (Figure 31). Variation in residuals generally appears low at low temperatures when weakfish are absent from the Chesapeake Bay.

Figure 37. The overall relationship (all data) between residuals from log weakfish catches and bottom dissolved oxygen (mg/l). A = 1 observation, B = 2 observation, etc.


RESID
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
0
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DO

There also appears to be constriction in the magnitude of the residuals: the residuals appear to be smaller at temperatures of about 17-21° than at higher or lower temperatures.

Overall plots of residuals against salinity indicate no regression or other effects not already postulated in the model (Figure 32). The pattern of the residuals seems to form a circle, the smallest residuals occurring at the lowest and highest salinity values.

Overall plots of residuals against Areas (not shown) indicate no regression or other relations not already included in the model. Variation in residuals appears constant within Areas.

Overall plots of residuals against Months (not shown) indicate no regression or other relations not already included in the model. Variation in residuals generally appears comparatively low in the winter or early spring months when weakfish catches are low, high when weakfish catches are high.

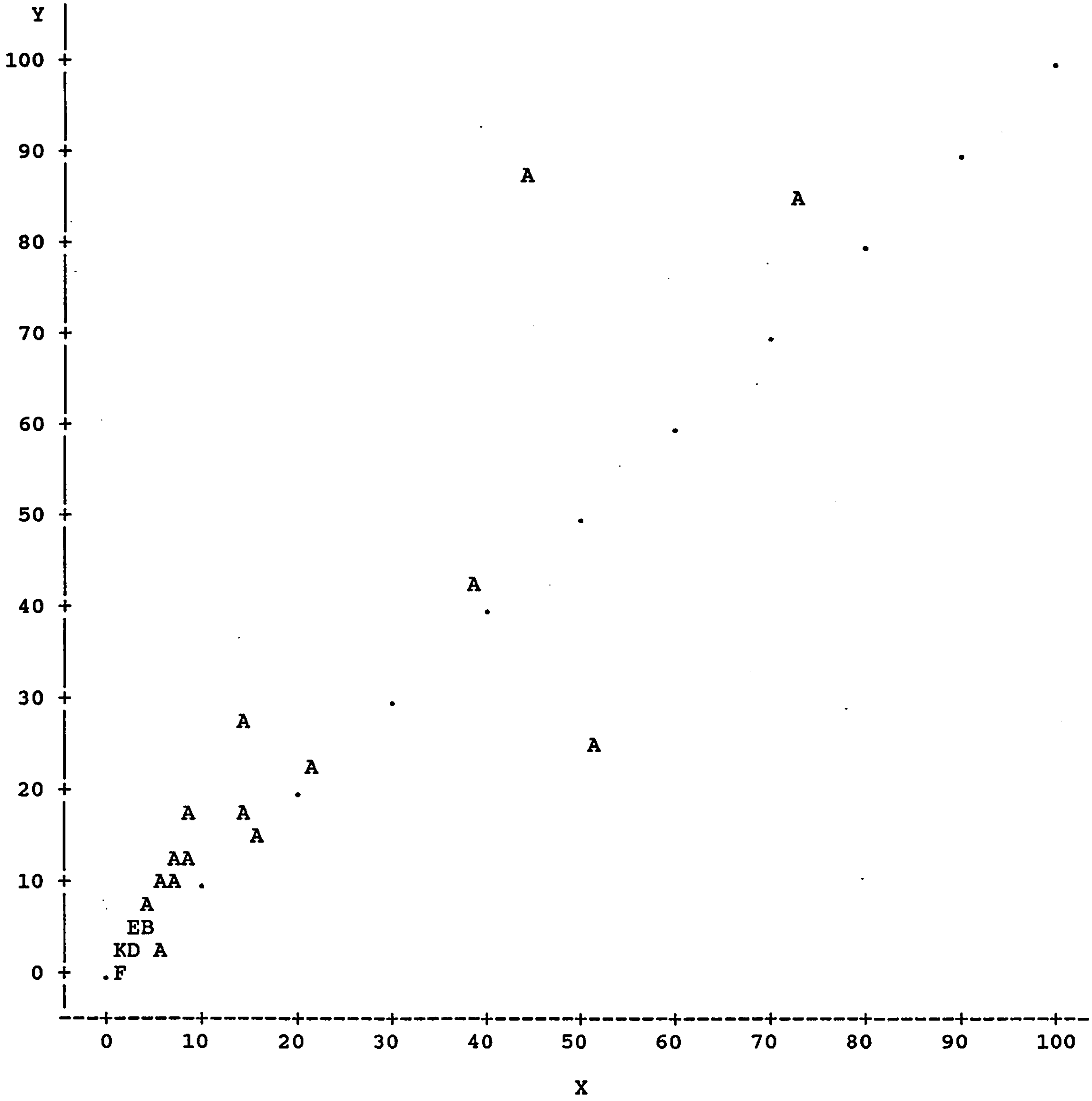
Atlantic Croaker

Choosing an Appropriate Transformation:

The log transformation appears not fully appropriate for the present counts of abundance data on Atlantic croaker. Plots of the untransformed standard deviation on the untransformed arithmetic mean within Months x Areas cells indicate they are not equal (Figure 38), because most data points are scattered above, though along, the 45 degree diagonal. The calculated slope ($b = 1.14$) of the regression of the untransformed standard deviation on the untransformed arithmetic mean is significantly different from a hypothesized $\beta = 1$ ($t = 3.56$; 142 df). Plots of the untransformed variance on the untransformed arithmetic mean (not shown) are much worse than the preceding plots. Nearly all data points are well above the diagonal. The calculated slope ($b = 77.93$) of the regression of the variance on the mean is significantly greater than a hypothesized $\beta = 1$ ($t = 16.25$; 142 df). These conditions indicate the square root transformation is not sufficient to normalize the counts of abundance, as indicated also by tests for homogeneity of variance noted later. The log transformation is better but still not completely adequate, because the standard deviation exceeds the mean, though not greatly.

The log transformation had the smallest standard error (0.29), had the second-smallest coefficient of variation (CV = 174.72), provided the best fit for the postulated model ($100r^2$ =

Figure 38. Relationship between standard deviation (y) and untransformed arithmetic mean counts of abundance (x) for Atlantic croaker. The 45° diagonal has slope b = 1, so y = x along it. A = 1 observation, B = 2 observations, etc.


Y
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
X
A
AA
EB
KD
F

58.10), and as noted later, provided fairly reasonable normality if not homogeneity of variance, and provided the greatest number of effective degrees of freedom (Table 46). The square root transformation was superior to the log in having a smaller CV, but it was less desirable in all the other properties. Untransformed data had the least desirable properties of all. Although the log transformation does not well-fulfill the assumptions of ANOVA, it was used to guide interpretation of the data, because it best met the assumptions and because ANOVA is generally robust.

General Data Description:

Atlantic croaker were the eleventh most abundant fish in the sampling frame. They made up 0.3% of the overall catch (Chittenden 1989).

The overall geometric mean catch was 0.47 Atlantic croaker, with 95% confidence limits about the mean being 0.39-0.55 (Table 47). The overall mean log catch was 0.17, with 95% confidence limits being 0.14-0.19. The standard error of the mean log catch was 0.29 and the coefficient of variation was 174.72 (Table 46). The maximum catch was 194 croaker and the minimum was 0.

Atlantic croaker do not necessarily occur year-round in the Chesapeake Bay. None were captured January-May (Table 48), and they were not frequently captured in June, being absent in most strata then (10 of 12).

Table 46. Summary of the comparative properties of listed transformations on Atlantic croaker abundance counts.

Property	Transformation log	 none	 Square Root
Mean	0.17	2.76	1.16
Std. error	0.29	11.87	1.07
$100r^2$	58.10	44.52	54.86
CV	174.72	429.58	92.31
Independence of Residuals	yes	yes	yes
Homogeneity of Variance Using Cochran's C.	no, maybe reasonable with zeros deleted	no	no
Normality	reasonable	did not examine	did not examine
Homogeneity of Slopes	reasonable	did not examine	did not examine

Table 47. Summary statistics on overall log Atlantic croaker abundance, with a geometric mean (GM) back-transformation. No transformation was applied to the sample size (n) and the minimum-maximum counts.

	LOG	GM
n	576	--
Min-Max	0-194	--
Mean	0.17	0.47
95% Confidence Limits	0.14-0.19	0.39-0.55

Table 48. Summary of Atlantic croaker presence or absence in the Month-Area Cells. X = Present; - = Absent.

	UPPER BAY				MIDDLE BAY				LOWER BAY				TOTAL PRESENT
Month	ESL (01)	WSL (02)	CP (03)	DP (04)	ESL (05)	WSL (06)	CP (07)	DP (08)	ESL (09)	WSL (10)	CP (11)	DP (12)	
Jan	X	X	X	X	X	X	X	X	X	X	X	X	12
Feb	-	-	-	-	-	-	-	-	-	-	-	-	0
Mar	-	-	-	-	-	-	-	-	-	-	-	-	0
Apr	-	-	-	-	-	-	-	-	-	-	-	-	0
May	-	-	-	-	-	-	-	-	-	-	-	-	0
Jun	-	-	-	-	-	-	-	-	-	-	-	X	1
Jul	-	-	-	-	-	X	-	X	-	-	-	-	2
Aug	-	-	-	-	-	X	X	X	-	X	X	X	6
Sep	X	X	X	X	-	X	X	X	X	X	X	X	11
Oct	X	X	X	X	-	-	X	X	X	X	X	-	9
Nov	X	X	X	X	-	X	X	-	-	X	-	-	7
Dec	X	-	X	X	X	X	X	X	-	X	X	X	10
Total Present	5	4	5	5	2	6	6	6	3	6	5	5	52

Overview of the ANOVA-ANCOVA:

The postulated models explain much of the total variation in Atlantic croaker catches. A log transformation explained about 59% of the total variation (Table 49). A little less is explained (Table 46) using a square root transformation (54.86%) and much less with no transformation (44.52%).

The overall log ANCOVA (or ANOVA) model was significant at $\alpha = 0.01$ (Table 49). The Months and Areas main effects were both highly significant. The Months main effect was only a little more important than the Areas effect, $100r^2$ values being 16.27% for Months and 6.39% for Areas. Interaction was significant and explained more variation (35.43%) than either main effect. The significant Interaction implies that spatial and temporal factors have a complex effect on the distribution of Atlantic croaker, eg. -- the simple effects of Areas, for example, are not constant; rather they vary from month to month.

The temperature covariate was not significant, though the salinity covariate was (Table 49). Neither covariate explained much variation in Atlantic croaker catches (0.72%, salinity; 0.02%, temperature) beyond that associated with the Areas and Months effects, whether significant or not. Therefore, the covariates were deleted from the model, and further analyses were made using only the ANOVA model with its main effects and interactions.

The overall log ANOVA model finally accepted explained 58.10% of the variation in Atlantic croaker catches (Table 46).

Table 49. Summary of the ANCOVA on Atlantic croaker, log transformation, with $100r^2$ values.

Source of Variation	df	SS	MS	F	$100r^2$
Corr. Tot.	575	87.77	--	--	100.00
Model	145	51.64	0.36	4.24 **	58.84
Months (M)	11	14.28	1.30	15.45 **	16.27
Areas (A)	11	5.61	0.51	6.07 **	6.39
M x A	121	31.10	0.26	3.06 **	35.43
Sal	1	0.63	0.63	7.53 **	0.72
Temp	1	0.02	0.02	0.20 NS	0.02
Error	430	36.13	0.08	--	41.16

Its most important component was Interaction, then the Months main effect. The Areas main effect was not very important. Random variation, or variation not recognized and not included in the model, accounted for 42% of the total variation.

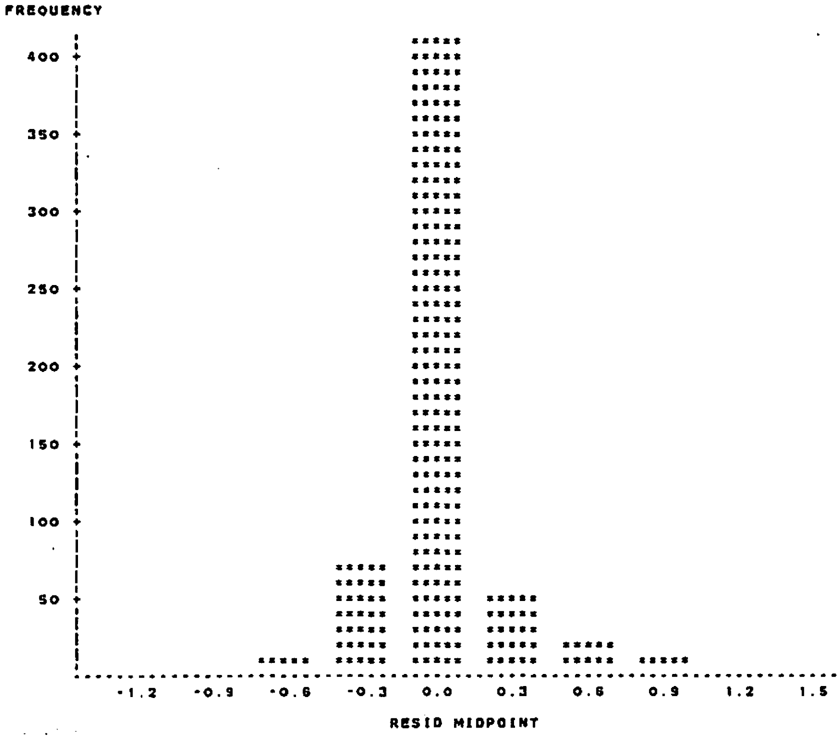
Validity of the Assumptions of the ANCOVA-ANOVA models:

The assumptions of the ANOVA-ANCOVA models appear to be not well-fulfilled when a log transformation is used on the Atlantic croaker catch data, but it is the best transformation considered.

The assumption of normality of the residuals is a fairly reasonable approximation, though not true. The frequency distribution of the residuals from the log ANOVA model (Figure 39) appears to be fairly reasonably normal, though possibly slightly skewed. The Kolomogorov D statistic, however, is significant ($D = 0.333$; $n = 576$) at $\alpha = .01$, which indicates the distribution of the residuals is not truly normal. The significant D statistic, in part, reflects an exceptionally large sample size which can detect even very small departures from normality.

The assumption of homogeneity of within-cell variance does not hold well using a log transformation on the catch data. Cochran's C statistic ($C = 0.1028$; 3 df; $n = 144$) is significant at $\alpha = .01$. The square root and no transformation perform even more poorly. Cochran's C statistic ($C = 0.2344$) is significant at $\alpha = .01$ using a square root transformation; similarly, Cochran's C ($C = 0.376$) is significant at $\alpha = .01$ with no

Figure 39. Frequency distribution of the residuals to evaluate the assumption of normality in Atlantic croaker.


FREQUENCY
400
350
300
250
200
150
100
50
-1.2
-0.9
-0.6
-0.3
0.0
0.3
0.6
0.9
1.2
1.5
RESID MIDPOINT

transformation.

The assumption of homogeneous, linear regression on the covariates within cells appears reasonable, or there was no regression. The residuals from the ANOVA model were plotted (not shown) on temperature within cells and on salinity. A relationship between the residuals and temperature or between the residuals and salinity was apparent in only a few cells (of 144). These conclusions of little or no within-cell relation between residuals and temperature or salinity are illustrated by overall plots (all data) of the relationships between temperature and residuals and salinity and residuals (Figure 40, C-4).

Interpretation of Interaction and Main Effects to Evaluate Spatial/Temporal Distributions:

Atlantic croaker catches show great variation between months that forms a clear annual pattern of change from a late winter-spring low to a fall-early winter peak. No croaker were captured in the winter and spring months of January through May (Figure 42, Table 50). Monthly catches generally rose after June to reach a peak in the late fall-early winter months of December and January. Catches then sharply declined after January to their winter-spring lows. Tukey's multiple comparisons tests (Table 51), which elaborate on the significant F tests for Months, show significantly more croaker were caught in the fall and winter months of September through January than in the winter, spring and early summer months of February through June. Intermediate size catches in the summer and fall months of July through

Figure 40. The overall relationship (all data) between residuals from log Atlantic croaker catches and bottom temperature (C^{o}). A = 1 observation, B = 2 observations, etc.

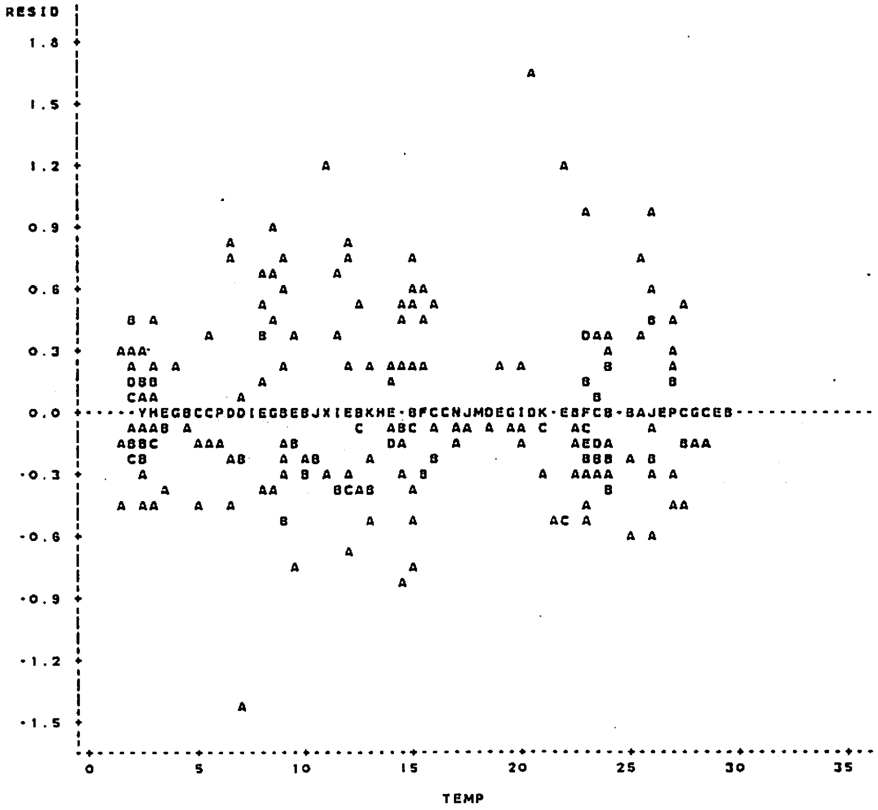

RESID
1.8
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
0
5
10
15
20
25
30
35
TEMP

Figure 41. The overall relationship (all data) between residuals from log Atlantic croaker catches and bottom salinity (parts per thousand). A = 1 observation, B = 2 observations, etc.

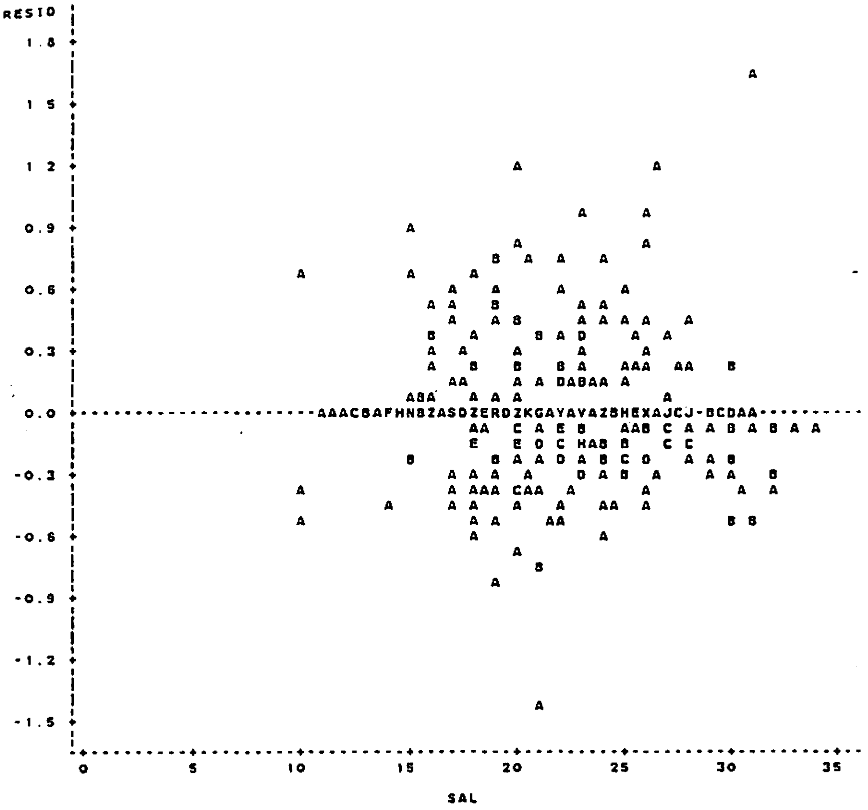

RESID
1.8
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
0
5
10
15
20
25
30
35
SAL

Figure 42. The monthly (Mo) pattern of mean log Atlantic croaker catches (LGAB) in the mainstem Chesapeake Bay, Virginia.

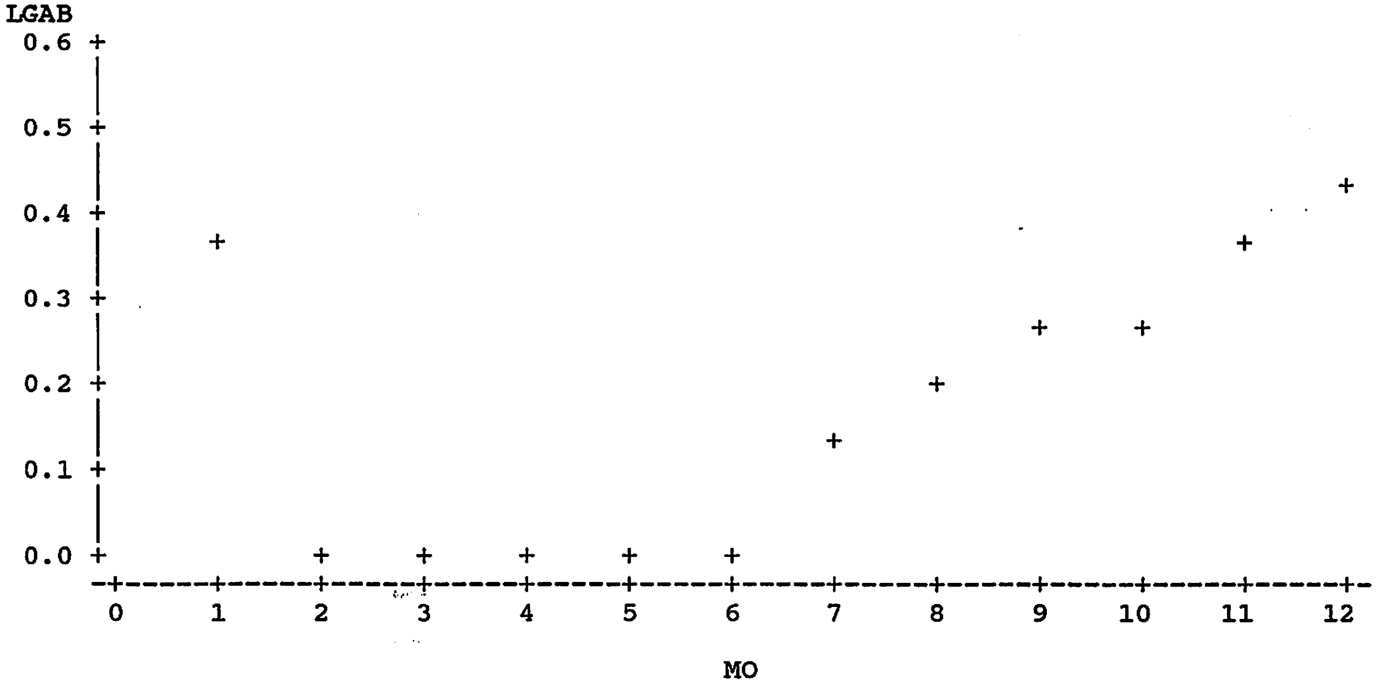

LGAB
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
MO

Table 50. Summary of 95% confidence limits (CL) about monthly mean log abundance of Atlantic croaker, with a geometric mean (GM) back-transformation.

Month	log (x + 1)	CL	GM	CL
Jan	0.37	0.29-0.46	1.36	0.94-1.87
Feb	0.00	-0.08-0.08	0.00	-0.18-0.22
Mar	0.00	-0.08-0.08	0.00	-0.18-0.22
Apr	0.00	-0.08-0.08	0.00	-0.18-0.22
May	0.00	-0.08-0.08	0.00	-0.18-0.22
Jun	0.01	-0.07-0.10	0.03	-0.15-0.25
Jul	0.12	0.04-0.21	0.32	-0.09-0.61
Aug	0.21	0.12-0.29	0.61	0.32-0.95
Sep	0.26	0.17-0.34	0.82	0.50-0.21
Oct	0.26	0.17-0.34	0.80	0.48-1.19
Nov	0.36	0.28-0.44	1.29	0.88-1.78
Dec	0.42	0.33-0.50	1.61	1.15-2.18

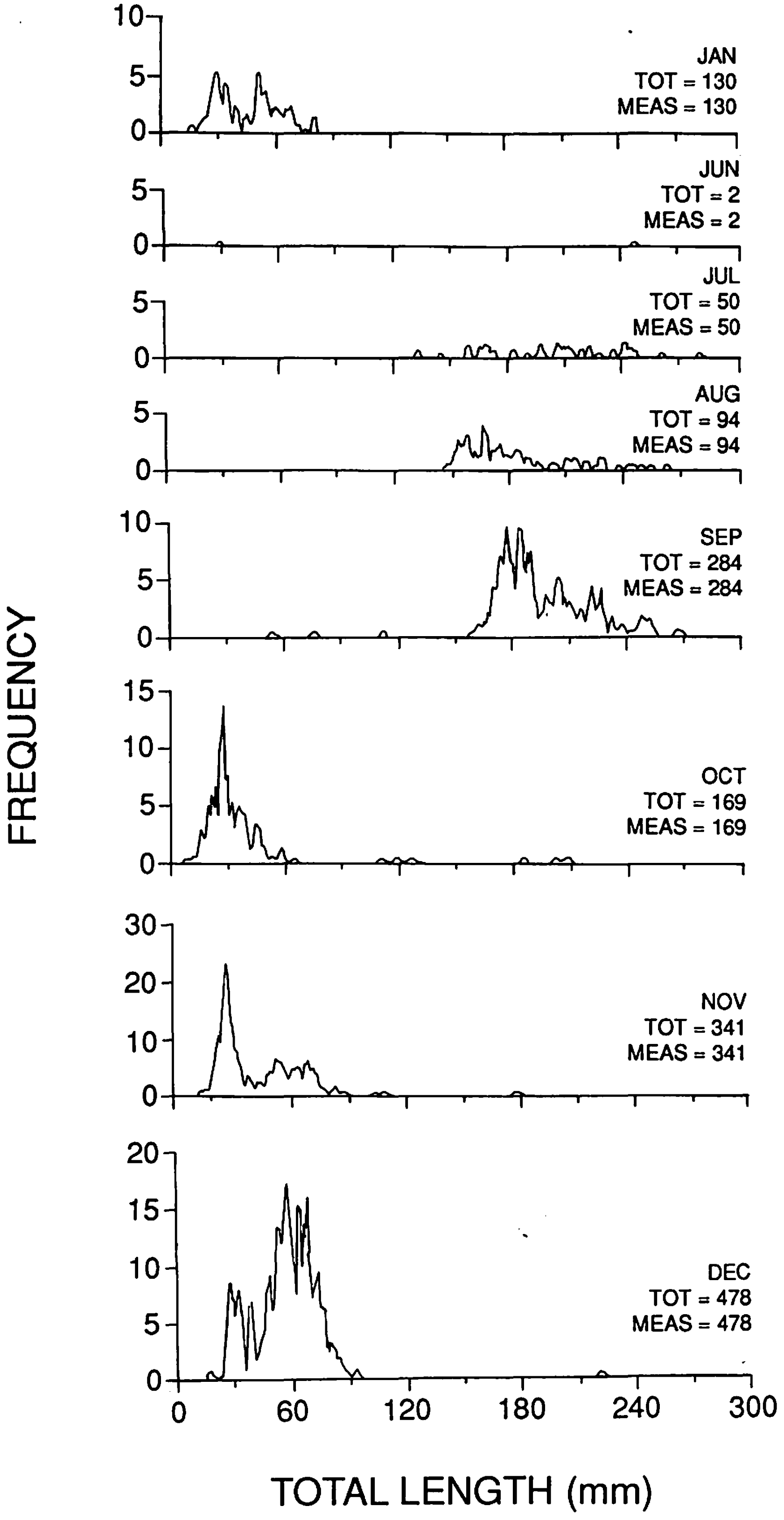
Table 51. Summary of Tukey's hsd multiple comparisons tests on log Atlantic croaker abundance. Means with different letters are significantly different.

Month	n	MEAN log	GM	Significance
Dec	48	0.42	1.61	a
Jan	48	0.37	1.36	a b
Nov	48	0.36	1.29	a b
Sep	48	0.26	0.82	a b c
Oct	48	0.26	0.80	a b c
Aug	48	0.21	0.61	b c d
Jul	48	0.12	0.32	c d e
Jun	48	0.01	0.03	d e
Feb	48	0.00	0.00	e
Apr	48	0.00	0.00	e
Mar	48	0.00	0.00	e
May	48	0.00	0.00	e

October were, variously, significantly different or not from catches in the months of September through January, when croaker were most abundant, and February through June, when croaker were absent or not abundant.

The annual pattern of catches reflects migratory movements of Atlantic croaker into and out of the Chesapeake Bay, their survivorship, and their recruitment to and decruitment from the sampling frame and gear. With few exceptions only two age groups of croaker are captured by the sampling gear as indicated in length frequencies, particularly in September and October (Figure 43). These age groups consist of the recently-recruited young-of-the-year, which were some 15-65 mm TL in October, and presumably fish of about age I, which were some 165-255 mm TL in September. The latter group may contain some older fish, something that can be firmly established only through age determination by hard parts. Neither age group occurred in the Chesapeake Bay in the winter and early spring months as evidenced by the absence of any croaker in the catch. With few exceptions only approaching-age I croaker were captured from July through September. This age group can be followed readily in the length frequencies until September after which it migrates to the ocean and apparently permanently "decruits" from the sampling gear or sampling frame. Young-of-the-year croaker begin to recruit to the sampling frame in large numbers in October and apparently continue to do so through at least January, because the minimum size and left tail of the frequency distribution remains largely

Figure 43. Monthly length frequencies of Atlantic croaker. Frequencies are moving averages of three.



10
5
0
JAN
TOT = 130
MEAS = 130
5
0
JUN
TOT = 2
MEAS = 2
5
0
JUL
TOT = 50
MEAS = 50
5
0
AUG
TOT = 94
MEAS = 94
10
5
0
SEP
TOT = 284
MEAS = 284
15
10
5
0
OCT
TOT = 169
MEAS = 169
30
20
10
0
NOV
TOT = 341
MEAS = 341
20
15
10
5
0
DEC
TOT = 478
MEAS = 478
0
60
120
180
240
300
FREQUENCY
TOTAL LENGTH (mm)

constant from October through January. It is primarily this group which made up croaker catches from October through January when it disappeared, not to reappear again until, apparently, the following June. The period October through January, therefore, represents a period when young-of-the-year croaker are recruiting to the Chesapeake Bay, and July through September represents a period when about age I croaker, apparently, are moving through the Chesapeake Bay on their annual movement to overwinter in the ocean.

There were large, intra-annual changes in patterns of Atlantic croaker abundance, not a constancy, across the Chesapeake Bay and along an upbay-downbay axis. These changes in patterns explain the significant F test for interaction.

Across-bay patterns of Atlantic croaker abundance showed large changes during the year. There was little or no difference in abundance between the combined littoral waters of the Eastern and Western Shores and the combined deeper waters of the Central Plain and Deeps, and no significant difference, in the winter, spring, and early summer months of February through July when they were absent, or not abundant, in the Chesapeake (Figure 44; Table 52). However, this pattern changed so that in almost all months when croaker were abundant -- August through December -- they were more abundant in the deeper Central Plain and Deeps waters than in the littoral waters of the Eastern and Western Shores. The differences between the littoral and deeper areas are significant in each of these months (Littoral mean GM = 0.42;

Figure 44. The monthly (Mo) pattern of mean log Atlantic croaker catches (LGAB) in the mainstem Chesapeake Bay, Virginia by Across-Bay Region. Regions are Eastern Shore Littoral (1), Western Shore Littoral (2), Central Plain (3), and Deeps (4). When the number for a region is not indicated, the data value is the same as for the indicated region number.

```
LGAB |
 0.8 +
     |
     |
     |                                                                                    3,4
 0.6 +       2
     |                                                                             4
     |       3                                                                     3
     |                                                               4
 0.4 +                                                                      3,4
     |                                                        3
     |       4                                                4      3
     |                                                                             2
 0.2 +                                                 2,4                                1,2
     |       1                                                2      1,2    2      1
     |                                                 3                    1
     |                                          3
 0.0 +              1      1      1      1      1      1      1
     |
     -+------+------+------+------+------+------+------+------+------+------+------+------+-
      0      1      2      3      4      5      6      7      8      9     10     11     12

                                               MO
```

Table 52. Summary of individual degree of freedom contrast tests to evaluate differences in log Atlantic croaker abundance between Littoral waters (ESL and WSL) and the deeper Central Plain - Deeps waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.01	0.16	ns	0.36-0.39	1.27-1.45
Feb	0.00	0.00	ns	0.00-0.00	0.00-0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00-0.00
Apr	0.00	0.00	ns	0.00-0.00	0.00-0.00
May	0.00	0.00	ns	0.00-0.00	0.00-0.00
Jun	0.01	0.09	ns	0.00-0.03	0.00-0.06
Jul	0.03	0.31	ns	0.10-0.14	0.25-0.39
Aug	0.70	8.27	**	0.08-0.33	0.22-1.12
Sep	0.60	7.03	**	0.15-0.37	0.41-1.35
Oct	0.91	10.70	**	0.12-0.39	0.31-1.47
Nov	1.26	14.84	**	0.20-0.52	0.58-2.33
Dec	2.30	27.07	**	0.19-0.64	0.58-3.33

Deeper waters mean GM = 1.92).

The comparative pattern of Atlantic croaker abundance remained the same year-round in the deeper waters. There was no significant difference in croaker abundance between the Central Plain and Deeps waters within any month, and no pattern to the observed differences, ones which were generally small (Figure 44; Table 53).

The comparative pattern of Atlantic croaker abundance varied only a little during the year in the littoral waters. There was little or no difference in abundance, and no significant differences, between the Eastern and Western Shore Littoral zones during most of the year, including periods of both low and high abundance (Figure 44; Table 54). In January, croaker were significantly more abundant in the Western Shore Littoral than in the Eastern Shore Littoral (GM = 2.86, WSL; GM = 0.33, ESL), the only month when there was significance.

Upbay-downbay patterns of Atlantic croaker abundance showed large changes during the year. There was little or no difference in abundance, and no significance differences, between the Upper, Middle, and Lower Bay regions in the winter, spring, and early summer months of February through July when croaker were absent or not abundant in the Chesapeake Bay (Figure 45; Tables 55, 56). However, the pattern of abundance changed thereafter. Croaker were significantly more abundant in the Lower Bay waters during August and September as the age I croaker migrated to the ocean. Similarly in August, croaker were more abundant in the Middle

Table 53. Summary of individual degree of freedom contrast tests to evaluate differences in log Atlantic croaker abundance between Central Plain and Deeps waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.26	3.10	**	0.49-0.28	2.12-0.93
Feb	0.00	0.00	ns	0.00-0.00	0.00-0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00-0.00
Apr	0.00	0.00	ns	0.00-0.00	0.00-0.00
May	0.00	0.00	ns	0.00-0.00	0.00-0.00
Jun	0.00	0.00	ns	0.03-0.03	0.06-0.06
Jul	0.03	0.36	ns	0.11-0.18	0.28-0.51
Aug	0.04	0.51	ns	0.37-0.28	1.34-0.93
Sep	0.12	1.39	ns	0.30-0.44	1.00-1.76
Oct	0.01	0.06	ns	0.41-0.38	1.56-1.39
Nov	0.03	0.33	ns	0.49-0.56	2.08-2.60
Dec	0.00	0.02	ns	0.63-0.64	3.25-3.41

Table 54. Summary of individual degree of freedom contrast tests to evaluate differences in log Atlantic croaker abundance between the Eastern Shore Littoral and Western Shore Littoral waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	1.27	14.97	**	0.13-0.59	0.33-2.86
Feb	0.00	0.00	ns	0.00-0.00	0.00-0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00-0.00
Apr	0.00	0.00	ns	0.00-0.00	0.00-0.00
May	0.00	0.00	ns	0.00-0.00	0.00-0.00
Jun	0.00	0.00	ns	0.00-0.00	0.00-0.00
Jul	0.23	2.69	ns	0.00-0.20	0.00-0.57
Aug	0.17	2.02	ns	0.00-0.17	0.00-0.48
Sep	0.00	0.00	ns	0.15-0.14	0.42-0.39
Oct	0.04	0.51	ns	0.08-0.16	0.19-0.45
Nov	0.11	1.26	ns	0.13-0.26	0.35-0.84
Dec	0.00	0.01	ns	0.19-0.20	0.56-0.59

Figure 45. The monthly pattern (Mo) of mean log Atlantic croaker catches (LGAB) in the mainstem Chesapeake Bay, Virginia by Up-Down Bay Region. Regions are Upper Bay (1), Middle Bay (2), and Lower Bay (3). When the number for a region is not indicated, the data value is the same as for the indicated region number.

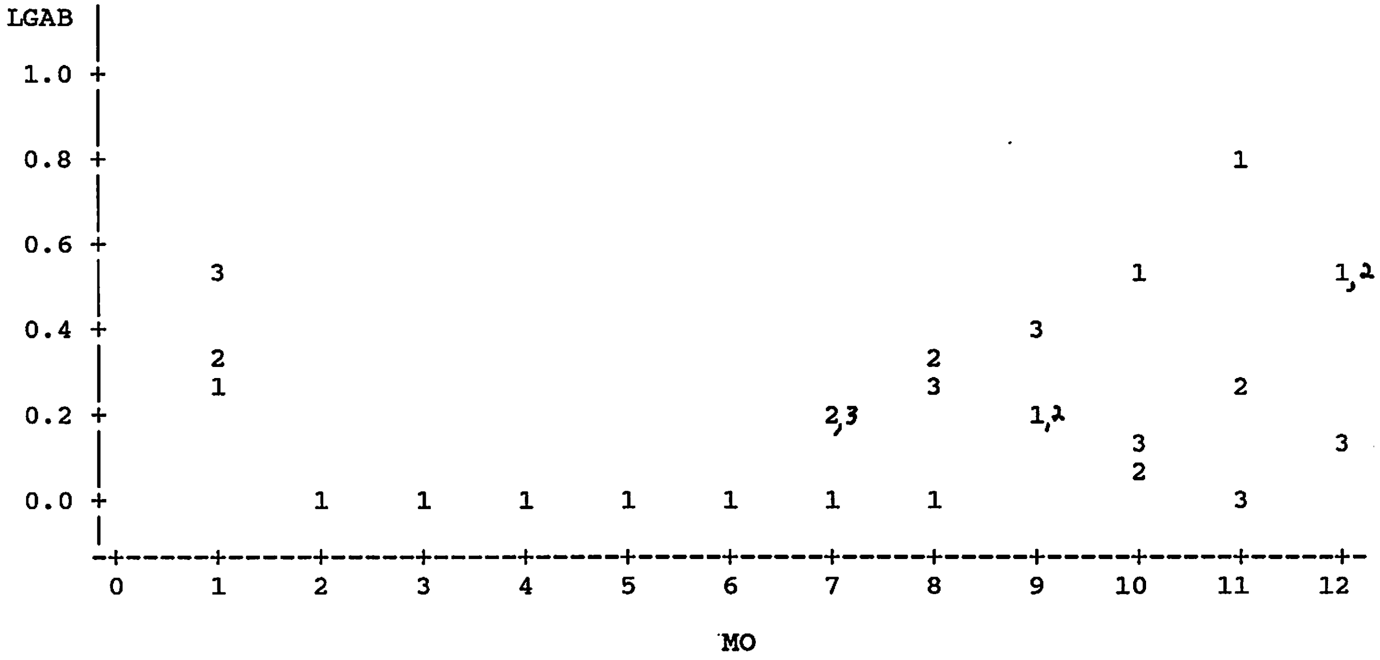

LGAB
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
MO
1
2
3
1,2
2,3

Table 55. Summary of individual degree of freedom contrast tests to evaluate differences in log Atlantic croaker abundance between the Upper and Lower Bay waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.62	7.24	**	0.27-0.55	0.86-2.53
Feb	0.00	0.00	ns	0.00-0.00	0.00-0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00-0.00
Apr	0.00	0.00	ns	0.00-0.00	0.00-0.00
May	0.00	0.00	ns	0.00-0.00	0.00-0.00
Jun	0.00	0.00	ns	0.02-0.02	0.04-0.04
Jul	0.22	2.64	ns	0.00-0.17	0.00-0.47
Aug	0.59	6.90	**	0.00-0.27	0.00-0.87
Sep	0.34	4.02	*	0.19-0.39	0.54-1.48
Oct	1.44	16.91	**	0.55-0.13	2.57-1.34
Nov	4.95	58.09	**	0.81-0.02	5.38-0.04
Dec	1.29	15.12	**	0.56-0.16	2.66-0.45

Table 56. Summary of individual degree of freedom contrast tests to evaluate differences in log Atlantic croaker abundance between the Middle Bay and the average in the Upper and Lower Bay waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.12	1.46	ns	0.30-0.41	1.00-1.56
Feb	0.00	0.00	ns	0.00-0.00	0.00-0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00-0.00
Apr	0.00	0.00	ns	0.00-0.00	0.00-0.00
May	0.00	0.00	ns	0.00-0.00	0.00-0.00
Jun	0.00	0.04	ns	0.00-0.02	0.00-0.04
Jul	0.13	1.55	ns	0.20-0.08	0.57-0.21
Aug	0.48	5.58	*	0.35-0.14	1.22-0.37
Sep	0.09	1.05	ns	0.20-0.29	0.58-0.95
Oct	0.69	8.08	**	0.09-0.34	0.22-1.19
Nov	0.26	3.05	ns	0.26-0.41	0.80-1.58
Dec	0.28	3.32	ns	0.53-0.36	2.35-1.31

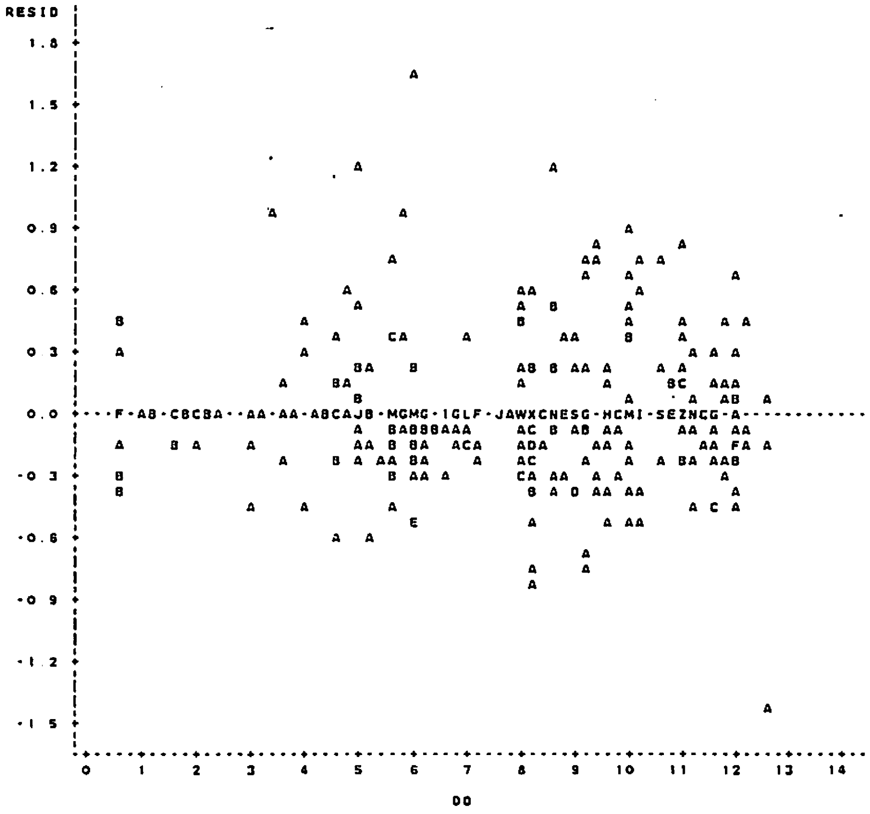
region waters than the average of their abundance in the Upper and Lower Bay, a pattern that again reflects significantly greater abundance in the Lower and Middle Bay as croaker migrate out of the bay. Croaker were significantly more abundant in the Upper Bay than in the Lower Bay waters in the mid to late fall months of October through December as the young-of-the-year recruited. Similarly, they were significantly less abundant in October and November in the Middle regions than the average of the Lower and Upper regions, a pattern that again reflects significantly greater abundance in the Upper Bay as croaker recruit. In January (of the preceding year) recruiting young-of-the-year croaker were significantly more abundant in the Lower Bay waters than in the Upper Bay. Presumably, this shift in where they recruit reflects lower temperatures in January.

Other Sources of Variation in Atlantic Croaker Catches:

Overall plots of residuals against bottom D.O. indicate no strong relationship (Figure 46). The two variables are independent over much of the D.O. range. There is no pattern of negative residuals at low D.O. (D.O. < 2 mg/l) to suggest lower abundance in, or avoidance of, low D.O. areas.

Overall plots of residuals against temperature indicate no regression or other relations not already postulated in the model (Figure 40). Variation in residuals generally appears low at low temperatures. There also appears to be constriction in the magnitude of the residuals: the residuals appear to be smaller

Figure 46. The overall relationship (all data) between residuals from log Atlantic croaker catches and bottom dissolved oxygen (mg/l). A = 1 observation, B = 2 observation, etc.


RESID
1.8
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
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DD

at temperatures of about 17-21° than at higher or lower temperatures.

Overall plots of residuals against salinity indicate no regression or other effects not already postulated in the model (Figure 41).

Overall plots of residuals against Areas (not shown) indicate no regression or other relations not already included in the model. Variation in residuals appears constant within Areas.

Overall plots of residuals against Months (not shown) indicate no regression or other relations not already included in the model.

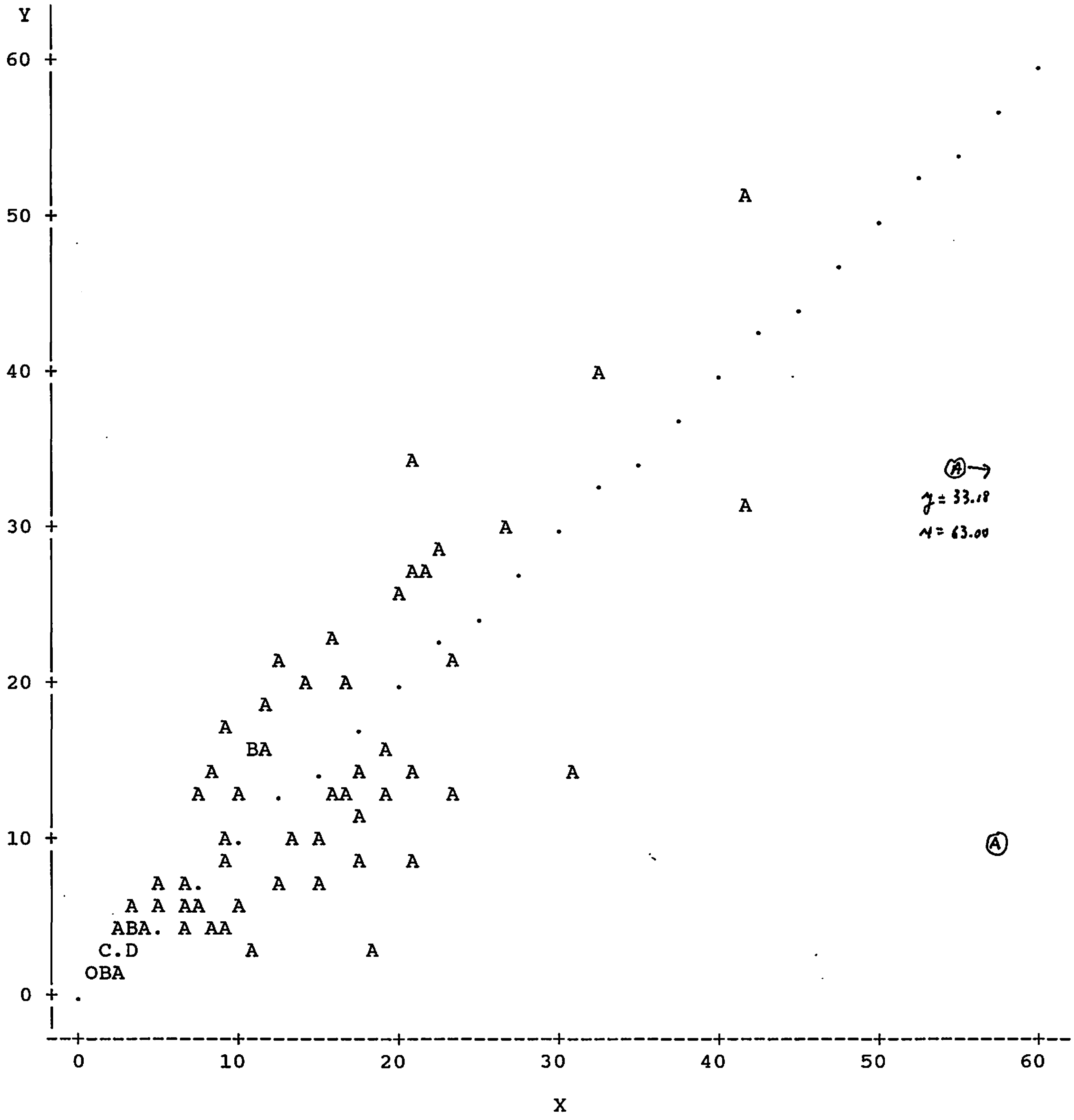
Blue Crab

Choosing an Appropriate Transformation:

The log transformation appears appropriate for the present counts of abundance data on blue crabs. Plots of the untransformed standard deviation on the untransformed arithmetic mean within Months x Areas cells indicate they are reasonably equal (Figure 47), because data points are scattered along the 45 degree diagonal. The calculated slope ($b = 0.75$) of the regression of the untransformed standard deviation on the untransformed arithmetic mean, however, is significantly below a hypothesized $\beta = 1$ ($t = -6.64$; 130 df). This reflects two influential data points (circled on Figure 47) with very small standard deviations and large means. Deleting these two data points, the calculated slope ($b = 0.95$) is much improved and not significantly different from a hypothesized $\beta = 1$ ($t = -1.31$; 128 df). In contrast, plots of the variance on the arithmetic mean (not shown) found all data points above or well above the diagonal. The calculated slope ($b = 22.59$) of the regression of the variance on the mean is significantly greater than a hypothesized $\beta = 1$ ($t = 12.06$; 130 df). These conditions indicate the square root transformation is not sufficient to normalize the counts of abundance, but the log transformation is reasonable.

The log transformation had the smallest standard error (0.38), the second-smallest coefficient of variation (CV =

Figure 47. Relationship between standard deviation (y) and untransformed arithmetic mean counts of abundance (x) for blue crab. The 45° diagonal has slope b = 1, so y = x along it. A = 1 observation, B = 2 observations, etc.



Ⓐ→
y = 33.18
x = 63.00

80.02), provided the best fit for the postulated model ($100r^2$ = 67.41), and, as noted later, provided homogeneity of variance and normality, and the greatest number of effective degrees of freedom (Table 57). Using these criteria, the square root transformation was superior to the log only in having a smaller CV; it was much less desirable in all other properties. Untransformed data had the least desirable properties of all.

General Data Descriptions:

Blue crabs were the fourth most abundant nekton taxon in the sampling frame. They were about as abundant as the northern searobin which made up 1.4% of the overall catch of fish (Chittenden 1989).

The overall geometric mean catch was 2.02 blue crabs, with 95% confidence limits about the mean being 1.80-2.26 (Table 58). The overall mean log catch was 0.48, with 95% confidence limits being 0.45-0.51. The standard error of the mean log catch was 0.38 and the coefficient of variation was 80.02 (Table 57). The maximum catch was 111 blue crabs and the minimum was 0.

Blue crabs are resident year-round in the Chesapeake Bay. However, they burrow into the bottom sediments to overwinter in cold weather, so few or none were captured January-April (Table 59). They were widely distributed throughout the sampling frame in most other months of the year.

Table 57. Summary of the comparative properties of listed transformations on blue crab abundance counts.

	Transformation		
Property	log	none	Square Root
Mean	0.48	7.56	2.05
Std. error	0.38	11.89	1.40
$100r^2$	67.41	53.87	61.82
CV	80.02	157.34	68.03
Independence of Residuals	yes	yes	yes
Homogeneity of Variance Using Cochran's C.	yes	no	no
Normality	reasonable	did not examine	did not examine
Homogeneity of Slopes		did not examine	did not examine

Table 58. Summary statistics on overall log blue crab abundance, with a geometric mean (GM) back-transformation. No transformation was applied to the sample size (n) and the minimum-maximum counts.

	LOG	GM
n	528	--
Min-Max	0-111	--
Mean	0.48	2.02
95% Confidence Limits	0.45-0.51	1.80-2.26

Table 59. Summary of blue crab presence or absence in the Month-Area Cells. X = Present; - = Absent.

	UPPER BAY				MIDDLE BAY				LOWER BAY				TOTAL PRESENT
Month	ESL (01)	WSL (02)	CP (03)	DP (04)	ESL (05)	WSL (06)	CP (07)	DP (08)	ESL (09)	WSL (10)	CP (11)	DP (12)	
Jan	-	-	X	-	-	-	-	-	-	-	-	X	2
Feb	-	-	-	-	-	-	-	-	-	-	-	-	0
Mar	-	-	-	-	-	-	-	-	-	-	-	-	0
Apr	-	-	X	X	X	X	-	X	-	X	X	X	8
May													
Jun	-	X	-	X	X	X	X	X	-	X	X	X	9
Jul	X	X	X	X	X	X	X	X	X	X	X	X	12
Aug	X	X	X	X	X	X	X	X	X	X	X	X	12
Sep	X	X	X	X	X	X	X	X	X	X	X	X	12
Oct	X	X	X	X	X	X	X	X	X	X	X	X	12
Nov	X	X	X	X	X	X	X	X	X	X	X	X	12
Dec	X	-	X	X	X	X	X	X	X	X	X	X	11
Total Present	6	6	8	8	8	8	7	8	6	8	8	9	90

Overview of the ANOVA-ANCOVA:

The postulated models explain much of the total variation in blue crab catches. A log transformation explained about 69% of the total variation (Table 60). Somewhat less is explained (Table 57) using a square root transformation (61.82%) and much less with no transformation (53.87%).

The overall log ANCOVA (or ANOVA) model was significant at $\alpha = 0.01$ (Table 60). The Months and Areas main effects were both highly significant. The Months main effect was much more important than the Areas effect -- almost 22 times as important -- in explaining variation in blue crab catches, $100r^2$ values being 47.69% for Months and 2.69% for Areas. Interaction was significant but explained much less variation (17.04%) than the Months main effect. The significant Interaction implies that spatial and temporal factors have a complex effect on the distribution of blue crabs, eg. -- the simple effects of Areas, for example, are not constant; rather they vary from month to month.

Both the salinity and temperature covariates were significant. However, neither covariate explained much variation in blue crab catches (0.67 and 0.73%, respectively) beyond that associated with the Areas and Months effects (Table 60). Therefore, the covariates were deleted from the model, and further analyses were made using only the ANOVA model finally accepted with its main effects and interactions.

The overall log ANOVA model explained 67.41% of the

Table 60. Summary of the ANCOVA on blue crab, log transformation, with $100r^2$ values.

Source of Variation	df	SS	MS	F	$100r^2$
Corr. Tot.	527	179.63	--	--	100.00
Model	133	123.61	0.92	6.54 **	68.81
Months (M)	10	85.66	85.66	60.25 **	47.69
Areas (A)	11	4.83	0.44	3.09 **	2.69
M x A	110	30.61	0.29	1.96 **	17.04
Sal	1	1.20	1.05	8.46 *	0.67
Temp	1	1.31	1.26	9.23 *	0.83
Error	394	56.02	0.14	--	31.19

variation in blue crab catches (Table 57). Its most important component by far was the Months main effect (Table 60). Interaction was next in importance. The Areas main effect was comparatively unimportant. Random variation, or variation not recognized and not included in the model, accounted for 33% of the total variation.

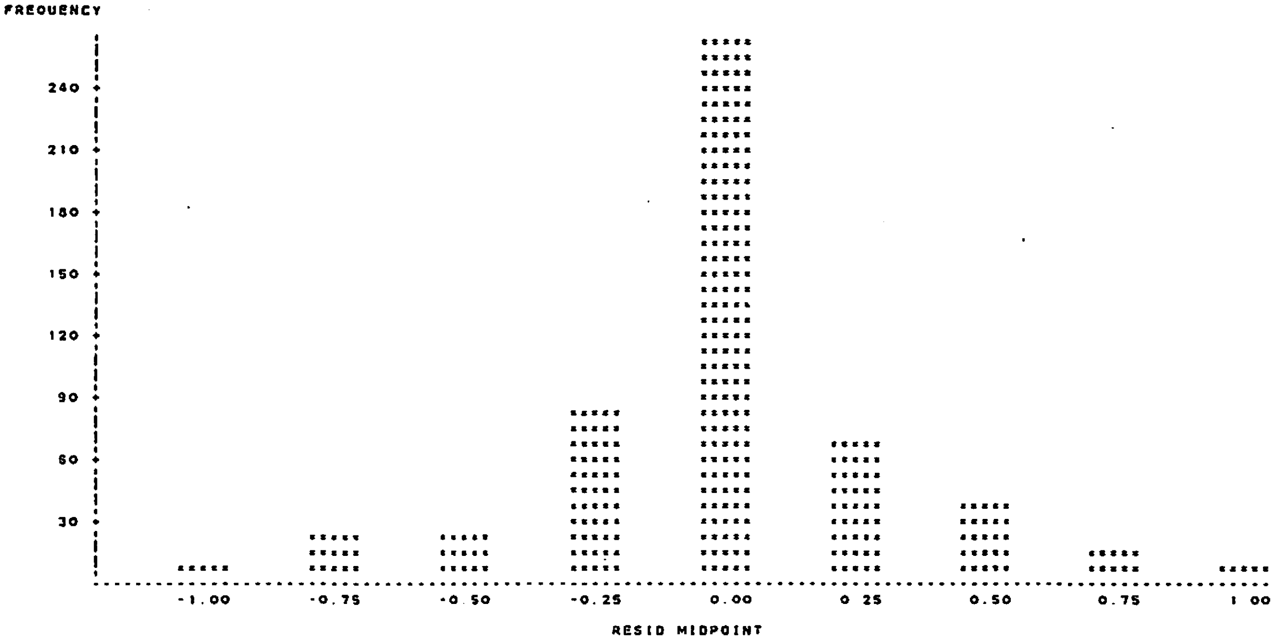
Validity of the Assumptions of the ANCOVA-ANOVA models:

The assumptions of the ANOVA-ANCOVA models appear to be well-fulfilled, if not exactly fulfilled, when a log transformation is used on the blue crab catch data.

The assumption of normality of the residuals is a reasonable approximation, though not true. The frequency distribution of the residuals from the log ANOVA model (Figure 48) appears to be <u>reasonably</u> normal, with zero mean and reasonable symmetry about the mean. The Kolomogorov D statistic, however, is significant ($D = 0.178$; $n = 528$) at $\alpha = .01$, which indicates the distribution of the residuals is not truly normal. The significant D statistic, in part, reflects an exceptionally large sample size which can detect even very small departures from normality. The small departure from normality should not contradict the basic conclusion indicated by the residual plot: the assumption is reasonable albeit not exact.

The assumption of homogeneity of within-cell variance is reasonable using a log transformation on the catch data. Cochran's C statistic ($C = 0.0467$; 3 df; $n = 132$) is not

Figure 48. Frequency distribution of the residuals to evaluate the assumption of normality in blue crab.


FREQUENCY
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210
180
150
120
90
60
30
-1.00
-0.75
-0.50
-0.25
0.00
0.25
0.50
0.75
1.00
RESID MIDPOINT

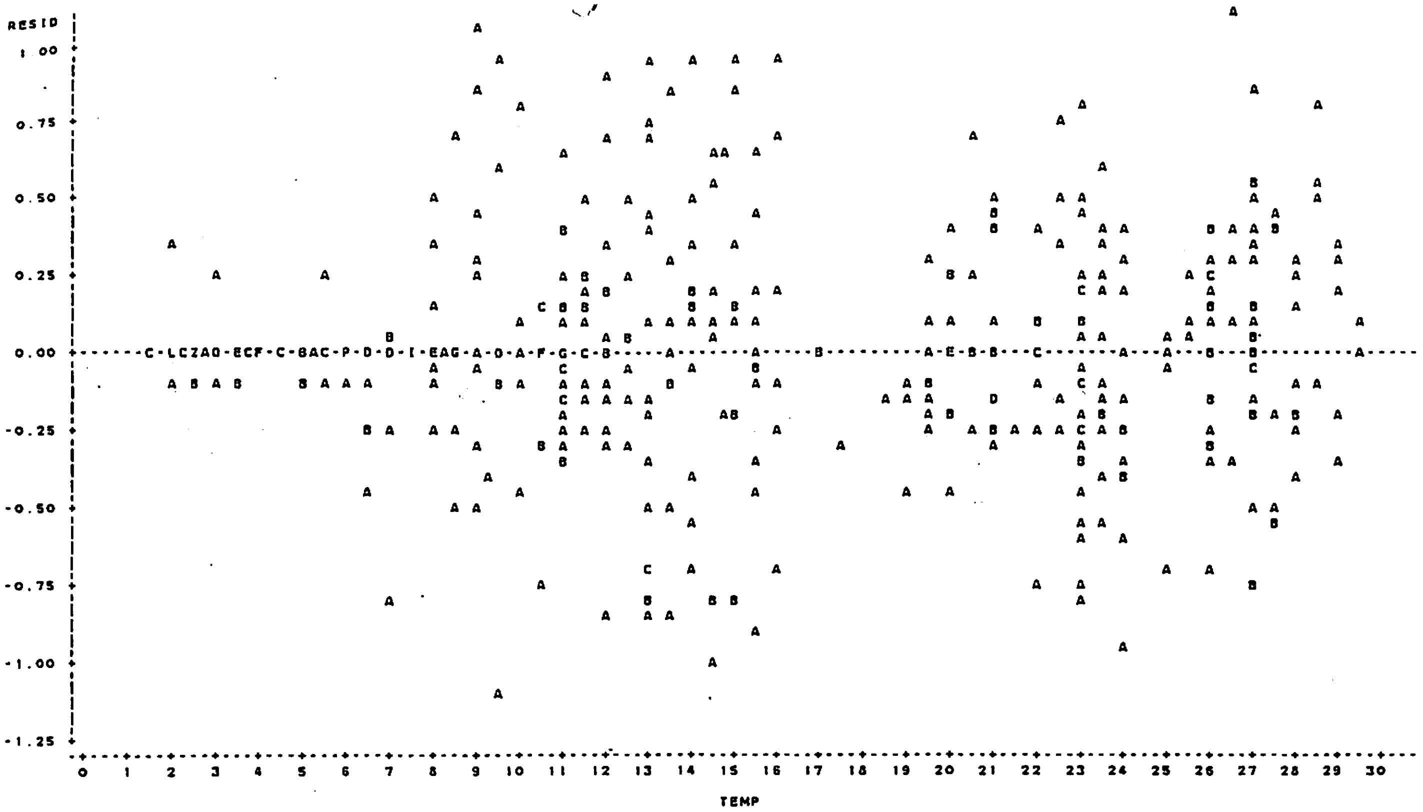
significant at $\alpha = .05$. In contrast, Cochran's C statistic (C = 0.0809) is significant at $\alpha = .01$ using a square root transformation; similarly, Cochran's C (C = 0.144) also is significant at $\alpha = .01$ with no transformation.

The assumption of homogeneous, linear regression on the covariates within cells also appears reasonable, or there was no regression. The residuals from the ANOVA model were plotted (not shown) on temperatures within cells and on salinity. A relationship between the residuals and temperature or between the residuals and salinity was apparent in only a few cells (of 144). These conclusions of little or no within-cell relation between residuals and temperature or salinity are illustrated by overall plots (all data) of the relationships between temperature and residuals and salinity and residuals (Figures 49, 50).

Interpretation of Interaction and Main Effects to Evaluate Spatial/Temporal Distributions:

Blue crab catches show great variation between months that forms a clear annual pattern of change from a winter-spring low to a summer-fall peak. Few or no blue crabs were captured in the winter and early spring months of January through April (Figure 51; Table 61). Monthly catches gradually rose after June to reach a peak in the summer and fall months of July through November. Catches then sharply declined after December towards their winter lows. Tukey's multiple comparisons tests (Table 62), which elaborate on the significant F test for Months, show significantly more blue crabs were caught in the summer and fall

Figure 49. The overall relationship (all data) between residuals from log blue crab catches and bottom temperature (C°). A = 1 observation, B = 2 observations, etc.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0.75
0.50
0.25
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-0.25
-0.50
-0.75
-1.00
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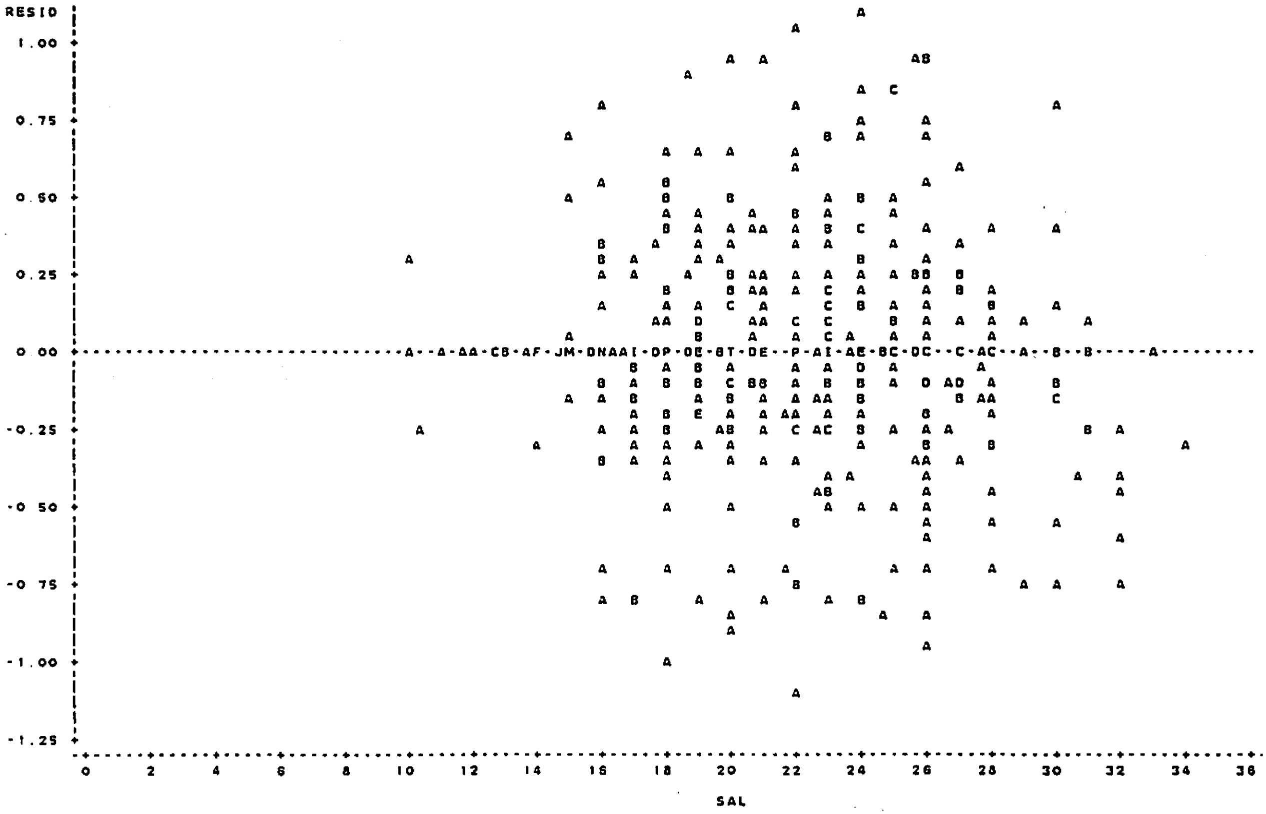
30
TEMP

Figure 50. The overall relationship (all data) between residuals from log blue crab catches and bottom salinity (parts per thousand). A = 1 observation, B = 2 observations, etc.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-0.25
-0.50
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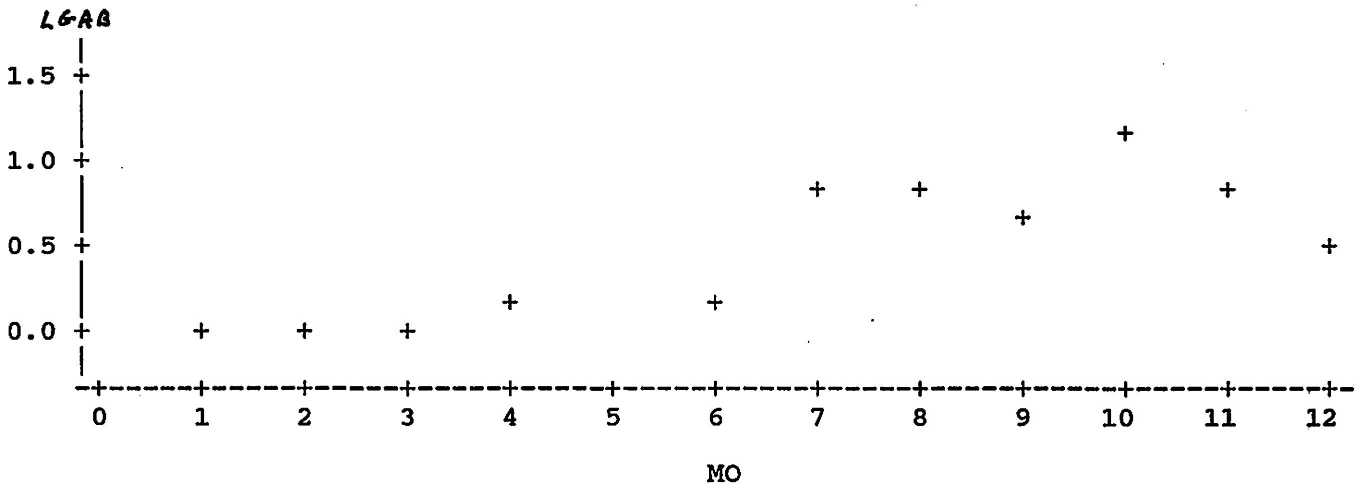
36
SAL

Figure 51. The monthly (Mo) pattern of mean log blue crab catches (LGAB) in the mainstem Chesapeake Bay, Virginia.


LGAB
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MO

Table 61. Summary of 95% confidence limits (CL) about monthly mean log abundance of blue crab, with a geometric mean (GM) back-transformation.

Month	log	CL	GM	CL
Jan	0.02	-0.10-0.13	0.04	-0.20-0.34
Feb	0.00	-0.11-0.11	0.00	-0.23-0.29
Mar	0.00	-0.11-0.11	0.00	-0.23-0.29
Apr	0.18	0.06-0.29	0.50	0.16-0.94
May	--	--	--	--
Jun	0.21	0.10-0.32	0.62	0.25-1.09
Jul	0.88	0.77-0.99	6.60	4.88-8.83
Aug	0.83	0.72-0.94	5.75	4.22-8.72
Sep	0.73	0.61-0.84	4.31	3.11-5.87
Oct	1.12	1.01-1.23	12.27	9.26-16.16
Nov	0.91	0.80-1.02	7.08	5.25-9.45
Dec	0.42	0.31-0.53	1.63	1.03-2.40

Table 62. Summary of Tukey's hsd multiple comparisons tests on log blue crab abundance. Means with different letters are significantly different.

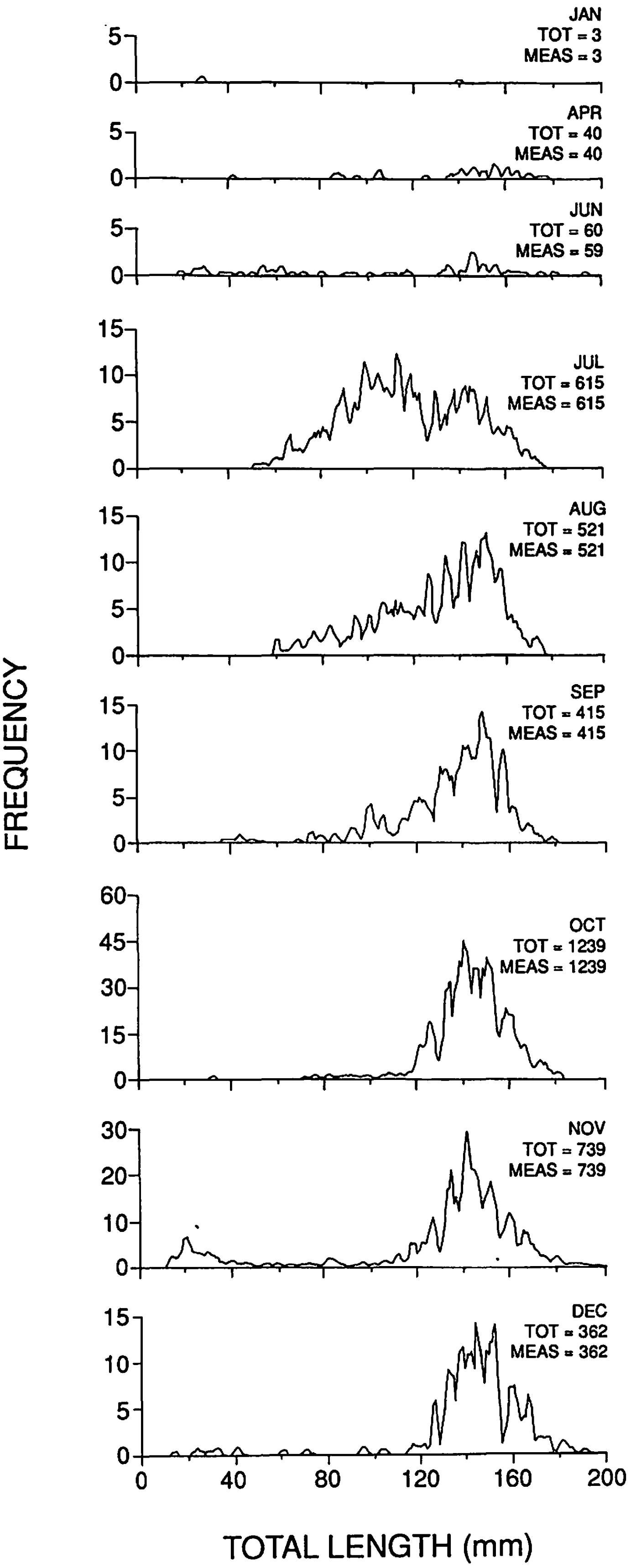
		MEAN		
Month	n	log	GM	Significance
Oct	48	1.12	12.27	a
Nov	48	0.91	7.08	a b
Jul	48	0.88	6.60	a b
Aug	48	0.83	5.75	b
Sep	48	0.73	4.31	b
Dec	48	0.42	1.63	c
Jun	48	0.21	0.62	c d
Apr	48	0.18	0.50	c d
Jan	48	0.02	0.04	d
Mar	48	0.00	0.00	d
Feb	48	0.00	0.00	d

months of July through November than in the winter, spring and early summer months of January through June. Intermediate size catches in April, June, and December generally were significantly different from all other months.

The annual pattern of catches reflects movements of blue crabs into the mainstem Chesapeake Bay, their overwinter burrowing in the bottom muds, their survivorship, and recruitment to the sampling frame as indicated in length frequencies, particularly in November and July-August (Figure 52). These age groups consist of recently-recruited young-of-the-year, which were some 15-40 mm in November, and adult crabs, which were some 120-180 mm in most months including November and presumably about age I or II. Adult crabs predominate in the sampling frame from August through December after which they disappear, presumably having burrowed into the bottom sediments to overwinter. Young-of-the-year crabs begin to recruit to the sampling frame in October and, especially, November. Their recruitment apparently continues, after a winter hiatus, through June after which it largely ceases or takes on a different form. Large numbers of immature crabs about 50-120 mm appear in the sampling frame in July and August. They apparently gradually blend with the adults as they mature in September.

Blue crabs are widely distributed throughout the sampling frame in the summer and fall months of July through December. They occur in the Eastern Shore Littoral, Western Shore Littoral, Central Plains, and Deeps waters and in the Upper, Middle and

Figure 52. Monthly length frequencies of blue crabs. Frequencies are moving averages of three. Total lengths are spine tip to spine tip.


JAN
TOT = 3
MEAS = 3
APR
TOT = 40
MEAS = 40
JUN
TOT = 60
MEAS = 59
JUL
TOT = 615
MEAS = 615
AUG
TOT = 521
MEAS = 521
SEP
TOT = 415
MEAS = 415
OCT
TOT = 1239
MEAS = 1239
NOV
TOT = 739
MEAS = 739
DEC
TOT = 362
MEAS = 362
FREQUENCY
0
5
10
15
30
45
60
20
0
40
80
120
160
200
TOTAL LENGTH (mm)

Lower bay portions of the sampling frame (Table 59; Figures 53, 54).

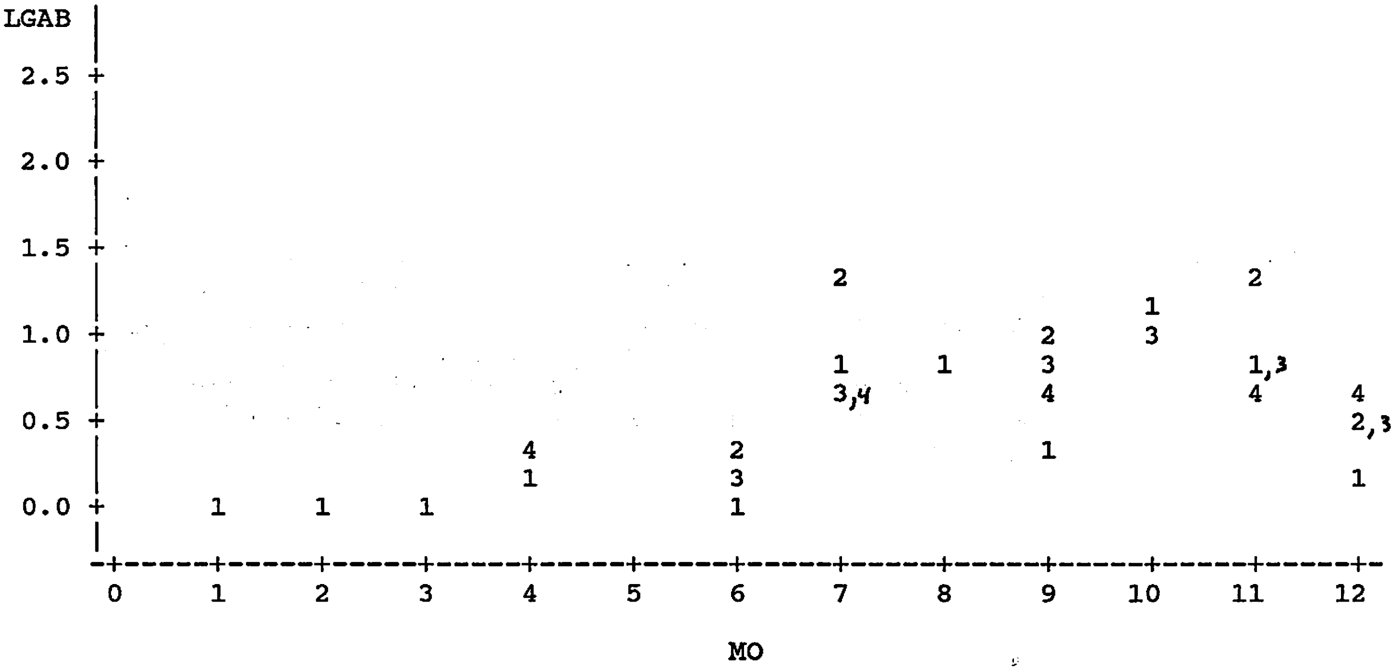
There were intra-annual changes in patterns of blue crab abundance, not a constancy, across the Chesapeake Bay and along an upbay-downbay axis. These changes in patterns explain the significant F test for interaction.

Across-bay patterns of blue crab abundance show large changes during the year. There was little or no difference in abundance of blue crabs between the combined littoral waters of the Eastern and Western Shores and the combined deeper waters of the Central Plain and Deeps, and no significant difference, in all months except July when blue crabs were more abundant in the Littoral waters (Figure 53; Table 63). Periods of no significant difference included the January through June period when they were absent, burrowed in the mud, or not abundant, in the Chesapeake Bay. Similarly, it also included most months when blue crabs were abundant, August through November.

The comparative pattern of blue crab abundance remained the same year-round in the deeper waters. There was no significant difference in blue crab abundance between the Central Plain and Deeps waters within any month and no apparent pattern to the small differences observed (Figure 53; Table 64).

The comparative pattern of blue crab abundance varied greatly during the year in the Littoral waters. There was little or no difference in abundance, and no significant differences, between the Eastern and Western Shore Littoral zones during the

Figure 53. The monthly (Mo) pattern of mean log blue crab catches (LGAB) in the mainstem Chesapeake Bay, Virginia by Across-Bay Region. Regions are Eastern Shore Littoral (1), Western Shore Littoral (2), Central Plain (3), and Deeps (4). When the number for a region is not indicated, the data value is the same as for the indicated region number.


LGAB
2.5
2.0
1.5
1.0
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0.0
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7
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9
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11
12
MO
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1,3
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2,3
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4
1
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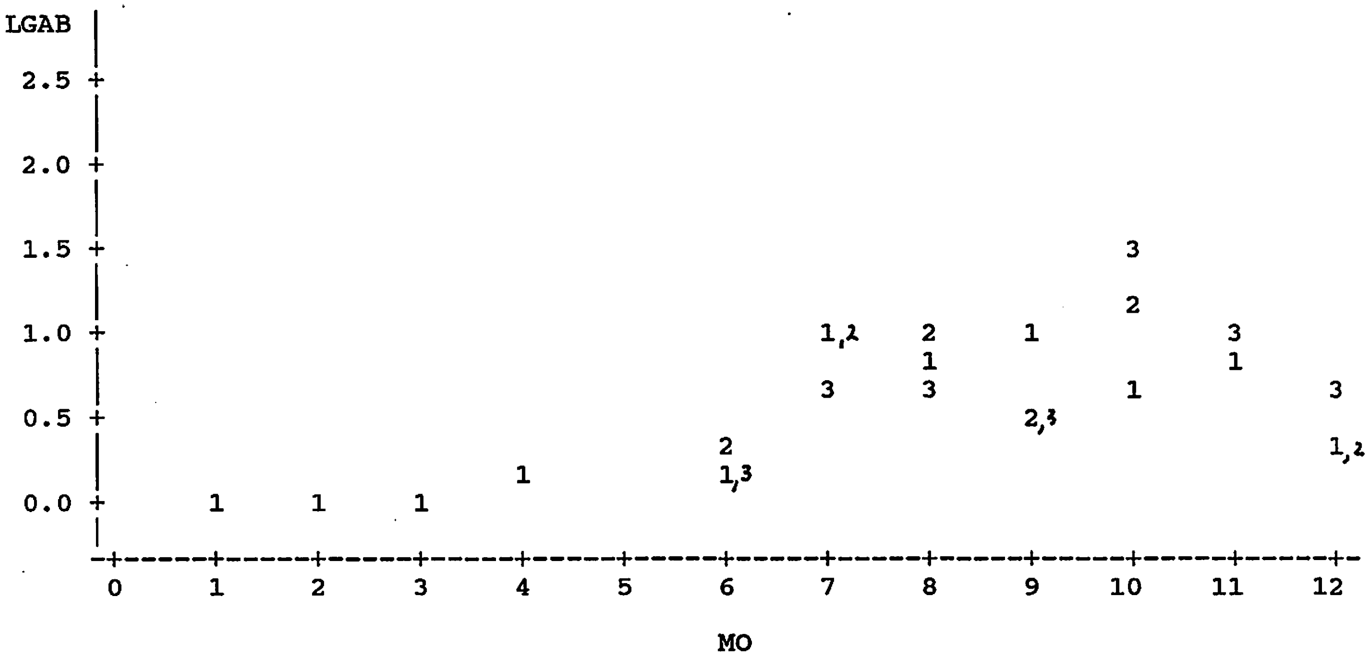
1
1
1

Figure 54. The monthly pattern (Mo) of mean log blue crab catches (LGAB) in the mainstem Chesapeake Bay, Virginia by Up-Down Bay Region. Regions are Upper Bay (1), Middle Bay (2), and Lower Bay (3). When the number for a region is not indicated, the data value is the same as for the indicated region number.


LGAB
2.5
2.0
1.5
1.0
0.5
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0
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12
MO
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2,3
1,3

Table 63. Summary of individual degree of freedom contrast tests to evaluate differences in log blue crab abundance between Littoral waters (ESL and WSL) and the deeper Central Plain - Deeps waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.01	0.09	ns	0.00-0.03	0.00- 0.08
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Apr	0.26	1.74	ns	0.10-0.25	0.27- 0.77
Jun	0.03	0.19	ns	0.23-0.18	0.71- 0.53
Jul	1.77	11.98	**	1.07-0.69	10.83- 3.88
Aug	0.09	0.60	ns	0.87-0.79	6.44- 5.11
Sep	0.00	0.03	ns	0.73-0.72	4.43- 4.20
Oct	0.02	0.16	ns	1.15-1.10	12.97-12.60
Nov	0.54	3.66	ns	1.01-0.80	9.31- 5.33
Dec	0.51	3.43	ns	0.32-0.52	1.07- 2.33

Table 64. Summary of individual degree of freedom contrast tests to evaluate differences in log blue crab abundance between Central Plain and Deeps waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

Contrast	SS	F	Sig	MEANS log	MEANS GM
Jan	0.03	0.17	ns	0.00-0.06	0.00- 0.16
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Apr	0.02	0.14	ns	0.22-0.28	0.66- 0.90
Jun	0.17	1.15	ns	0.10-0.27	0.26- 0.86
Jul	0.05	0.31	ns	0.73-0.65	4.40- 3.42
Aug	0.00	0.01	ns	0.78-0.79	5.00- 5.21
Sep	0.31	2.06	ns	0.83-0.60	5.74- 3.01
Oct	0.02	0.17	ns	1.07-1.13	10.71-12.56
Nov	0.07	0.44	ns	0.85-0.75	6.13- 4.61
Dec	0.15	0.98	ns	0.44-0.60	1.78- 2.98

January through April period when catches were low (Figure 53; Table 65). However, during the period June through December, when catches were high or intermediate, blue crabs were significantly more abundant in most months in the Western Shore Littoral than in the Eastern Shore Littoral. There was no significant difference in August and October.

Upbay-downbay patterns of blue crab abundance showed large changes during the year. There was little or no difference in abundance, and no significant differences, between waters of the Upper, Middle, and Lower Bay regions in the winter, spring, and early summer months of January through July when blue crabs are absent, burrowed in the mud, or not abundant in the Chesapeake Bay (Figure 54; Tables 66, 67). However, patterns of abundance change greatly in months of higher catches. Blue crabs were significantly more abundant in the Upper Bay waters than in the Lower Bay in most months from July through October, except August. In December, however, blue crab catches were significantly higher in the Lower Bay. Blue crab catches in the Middle region waters did not differ significantly from the average of their abundance in the Upper and Lower Bay in all months except September.

Other Sources of Variation in Blue Crab Catches:

Overall plots of residuals against bottom D.O. indicate no strong relationship (Figure 55). The two variables are independent over much of the D.O. range. At low D.O. (D.O. < 2

Table 65. Summary of individual degree of freedom contrast tests to evaluate differences in log blue crab abundance between the Eastern Shore Littoral and Western Shore Littoral waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

Contrast	SS	F	Sig	MEANS log	MEANS GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Apr	0.00	0.00	ns	0.10-0.10	0.27- 0.26
Jun	0.59	4.00	*	0.08-0.39	0.19- 1.45
Jul	1.29	8.70	**	0.84-1.30	5.94-19.16
Aug	0.00	0.03	ns	0.86-0.88	6.23- 6.67
Sep	2.84	19.23	**	0.39-1.08	1.46-11.00
Oct	0.08	0.52	ns	1.20-1.09	14.93-11.26
Nov	1.46	9.89	**	0.77-1.26	4.84-17.20
Dec	1.23	8.34	**	0.09-0.54	0.23- 2.49

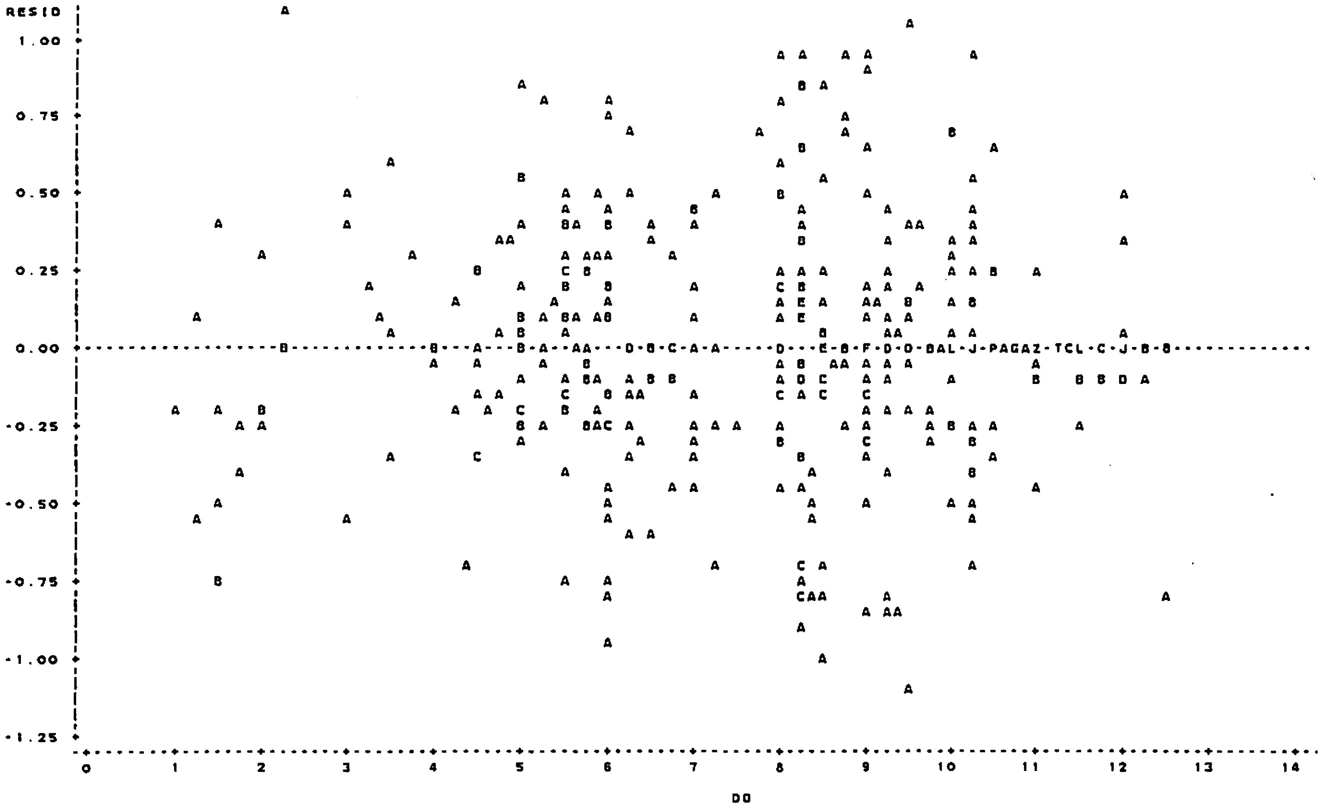
Table 66. Summary of individual degree of freedom contrast tests to evaluate differences in log blue crab abundance between the Upper and Lower Bay waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.01	ns	0.03-0.02	0.07- 0.04
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Apr	0.00	0.00	ns	0.16-0.15	0.46- 0.41
Jun	0.00	0.03	ns	0.19-0.17	0.56- 0.49
Jul	1.53	10.34	**	1.06-0.62	10.40- 3.17
Aug	0.19	1.27	ns	0.85-0.70	6.11- 5.00
Sep	1.68	11.34	**	1.04-0.58	9.89- 2.80
Oct	4.91	33.20	**	0.70-0.49	4.05-29.64
Nov	0.44	2.98	ns	0.81-1.05	5.51-10.17
Dec	1.09	7.40	**	0.30-0.67	1.00- 3.70

Table 67. Summary of individual degree of freedom contrast tests to evaluate differences in log blue crab abundance between the Middle Bay and the average in the Upper and Lower Bay waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.01	0.04	ns	0.00-0.02	0.00- 0.06
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Apr	0.03	0.23	ns	0.21-0.16	0.63- 0.43
Jun	0.06	0.43	ns	0.26-0.18	0.82- 0.52
Jul	0.17	1.17	ns	0.97-0.84	8.24- 5.89
Aug	0.28	1.88	ns	0.94-0.78	7.64- 4.96
Sep	0.66	4.46	*	0.56-0.81	2.63- 5.43
Oct	0.08	0.52	ns	1.18-1.09	14.11-11.44
Nov	0.05	0.35	ns	0.86-0.93	6.25- 7.52
Dec	0.44	2.96	ns	0.28-0.49	0.92- 2.07

Figure 55. The overall relationship (all data) between residuals from log blue crab catches and bottom dissolved oxygen (mg/l). A = 1 observation, B = 2 observation, etc.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mg/l), most residuals seem to be negative or to have small positive values. This would suggest lower abundance in, or avoidance of, low D.O. areas. However, the pattern is not completely clear.

Overall plots of residuals against temperature indicate no regression or other relations not already postulated in the model (Figure 49). Variation in residuals generally appears low at temperatures when blue crabs burrow in the mud. There also appears to be contriction in the magnitude of the residuals: the residuals appear to be smaller at temperatures of about 17-20° than at higher or lower temperatures.

Overall plots of residuals against salinity indicate no regression or other effects not already postulated in the model (Figure 50). The pattern of the residuals seems to form almost an oval, the smallest residuals occurring at the lowest and highest salinity values.

Overall plots of residuals against Areas (not shown) indicate no regression or other relations not already included in the model. Variation in residuals appears constant within Areas.

Overall plots of residuals against Months (not shown) indicate no regression or other relations not already included in the model. Variation in residuals generally appears low or comparatively low in the winter or early spring months when blue crab catches are low. It then gradually increases to higher values when catches are high.

General Species Discussion

Appropriate Transformations and Model Assumptions:

For each species, the log transformation was superior to the square root or no transformation for the present counts of abundance data. The slope of the correlation between the arithmetic mean count of abundance within Months x Areas cells and its standard deviation was generally not significantly different from b = 1, except in Atlantic croaker, though in some species this required this deletion of one or two Months x Areas cells. Equality of the within-cell means and standard deviations indicates the log transformation is appropriate. The slope of the correlation between the means and variances always significantly exceeded b = 1, an inidication that the square root transformation is not sufficient. The log transformation generally provided the smallest standard error, the best model fit as judged by $100r^2$ values, the greatest number of effective degrees of freedom (as noted later), reasonable normality, and reasonable or the most nearly reasonable homogeneity of variance. The square root transformation generally provided the smallest coefficient of variation, but it was inferior to the log transformation in all the other respects. No transformation had the least desirable properties of the three transformations considered. Given these considerations, the log transformation was used for detailed analyses in each species.

For each species, the assumptions of ANOVA/ANCOVA were reasonably well met, or best met, using a log transformation. The assumptions were well met for blue crabs and weakfish and reasonably well met for bay anchovy, spot, and northern searobin. The assumptions were not well-met for Atlantic croaker, though they were not violently unfulfilled. For each species, the assumption of normality was reasonable in the sense that the shape of the frequency distribution in overall residual plots was quite reasonably normal. However, in each case, the Kolomogorov D statistic found it significantly non-normal. In large part, this significance reflects the very large sample sizes used, 576 observations in all species except blue crabs for which there were 528 observations. Such large sample sizes can detect even small departures from normality, and that apparently occurred.

For some species -- blue crabs, bay anchovy, and weakfish -- the assumption of homogeneity of variance was well met since. Cochran's C statistic for testing homogeneity of variance within the Months x Areas cells was not significant. For other species -- spot and northern searobin -- significance in these tests reflects only one or two Months x Areas cells; deleting them, the tests are not significant. For Atlantic croaker, the test for homogeneity of variance in a log transformation was significant; however, the assumption did not seem violently abused, because the slope (b = 1.14) was not very much different from b = 1 for the correlation between the mean and standard deviation.

Appropriateness of the ANOVA/ANCOVA Model:

For each species, the fitted models explained much of the total variation in the counts of abundance data. For three species, the ANOVA model finally accepted explained nearly 70% or more of the total variation -- northern searobin (75%), spot (74%), and blue crab (67%). The accepted ANOVA model explained some 60% of the total variation in two other species -- weakfish (63%) and Atlantic croaker (59%). The model had the least explanatory power in the bay anchovy, for which it explained only 54% of the total variation. Except for the blue crab, the five species for which the model best fit are all species which migrate from the Chesapeake to overwinter. Their counts of abundance go to zero for several months of the year and show a regular intra-annual pattern of change from low to high abundance. The blue crab is a year-round resident of the Chesapeake Bay, but it uses a different mechanism to achieve the same pattern of abundance. Blue crabs burrow in the bottom sediments while overwintering, thereby achieving negligible abundance in trawl catches, because the trawl does not dig deep enough in the sediments to capture crabs. The species with the worst model fit -- the bay anchovy -- is a year-round resident of the mainstem Chesapeake Bay. As noted below, as a result of this residency, the Months factor so important in the other species explained comparatively little variation in bay anchovy catches.

The Months main effect was usually the single most important factor in the model. It was generally far more important than the Areas main effect in explaining variation in catches. The

Months main effect explained almost half the total variation in catches for blue crabs (47.69%), spot (47.60%), and northern searobin (47.10%). In these species, the Months main effect was some ten times or more as important as the Areas main effect, which accounted for only 2.69% of the total variation in blue crabs, 4.81% in spot, and 5.27% in northern searobin. The Months main effect, though still predominant, was less important in weakfish and Atlantic croaker, species for which it still explained two or three times as much variation as the Areas main effect. The Months main effect explained only 27.97% of the total variation in weakfish and only 16.27% in Atlantic croaker, while the Areas main effect explained 10.83% and 6.3% in these respective species. For the year-round resident bay anchovy, the Months main effect was the least important factor in the model (ignoring the covariates). The Months main effect explained only 12.73% of the total variation in bay anchovy compared to the 16.22% explained by the Areas main effect.

The Interaction term was generally second in explanatory power in the accepted model. It explained some 21-24% of the total variation in bay anchovy, weakfish, northern searobin, and spot. It explained only 17% in blue crabs, but 35% in Atlantic croaker. The always significant Interaction implies that the Months and Areas main effects are not constant; rather, the Areas effect, for example, varies from month to month. The significant Interaction largely reflects life history attributes like migrations, movements, recruitment, and "decruitment", whose effects vary from month to month in the course of the year. Much of the Interaction effect is closely linked with the Months effect. The implication of this is that the time element is very important in constructing a sampling frame.

The Areas main effect was generally the least important factor in the model. For each species, it explained but little of the total variation in catch. The Areas main effect explained only some 2-6% of the total variation in blue crabs, spot, northern searobin, and Atlantic croaker. It explained only some 11% of the total in weakfish. It was most important in the bay anchovy, but even in that species it explained only 16.22% of the total variation. The apparent implication of the general unimportance of the Areas main effect is that, for practical purposes, the sampling frame is generally quite homogeneous in its physical, chemical, and biological characteristics at any point in time. This basic fact seems true although, in part, the areal stratification scheme used may not have fully captured the available non-homogeneity in the sampling frame.

For each species, the temperature and salinity covariates in the model were often non-significant, and they both always had negligible explanatory power, eg -- they each explained less than 1% of the total variation in each species. The temperature covariate was significant in spot, northern searobin, Atlantic croaker, and blue crabs. The salinity covariate was significant in spot, northern searobin, Atlantic croaker, and blue crabs. Lack of significance in the temperature and salinity covariates probably reflects the fact that their effects overlap with the Months and Areas factors, and that the latter factors successfully capture the effects of temperature and salinity in the sampling frame.

The accepted model was generally quite successful in explaining catch variation. Only some 25-33% of the total variation was not explained in spot, northern searobin, and blue crabs. Some 37% was not explained in weakfish, and 41% in Atlantic croaker. Nearly half the variation (46%) was not explained in the bay anchovy.

Several factors were evaluated -- with little or no success -- by using residual plots to expand the explanatory power of the model. For each species, residual plots indicated quadratic or higher effects had no explanatory power for the Months and Areas factors, and for the temperature and salinity covariates. No explanatory power was associated with bottom dissolved oxygen for D.O. values above some 2 mg/l. Little explanatory power was associated with D.O. values below 2 mg/l, although avoidance may have been indicated in some species. Generally, few collections were made at D.O. levels below 2 mg/l, and indications of negative biological responses were not clear.

Spatial/Temporal Distributions:

No previous publication has presented detailed statistical analyses of nekton distributions in the mainstem Chesapeake Bay in time and space.

There were large differences in time and space in species abundance and distribution patterns. The predominant factor in this was generally time, the Months factor as noted above. The spatial factor, Areas, generally had comparatively little effect on species abundance and distribution patterns. As reflected in Interaction, the time and space patterns were not constant; rather the effect in space varied with time, from Month to Month for example.

Most species exhibited a general low in the abundance of trawl-vulnerable stages during the winter and the early spring or late fall months. This was the case in spot, weakfish, blue crabs, northern searobin, and Atlantic croaker. Most of these species are absent from Chesapeake Bay during winter, because they generally overwinter in the ocean. The exceptions to this are the blue crab, which burrows in the sediments and is not vulnerable to winter trawling, and the Atlantic croaker, which may recruit, in part, during winter months. Peak abundance in the former species generally occurs in late spring, summer, and/or fall. Because the present trawling generally captured age I and younger individuals, the annual abundance patterns generally reflect patterns of reproduction and recruitment to the sampling frame, intra-annual survivorship of the young, and migrations of individuals approaching age I from the sampling frame or decruitment of larger specimens from it. The timing of these attributes generally drives month to month variation in spatial distributions and abundances.

The bay anchovy, though a year-round resident of the Chesapeake Bay, exhibited a more complex annual pattern than the other species. It showed two peaks and troughs in abundance which apparently reflect the production, recruitment, survivorship, and movement of two intra-annual cohorts. Bay anchovy exhibited an initial trough in abundance in February, then gradually increased in abundance through the spring to an initial peak in abundance during the early summer month of June. Abundance subsequently declined after June to form a second trough from August through October. Abundance then rose abruptly to a second annual peak in the late fall-early winter months of December and January. As with the other species, this annual pattern in abundance reflects intra-annual patterns of reproduction, recruitment, survivorship, and movements.

There seems to be no unimportant month in the sampling frame in the sense that one species or another, in one life history stage or another, is abundant each month of the year. Even in the winter months when migratory, or burrowing, species like blue crabs, spot, weakfish, northern searobin, and Atlantic croaker were generally absent, some species or life stages are or may be abundant. Bay anchovy, for example, formed a peak of abundance in December and January, and large numbers of Atlantic croaker young recruited in January. Seemingly, February and March would be the least important month, from the perspective of abundance, for the species specifically addressed herein. However, even then the sampling frame is important, because other species use it as an overwintering area, for examples, the silversides, *Menidia menidia*, and the blueback herring, *Alosa aestivalis*.

For each species addressed, there was one common property in their across-bay spatial distributions: there was no significant difference in their abundance in any month in the deeper waters of the sampling frame, eg, they were equally abundant in the Central Plain and Deeps waters within months. The only exception to this was in June when northern searobins were significantly more abundant in the Central Plain waters. As a result, it would appear that there is little reason to distinguish and maintain a Deeps category in future studies.

For most species addressed, there were two other common properties in their across-bay spatial distributions: 1) in months when they were not abundant, there was generally no significant difference between the combined littoral waters of the Eastern and Western Shores and the combined deeper waters of the Central Plain and Deeps; this phenomenon was true for the blue crab and, especially, spot, northern searobin, weakfish, and Atlantic croaker, particularly in the winter and spring months, and 2) in months when they were abundant, they were generally significantly more abundant in the combined deeper waters of the Central Plain and Deeps than in the combined littoral waters of the Eastern and Western Shores; this phenomenon was true in, especially, spot, weakfish, Atlantic croaker, and also, but less regularly, the bay anchovy. The latter phenomenon was not true in blue crabs, for which there was little or no difference in any month between the combined deeper waters and the combined littoral waters, except in July when they were significantly more abundant in the littoral waters. It was also not true in the northern searobin.

Comparative patterns of abundance in the Eastern Shore and Western Shore littoral waters varied from species to species. The only common pattern was that, in all species, there was no significant difference between the Eastern and Western Shores in months when species abundance was low. This may reflect, in part, a simple fact of statistics: it becomes difficult to estimate abundance and detect differences when abundance is low and variation is thereby constrained. For the bay anchovy, there was no significant difference in abundance between the Eastern and Western Shores in February and March, months in the initial trough of abundance, nor in August, a month in the second trough of abundance in this species. For the other species, in general, there were no significant differences between the Eastern and Western Shores from December through April, details differing from species to species in other months. The brief paragraphs to follow detail patterns from species to species.

For the bay anchovy, observed abundance was generally greater in the Western Shore Littoral than in the Eastern Shore Littoral. Observed differences were significant in only seven months, but they included the months of greatest abundance.

For spot, observed abundance was generally greater in the Western Shore Littoral than in the Eastern Shore Littoral.

However, observed differences were significant only in May, August, September, and November. Observed differences were not significant in the other months. Spot were significantly more abundant along the Western Shore only in May, September, and November. They were significantly more abundant along the Eastern Shore in August.

For the northern searobin, observed abundance was generally greater in the Eastern Shore Littoral than in the Western Shore Littoral. However, differences were significant only in June and September when searobins were more abundant along the Eastern Shore.

For the weakfish, abundance was usually not great in either the Eastern Shore or Western Shore Littoral. The exception to this pattern was the period September through November as weakfish disperse from the Chesapeake. Observed abundance of weakfish was greater in the Western Shore Littoral than in the Eastern Shore Littoral each month in this period of movement. Observed differences were significant in September and November.

For the Atlantic croaker, there was little or no difference in observed abundance between the Eastern Shore and Western Shore Littoral for most of the year. Differences were significant only in January, a month when young-of-the-year were recruiting to the sampling frame. They were more abundant along the Western Shore then.

For the blue crab, observed abundance was generally greater in the Western Shore Littoral than in the Eastern Shore Littoral.

Observed differences were generally significant during their period of greatest abundance, June through December. Exceptions were August and October when there was little observed difference between the two shores.

For most species addressed, there was one common property in their upbay-downbay distributions: there was no significant difference between their abundance in the Upper, Middle, and Lower Bay regions during months when they were not abundant in the sampling frame. This was true for blue crabs, spot, weakfish, northern searobin, and Atlantic croaker, particularly in the winter and spring months. Again this may reflect, at least in part, a simple fact of statistics: it becomes difficult to estimate abundance and detect differences when abundance is low and variation is thereby constrained.

For all species addressed, there were distinct intra-annual patterns in their upbay-downbay distributions, patterns that largely reflect recruitment, nurseries, and movements into and from the Chesapeake. The general pattern is that abundance shifts towards the Lower Bay in the fall as water temperatures drop and most species leave the bay. Abundance shifts towards the Upper Bay in the late spring and summer as recruitment occurs and nurseries form. Details of the intra-annual pattern are specific to each species. A brief paragraph follows for each species.

In the bay anchovy, abundance is great through much of the year. However, abundance shifts so that it is greatest in the

Lower Bay in the coldest months of the year. They were significantly more abundant in the Lower Bay in January and March. During the warmer months of the year, abundance is generally greatest towards the Upper Bay. Anchovies were generally significantly more abundant in the Upper Bay from May through November.

In spot, there was no significant upbay-downbay difference in abundance from January through April, a period when they were absent or not abundant. Abundance became greatest in the Upper Bay from the late spring through early fall. They were significantly more abundant in the Upper Bay from May through September. As spot disperse from the sampling frame in the fall, they again become homogeneously distributed along the upbay-downbay axis. There was no significant difference in abundance between the Upper, Middle, and Lower Bay regions from October through December.

In the northern searobin, there was no significant upbay-downbay difference in abundance from October through April, a period when they were not abundant. Soon after they enter the Chesapeake Bay in the spring, abundance becomes greatest in the more saline Lower Bay. Abundance is generally significantly greater in the Lower Bay than in the Upper Bay from March through September, their period of greatest abundance.

In the weakfish, there was no significant upbay-downbay difference in abundance from December through July, a period when they were not abundant. Soon after the young-of-the-year begin to recruit, abundance became greatest in the Middle Bay Region. Abundance was significantly greater there from August through October than it was in either the Upper or Lower Bay regions. In mid and late fall, as young weakfish move from the Chesapeake for the winter, greatest abundance shifts towards the Lower Bay. Abundance became significantly greater in the Middle and Lower Bay than it was in the Upper Bay in October and November.

In the Atlantic croaker, there was no significant upbay-downbay difference in abundance from February through July, a period when they were not abundant. Croaker became significantly more abundant in the Middle and Lower Bay regions than they were in the Upper Bay in August and September, a period when approaching age I fish apparently entered and migrated out of the sampling frame toward the ocean. As the young-of-the-year began to recruit in mid fall, abundance shifted so that it became greatest in the Upper Bay. Croaker were significantly more abundant in the Upper Bay than in the Middle and Lower Bay from October through December. In January, recruiting young-of-the-year croaker were significantly more abundant in the Lower Bay than in the Upper Bay, a downbay shift that presumably reflects lower temperatures in January.

In the blue crab, there was no significant upbay-downbay difference in abundance from January through July, a period when they were largely not abundant or were burrowed in the bottom sediments. Abundance formed an upbay-downbay gradient from July through october, a period when they were generally significantly more abundant in the Upper Bay than in the Lower Bay. In December, as temperatures decreased, catches became significantly greater in the Lower Bay than in the Upper Bay.

EFFICACY OF STRATIFIED RANDOM SAMPLING

Estimates of Means, Variances, Confidence Limits, and the Effective Number of Degrees of Freedom:

Estimates of the overall log means (y and $y_{(st)}$) and their variances (v_{ran} and $s^2_{y(st)}$) are presented in Table 68 for each species using completely random sampling and the present stratified random sampling design. The means presented represent indexes of annual abundance estimated for the two sampling designs. Similar statistics are presented in Tables 69-74 for monthly indexes of abundance on each species.

Means estimated by the two designs are, generally, roughly similar, though in some instances they are not (Tables 69-74). The estimates based on stratified random sampling are preferable, because they give the correct stratum weights (N_h/N) to the stratum means. Means based on completely random sampling, in contrast, use weights (n_h/n) based on the sample sizes, and these are not the correct weights since equal allocation was used.

Table 75 presents 95% confidence limits for the overall log means for each species based on stratified random sampling, along with a geometric mean back transformation. Tables 76-81 present similar statistics for monthly means on each species. Confidence limits for overall means are reasonably narrow, those for monthly means are much broader. The log transformation gave a much greater number of effective degrees of freedom for estimating confidence limits (Table 82) than did either the square root or no transformation. In general, the difference between

Table 68. Comparison, by species, of means $(\bar{y}, \bar{y}_{st})$ variances of the mean (v_{ran}, $s^2_{\bar{y}(st)}$) and the design effect (Deff) achieved by stratified random sampling in comparison to completely random sampling. Calculations used a log (y + 1) transformation.

Species	n	$\bar{y}$	$v_{(ran)}$	$\bar{y}$ (	$s^2_{\bar{y}}$ (st	Deff
Bay Anchovy	576	1.524	0.0027	1.662	0.0020	0.757
Spot	576	1.014	0.0025	1.057	0.0011	0.429
Northern Searobin	576	0.371	0.006	0.368	0.0002	0.358
Weakfish	576	0.320	0.0007	0.347	0.0005	0.652
Atlantic Croaker	576	0.167	0.0003	0.192	0.0002	0.700
Blue Crab	528	0.480	0.0006	0.452	0.0003	0.485

Table 69. Comparison, by month for bay anchovy, of log means ($\bar{y}, \bar{y}_{st}$), variances of the mean (v_{ran}, $s^2_{\bar{y}(st)}$) and the design effect (Deff) achieved by stratified random sampling in comparison to completely random sampling.

Month	$\bar{y}$	v_{ran}	$\bar{y}$ (s	$s^2_{\bar{y}(s}$	Deff
Jan	2.140	0.0227	2.312	0.0110	0.484
Feb	0.937	0.0066	0.968	0.0091	1.378
Mar	1.131	0.0251	1.235	0.0202	0.808
Apr	1.648	0.0251	1.757	0.0321	1.251
May	1.902	0.0234	2.005	0.0313	1.337
Jun	2.035	0.0273	2.238	0.0210	0.769
Jul	1.515	0.0260	1.700	0.0222	0.852
Aug	0.997	0.0420	1.001	0.0297	0.707
Sep	1.186	0.0435	1.240	0.0421	0.968
Oct	1.212	0.0254	1.373	0.0238	0.936
Nov	1.364	0.0278	1.576	0.0221	0.797
Dec	2.219	0.0310	2.494	0.0246	0.794

Table 70. Comparison, by month for spot, of log means ($\bar{y}$, $\bar{y}_{st}$), variances of the mean (v_{ran}, $s^2_{\bar{y}(st)}$) and the design effect (Deff) achieved by stratified random sampling in comparison to completely random sampling.

Month	$\bar{y}$	v_{ran}	$\bar{y}$ (s	$s^2_{\bar{y}(s}$	Deff
Jan	0.000	0.0000	0.000	0.0000	-
Feb	0.000	0.0000	0.000	0.0000	-
Mar	0.006	0.0001	0.010	0.0001	1.521
Apr	0.084	0.0012	0.081	0.0011	0.873
May	0.471	0.0063	0.446	0.0038	0.607
Jun	1.694	0.0284	1.731	0.0086	0.304
Jul	2.006	0.0214	2.132	0.0185	0.865
Aug	1.891	0.0266	1.853	0.0168	0.632
Sep	1.509	0.0255	1.525	0.0233	0.913
Oct	2.033	0.0138	2.026	0.0182	1.314
Nov	1.396	0.0206	1.550	0.0204	0.989
Dec	1.072	0.0400	1.228	0.0402	1.006
			3		

Table 71. Comparison, by month for northern searobin, of log means ($\bar{y}, \bar{y}_{st}$), variances of the mean (v_{ran}, $s^2_{y(st)}$) and the design effect (Deff) achieved by stratified random sampling in comparison to completely random sampling.

Month	$\bar{y}$	v_{ran}	$\bar{y}_{st}$	$s^2_{\bar{y}(st)}$	Deff
Jan	0.000	0.0000	0.000	0.0000	-
Feb	0.000	0.0000	0.000	0.0000	-
Mar	0.045	0.0003	0.045	0.0003	0.985
Apr	0.801	0.0051	0.855	0.0044	0.855
May	0.820	0.0064	0.847	0.0053	0.823
Jun	1.282	0.0085	1.277	0.0060	0.712
Jul	0.764	0.0150	0.756	0.0061	0.388
Aug	0.142	0.0031	0.156	0.0043	1.365
Sep	0.348	0.0031	0.272	0.0024	0.799
Oct	0.119	0.0012	0.129	0.0018	1.508
Nov	0.108	0.0009	0.066	0.0006	0.633
Dec	0.019	0.0001	0.022	0.0002	1.372

Table 72. Comparison, by month for weakfish, of log means ($\bar{y}, \bar{y}_{st}$), variances of the mean (v_{ran}, $s^2_{\bar{y}(st)}$) and the design effect (Deff) achieved by stratified random sampling in comparison to completely random sampling.

Month	$\bar{y}$	v_{ran}	$\bar{y}_{st}$	$s^2_{\bar{y}(s}$	Deff
Jan	0.000	0.0000	0.000	0.0000	-
Feb	0.000	0.0000	0.000	0.0000	-
Mar	0.000	0.0000	0.000	0.0000	-
Apr	0.000	0.0000	0.000	0.0000	-
May	0.103	0.0012	0.077	0.0005	0.455
Jun	0.101	0.0017	0.105	0.0018	1.051
Jul	0.404	0.0071	0.456	0.0083	1.167
Aug	0.661	0.0140	0.740	0.0136	0.974
Sep	0.743	0.0188	0.833	0.0158	0.837
Oct	0.893	0.0166	0.914	0.0142	0.860
Nov	0.719	0.0085	0.782	0.0067	0.795
Dec	0.211	0.0048	0.247	0.0059	1.236

Table 73. Comparison, by month for Atlantic croaker, of log means ($\bar{y}, \bar{y}_{st}$), variances of the mean (v_{ran}, $s^2_{\bar{y}(st)}$) and the design effect (Deff) achieved by stratified random sampling in comparison to completely random sampling.

Month	$\bar{y}$	v_{ran}	$\bar{y}_{st}$	$s^2_{\bar{y}(s}$	Deff
Jan	0.373	0.0032	0.441	0.0021	0.642
Feb	0.000	0.0000	0.000	0.0000	-
Mar	0.000	0.0000	0.000	0.0000	-
Apr	0.000	0.0000	0.000	0.0000	-
May	0.000	0.0000	0.000	0.0000	-
Jun	0.013	0.0001	0.012	0.0001	1.330
Jul	0.121	0.0017	0.100	0.0012	0.718
Aug	0.206	0.0032	0.213	0.0016	0.513
Sep	0.260	0.0036	0.246	0.0039	1.105
Oct	0.256	0.0053	0.317	0.0053	0.995
Nov	0.360	0.0083	0.449	0.0057	0.684
Dec	0.417	0.0095	0.515	0.0085	0.889

Table 74. Comparison, by month for blue crab, of log means ($\bar{y}$, $\bar{y}_{st}$), variances of the mean (v_{ran}, $s^2_{\bar{y}(st)}$) and the design effect (Deff) achieved by stratified random sampling in comparison to completely random sampling.

Month	$\bar{y}$	v_{ran}	$\bar{y}_{st}$	$s^2_{\bar{y}(st)}$	Deff
Jan	0.016	0.0001	0.014	0.0001	1.077
Feb	0.000	0.0000	0.000	0.0000	-
Mar	0.000	0.0000	0.000	0.0000	-
Apr	0.176	0.0014	0.169	0.0015	1.063
May	-	-	-	-	-
Jun	0.208	0.0019	0.183	0.0020	1.057
Jul	0.881	0.0053	0.896	0.0052	0.989
Aug	0.829	0.0052	0.830	0.0063	1.216
Sep	0.725	0.0048	0.816	0.0046	0.952
Oct	1.123	0.0084	1.096	0.0063	0.744
Nov	0.907	0.0064	0.930	0.0066	1.020
Dec	0.419	0.0072	0.472	0.0075	1.047

Table 75. Summary of statistics by species on overall log abundance using stratified random sampling, with a geometric mean (GM) back transformation.

Species	$\bar{Y}_{st}$	Effective d.f.	95% CL	GM	95% CL
Bay Anchovy	1.622	150	1.573-1.750	44.868	36.390-55.269
Spot	1.057	89	0.992-1.212	10.401	8.823-12.233
Northern Searobin	0.368	71	0.339-0.398	1.334	1.180-1.498
Weakfish	0.347	70	0.304-0.390	1.224	1.013-1.457
Atlantic Croaker	0.192	64	0.164-0.221	0.557	0.459-0.662
Blue Crab	0.452	94	0.419-0.486	1.833	1.623-2.059

January through April period when catches were low (Figure 53; Table 65). However, during the period June through December, when catches were high or intermediate, blue crabs were significantly more abundant in most months in the Western Shore Littoral than in the Eastern Shore Littoral. There was no significant difference in August and October.

Upbay-downbay patterns of blue crab abundance showed large changes during the year. There was little or no difference in abundance, and no significant differences, between waters of the Upper, Middle, and Lower Bay regions in the winter, spring, and early summer months of January through July when blue crabs are absent, burrowed in the mud, or not abundant in the Chesapeake Bay (Figure 54; Tables 66, 67). However, patterns of abundance change greatly in months of higher catches. Blue crabs were significantly more abundant in the Upper Bay waters than in the Lower Bay in most months from July through October, except August. In December, however, blue crab catches were significantly higher in the Lower Bay. Blue crab catches in the Middle region waters did not differ significantly from the average of their abundance in the Upper and Lower Bay in all months except September.

Other Sources of Variation in Blue Crab Catches:

Overall plots of residuals against bottom D.O. indicate no strong relationship (Figure 55). The two variables are independent over much of the D.O. range. At low D.O. (D.O. < 2

Table 65. Summary of individual degree of freedom contrast tests to evaluate differences in log blue crab abundance between the Eastern Shore Littoral and Western Shore Littoral waters. Each sum of squares (SS) has one degree of freedom. Means (Log, GM) are presented for the two regions in their sequence in the title.

				MEANS	
Contrast	SS	F	Sig	log	GM
Jan	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Feb	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Mar	0.00	0.00	ns	0.00-0.00	0.00- 0.00
Apr	0.00	0.00	ns	0.10-0.10	0.27- 0.26
Jun	0.59	4.00	*	0.08-0.39	0.19- 1.45
Jul	1.29	8.70	**	0.84-1.30	5.94-19.16
Aug	0.00	0.03	ns	0.86-0.88	6.23- 6.67
Sep	2.84	19.23	**	0.39-1.08	1.46-11.00
Oct	0.08	0.52	ns	1.20-1.09	14.93-11.26
Nov	1.46	9.89	**	0.77-1.26	4.84-17.20
Dec	1.23	8.34	**	0.09-0.54	0.23- 2.49

Table 76. Summary of statistics for bay anchovy on log monthly abundance using stratified random sampling, with a geometric mean (GM) back transformation.

Month	$\bar{Y}_{st}$	Effective d.f.	95% CL	GM	95% CL
Jan	2.312	14	2.087-2.537	204.265	121.280-343.569
Feb	0.968	16	0.766-1.170	8.284	4.829-13.785
Mar	1.235	11	0.922-1.548	16.174	7.352-34.316
Apr	1.757	17	1.379-2.135	56.184	22.941-135.585
May	2.005	16	1.630-2.380	100.185	41.657-239.018
Jun	2.238	9	1.911-2.566	172.080	80.394-367.046
Jul	1.699	18	1.386-2.012	49.030	23.348-101.800
Aug	1.001	13	0.629-1.374	9.027	3.254-22.635
Sep	1.240	14	0.800-1.680	16.375	5.309-46.854
Oct	1.373	13	1.039-1.706	22.585	9.951-49.792
Nov	1.576	10	1.245-1.908	36.674	16.561-79.826
Dec	2.494	21	2.168-2.820	311.003	146.271-660.000

Table 77. Summary of statistics for spot on a log monthly abundance using stratified random sampling, with a geometric mean (GM) back transformation.

Month	$\bar{Y}_{st}$	Effective d.f.	95% CL	GM	95% CL
Jan	0.000	-	-	0.000	-
Feb	0.000	-	-	0.000	-
Mar	0.010	3	0.000-0.040	0.022	0.000-0.096
Apr	0.081	7	0.004-0.157	0.204	0.009-0.437
May	0.446	18	0.315-0.576	1.790	1.067-2.767
Jun	1.731	16	1.534-1.928	52.845	33.202-83.770
Jul	2.132	14	1.840-2.424	134.527	68.212-264.381
Aug	1.853	9	1.560-2.146	70.295	35.292-139.056
Sep	1.525	17	1.203-1.847	32.478	14.957-69.237
Oct	2.026	14	1.737-2.315	105.236	53.594-205.728
Nov	1.550	16	1.248-1.852	34.484	16.684-70.200
Dec	1.283	15	0.856-1.711	18.204	6.180-50.363

Table 78. Summary of statistics for northern searobin on log monthly abundance using stratified random sampling, with a geometric mean (GM) back transformation.

Month	$\bar{Y}_{st}$	Effective d.f.	95% CL	GM	95% CL
Jan	0.000	-	-	0.000	-
Feb	0.000	-	-	0.000	-
Mar	0.045	10	0.004-0.086	0.109	0.009-0.220
Apr	0.855	18	0.716-0.995	6.169	4.203-8.877
May	0.847	10	0.685-1.009	6.033	3.841-9.217
Jun	1.277	15	1.112-1.442	17.926	11.934-26.695
Jul	0.756	14	0.588-0.924	4.696	2.869-7.386
Aug	0.156	5	0.000-0.325	0.433	0.000-1.112
Sep	0.272	14	0.166-0.378	0.869	0.464-1.386
Oct	0.129	17	0.039-0.218	0.345	0.095-0.653
Nov	0.066	10	0.013-0.119	0.164	0.031-0.315
Dec	0.022	7	0.000-0.055	0.053	0.000-0.134

Table 79. Summary of statistics for weakfish on log monthly abundance using stratified random sampling, with a geometric mean (GM) back transformation.

Month	$\bar{Y}_{st}$	Effective d.f.	95% CL	GM	95% CL
Jan	0.000	-	-	0.000	-
Feb	0.000	-	-	0.000	-
Mar	0.000	-	-	0.000	-
Apr	0.000	-	-	0.000	-
May	0.077	4	0.012-0.142	0.194	0.029-0.386
Jun	0.105	11	0.012-0.198	0.273	0.027-0.579
Jul	0.456	15	0.261-0.650	1.854	0.824-3.467
Aug	0.740	10	0.480-1.000	4.496	2.022-8.996
Sep	0.833	12	0.559-1.106	5.807	2.626-11.777
Oct	0.914	14	0.658-1.170	7.196	3.546-13.774
Nov	0.782	13	0.605-0.960	5.056	3.027-8.107
Dec	0.247	12	0.080-0.415	0.767	0.022-1.597

Table 80. Summary of statistics of Atlantic croaker on log monthly abundance using stratified random sampling, with a geometric mean (GM) back transformation.

Month	$\bar{Y}_{st}$	Effective d.f.	95% CL	GM	95% CL
Jan	0.411	17	0.346-0.537	1.763	1.217-2.444
Feb	0.000	-	-	0.000	-
Mar	0.000	-	-	0.000	-
Apr	0.000	-	-	0.000	-
May	0.000	-	-	0.000	-
Jun	0.012	3	0.000-0.044	0.028	0.000-0.106
Jul	0.100	7	0.017-0.183	0.260	0.041-0.525
Aug	0.213	10	0.123-0.304	0.635	0.328-1.013
Sep	0.246	12	0.109-0.382	0.760	0.284-1.412
Oct	0.317	10	0.155-0.479	1.074	0.430-2.010
Nov	0.449	11	0.283-0.615	1.811	0.919-3.117
Dec	0.515	14	0.317-0.712	2.272	1.077-4.155

Table 81. Summary of statistics for blue crab on log monthly abundance using stratified random sampling, with a geometric mean (GM) back transformation.

Month	$\bar{Y}_{st}$	Effective d.f.	95% CL	GM	95% CL
Jan	0.014	3	-	0.032	-
Feb	0.000	-	-	0.000	-
Mar	0.000	-	-	0.000	-
Apr	0.169	8	0.079-0.260	0.477	0.199-0.820
May	-	-	-	-	-
Jun	0.183	10	0.088-0.279	0.525	0.223-0.901
Jul	0.896	13	0.741-1.051	6.878	4.541-10.254
Aug	0.830	15	0.650-1.009	5.754	3.464-9.219
Sep	0.816	15	0.673-0.958	5.544	3.713-8.087
Oct	1.096	15	0.926-1.266	11.464	7.429-17.430
Nov	0.930	19	0.759-1.102	7.517	4.737-11.645
Dec	0.472	11	0.288-0.657	1.967	0.939-3.541

Table 82. Summary of Effective Degrees of Freedom, by Species, for Overall Abundance Calculated Using a Log, Square Root, and no Transformation.

	Transformation		
Species	Log	Square Root	None
Bay Anchovy	150	101	35
Spot	89	11	4
Northern Searobin	71	47	30
Weakfish	70	38	17
Atlantic Croaker	64	29	11
Blue Crab	94	60	26

transformations and the effective degrees of freedom they provide to estimate t-values is not extremely important for overall means. For overall means for most species, some 20 or more degrees of freedom are provided by all the transformations, and there is not a large reduction in t with each additional degree of freedom. This is not the case with monthly means, for which the choice of an appropriate transformation becomes a matter of some importance. Even the log transformation provided less than 20 effective degrees of freedom for monthly means in all instances for all species (Table 83). Large changes occur in t values with each additional degree of freedom in this range, so the square root and no transformation would provide much broader confidence limits than the log transformation.

Estimates of the Design Effect:

The design effect (deff) is presented for each species in Table 68 to compare, for overall, annual means, the present stratified random sampling design, and completely random sampling. Similar statistics are presented in Tables 68-74 for monthly deff values on each species.

The present stratification scheme in time and space appears to have had success in reducing the variance of the overall annual means. There was a substantial reduction for each species. Deff values of 0.358-0.485 indicate that stratification reduced the variance of the overall, annual mean to about a third to half the value for a completely random sample in northern

Table 83. Summary of Monthly Effective Degrees of Freedom, by Species, Using a Log Transformation.

Month	Bay Anchovy	Spot	Northern Searobin	Weakfish	Atlantic Croaker	Blue Crab
Jan	14	-	-	-	17	3
Feb	16	-	-	-	-	-
Mar	11	3	10	-	-	-
Apr	17	7	18	-	-	8
May	16	18	10	4	-	-
Jun	9	16	15	11	3	10
Jul	18	14	14	15	7	13
Aug	13	9	5	10	10	15
Sep	14	17	14	12	12	15
Oct	13	14	17	14	10	15
Nov	10	16	10	13	11	19
Dec	21	15	7	12	14	11

searobin, spot, and blue crabs. Much less reduction in the variance was achieved for bay anchovy, Atlantic croaker, and weakfish. Deff values for these species of 0.652-0.757 indicate that stratification reduced the variance of the overall, annual mean only to about two-thirds to three-quarters the value for a completely random sample.

The present stratification scheme appears to have not been very effective in reducing the variance of the monthly means. Ignoring months when a species was not available and there was no design effect, the variance from stratified random sampling (SRS) often exceeded that for completely random sampling (CRS), or the variance was reduced only 15% or less by stratification. Details follow for individual species. For the blue crab, the present stratification design was not at all effective within months. In this species, the variance of SRS exceeded that of CRS in sixe of the eight months for which a deff could be estimated, and the variance of SRS was 85-100% of that for CRS in two other months; in no month was the variance of SRS less than some 75% of that for CRS. For the bay anchovy, the present stratification design was not very effective within months. In this species, the variance of SRS exceeded that of CRS in three months, and the variance of SRS was 85-100% of that for CRS in three other months; in only one month was the variance of SRS less than some 70% of that for CRS. For spot, the present stratification scheme was not effective within months. In this species, the variance of SRS exceeded that of CRS in three months, and the variance of

SRS was 85-100% of that for CRS in four other months; in only one month was the variance of SRS less than some 60% of that for CRS. For northern searobin, the present stratification scheme was not very effective within months. In this species, the variance of SRS exceeded that of CRS in three months, and the variance of SRS was 85-100% of that for CRS in two other months; only in one month was the variance of SRS much less than some 65% of that for CRS. For weakfish, the present stratification scheme was not very effective within months. In this species, the variance of SRS exceeded that of CRS in three months, and the variance of SRS was 85-100% of that for CRS in two other months; only in one month was the variance of SRS much less than some 80% of that for CRS. For Atlantic croaker, the present stratification scheme was not very effective within months. In this species, the variance of SRS exceeded that of CRS in two months, and the variance of SRS was 85-100% of that for CRS in two other months; only in one month was the variance of SRS much less than some 65% of that for CRS.

Discussion of the Efficacy of Stratified Sampling:

The stratified random sampling design employed in the present studies has had mixed success in comparison to completely random sampling, success which depends, in part, on the goals envisioned. The design has been effective for developing overall, or annual, indexes of abundance. The degree of effectiveness varies from species to species. In blue crabs, spot, and northern searobin, the present design successfully reduced the variance of the mean to about a third to a half that for completely random sampling. For bay anchovy, Atlantic croaker, and weakfish, the variance was reduced to about 65-75% of that from completely random sampling. In large part, it appears that success reflects removal, or minimization, of the effects of time on catches. This effect was indicated by evaluations of the ANOVA model, for which the Months effect generally was the most important source of variation in catches. In addition to variance reduction, the stratified random sampling design has had two other important benefits on estimation of abundance: 1) it has achieved a broad coverage of the sampling frame in time and space, so it eliminates or greatly reduces the probability of wild samples, and 2) as a second result of the broad coverage, it provides information about all areas of the sampling frame and times of the year, something important in evaluating long term trends, environmental impacts, etc.

The present stratified random sampling design has not been effective for developing monthly indexes of abundance. This is so from the perspective of variance reduction, because the just-described two benefits of stratification also apply on a monthly basis. From the perspective of variance reduction, the present design achieved a variance that was often larger than that of completely random sampling, or it achieved negligible reduction in the variance. The reason for this lack of variance reduction with monthly indices is that stratification sacrifices many degrees of freedom; these degrees of freedom are lost to variance reduction without the hoped-for removal of important sources of variation through successful experimental design. This effect was indicated by the evaluations of the ANOVA model, for which the Areas effect explained little or negligible amounts of variation in catches. The Months effect, so important in the annual indices, does not impact on the monthly indices.

The non-effectiveness of the present stratified random sampling design with monthly indices of abundance apparently reflects a largely homogeneous sampling frame within months. Although some other spatial scheme may be somewhat more effective, it seems probable that its benefits would not be great. Many potential sources of variation in catch are largely correlated with the bathymetry and areal aspects of the sampling frame used in the present stratification. The generally important Interaction effect in the ANOVA, moreover, suggests that any spatially-based stratification scheme would not have a constant effect: rather, its effects would vary from month to month with the ebb and flow of life history phenomena like the recruitment, decruitment, survivorship, and movements. The present model, moreover, was generally successful in explaining some one half to three quarters of the variation in catch, depending on species. As a result, there seems to be limited opportunity for further variance reduction through experimental design. For the future, it appears that the Deeps strata could be merged with the Central Plains strata with little or not loss, since there was invariably no significant difference in abundance between them for any species. The number of collections assigned to the present Deeps stratum could be ??????? amongst the remaining strata. Some further benefit might be achieved by using proportional allocation rather than the equal allocation used to simplify the present studies.

The options that remain for variance reduction and confidence limit improvement are limited as indicated in a general statement for confidence limits (CL).

$$CL = estimator \pm t_{\alpha} \quad \frac{Variance\ of\ the\ Estimator}{n}$$

Only the elements given in the statement can be addressed, and a combination of them may be needed:

1) Improvement can be gained, in principle, by increasing the number of collections (n) in the index. However, that will cost additional money, if the sampling frame in maintained, and the benefits of this approach may be limited without a large increase in the sample size.
2) Improvement can be gained, in principle, by reducing the variance of the estimate using an improved experimental design. That was the approach attempted in the present studies. However, the present ANOVA model successfully explained some 50-75% of the variation in catches depending on species. There appears to be little room for further variance reduction this way. Further variance reduction this

way will probably require a much finer-scale knowledge of spatial variation than the present studies used, and, given the significant Interaction, it may still not be much more effective.

3) Improvement can be gained, in principle, by manipulating the α level which determines the t-value. The α level is a measure of the risk with which some level of error is to be tolerated. Narrower confidence limits can be gotten by increasing the risk, eg. -- by choosing $\alpha = .10$, $\alpha = .20$, or some other level more risky than the $\alpha = .05$ used in the present studies, and

4) Improvement can be gained, in principle, by manipulating the estimator. Rather than using y or y_{st}, for example, to provide an index of abundance, some other estimator such as a regression mean might be used.

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