Initial Information on the Atlantic Croaker, a Final Report on "Development of Age Determination Methods, Life History- Population Dynamics Information, and Evaluation of Growth Overfishing Potential for Important Recreational Fishes"

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ABSTRACT / SUMMARY

Observational data on abundance of Atlantic croaker, Micropogonias undulatus, and boxes of specimens from which to obtain biological data for life history/population dynamics work, were collected at weekly or fortnightly intervals from Chesapeake Bay commercial fisheries, primarily pound nets, in 1988 and 1989. A special collection of 24 boxes of one commercial grade was purchased from one fishery in 1989 to evaluate box-to-box variation in total lengths and sex ratios, and how it affects interpretation of routinely collected data. Length composition data from 25 years of York River trawling were used to compare length frequencies in trawl and pound net catches.

Size compositions were markedly different in pound net and trawl catches. Sizes were much smaller in trawl catches (generally $\leq$ 200 mm TL; maximum some 290 mm in some 24,000 fish measured from 1956-1980), than in pound net food grade catches (generally $\geq$ 210 mm; maximum 400 mm in only some 700 and 800 specimens measured in 1988 and 1989, respectively). A large fraction of the pound net catch, some 10-25%, exceeded 300 mm, a size not even captured in York River trawling.

There was little or no difference in length compositions among boxes (8 mm maximum difference), and only a minor, but significant trend in size with the chronology of processing boxes. The regression effect was not visible in plots of mean length on box number in the processing chronology, so the declared significance must largely reflect a very large sample

size (n = 2,688). Within-box variation accounted for more than 98% of the total variation in length.

Within-box variation accounted for more than 98% of the total variation in sex ratio, and confidence limits about the mean were narrow, values being 59% $\pm$ 2. However, there were one outlier value, significant, differences among boxes, and a mild, but significant, curvilinear trend with the chronology of processing boxes, phenomena for which we can offer no biological explanation if they are real. Confidence limits for individual per-box sex ratios seemed unpleasantly wide about the mean, 51-67%, even after deleting the outlier. This latter feature is worrisome and implies that per-day percentage data may give less confidence than desirable.

Information presented herein should be viewed with varying degrees of reservation, as discussed, because it is based on non-random sampling in time and space due to two sources of difficulty in collecting data: 1) small catches at certain times or areas so that we had no fish to purchase, and 2) poor or erratic cooperation in that some target fisheries refused to sell specimens on which to collect biological data. The problem of small catches primarily affects "trend-type data", eg -- indices used to estimate spawning periodicity, time-trends in sex ratios etc. Trends observed are probably representative, though such data are not complete in their extent. The problem of poor cooperation primarily affects "composition-type data", eg -- overall age and size compositions, maturity, mortality, and growth. Such data may not be representative and should be viewed with reservation, because it is based on non-random sampling and improper weighting of component data.

Adult croaker occur in Chesapeake Bay early April-mid October. Abundance at

Lynnhaven showed an apparently bimodal periodicity in large catches, April when croaker enter the Bay and early August-mid September when they leave it. Adult croaker, seemingly, enter the Bay primarily along the Western Shore in the spring, because large catches were then made at Lynnhaven in contrast to the lower Eastern Shore where no croaker were captured until late May.

Spawning periodicity is not yet fully clear, because we have not yet been able to obtain a comprehensive time series of specimens in one year. However, adults do not approach spawning condition in the period April-mid July. They seemingly mature rapidly after mid July. We collected no adult females in the Gravid, Ripe, or Spawning/Spent stages in either year, so spawning apparently occurs outside the Bay.

The most important size ranges observed were 230-330 mm total length in 1988 and 220-270 mm in 1989. Minimum sizes captured were 200-210 mm each year, the similarity probably reflecting the commercial grading process. Maximum sizes observed were 369 mm in 1989 and 400 mm in 1988.

Overall sex ratios observed were 42.7% male in 1988 and 37.2% in 1989. Time trends in sex ratios -- predominantly male before and then predominantly female after about late July-early August -- combined with large pound net catches in August near the Bay mouth, indicate an exodus of croaker from the Bay about August. Males tend to leave the Bay first. Size-specific sex ratios show a more or less linear decrease in the percentage male from 50-65% male at 215-235 mm to 12-15% male at 295-365 mm, depending on year. The largest croaker tend to be females, and all the largest ones were female, fish > 375 mm in 1988 and > 335 mm in 1989.

Most, if not all, female croaker observed in the pound net catches were maturing to spawn in the year they were captured. Females entered the Late Developing stage over a broad size range each year, 215-390 mm in 1988 and 225-375 mm in 1989. The larger, presumably older, females appear to mature first as the spawning season approaches.

The otolith was the most reliable structure for ageing in comparison to scales, fin rays, and fin spines, the other hard parts evaluated. Otoliths showed much higher agreement between readers and clearer rings. The counting path along the sulcal groove of the otolith was clearest.

A von Bertalanffy growth function fit to 77 fish indicated rapid growth in the first two years of life. The asymptotic length was 267 mm, which may be very low, and the fit of K and t_0 were statistically poor.

The oldest fish among the 102 croaker aged to date were age V or age VI. Theoretical total mortality rates are 37-60% for maximum ages between five and ten years, rates being 55-60% for five or six year life spans. Weight, girth, and length relationships are given.

INTRODUCTION

Little information has been published on which to build modeling and wise, routine, day-to-day management of estuarine and coastal fishes in the Chesapeake. Such management usually entails concerns such as minimum size limits, maximum size limits, slot limits, minimum mesh sizes, catch and/or effort quotas, closed seasons, closed areas etc. These concerns can be readily addressed through yield-per-recruit and eggs-per-recruit modeling (Beverton and Holt 1957; Gulland 1969, 1983; Ricker 1975; Campbell 1985; Ennis 1985). Yield-per-recruit models evaluate growth overfishing potential and how biomass production and age-specific standing stocks are affected by growth and mortality schedules. Eggs-per-recruit models evaluate how egg production is affected by mortality, maturity, fecundity, and sex ratio schedules. Management agencies can manipulate these various schedules in fish stocks by regulating minimum size limits and other concerns noted above. Specific information required to model how management affects egg production, biomass production, age-specific standing stocks, and growth overfishing potential is determined by the model chosen for use. In general, it is directed at adults and simply includes the schedules noted above, and parameters such as times at entry to and passage from the exploited phase of life, spatial and temporal distributions, movements, and spawning periodicity.

Little published information on these topics is available for the Chesapeake on many species of recreational importance including Atlantic croaker (hereafter referred to as croaker), weakfish, black drum, spot, Spanish mackerel, bluefish, and spotted seatrout. Much of what has been published for the Chesapeake on these topics is historical, eg --information from the

1950's or 1960's such as that of Pacheco (1962) on spot and Massmann (1963) on weakfish. This information may not be accurate now given the large changes in the Chesapeake fisheries since its collection. Much other published information is from the Carolinian Province. This may not apply to the Chesapeake given what appears to be large zoogeographic change in the Cape Hatteras-Cape Fear area in the population dynamics of many species including croaker and American shad (White and Chittenden 1977) and weakfish (Shlossman and Chittenden 1981). The little modeling which has been done to provide management advice for the Chesapeake is largely unpublished (for examples, Chittenden 1977a; Boreman and Seagraves 1984). Chittenden (1977b) suggested that modeling with parameters appropriate to the Carolinian Province would not apply to northern waters, because fishes there are more sensitive to growth overfishing than Carolinian fishes. Finally, the age information on which the few available pertinent parameters are based may not be reliable. Methods of age determination do not exist or have not been validated, verified, or repeated (Beamish and McFarlane 1983, 1987) in many Chesapeake fishes such as croaker, black drum, spot, or even weakfish. This is a serious failure in knowledge because "per-recruit" models require reliable age determination.

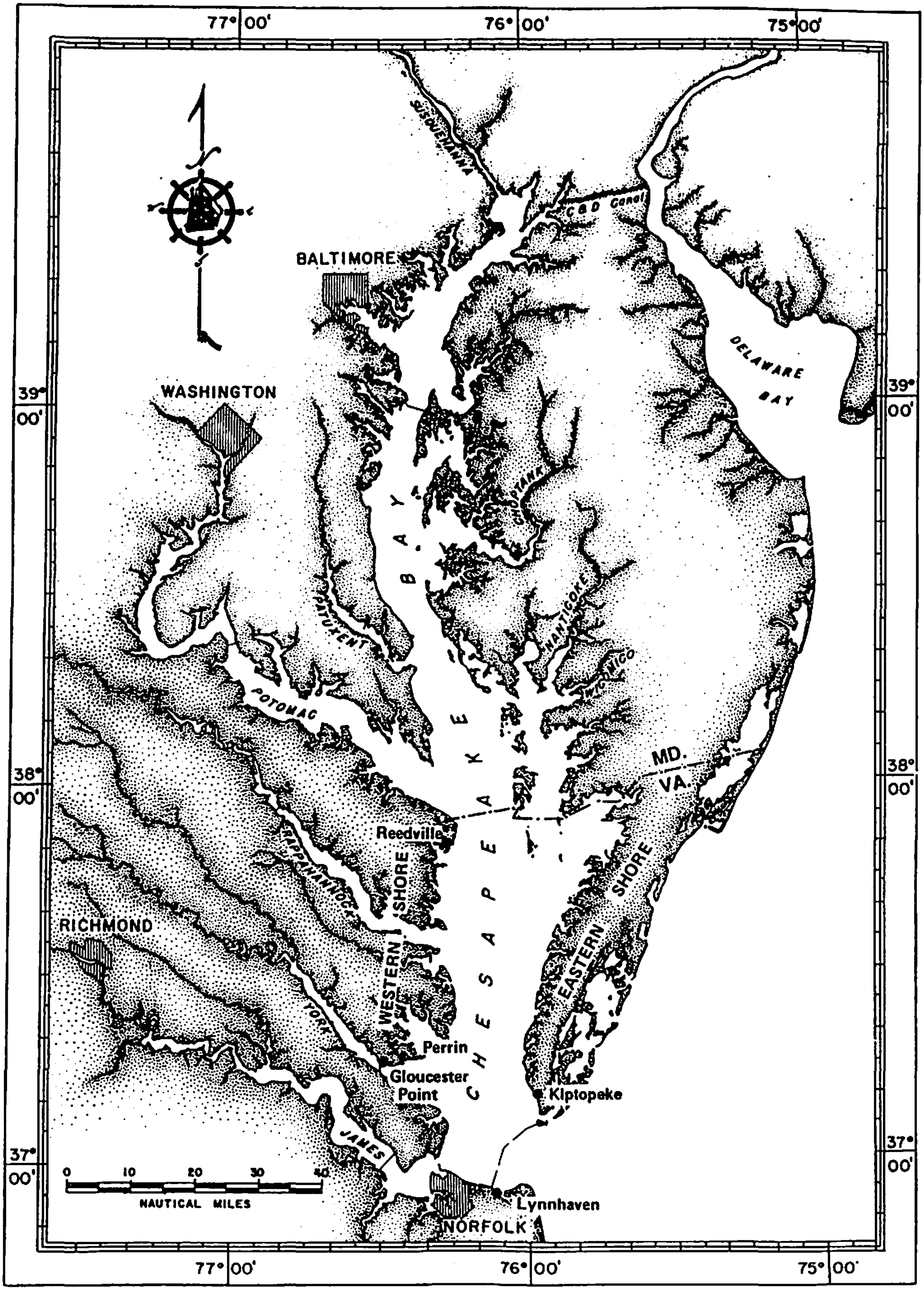
This multi-year project will provide modeling, basic information on life histories and population dynamics, and methods of age determination for species important (Richards 1962, 1965) to Chesapeake recreational fisheries. Species now being addressed include croaker, weakfish, and black drum. Data collection goals focused on croaker in 1988 and on croaker and weakfish in 1989. The present final report describes initial results on croaker age determination techniques and life history-population dynamics information. Results on other species will be described in subsequent final reports.

METHODS

Data and specimens were collected at commercial fisheries in the Chesapeake, primarily pound nets, in 1988 and 1989. An initial sampling frame listing all the pound net fisheries in Virginia waters of the Chesapeake was compiled for such work in 1985, and each fishery was visited then to evaluate their operating procedures (Chittenden 1987), and their willingness and ability to cooperate and provide biological data. Four fisheries, located at widely separated points in the Chesapeake Bay, were identified as being most likely to cooperate and were used in the present studies. They included fisheries along the Western Shore at Reedville, on the lower York River, and at Lynnhaven, and a fishery along the lower Eastern Shore near Kiptopeke (Fig. 1), a location hereafter referred to as "Eastern Shore". In 1989 they fished, respectively, 2, 7, 5, and 7 pound nets, though not all everyday. A fifth fishery was added in 1989, a York River seafood processor who obtained haul seine catches of croaker, primarily from the York River. Chittenden (1987) describes operational procedures in the pound net and haul seine fisheries.

In 1988, we contacted each of the four initial fisheries -- by personal visit or by telephone -- at about two-week intervals from late July through mid-October. In 1989, we contacted the fisheries at weekly or fortnightly intervals from late March through late November. Tables 1 and 2 summarize weeks and locations when we were able to purchase specimens in the respective years. Table 3 and Figure 2 summarize by location the monthly and daily distribution of contacts which successfully resulted in catch-size estimates. We had

Figure 1. Chesapeake Bay geography.



77° 00'
76° 00'
75° 00'
39° 00'
38° 00'
37° 00'
SUSQUEHANNA
C & D Canal
BALTIMORE
WASHINGTON
DELAWARE BAY
CHOPTANK
PATUXENT
NANTICOKE
WICOMICO
POTOMAC
MD.
VA.
Reedville
RAPPAHANNOCK
WESTERN SHORE
EASTERN SHORE
CHESAPEAKE BAY
RICHMOND
YORK
Perrin
Gloucester Point
Kiptopeke
JAMES
0 10 20 30 40
NAUTICAL MILES
Lynnhaven
NORFOLK

Table 1. Weeks and locations of Atlantic croaker purchases in 1988.

Month		LOCATION			
		Reedville	York River	Lynnhaven	Eastern Shore
Jul	1				
	2				X
	3				
	4	X	X		
Aug	1				
	2			XX	
	3				XX
	4				XX
Sep	1				
	2			XX	
	3				
	4				

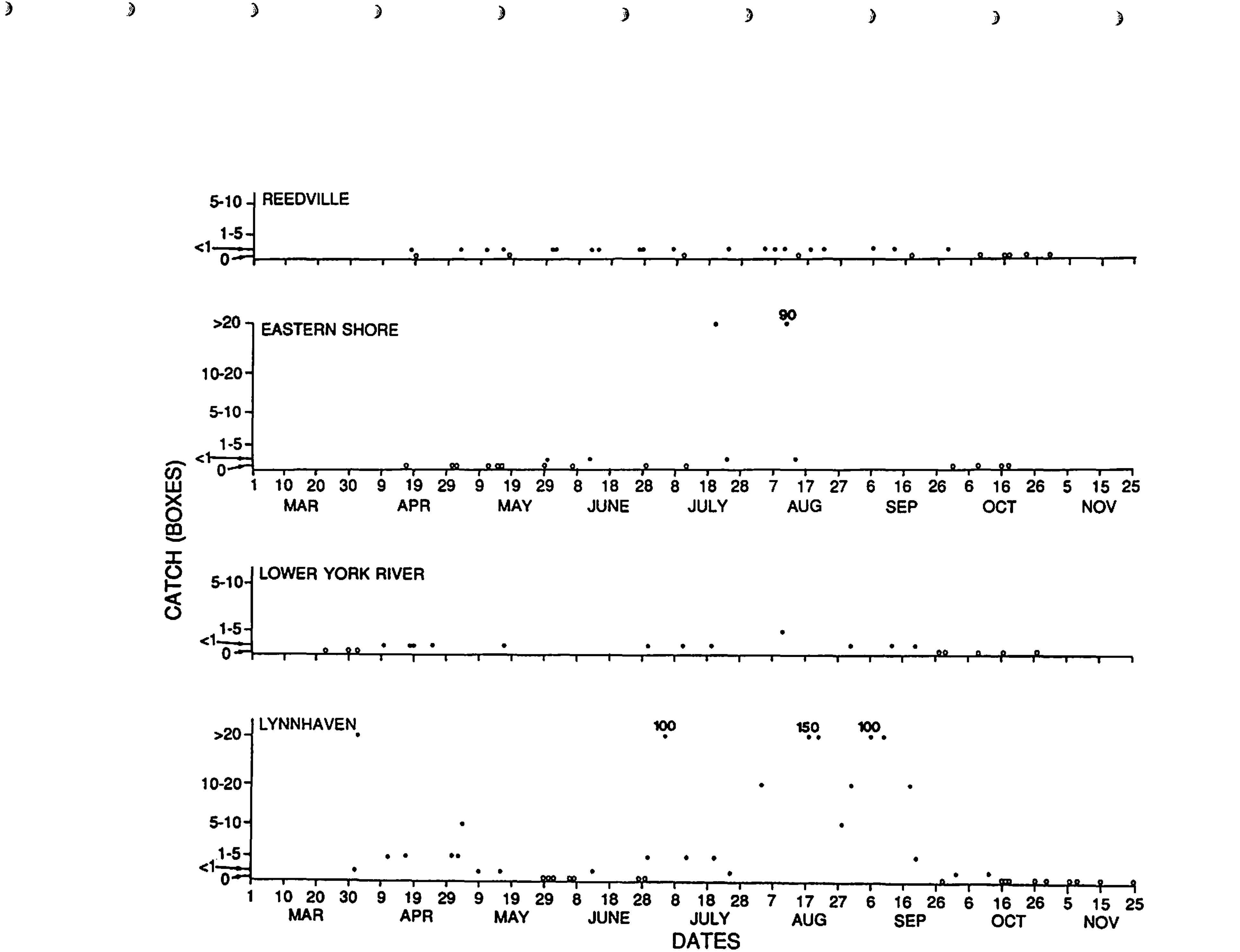
Table 2. Weeks and locations of Atlantic croaker purchases in 1989.

Month		LOCATION		
	Reedville	York River	Lynnhaven	Eastern Shore
Apr 1				
2		X		
3				
4				
May 1				
2				
3				
4				
Jun 1				
2		XX		
3				
4				
Jul 1				
2		X		
3				
4	X	XX		
Aug 1				
2				
3				X
4		XX		

Table 3. Monthly and spatial distribution of pound net fishery records providing catch size estimates for Atlantic croaker, 1989. Figure 2 gives a finer breakdown. NF means no fishing was done.

Location	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
Lynnhaven	0	4	7	7	4	5	5	7	4	43
York River	2	5	1	1	2	2	4	3	NF	20
Reedville	NF	2	5	4	3	6	4	5	NF	29
Eastern Shore	NF	1	7	3	3	2	0	3	NF	19
Total	2	12	20	15	12	15	13	18	4	111

Figure 2. Estimates of daily Atlantic croaker catches, 1989, in the Chesapeake Bay at Lynnhaven, Reedville, lower York River, and Eastern Shore.


REEDVILLE
EASTERN SHORE
90
LOWER YORK RIVER
LYNNHAVEN
100
150
100
5-10
1-5
<1
0
>20
10-20
CATCH (BOXES)
1 10 20 30 9 19 29 9 19 29 8 18 28 8 18 28 7 17 27 6 16 26 6 16 26 5 15 25
MAR
APR
MAY
JUNE
JULY
AUG
SEP
OCT
NOV
DATES

intended, and attempted, randomized selection of the fisheries contacted on given days, but these intentions almost immediately broke down as described in the Discussion section.

At each personal visit contact, we attempted to purchase one box of each grade of croaker captured, or less than one box if only that was available. As Chittenden (1987) recommended, this purchase was made at, or after, the weighing scale, the point at which the routine commercial processing operations have already identified the catch to species, sorted it to market grade, and weighed out 50-pound lots. The purpose of the purchases was to obtain specimens on which to collect biological data.

Fish purchased to collect biological data were iced, held in coolers, and returned to the laboratory for detailed processing. On each specimen, except in a few instances with small-grade fish in 1989 as noted below, we measured, using electronic computer-compatible weighing and measuring boards, total length (TL) and fork length (FL) in millimeters, girth (G) in millimeters at the anterior point of insertion of the dorsal fin, and total weight (TW) and total gonad weight (GW) to 0.1 grams. We also recorded sex and gonad maturity stage, and took hard part samples for aging, including scales, pectoral and dorsal fin rays, and otoliths (sagittae). Gonad maturity stages were assigned to males and females using slight modifications (Table 4) of Kesteven's (1960) system cited in Bagenal and Braum (1971). Scale samples were removed with a scalpel from an area near the posterior tip of the pectoral fin below the lateral line and placed in coin envelopes for storage before further preparation. Pectoral fin rays were obtained using a scissors to cut the fin below the base of the rays. Dorsal fin spines and rays were similarly obtained using a scissors after a preliminary sagittal-type cut with a scalpel along either side of the fin. Fin rays were stored in the same coin envelopes as the scales. Otoliths were removed using a knife to make a dorsal-ventral cut on

Table 4. Description of gonad maturity stages assigned to female Atlantic croaker.

Stage	Description
1. Immature	Gonads very small, not yet developing; young fish that have not yet reproduced.
2. Early Developing	Ovaries small but developing, yellowish to orangish; eggs not distinguished easily by naked eye, opaque.
3. Late Developing	Ovaries more developed, yellowish to orangish; eggs easily distinguished by naked eye, all opaque.
4. Gravid	Ovaries near maximum development, yellowish to orangish; <50% of the eggs translucent, most opaque.
5. Ripe	Ovaries at maximum development; pre-spawning; >50% of the eggs translucent; translucent eggs may run freely on pressure if not lost in handling.
6. Spawning/Spent	Ovaries now much smaller than maximum development; spawning and post-spawning; ovaries flaccid and flabby, appear as deflated sacs; may be bloody and contain left-over eggs.
7. Resting	Ovaries very small, fish large enough to have spawned; eggs discharged or not yet developed, not distinguishable to naked eye.

top of the head immediately behind the operculum, then cleaned and stored dry in labeled plastic cell well trays. Some 708 croaker were processed for biological data in 1988 and 811 in 1989. As noted above, in a few instances with small grade fish in 1989, only 100 fish/box were processed for all biological data, though all fish were measured for total length. The 100 fish were the first 100 removed from the box, a non-random process with an unknown, though probably small, degree of bias.

Length frequencies of croaker from pound net collections in 1988 and 1989 were compared against those from trawl collections to evaluate the general size selection properties of these gears and their comparative ability to provide data for management purposes. Trawl data used for comparison, described earlier in Chittenden (1989), were based on the entire catch of croaker -- nearly 25,000 fish -- taken in routine York River trawl monitoring by the Virginia Institute of Marine Science (VIMS) from January-December in the period 1956-1980.

To evaluate the relative magnitudes of within versus among box variation in croaker compositions, and provide an estimate of variation about points in percentage-type data, 24 boxes of medium grade croaker were purchased from a pound net catch of 86 boxes made on the Eastern Shore in mid August 1989. From the total catch, we selected the first and last two boxes processed in the routine commercial sorting/grading operations and every fourth box in between. Each fish in each selected box was measured for length and sexed.

The experimental design to examine within versus among box variation was a one-way, completely randomized analysis of variance (ANOVA). The main objectives were to determine (1) comparative magnitudes of within- versus among-box variation in length and sex-ratio compositions, (2) if there were significant differences in fish mean length or sex ratio between boxes, and (3) if an important trend in fish mean length or sex ratio existed from the start to the completion of the commercial sorting and grading process.

A one-way ANOVA and regression were used with untransformed data to analyze lengths. For sex ratios, sex data were expressed as zeros (male) and ones (female), and a one-way ANOVA and regression was used to test differences between boxes, a procedure more powerful than a Chi-square test (Li, 1964). We calculated 95% confidence limits for the mean proportion of males, following procedures appropriate to cluster sampling using the normal approximation for confidence limits of a ratio (Cochran, 1977; p 64), because the number of fish varied among boxes. Similarly, 95% confidence limits for individual proportions about the mean were calculated by substituting the standard deviation for the standard error. Finally, for general guidance, we used the r_{22} ratio (Dixon and Massey 1969), which assumes a normal distribution and equal sample sizes, to evaluate whether or not one sex ratio was an outlier. The assumptions are probably reasonable approximations, because each ratio was well within the $p = 0.30$-0.70 guidelines for a valid normal approximation to the binomial (Cochran 1977), and each was based on a large sample size ($n \geq 106$), though number of fish/box varied from 106-124.

Data on temporal and spatial distributions consist of 117 regular, on-site personal visits to make an observation of croaker abundance in unloading/sorting operations (Table 3), or telephone calls to the fisheries. For each observation, we logged a general record about the size of the croaker catch. Subsequently, records were ranked into the following categories: 1) none caught, 2) <1 50-lb box caught, 3) >1-5 boxes caught, 4) >5-10 boxes, 5) >10-20 boxes, and 6) >20 boxes. The first category is probably error free in essence, but the others may show some overlap, because the records are general, not exact measurements. However, such error is probably small and should not affect broad temporal/spatial patterns described.

Maturation and spawning periodicity were evaluated using gonad maturity stages and gonadosomatic indexes (GSI). GSI's were calculated as:

$$GSI = (100)\ (GW/TW)$$

where:

GW = gonad weight, and

TW = total body weight

All length measurements presented herein are total length unless stated otherwise, and all length frequencies are moving averages of three.

To prepare scales for aging, five unregenerated scales from each fish were placed in water in a Petri dish for five minutes and then gently brushed with a soft-bristled tooth brush to remove attached epidermal tissue. Three selected scales were then dried and taped (Scotch) to an acetate sheet with their outer surface facing down. The sheet was then inserted between two blank sheets and pressed with a Carver laboratory scale press for two minutes at 6,000 pounds of pressure, and at 160° F temperature. Impressions were read under a dissecting microscope at 7-25 X magnification with transmitted light and bright field. Marks similar to annuli were distinguished by standard criteria (Lagler 1956). Attention was paid to cutting-over of circuli in the lateral field and differential spacing of circuli. Marks were interpreted as true annuli if these characteristics were consistent in the three scales examined per fish.

To prepare fin rays for aging, the largest ray from each fin was used for ease of work, namely, the third spine and third ray from the spiny and soft dorsal fins, respectively, and the fifth ray from the left pectoral. Preliminary observations of sections from different rays indicated no within-fin difference among rays. Fin rays and spines were cleaned of covering tissues and transversely cross-sectioned into two halves. The proximal halves were then mounted with thermoplastic cement on cardboard slips and sectioned with a thin diamond blade using a Buehler low-speed Isomet saw. At least three transverse serial sections, 300-500µ thick, were made on the proximal halves starting at the base of the fin element. Sections were then mounted on labeled microscope slides with Flo-texx clear mounting medium. Markings on the sections appeared as alternating light, opaque bands and dark bands under transmitted light. Opaque marks were interpreted as annuli and read using transmitted light under a dissecting microscope with alternating light and dark field at 45-90 X magnification. Opaque marks were counted as true annuli if they had a distinct optical density difference from surrounding areas, if they could be traced around the entire section, and if their spacing formed a sequence of regularly decreasing increments.

To prepare otoliths for aging, they were attached to cardboard slips with thermoplastic cement, and sectioned using a thin diamond blade on a Buehler low-speed Isomet saw. At least three serial sections, 350-500µ in thickness, were obtained from either the left or right otolith, as randomly selected from each fish. Sections were made through the nuclear region to ensure that at least one section would contain the otolith core. Sections were then mounted on labeled microscope slides with Flo-texx clear mounting medium. Opaque marks were interpreted as annuli and read under a dissecting microscope at 10-20 X magnification with transmitted light and bright field. Some sections were also experimentally stained before mounting, using a technique developed by Bouain and Siau (1988). Opaque marks were counted as true annuli if they had a distinct optical density difference from surrounding areas and if they could be traced within and on either side of the sulcus acusticus.

Croaker otolith internal structure is different from that normally shown in ageing manuals. Since croaker are fall spawners and reach their first winter as young juveniles, a darker than usual nucleus is visible under transmitted light. Annuli are probably formed in the late winter or early spring. Hence, there is a difference between the actual birthdate anniversary and the cohort year class assignment. We counted annuli starting with the first dark band after the edge of the nucleus. A fish classified as age I may actually be slightly older than one year of age.

Two experiments were conducted to develop methods of age determination: 1) a comparison of hard-parts experiment designed to select the best hard part for determining age, and 2) a counting path experiment designed to select for otoliths the best counting path and sectioning plane. In both, "best" was evaluated in terms of ease of reading (a qualitative evaluation) and precision of age estimation (a quantitative evaluation).

Both experiments were arranged as three-way factorials in a completely randomized design. In both experiments, also, specimens on which hard parts were obtained for study were randomly selected in equal numbers from a group of small-grade and a group of large-grade croaker capture in mid August 1988 at Lynnhaven. Sample sizes in each experiment were set so that each had a minimum of about 25 degrees of freedom for error in pre-planned analysis of variance (ANOVA) tables. We used 56 fish for the comparison of hard parts experiment and 40 fish for the counting path experiment.

Factors evaluated in the comparison of hard parts experiments were: 1) type of hard part at five levels (otoliths, scales, pectoral fin rays, dorsal fin rays, and dorsal spines), and 2) independent readings by different hard part readers at two levels (reader A and reader B). Factors evaluated in the otolith counting path experiment were: 1) counting path, or otolith sectioning plane (Fig. 18) at four levels (longitudinal-rostral, longitudinal-post-rostral, transverse-proximal, and oblique-proximal, and 2) hard part reader at two levels (reader A and reader B). The full experiment was not analyzed as a parametric ANOVA because the Kruskal-Wallis non-parametric test (Hollander and Wolfe 1973) was sufficient to analyze the main factor of interest, the hard part comparisons, and differences between readers were minor.

To evaluate the best structure or path, two types of observations were made in each experiment: 1) a quantitative observation, the count of rings or annuli on the hard part, and 2) a qualitative one, the readability of the hard part. Readability was assessed based on a defined set of criteria: 1) ability to follow ring structure throughout the otolith section, 2) clarity of rings, 3) presence or absence of confusing checks or false annuli, 4) distinctiveness of annuli, 5) presence of any "hard-to-read" zones, and 6) agreement between readers. A score system from zero to two was established to measure readability, a low score (1) indicating poor reading quality, a high score (2) indicating good reading quality, and a zero score indicating quality so poor that no age could be assigned. Qualitative data were analyzed using a Kruskal-Wallis test followed by a distribution-free multiple comparison test (Hollander and Wolfe 1973).

Quantitative age data were further analyzed using two different measures of variation: 1) the Index of Average Percent Error (IAPE), the average error in aging each fish expressed as a fraction of the age estimate times 100 (Beamish and Fournier, 1981), and 2) the Coefficient of Variation (CV), expressed as (100) s/y where s is the standard deviation and y the arithmetic mean (Chang, 1982). Relative precision of different hard parts was then obtained from the IAPE and CV results, a high value indicating poor precision and a low value indicating high precision.

A von Bertalanffy growth function was fit to 77 croaker aged in the comparison of hard parts and otolith counting path experiments. The ages were taken from total length-at-age data. The VBGF was fit using the Saila et al. 1988 program FISHPARM which uses nonlinear regression for the fit.

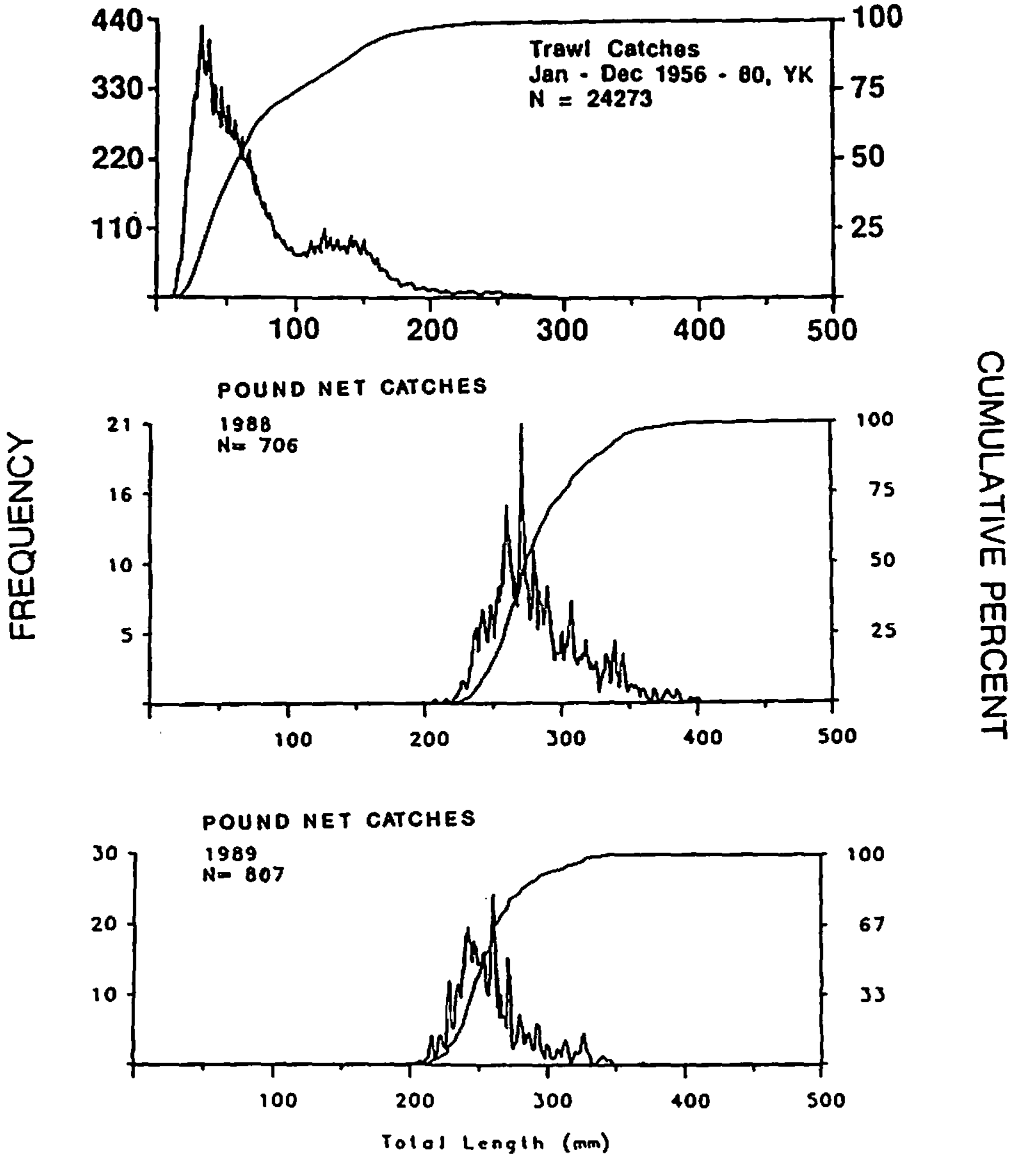
To develop preliminary estimates of maximum age and mortality rates, the six largest specimens collected were aged using otolith sections. These ages were supplemented with maximum ages derived from the other age determination experiments described above. Preliminary maximum age was used to estimate average total annual mortality rate following theory in Royce (1972, pg 238) and Hoenig (1983).

RESULTS

Comparative Size Compositions in Trawl and Pound Net Catches:

Size compositions of croaker in trawl catches are distinctly different from pound net catches graded as foodfish. Trawling captures primarily fish smaller than 200 mm TL (Fig. 3). Relatively few >200 mm were captured in trawling, and they ranged only to some 290 mm in nearly 25,000 specimens measured. Over two years of collections, in contrast, pound nets captured and graded as food no fish smaller than some 200 mm. They ranged to 400 and 369 mm, though only 705 and 807 specimens were collected in the respective years. A

Figure 3. Overall length frequency of Atlantic croaker -- all fish pooled -- in 1988 and 1989 pound net catches and VIMS monthly trawl surveys, 1956-1980.



Trawl Catches
Jan - Dec 1956 - 80, YK
N = 24273
440
330
220
110
100
75
50
25
100
200
300
400
500
POUND NET CATCHES
1988
N= 706
21
16
10
5
100
75
50
25
100
200
300
400
500
POUND NET CATCHES
1989
N= 807
30
20
10
100
67
33
100
200
300
400
500
Total Length (mm)
FREQUENCY
CUMULATIVE PERCENT

large fraction of the pound net catch exceeded 300 mm -- some 10-25% -- depending on year, a size not even captured in some 25 years of York River trawling.

Within vs Among Box Variation in Catch Composition:

There was little difference in length composition among boxes in the processing sequence. Within-box mean lengths varied only from 245 to 253 mm, and standard deviations varied from 12.73 to 20.61; maxima and minima also showed little difference (Table 5, Fig. 4). The small differences in mean length among boxes were not significant (Table 6). However, the more powerful regression of length on box number was significant, primarily due to its quadratic component (Table 6). The non-significant lack-of-fit indicates that linear and quadratic regression components adequately describe any trend, one essentially invisible in a plot of means (Fig. 5).

Among-box variation in length was negligible, as compared to within-box variation. Within-box variation accounted for more than 98% of the total variation in length (Table 6). Among-box variation accounted for only 1.09%.

There was, seemingly, more worrisome variation in sex ratio among boxes in the processing sequence. Within-box sex ratios varied from 40.74% male, which is an outlier at α=0.02, to 66.67% male (Table 5). Ignoring that low value, sex ratios varied from 52.14 to 66.67% male. Sex ratios gradually increased, on average, to a broad maximum in the intermediate boxes, then decreased to end values similar to those in the beginning. Differences in sex ratio among boxes (outlier included) were significant (Table 7), and there was a significant, but mild, curvilinear trend in sex ratio with the processing sequence (Fig. 6). This trend was significant with and without the outlier. The non-significant cubic

Table 5. Sequential summary, by box, of sample sizes, arithmetic mean lengths, and their maxima, minima, variances and standard deviations, and the proportion male.

Sequential Box Number	n	$\bar{y}$	s^2	s	Min	Max	Proportion Male
1	117	248.56	162.05	12.73	223	284	52.14
2	114	249.26	177.08	13.31	223	280	52.63
6	106	252.58	183.87	13.56	222	287	54.72
10	110	249.73	281.14	16.77	220	301	55.45
14	109	249.99	328.25	18.12	211	291	40.74
18	120	248.73	222.64	14.92	212	296	66.67
22	120	247.56	204.92	14.31	220	291	56.67
30	118	249.57	277.62	16.66	215	305	59.32
34	120	245.62	306.36	17.50	205	290	61.67
38	113	247.99	392.63	19.81	212	312	54.87
42	123	247.50	332.29	18.23	212	298	60.16
46	123	246.81	424.76	20.61	211	346	60.98
50	116	246.22	293.91	17.14	212	306	60.34
54	116	247.18	306.64	17.51	211	301	63.79
58	121	248.68	310.51	17.62	207	318	65.29
62	117	247.58	303.93	17.43	216	290	64.96
66	113	249.48	352.71	18.78	207	301	61.06
70	121	244.72	307.76	17.54	211	308	65.29
74	124	245.82	254.15	15.94	215	295	62.90
78	118	249.15	338.87	18.41	210	301	58.47
82	118	248.69	301.55	17.37	211	293	54.24
85	112	251.40	411.10	20.28	201	314	55.36
86	119	245.85	238.05	15.43	214	301	56.30

Figure 4. Length frequencies of medium-grade Atlantic croaker, by box, in pound-net catches along the Eastern Shore after routine sorting and grading.

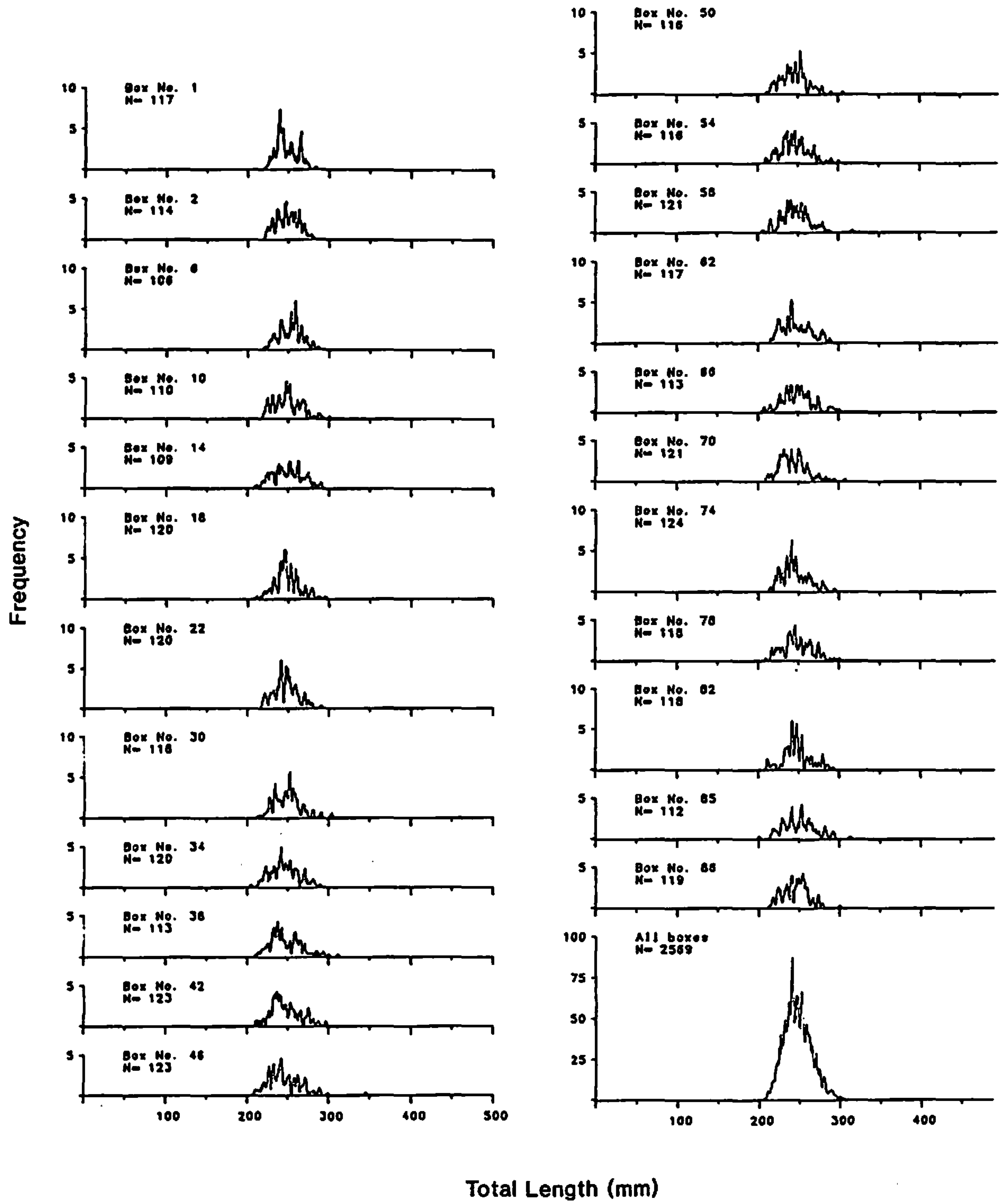

Box No. 1
N= 117
Box No. 2
N= 114
Box No. 6
N= 106
Box No. 10
N= 110
Box No. 14
N= 109
Box No. 18
N= 120
Box No. 22
N= 120
Box No. 30
N= 118
Box No. 34
N= 120
Box No. 38
N= 113
Box No. 42
N= 123
Box No. 46
N= 123
Box No. 50
N= 116
Box No. 54
N= 116
Box No. 58
N= 121
Box No. 62
N= 117
Box No. 66
N= 113
Box No. 70
N= 121
Box No. 74
N= 124
Box No. 78
N= 118
Box No. 82
N= 118
Box No. 85
N= 112
Box No. 86
N= 119
All boxes
N= 2569
Frequency
100
200
300
400
500
Total Length (mm)

Table 6. Summary of analysis of variance of length composition data for pound-net catches of medium grade Atlantic croaker.

Source of Variation	df	SS	MS	F	P Value	Sum of Squares as Percent of Total
Total	2,687	795,664.55				100.00
Among Boxes	22	8,584.19	390.19	1.32	0.14	1.08
Regression	2	2,142.26	1,071.13	3.32	0.02	0.27
Linear	1	777.77	777.77	2.63	0.10	0.10
Quadratic	1	1,364.49	1,364.49	4.62	0.03	0.17
Lack of Fit	20	6,441.93	322.10	1.12	0.65	0.81
Within Boxes	2,665	787,080.47	295.34			98.92

Figure 5. Relationships between mean total length per box of Atlantic croaker and sequence of the box in the commercial processing chronology.

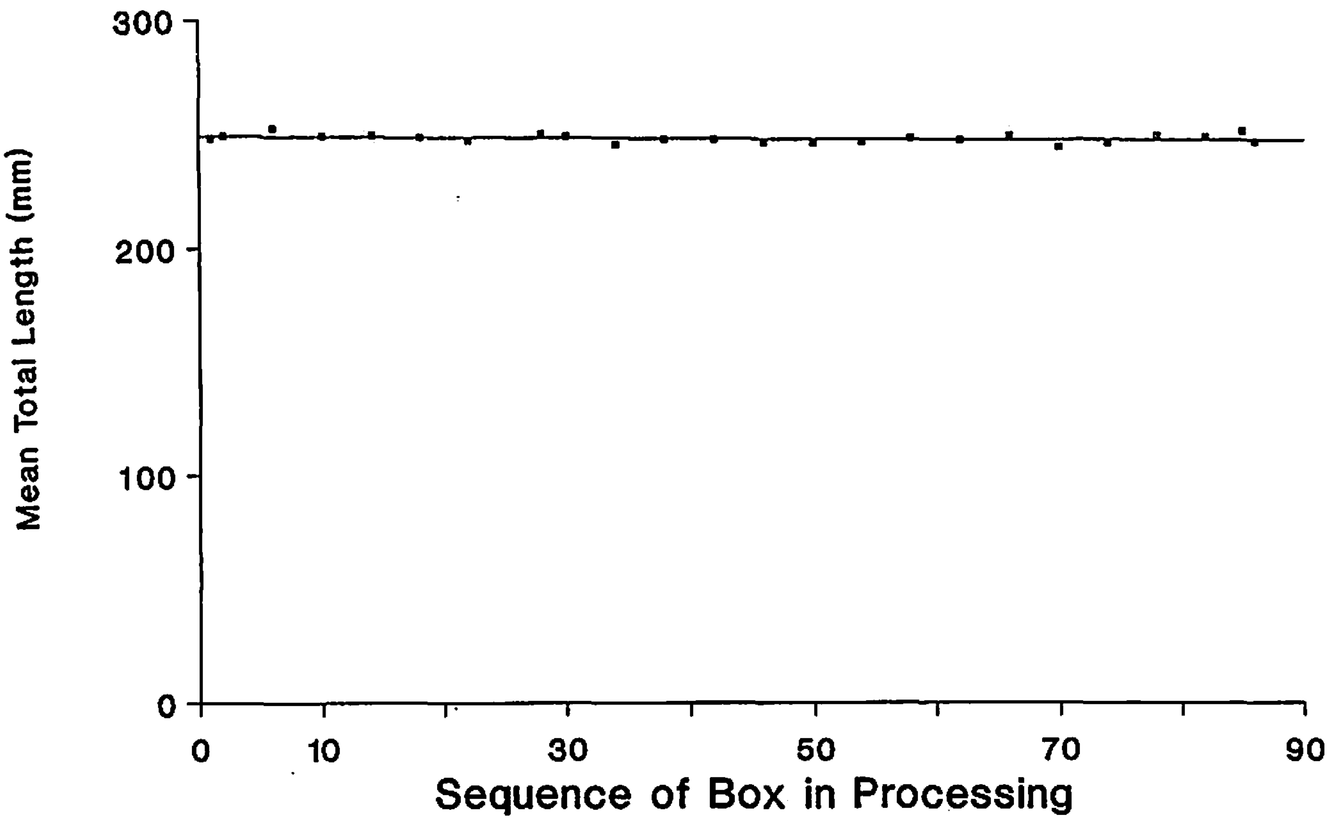
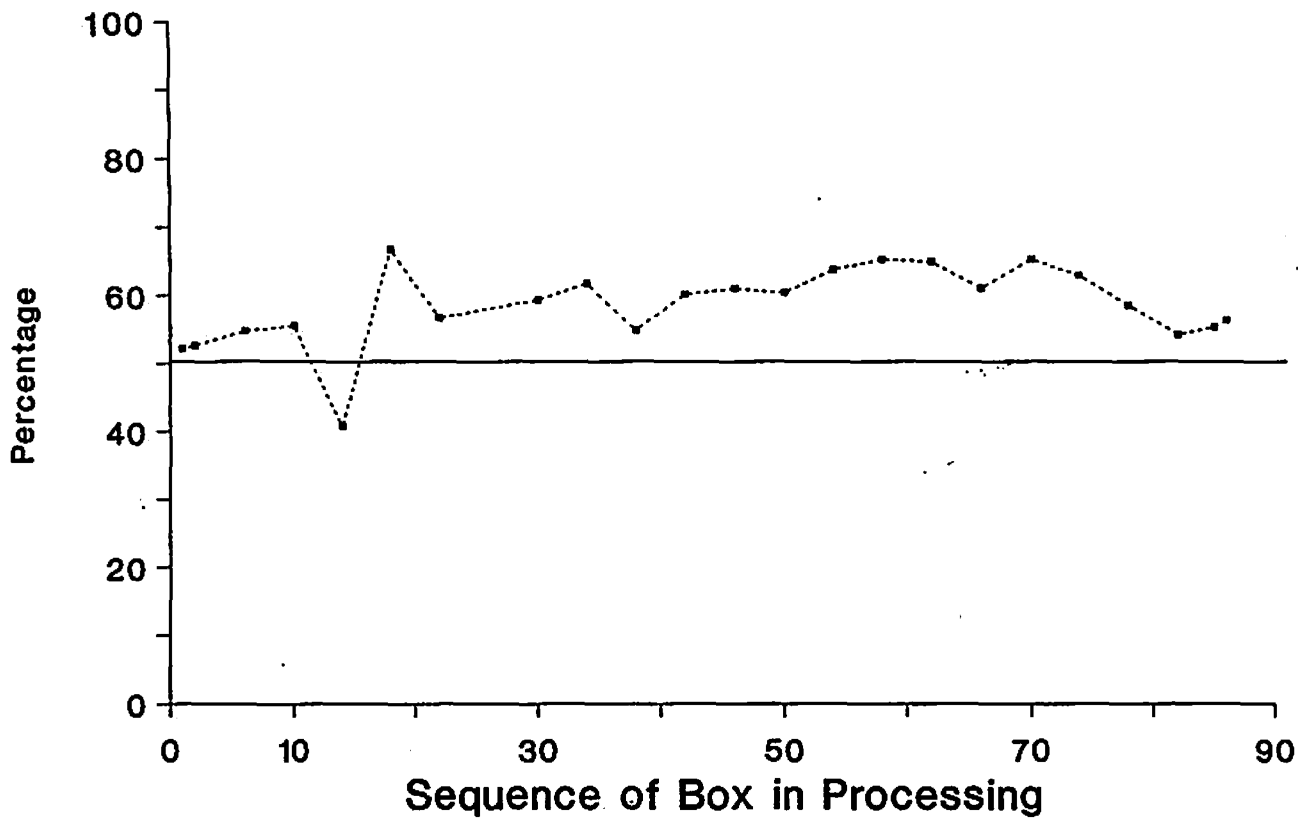

Mean Total Length (mm)
300
200
100
0
0
10
30
50
70
90
Sequence of Box in Processing

Table 7. Summary of analysis of variance of sex ratio data for pound-net catches of medium grade Atlantic croaker.

Source of Variation	df	SS	MS	F	P Value	Sum of Squares as Percent of Total
Total	2,687	651.98				100.00
Among Boxes	22	8.42	0.38	1.58	0.04	1.29
Regression	3	3.82	1.27	5.30	0.001	0.59
Linear	1	1.17	1.17	4.87	0.02	0.18
Quadratic	1	2.12	2.12	8.83	0.001	0.32
Cubic	1	0.53	0.53	2.21	0.14	0.08
Lack of Fit	19	4.60	0.24	1.00	0.74	0.70
Within Boxes	2,665	643.56	0.24			98.71

Figure 6. Relationships between sex ratios per box of Atlantic croaker, expressed as percentage male, and sequence of the box in the commercial processing chronology. A line indicating 50% male is drawn in to facilitate interpretation.


Percentage
100
80
60
40
20
0
0
10
30
50
70
90
Sequence of Box in Processing

component and lack-of-fit indicate that linear and quadratic regression components adequately describe the trend.

The overall percentage male was 59%. Its 95% confidence limits were 57 or 58-61%, as given by p $\pm$ 0.021 or p $\pm$ 0.017, when the outlier was included or excluded, respectively. For individual observations about the overall percentage, 95% confidence limits were 49-69%, as given by p $\pm$ 0.100 when the outlier was included, or 51-67%, as given by p $\pm$ 0.079 when the outlier was excluded.

Among-box variation in sex ratios was negligible, as compared to within-box variation. Within-box variation accounted for more than 98.5% of the total variation in sex ratio (Table 7). Among-box variation accounted for only 1.31%.

Temporal Distribution:

Adult croaker occur in Chesapeake Bay early April - mid October. They first appeared in 1989 on 1 April off Lynnhaven (Fig. 2). We have no records of earlier catches, although we had only three earlier contacts with the fishery. However, the fishermen at Lynnhaven reported those were the first croaker caught that year. In 1988, croaker disappeared from pound net catches after 30 September - 3 October when we recorded a few individuals (<10) at Lynnhaven and the lower York River. We had few contacts with the fishery thereafter, but calls on 14 October recorded no croaker caught at Lynnhaven, lower York River, and the Eastern Shore. This was an accumulated catch at Lynnhaven after several days of bad weather, moreover, and nets were then being removed for the year in the lower York River. In 1989, croaker disappeared from pound net catches after 12 October when we recorded a few individuals at Lynnhaven. Despite repeated contacts, we have no records of later catches.

Temporal abundance patterns of croaker in Chesapeake Bay show spatial variation. Abundance at Lynnhaven showed a distinctly bimodal pattern in 1989 (Fig. 2). Large catches were made there in April and, even more so, in early August - mid September. These periods of large catch were separated by a trough May-July when few or no croaker were caught, except for an episode of large catches in early July. Records in 1988 at Lynnhaven are not as complete. They began on 9 August when some 100 boxes of croaker were caught, a pattern similar to the large August catches in 1989. Few croaker were caught at Lynnhaven after 22 August in 1988. Abundance at Reedville in 1989 showed a uniformly low level from mid April, when fishing began, through late September, when they disappeared. Patterns in the lower York River in 1989 were generally similar to those at Reedville. Along the Eastern Shore in 1989, no croaker were recorded in mid April and most of May despite repeated contacts. Croaker first appeared there at the end of May, and catches remained at a uniformly low level until late July - early August when very large catches were made, apparently in episodes. Records in 1988 are very incomplete for the Eastern Shore, but catches of several hundred boxes per day were made about 23-24 August. Similarly, about early - mid August in 1985 Chittenden witnessed an enormous catch at that fishery that took several days to process -- some 1,000 boxes.

Spatial Distribution:

Adult croaker, seemingly, become widely distributed in summer throughout Virginia waters of the mainstem Chesapeake. Croaker were regularly captured in summer at Reedville, the lower York River, Lynnhaven, and along the Eastern Shore (Fig. 2).

The summer distribution of adult croaker in the Chesapeake is not clear from the present data. Catches were regularly low at Lynnhaven in May and June and along the lower Eastern Shore in June and July (Fig. 2). Catches were uniformly low at Reedville throughout the spring and summer and, seemingly, in the lower York River. However, little data are available from the York River from late April - early July and from mid July - late August.

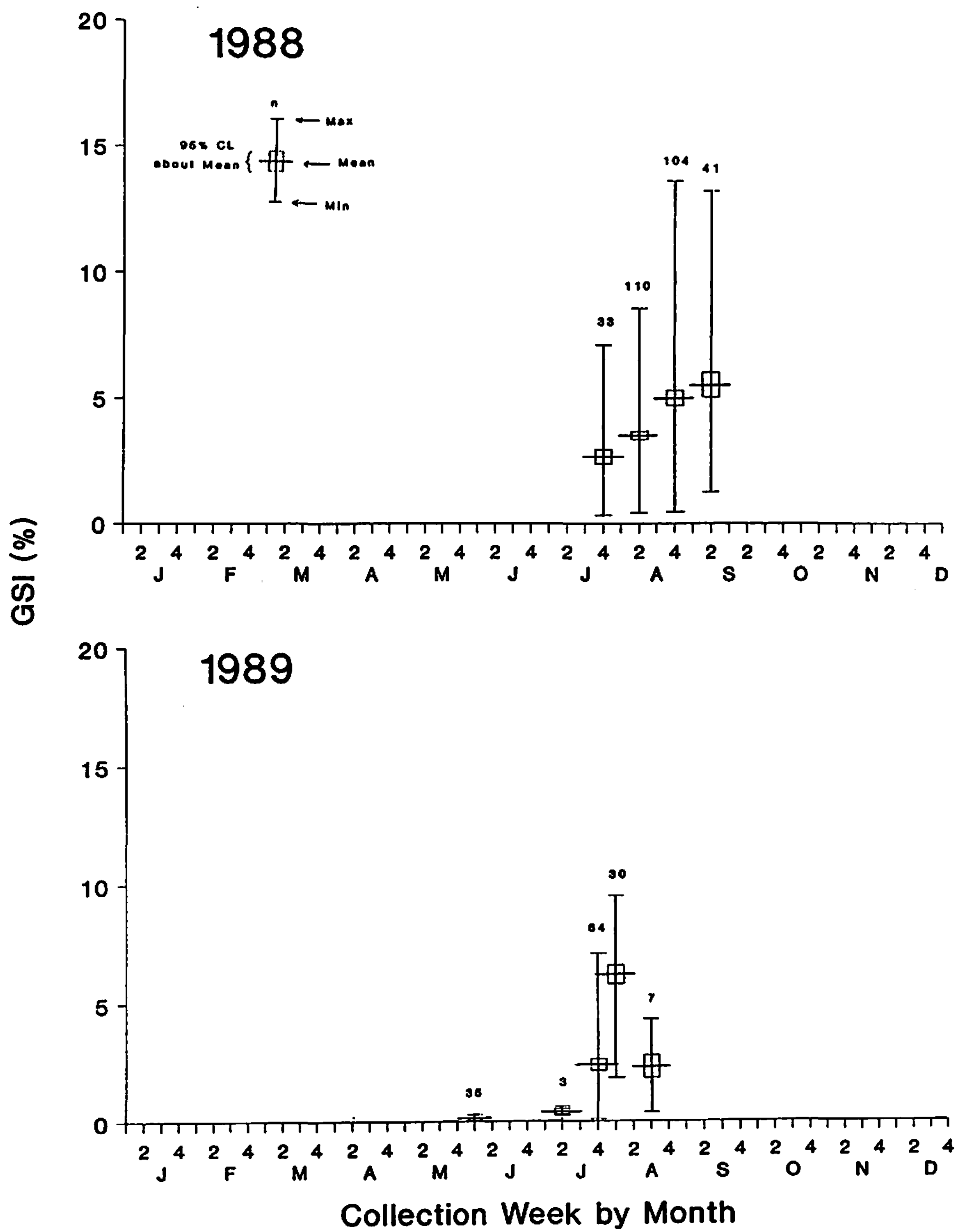
Spawning Periodicity:

Spawning periodicity is not yet fully clear, because we have not been able to obtain in any one year a comprehensive time series of specimens over the April - September period when adult croaker occur in the Chesapeake. Some patterns are clear, however.

Adult croaker do not approach spawning condition in the period April - early or mid July. Mean and maximum GSI values, and GSI ranges, were low for both males and females in early April, early June, and through the second week of July in 1989, the only year we were able to collect specimens in spring and early summer (Fig. 7, 8). Maximum GSI values never exceeded some 1 - 2% in that period. Females were primarily (>80%) in the Immature and Resting stages in early June and in the second week of July in 1989 (Fig. 9). Few females were then in the Late Developing stage.

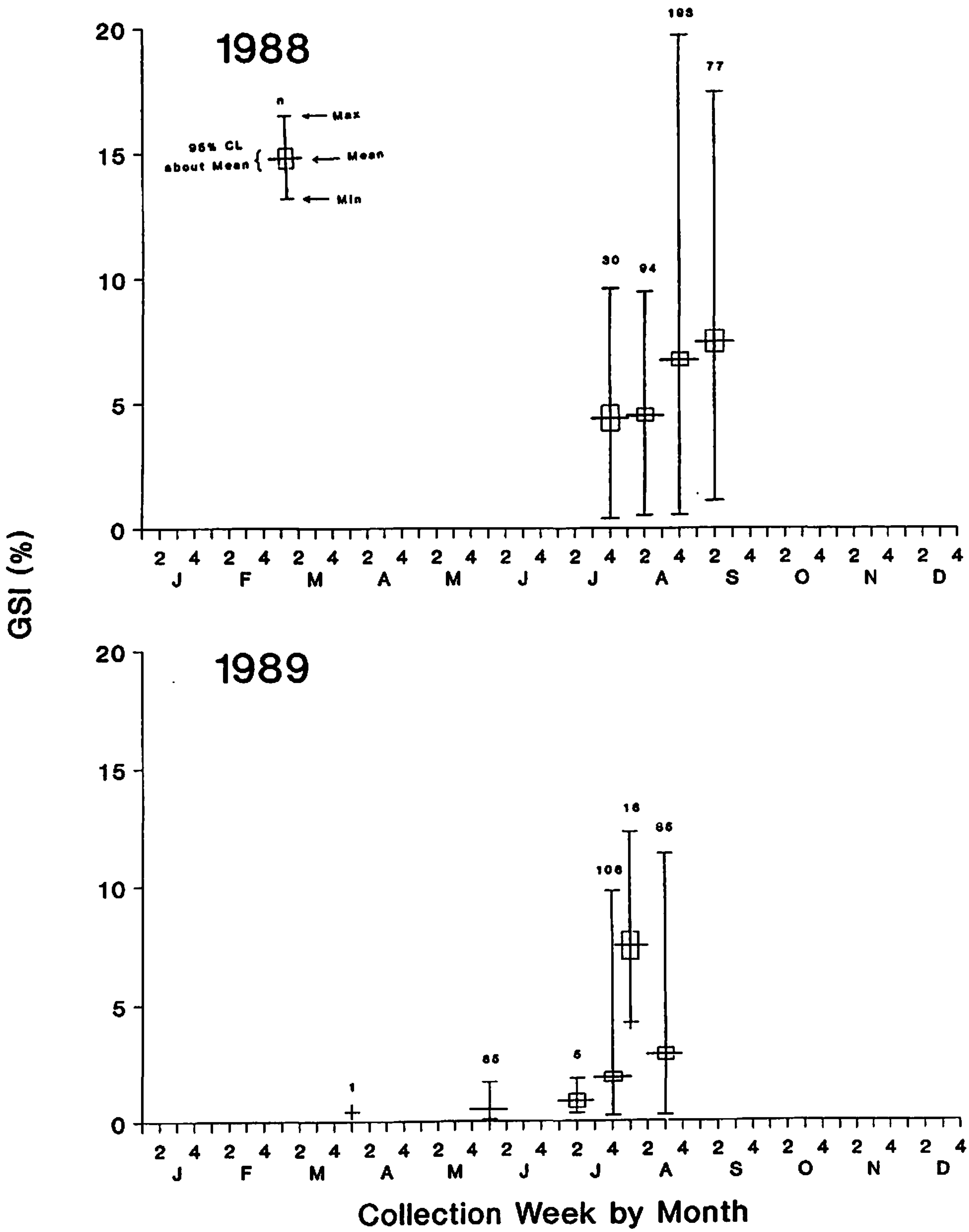
Adult croaker rapidly begin to mature after mid July. Mean and maximum GSI values, and GSI ranges, for males rapidly increased in late July and early August of 1989 from prior low values (Fig. 7), though, in a small sample, they declined in late August from their previous high point. Maximum GSI values for males rose from some 1% in mid July to 7-10% in late July and early August in 1989. Similar patterns in male GSI values and ranges occurred in 1988. Maximum male GSI values were some 7-13% in late July and early

Figure 7. Temporal patterns of gonadosomatic index (GSI) values in male Atlantic croaker in 1988 and 1989.



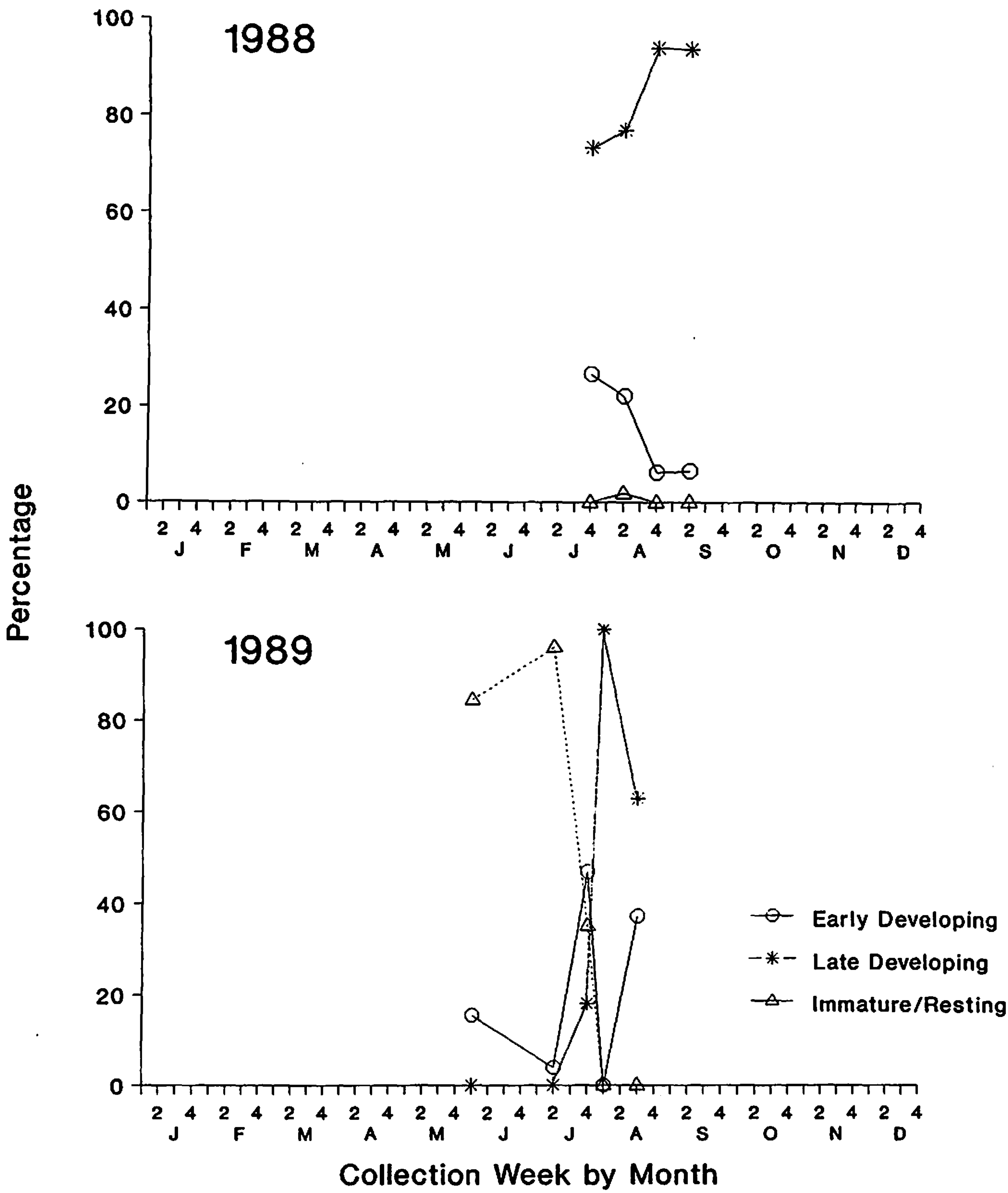
1988
1989
GSI (%)
Collection Week by Month
n
Max
95% CL about Mean
Mean
Min
33
110
104
41
35
3
64
30
7
J F M A M J J A S O N D

Figure 8. Temporal patterns of gonadosomatic index (GSI) values in female Atlantic croaker in 1988 and 1989.



1988
1989
GSI (%)
95% CL about Mean
Max
Mean
Min
n
193
77
30
94
16
85
106
65
5
1
20
15
10
5
0
2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4
J F M A M J J A S O N D
Collection Week by Month

Figure 9. Temporal patterns of percentage in each maturity stage for female Atlantic croaker in 1988 and 1989.


1988
1989
Percentage
100
80
60
40
20
0
2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4
J F M A M J J A S O N D
Early Developing
Late Developing
Immature/Resting
Collection Week by Month

August of 1988, though earlier values are not available for comparison. In females for 1989, maximum GSI values and GSI ranges, and means to a lesser extent, rapidly increased in late July and early August from prior low values (Fig. 8), though means, at least, then declined in late August from their previous high point. Maximum GSI values for females rose from some 3% in the second week of July to some 10-13% in late July and early August in that year. Similar patterns in female GSI values and ranges occurred in 1988. Maximum female GSI values were some 10-20% in late July - late August of 1988, though earlier values are not available for comparison. Females were primarily (60-100%) in the Late Developing stage in early and late August in 1989 (Fig. 9). Few females were then in the Immature and Resting stages. Similar maturity stage patterns occurred in females late July - early September in 1988 (Fig. 9).

No adult female croaker collected in the Chesapeake were ready to spawn. No females were assigned to Gravid or Ripe stages in either 1988 or 1989.

Size Compositions:

Overall observed croaker length compositions varied between years. The minimum sizes captured were similar between years at 200-207 mm (Fig. 3, Table 8), a phenomenon that probably reflects the commercial grading process. Maximum and mean sizes observed were generally larger in 1988 than in 1989. Mean sizes were 280.9 mm in 1988 and 258.8 mm in 1989. A comparatively large fraction of the observed catch -- 25% -- was greater than 300 mm in 1988 and many fish exceeded 350 mm. A comparatively small fraction -- 9% -- was greater than 300 mm in 1989 and few fish exceeded 350 mm. The most important size ranges observed were about 230-330 mm in 1988 and 220-270 in 1989. On a size-specific

Table 8. Descriptive statistics summarizing overall length compositions of all Atlantic croaker collected by year.

Statistic	1988	1989
n	705	807
mean	281.3	258.8
median	293	268
mode	270	260
Max.	400	369
Min.	207	200
s^2	1068.86	700.62
s	32.69	26.47
$\sqrt{s^2/n}$	1.25	0.94
95% CL$\bar{y}$	278.3-283.7	257.0-260.6
95% CLy	217.1-345.5	206.9-310.8
l_L (99.5%)	383	342
l_L (99%)	377	338

basis (Table 9), the most important 10-mm length intervals were in the range 250-269 mm in 1988, each interval in that range making up 10% or more of the observed catch. The most important intervals were 230-269 mm in 1989, each interval in that range making up 10% or more of the observed catch.

Typical maximum sizes (l_L) were smaller than the observed maxima and both varied between years. Values for l_L (99-99.5%) were 377-383 mm in 1988 and 338-342 mm in 1989 (Table 8). These values are some 17-23 and 27-31 mm smaller than observed maxima of 400 and 369 mm in 1988 and 1989, respectively. Values of l_L based on collections of large croaker only might be considered upper reasonable values. Such values were 385-394 mm in 1988 and 345-368 in 1989 (Table 10).

Observed length compositions generally showed an expected progression in size from small to large grades, but there was considerable overlap between grades. Small and medium croaker were less than 300 mm in length with few exceptions (Fig. 10, 11). They generally ranged from 200-300 mm in both grades with modal sizes usually being near 250 mm. There was much overlap between small and medium grades each year. Large croaker exceeded 250 mm with few exceptions (Table 10) and a large fraction of them -- usually some 50% or more -- exceeded 300 mm at least.

Croaker size compositions observed within-grades show considerable variation between collections. In 1988, large grade croaker on 9 August were much smaller than large grades in the other collections (Fig. 10, Table 11). In 1989, small grade croaker were generally larger in the last collection than in the earliest two (Fig. 11, Table 11). Medium grade croaker showed a decrease in size with time in 1989, and large grade croaker that year were considerably larger in the first collection.

Table 9. Size-specific length compositions of the observed overall Atlantic croaker catch in 1988 and 1989.

	1988		1989	
Length Interval	n	Percent	n	Percent
200-209	1	1.14	4	0.49
210-219	1	1.14	16	1.99
220-229	10	1.41	54	6.69
230-239	33	4.66	99	12.27
240-249	60	8.47	166	20.57
250-259	82	11.58	132	16.36
260-269	93	13.13	118	14.63
270-279	113	15.96	69	8.56
280-289	79	11.16	45	5.58
290-299	49	6.32	28	3.47
300-309	53	6.49	19	2.35
310-319	35	4.74	19	2.35
320-329	22	3.11	25	3.09
330-339	29	4.01	6	0.74
340-349	21	2.86	6	0.74
350-359	10	1.41	--	--
360-369	7	0.99	1	0.12
370-379	4	0.57	--	--
380-389	4	0.57	--	--
390-399	2	0.28	--	--
400 +	--	--	--	--
Totals	708	100	807	100

Table 10. Descriptive statistics summarizing overall length compositions of all large-grade Atlantic croaker collected by year.

Statistic	1988	1989
n	289	117
mean	306.9	305.9
median	310	306
mode	307	293
Max.	400	369
Min.	245	265
s^2	917.40	465.95
s	30.29	21.59
$\sqrt{s^2/n}$	1.82	2.03
95% CL$\bar{y}$	303.3-310.4	301.8-309.9
95% CLy	247.3-366.5	263.11-348.6
l_L (99.5%)	394	368
l_L (99%)	385	345

Figure 10. Within-grade chronological length frequencies of Atlantic croaker collected in 1988.

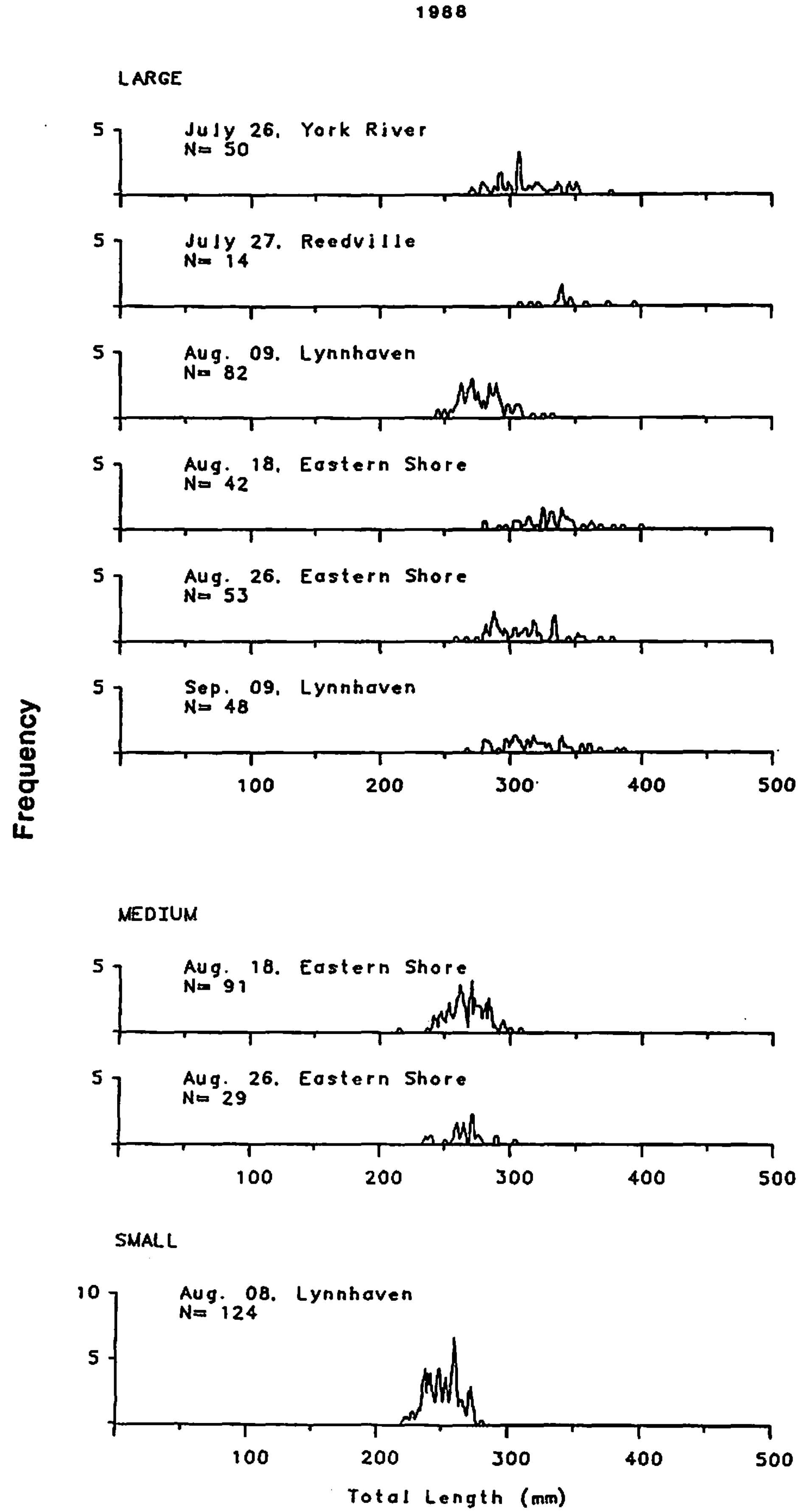

1988
LARGE
July 26, York River
N= 50
July 27, Reedville
N= 14
Aug. 09, Lynnhaven
N= 82
Aug. 18, Eastern Shore
N= 42
Aug. 26, Eastern Shore
N= 53
Sep. 09, Lynnhaven
N= 48
Frequency
MEDIUM
Aug. 18, Eastern Shore
N= 91
Aug. 26, Eastern Shore
N= 29
SMALL
Aug. 08, Lynnhaven
N= 124
5
10
100
200
300
400
500
Total Length (mm)

Figure 11. Within-grade chronological length frequencies of Atlantic croaker collected in 1989. HS indicates haul seine collections.

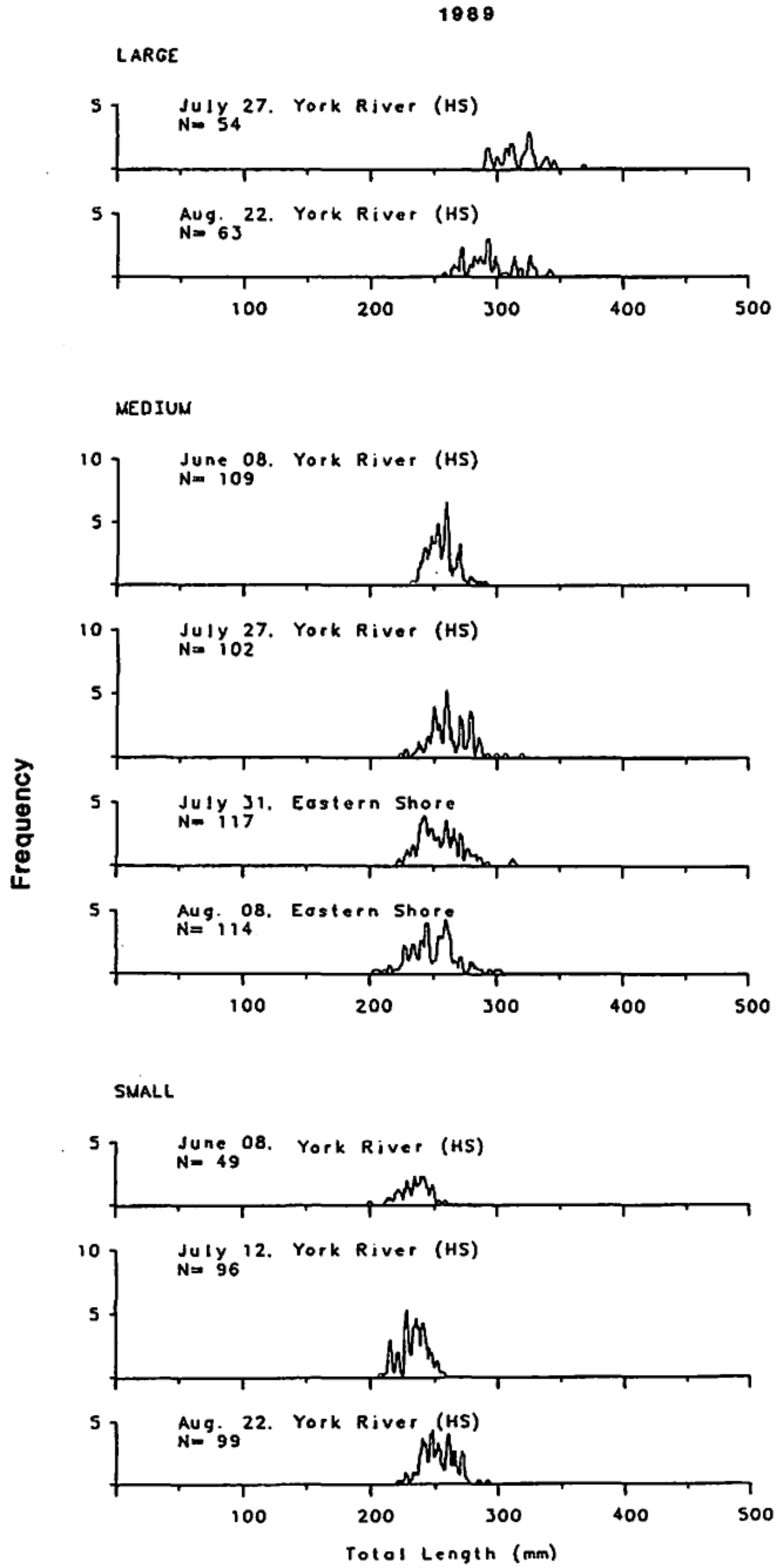

1989
LARGE
July 27. York River (HS)
N= 54
Aug. 22. York River (HS)
N= 63
MEDIUM
June 08. York River (HS)
N= 109
July 27. York River (HS)
N= 102
July 31. Eastern Shore
N= 117
Aug. 08. Eastern Shore
N= 114
SMALL
June 08. York River (HS)
N= 49
July 12. York River (HS)
N= 96
Aug. 22. York River (HS)
N= 99
Frequency
Total Length (mm)

Table 11. Descriptive statistics summarizing length composition by grade of individual Atlantic croaker collections.

Collection Date	Location	n	$\bar{y}$	s^2	Min	Max	95% CL$\bar{y}$	95% CLy
				LARGE				
1988								
Jul 26	York River	50	309.8	489.1	270	352	303.3-316.1	265.3-342.2
Jul 27	Reedville	14	344.3	545.9	308	395	329.5-359.1	292.9-395.7
Aug 9	Lynnhaven	82	279.1	312.6	245	333	275.1-283.0	243.9-314.2
Aug 18	E. Shore	42	329.8	621.9	281	400	321.9-337.8	279.4-380.3
Aug 26	E. Shore	54	310.5	664.2	259	378	303.3-317.7	258.7-362.2
Sep 9	Lynnhaven	48	318.5	775.6	267	386	310.2-326.7	262.4-374.6
1989								
Jul 27	York River	54	317.9	268.9	291	369	313.4-322.4	285.0-350.8
Aug 22	York River	63	295.6	408.3	265	343	290.4-300.7	255.2-336.0
				MEDIUM				
1988								
Aug 18	E. Shore	91	267.7	211.6	237	308	264.6-270.7	238.8-296.6
Aug 26	E. Shore	30	264.6	249.7	235	304	258.3-270.8	232.1-297.0
1989								
Jun 8	York River	109	255.9	111.8	233	287	253.9-258.0	235.0-276.9
Jul 27	York River	102	262.1	276.1	224	320	258.8-265.4	229.1-295.0
Jul 31	E. Shore	117	254.9	267.1	224	314	251.9-257.9	222.6-287.3
Aug 8	E. Shore	115	250.3	342.8	204	303	246.8-253.7	213.6-286.9

Continuation of Table 11

				SMALL				
1988								
Aug 8	Lynnhaven	124	251.5	167.71	221	281	249.2-253.8	225.9-277.1
1989								
Jun 8	York River	49	234.9	136.3	200	259	231.5-238.3	211.4-258.4
Jul 12	York River	96	234.1	110.1	208	257	231.9-236.2	213.2-254.9
Aug 22	York River	99	253.2	161.1	226	292	250.7-255.7	228.0-278.4
				MIXED				
1988								
Jul 7	E. Shore	16	281.1	633.9	241	329	266.6-295.6	226.7-335.5
Aug 23	York River	85	264.8	838.2	207	384	258.5-271.1	207.2-322.4
Sep 9	Lynnhaven	72	273.3	1063.3	207	317	265.5-281.1	208.2-338.3
1989								
Jul 24	Reedville	4	309.5	364.5	296	323	137.9-481.0	66.9-552.0

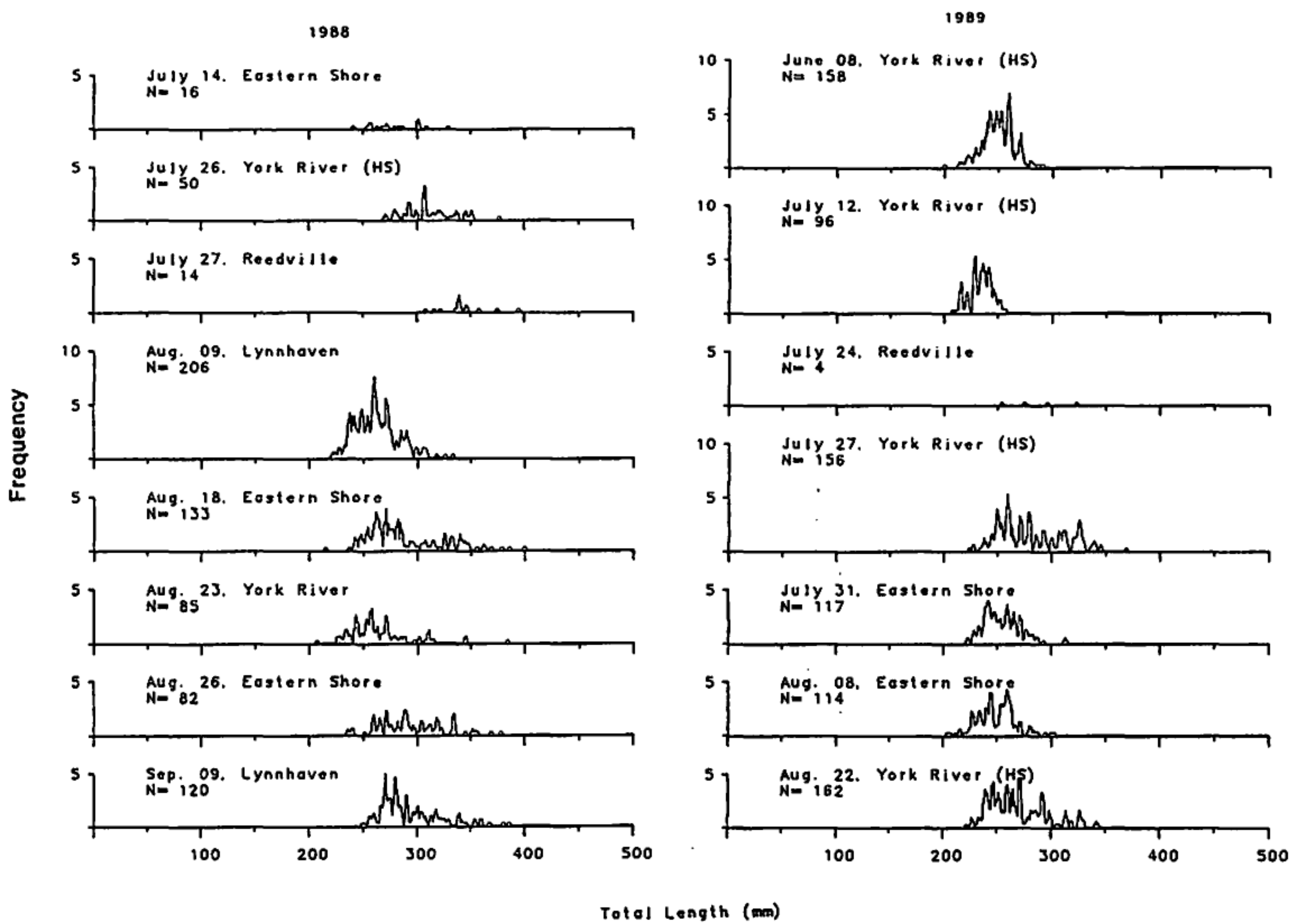
Observed croaker size compositions are plotted by date in Figure 12, and their supporting descriptive statistics are presented in Table 12.

Sex Ratios:

Overall croaker sex ratios were 42.7% and 37.2% male in 1988 and 1989 among 689 and 575 specimens regularly collected and sexed in those respective years (Table 13). Temporal trends in croaker sex ratios, seemingly, varied between years. In 1988, the percentage male was highest (some 55%) in an early period -- late July - early August -- when collections began and declined thereafter to much lower values (some 37%) in a later period -- late August - mid September (Fig. 13). The change in sex ratios occurred in a brief period of time -- between collections in the second and fourth week of August. The change, seemingly, does not represent a spatial change in areas where data were collected, because collections were made at Lynnhaven and the lower York River in both the early and late periods (Table 1, 2). In 1989, in contrast, no simple temporal pattern is clear (Fig. 13). Sex ratios in that year remained more or less stable at some 40-48% male from early June through late July. Subsequently, the sex ratio rose abruptly to some 65% male in a collection along the Eastern Shore in early August, then declined abruptly to only some 9.5% male in late August.

Croaker sex ratios appear more or less linearly related to size, there being a general decline in the percentage male with increasing length. Sex ratios in both 1988 and 1989 showed much variation, or very extreme values, at the smallest and largest sizes (Fig. 14), variation that reflects very small sample sizes in these length ranges. Sandwiched between the smallest and largest length ranges is an intermediate size range -- some 220-300+ mm --

Figure 12. Length-frequencies of Atlantic croaker by date, 1988 and 1989. HS indicates haul seine collections.



1988
July 14. Eastern Shore
N= 16
July 26. York River (HS)
N= 50
July 27. Reedville
N= 14
Aug. 09. Lynnhaven
N= 206
Aug. 18. Eastern Shore
N= 133
Aug. 23. York River
N= 85
Aug. 26. Eastern Shore
N= 82
Sep. 09. Lynnhaven
N= 120
1989
June 08. York River (HS)
N= 158
July 12. York River (HS)
N= 96
July 24. Reedville
N= 4
July 27. York River (HS)
N= 156
July 31. Eastern Shore
N= 117
Aug. 08. Eastern Shore
N= 114
Aug. 22. York River (HS)
N= 162
Frequency
Total Length (mm)

Table 12. Descriptive statistics summarizing length compositions of Atlantic croaker collections in 1988 and 1989. Grades are Mx, Mixed; L, Large; S, Small; and M, Medium.

Collection Date	Location	Grade	n	$\bar{y}$	s^2	Min	Max	95% CL$\bar{y}$	95% CLy
1988									
Jul 7	E. Shore	Mx	16	281.1	634.0	241	329	266.6-295.6	226.7-335.5
Jul 26	York River	L	50	309.7	489.1	270	352	303.3-316.1	265.3-354.2
Jul 27	Reedville	L	14	344.3	545.9	308	395	329.5-359.1	292.9-395.7
Aug 9	Lynnhaven	S, L	206	262.2	408.3	221	333	259.4-264.9	222.3-302.0
Aug 18	E. Shore	M, L	133	286.2	1196.6	215	400	280.2-292.1	217.2-354.6
Aug 23	York River	Mx	85	264.8	838.2	207	384	258.5-271.1	207.2-322.4
Aug 26	E. Shore	M, L	84	293.9	986.7	235	378	286.9-300.9	231.4-356.4
Sep 9	Lynnhaven	L, Mx	120	293.9	818.6	249	386	288.6-299.1	218.9-368.8
1989									
Jun 8	York River	S, M	158	249.2	215.4	200	287	246.9-251.5	220.2-278.2
Jul 12	York River	S	96	234.1	110.1	208	257	231.9-236.2	213.2-254.9
Jul 24	Reedville	Mx	4	309.5	364.5	296	323	137.9-481.0	66.9-552.0
Jul 27	York River	M, L	156	281.6	969.8	224	369	276.6-286.5	220.1-343.1
Jul 31	E. Shore	Mx	117	254.9	267.1	224	314	251.9-257.9	222.6-287.3
Aug 8	E. Shore	Mx	114	250.3	342.8	204	303	246.8-253.7	213.6-286.9
Aug 22	York River	S, L	162	269.0	696.2	222	343	264.9-273.1	216.9-321.1

Table 13. Sex ratio data for Atlantic croaker by week, 1988-1989, giving weekly numbers in each sex and overall percentages by year.

Week	Male	Female	Total
		1988	
07/04	34	30	64
08/02	111	95	206
08/04	107	193	300
09/02	42	77	119
Total	294	395	689
Overall Percentage	42.7	57.3	--
		1989	
04/01	1	0	1
06/01	61	97	158
07/02	45	51	96
07/04	67	111	178
08/01	31	15	47
08/03	9	86	95
Total	214	361	575
Overall Percentage	37.2	62.8	--

Figure 13. Temporal patterns of sex ratios in Atlantic croaker, expressed as percentage male, in 1988 and 1989. Sample sizes are indicated above each box.

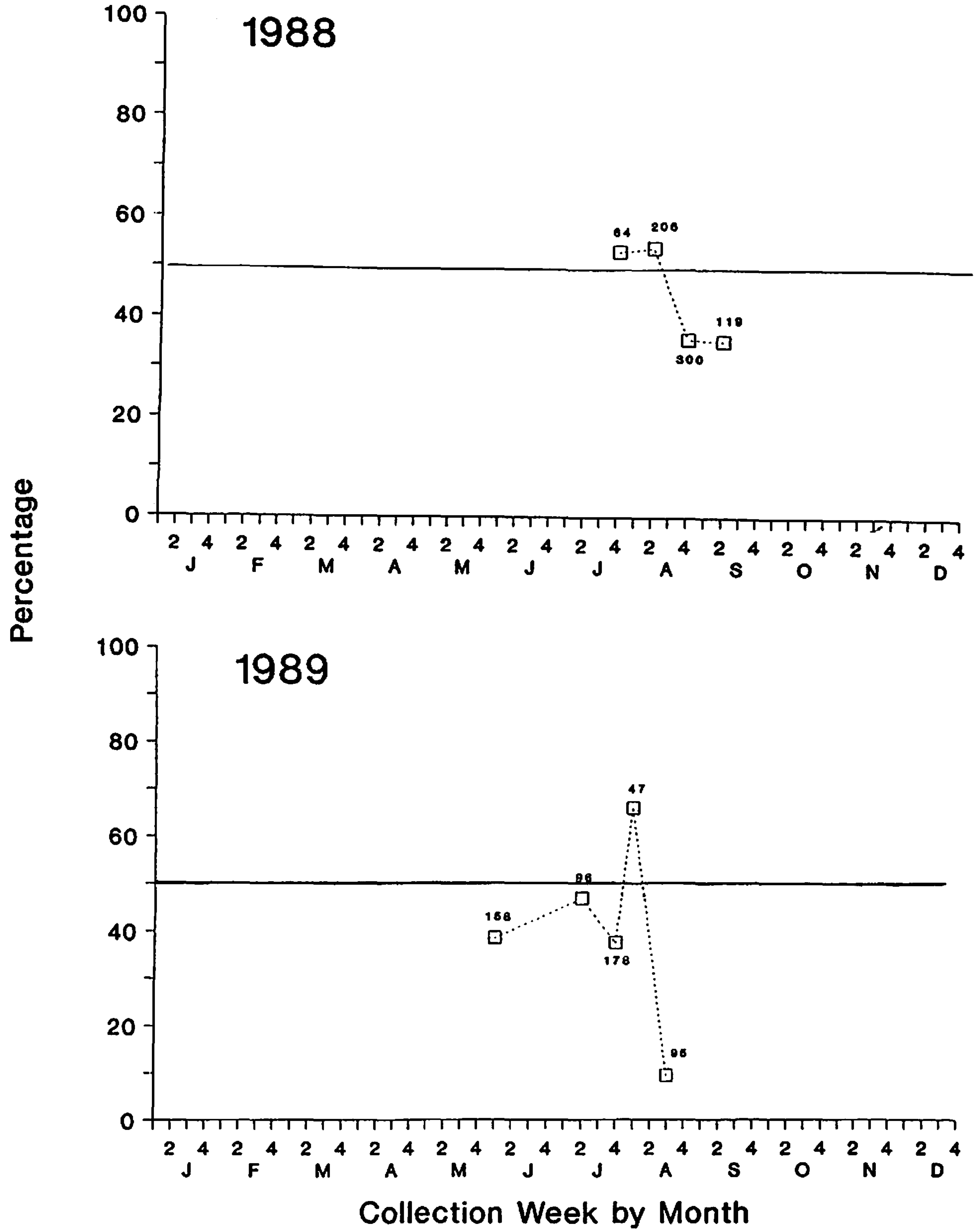
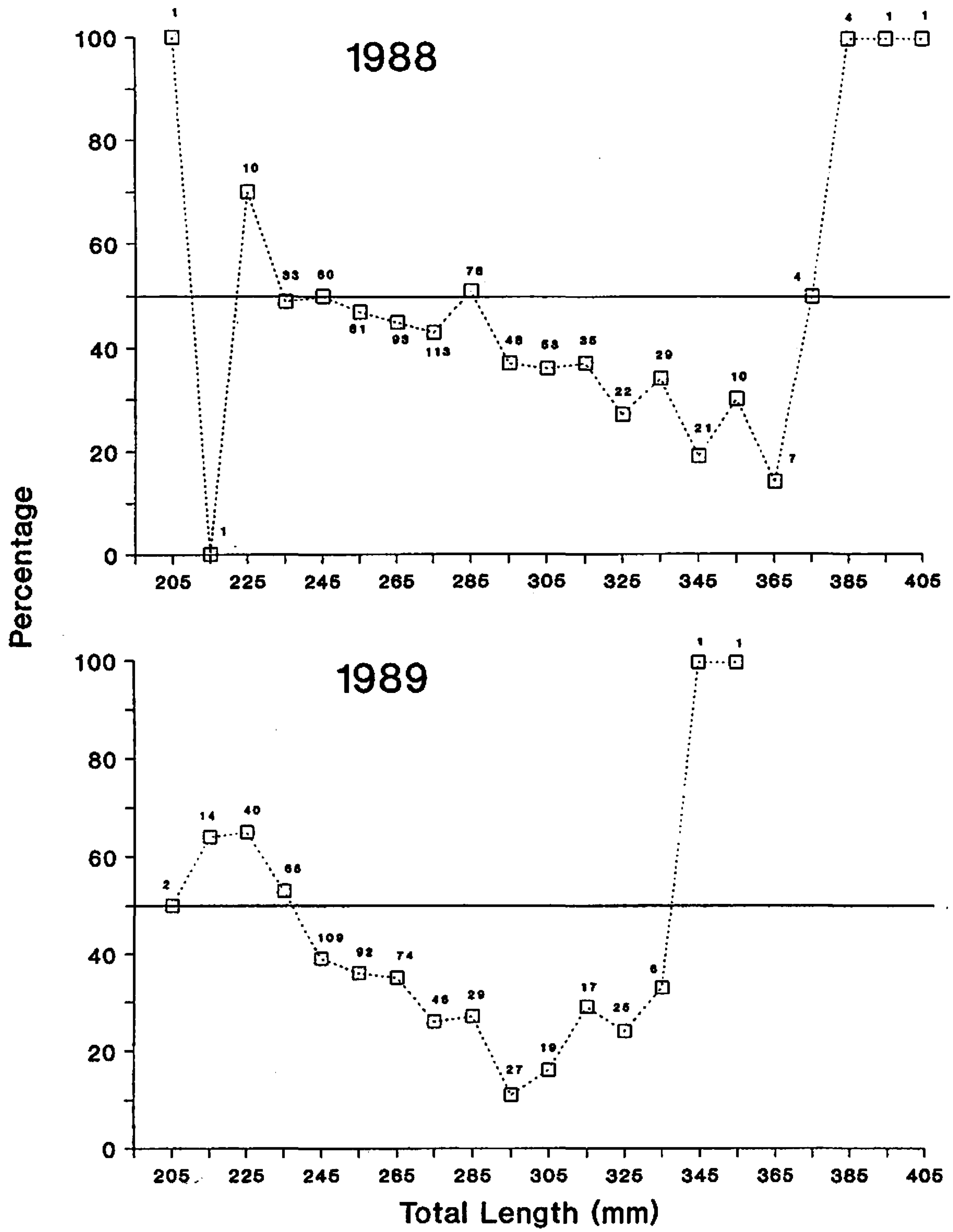

1988
1989
Percentage
100
80
60
40
20
0
64
206
300
119
158
96
178
47
95
2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4
J F M A M J J A S O N D
Collection Week by Month

Figure 14. Sex ratios of Atlantic croaker by 10-mm size interval, expressed as percentage male, in 1988 and 1989. Sample sizes are indicated above each box.


1988
1989
Percentage
Total Length (mm)
0
20
40
60
80
100
205
225
245
265
285
305
325
345
365
385
405

in which data are based on larger sample sizes (n > 10). Size-specific sex ratios in this intermediate size range showed a distinct more or less linear decrease in the percentage male with increasing size in both 1988 and 1989. Sex ratio in that range declined from some 50% male at 235 mm to some 15% male at 365 mm in 1988, and from some 65% male at 215-225 mm to some 12% male at 295-305 mm in 1989 (Fig. 14, Table 14). The sex ratio trend in 1989 showed an increasing percentage female at lengths greater than 295 mm. This trend, one based on reasonably large sample sizes, did not appear in 1988.

The largest croaker apparently tend to be females. Though the sample sizes in individual collections are very small (n = some 1-4), the very largest fish -- >375 mm in 1988 and > 335 mm in 1989 -- were all females (Fig. 14). That pattern may reflect a general continuation of the trend in 1989 in which the percentage female increased progressively at sizes greater than 295 mm.

Size at Maturity:

Maturity stage patterns in overall female croaker catches varied between years due to differences in collection periods. In 1988, a very large fraction of the females -- 88.12% -- were in the Late Developing stage, and very few -- <1% -- were in the Immature or Resting stages (Table 15). In contrast, in 1989, most fish -- 47.24% -- were in the Immature or Resting stages, and only 24.86% were in the Late Developing stage.

Larger, presumably older, female croaker appear to mature first as the spawning season approaches. The percentage of females in the Late Developing and Early Developing stages in 1988, and for fish collected in August of 1989, showed much variation, or very extreme values, at the smallest and largest sizes (Fig. 15, 16; Table 16, 17), variation that

Table 14. Overall size-specific sex ratios of the observed overall catch of Atlantic croaker in 1988 and 1989.

Length Interval	Total	Number Male	Percent Male	Number Female	Percent Female
			1988		
200-209	1	1	100.0	0	0.0
210-219	1	0	0.0	1	100.0
220-229	10	7	70.0	3	30.0
230-239	33	16	48.5	17	51.5
240-249	60	30	50.0	30	50.0
250-259	81	38	46.9	43	53.1
260-269	93	42	45.2	51	54.8
270-279	113	49	43.4	64	56.6
280-289	78	40	51.3	38	48.7
290-299	48	18	37.5	30	62.5
300-309	53	19	35.8	34	64.2
310-319	35	13	37.1	22	62.9
320-329	22	6	27.3	16	72.7
330-339	29	10	34.5	19	65.5
340-349	21	4	19.0	17	81.0
350-359	10	3	30.0	7	70.0
360-369	7	1	14.3	6	85.7
370-379	4	2	50.0	2	50.0
380-389	4	0	0.0	4	100.0
390-399	1	1	100.0	0	0.0
400-409	1	1	100.0	0	0.0
			1989		
200-209	2	1	50.0	1	50.0
210-219	14	9	64.3	5	35.7
220-229	40	26	65.0	14	35.0
230-239	68	36	52.9	32	47.1
240-249	109	43	39.4	66	60.6
250-259	92	33	35.9	59	64.1
260-269	74	26	35.1	48	64.9
270-279	46	12	26.1	34	73.9
280-289	29	8	27.6	21	72.4
290-299	27	3	11.1	24	88.9
300-309	19	3	15.8	16	84.2
310-319	17	5	29.4	12	70.6
320-329	25	6	24.0	19	76.0
330-339	6	2	33.3	4	66.7
340-349	6	0	0.0	6	100.0
350-359	--	--	--	--	--
360-369	1	0	0.0	1	100.0
400+	0	0	0.0	0	0.0

Table 15. Percentage compositions of the observed overall Atlantic croaker catch, for females by maturity stage, in 1988 and 1989 and for August, 1989. Maturity stages are defined in Table 4. No Gravid, Ripe, or Spawning/Spent Stage fish were observed.

Maturity Stage	1988 n	1988 Percent	1989 n	1989 Percent	August, 1989 n	August, 1989 Percent
Late Developing	356	88.12	90	24.86	70	68.63
Early Developing	47	11.63	101	27.90	32	31.37
Immature and Resting	1	0.25	171	47.24	0	0.00
Total	404	100.00	362	100.00	102	100.00

Figure 15. Patterns of percentage in each maturity stage for female Atlantic croaker by 10-mm size intervals in 1988 and 1989.

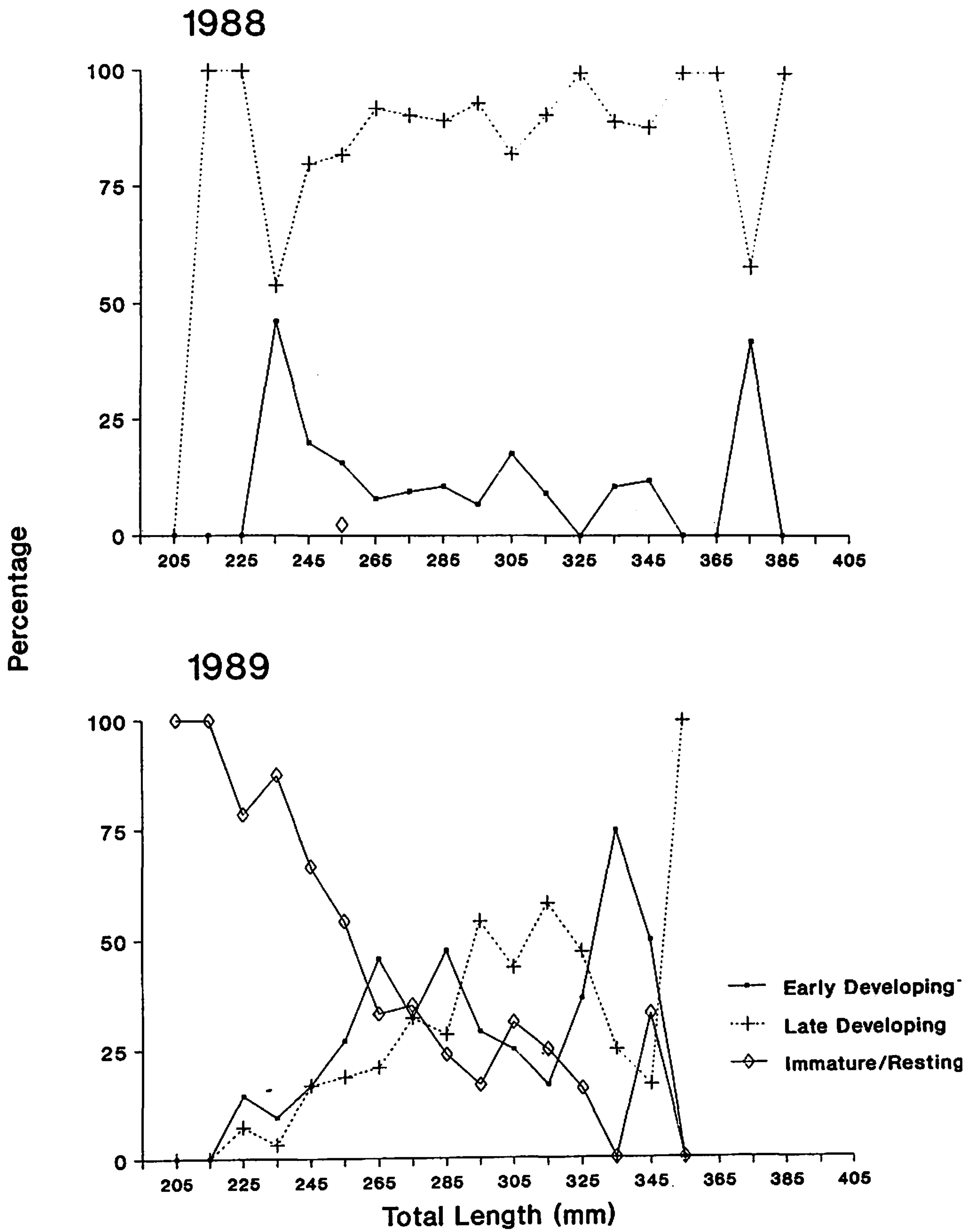
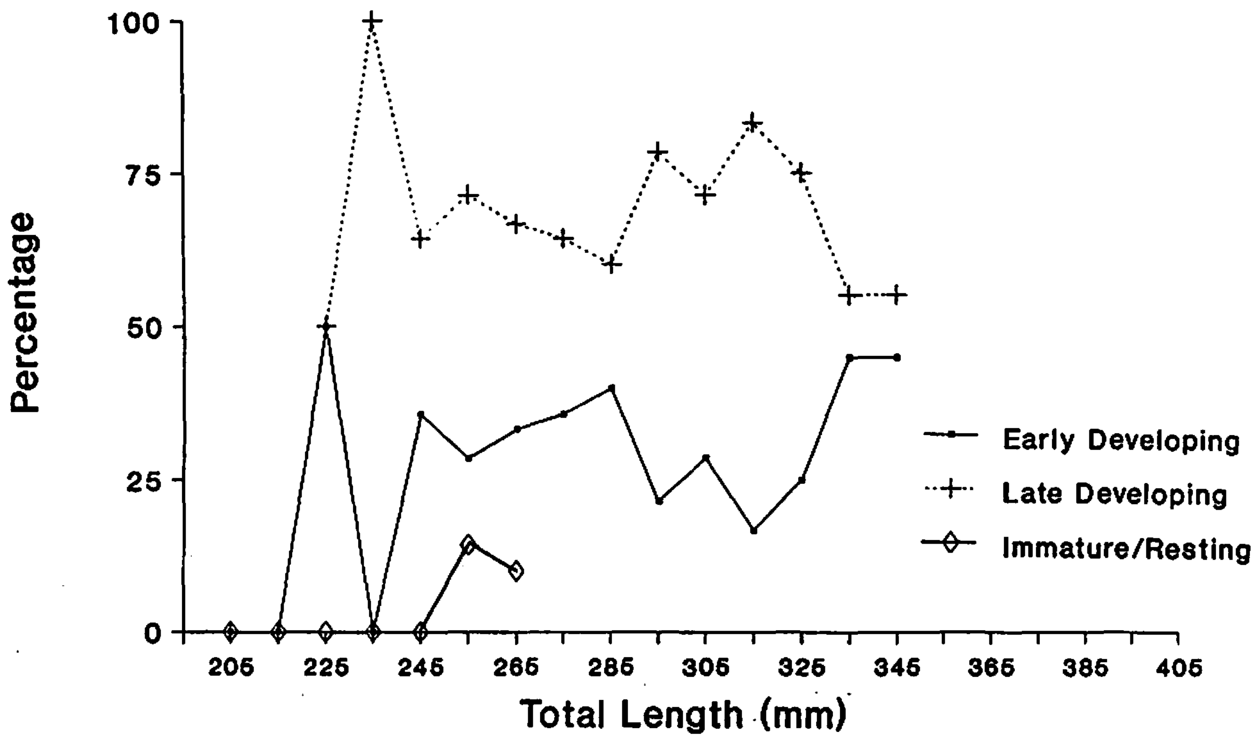

1988
100
75
50
25
0
205
225
245
265
285
305
325
345
365
385
405
Percentage
1989
Early Developing
Late Developing
Immature/Resting
Total Length (mm)

Figure 16. Patterns of percentage in each maturity stage for female Atlantic croaker by 10-mm size intervals in August, 1989.



100
75
50
25
0
Percentage
205
225
245
265
285
305
325
345
365
385
405
Total Length (mm)
Early Developing
Late Developing
Immature/Resting

Table 16. Size-specific maturity stage compositions of the observed overall female Atlantic croaker catch in 1988. Each line sums to 100%.

Length Interval	Immature/ Resting n	Immature/ Resting Percent	Early Developing n	Early Developing Percent	Late Developing n	Late Developing Percent
200-209	0	0.00	0	0.00	0	0.00
210-219	0	0.00	0	0.00	1	100.00
220-229	0	0.00	0	0.00	3	100.00
230-239	0	0.00	7	41.18	10	58.82
240-249	0	0.00	6	20.00	24	80.00
250-259	1	2.33	5	11.63	37	86.05
260-269	0	0.00	4	7.84	47	92.16
270-279	0	0.00	6	9.38	58	90.62
280-289	0	0.00	4	10.53	34	89.47
290-299	0	0.00	2	6.67	28	93.33
300-309	0	0.00	6	17.65	28	82.35
310-319	0	0.00	2	9.09	20	90.91
320-329	0	0.00	0	0.00	16	100.00
330-339	0	0.00	2	10.53	17	89.47
340-349	0	0.00	2	11.76	15	88.24
350-359	0	0.00	0	0.00	7	100.00
360-369	0	0.00	0	0.00	6	100.00
370-379	0	0.00	1	50.00	1	50.00
380-389	0	0.00	0	0.00	4	100.00
390-399	0	0.00	0	0.00	0	0.00
400+	0	0.00	0	0.00	0	0.00
Totals	1		47		356	

Table 17. Size-specific maturity stage compositions of the observed overall female Atlantic croaker catch in 1989. Each line sums to 100%.

	Immature/ Resting		Early Developing		Late Developing	
Length Interval	n	Percent	n	Percent	n	Percent
200-209	1	100.00	0	0.00	0	0.00
210-219	5	100.00	0	0.00	0	0.00
220-229	11	78.57	2	14.29	1	7.14
230-239	28	87.50	3	9.38	1	3.12
240-249	44	66.67	11	16.67	11	16.67
250-259	32	54.24	16	27.12	11	18.64
260-269	16	33.33	22	45.83	10	20.83
270-279	12	35.29	11	32.35	11	32.35
280-289	5	23.81	10	47.62	6	28.57
290-299	4	16.67	7	29.17	13	54.17
300-309	5	31.25	4	25.00	7	43.75
310-319	3	25.00	2	16.67	7	58.33
320-329	3	15.79	7	36.84	9	47.37
330-339	0	0.00	3	75.00	1	25.00
340-349	2	33.33	3	50.00	1	16.67
350-359	0	0.00	0	0.00	0	0.00
360-369	0	0.00	0	0.00	1	100.00
370-379	0	0.00	0	0.00	0	0.00
380-389	0	0.00	0	0.00	0	0.00
390-399	0	0.00	0	0.00	0	0.00
400+	0	0.00	0	0.00	0	0.00
Totals	171		101		90	

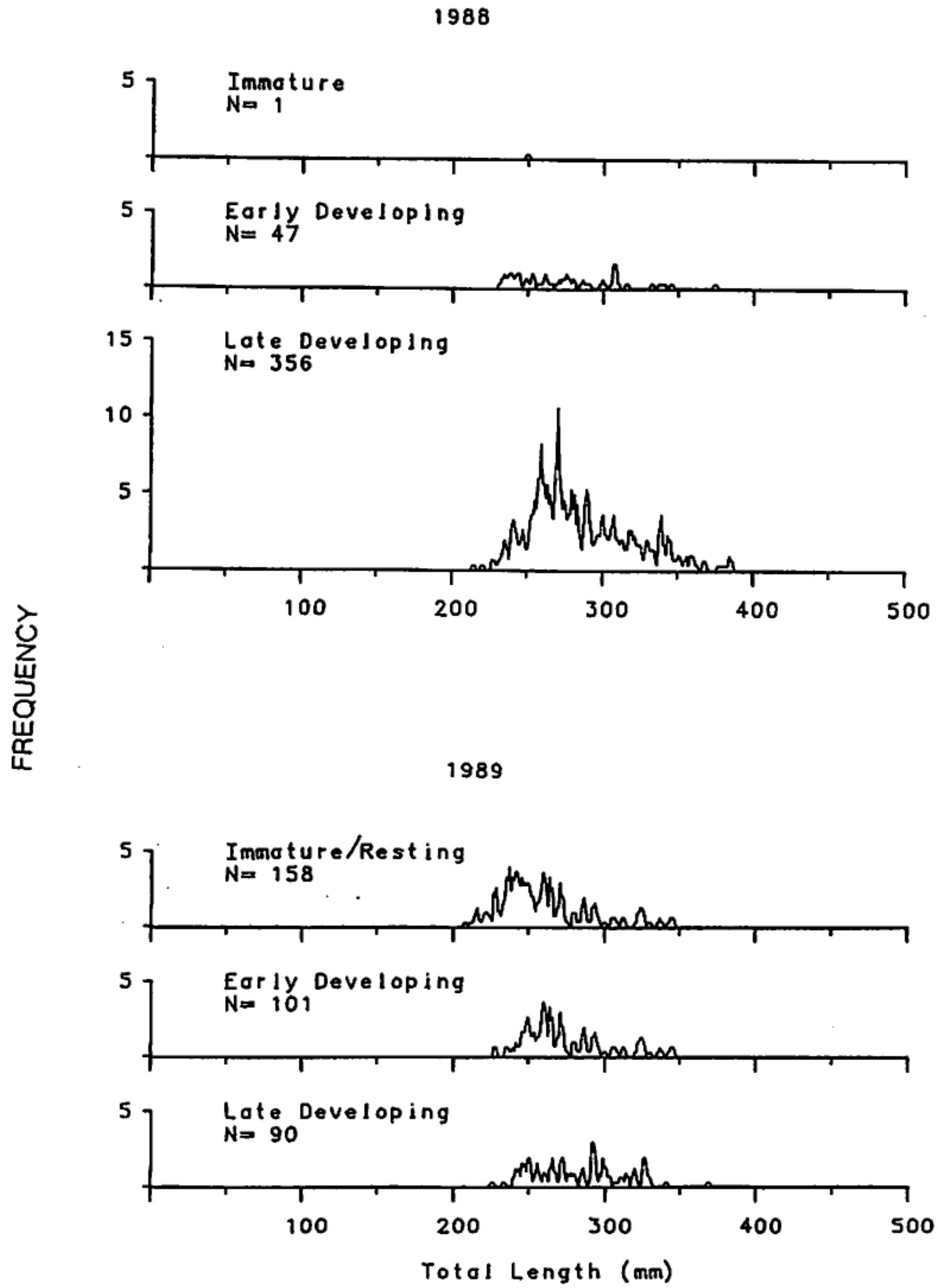
reflects very small sample sizes in these length ranges. Sandwiched between the smallest and largest sizes is an intermediate size range -- some 240-360 mm in 1988 and some 240-320 mm in 1989 -- in which data are based on larger sample sizes (n>10). The percentage of females in the Late Developing stage in these intermediate size ranges showed a more or less linear increase with increasing size, from 80% at 245 mm to 100% at 365 mm in 1988, and from some 62% at 245 mm to some 80% at 325 mm in 1989. Conversely, the percentage of females in the Early Developing stage in these intermediate size ranges showed a more or less linear decrease with increasing size, from some 20% at 245 mm to some 5% at 355 mm in 1988, and from some 35% at 245 mm to some 25% at 325 mm in 1989.

Most, if not all, food grade female croaker observed in the pound net catches were maturing to spawn in the year they were captured. We observed no fish in the Ripe, Gravid, or Spawning/Spent stages, apparently because spawning occurs in the ocean outside the Chesapeake. Fish entered the Late Developing stage over a broad size range, 215-390 mm in 1988 and 225-375 mm in 1989 (Fig. 17). The same size range of fish also entered the Early Developing stage in those years. In 1988, 88.12% of the females observed were in the Late Developing stage and 11.63% were in the Early Developing stage (Table 15). Less than 1% were in the Immature or Resting stages that year. Females in the Late Developing and Early Developing stages, combined, made up more than half the catch (52.76%) in 1989, respective percentages for the individual stages being 24.86 and 27.90%.

Development of Age Determination Methods:

Otoliths were much easier to read than the other hard parts evaluated. For the comparison of hard parts experiment, there were significant differences among hard parts in

Figure 17. Length frequencies of female Atlantic croaker by maturity stage in 1988 and 1989.



1988
Immature
N= 1
Early Developing
N= 47
Late Developing
N= 356
FREQUENCY
1989
Immature/Resting
N= 158
Early Developing
N= 101
Late Developing
N= 90
100
200
300
400
500
Total Length (mm)

ease of reading, the qualitative expression (Kruskal-Wallis test, X^2=183.91, df=4, P=0.0001). Distribution-free multiple comparisons testing found otoliths had higher mean scores and were significantly easier to read than the other hard parts (Table 18). There was no significant difference in mean scores and ease of reading among the other hard parts, though scales had the lowest mean scores and were essentially found unreadable.

Otoliths are more trustworthy and showed the highest degree of relative precision in reading. The CV and IAPE for otoliths both showed less than 1% variation between readers (Fig. 18), and there was 96.4% agreement between readers in their independent readings. The other hard parts varied in their relative precision, but all were much less precise than otoliths. Scales were least precise of all and showed only 64.6% agreement between readers.

Croaker otoliths were slightly different than the average otolith used to illustrate age and growth manuals. We present a hypothetical example of a fish born in Ocotber (Fig. 19). Since croaker have a broad spawning period in the fall, the 0 age fish overwinter as juveniles. This causes a darker nucleus than found in weakfish.

In paired comparisons with otolith readings, which we assume for now best indicate true age, all other hard parts showed great variation in assigned ages and, in fact, little or no relationship to otolith-assigned ages. There was no significant correlation (F=0.46; 1.49 df; P=0.50) between otolith and dorsal ray age counts (Fig. 20). Variability in dorsal ray age counts was high at each otolith count. For example, dorsal ray age counts varied from 1.5-5 for three otolith rings. There was no significant correlations (F=0.26; 1,49 df; P=0.62) between otolith and dorsal spine age counts. Variability in dorsal spine age counts was high at each otolith count. For example, dorsal spine age counts varied from 1-4 for three otolith rings. There was a significant correlation (F=7.17; 1, 47 df; P=0.01) between otolith and

Table 18. Summary of distribution-free multiple comparison tests based on Kruskal-Wallis ranked sums to qualitatively evaluate hard parts to age Atlantic croaker. n=number of age readings; Different letters indicate significant differences at $\alpha=0.05$.

Hard Part	n	Mean Score	Sum of Scores	Significance		
Otoliths	112	434.8	48,698.5	a		
Dorsal Rays	112	304.4	34,093.0		b	
Pectoral Rays	112	255.5	28,611.5		b	
Dorsal Spines	112	248.0	27,777.0		b	
Scales	112	159.8	17,900.0			c

Figure 18. Relative precision of age determination for each hard part, as expressed by the index of average percent error (IAPE) and coefficient of variation (V) in independent readings by two readers.

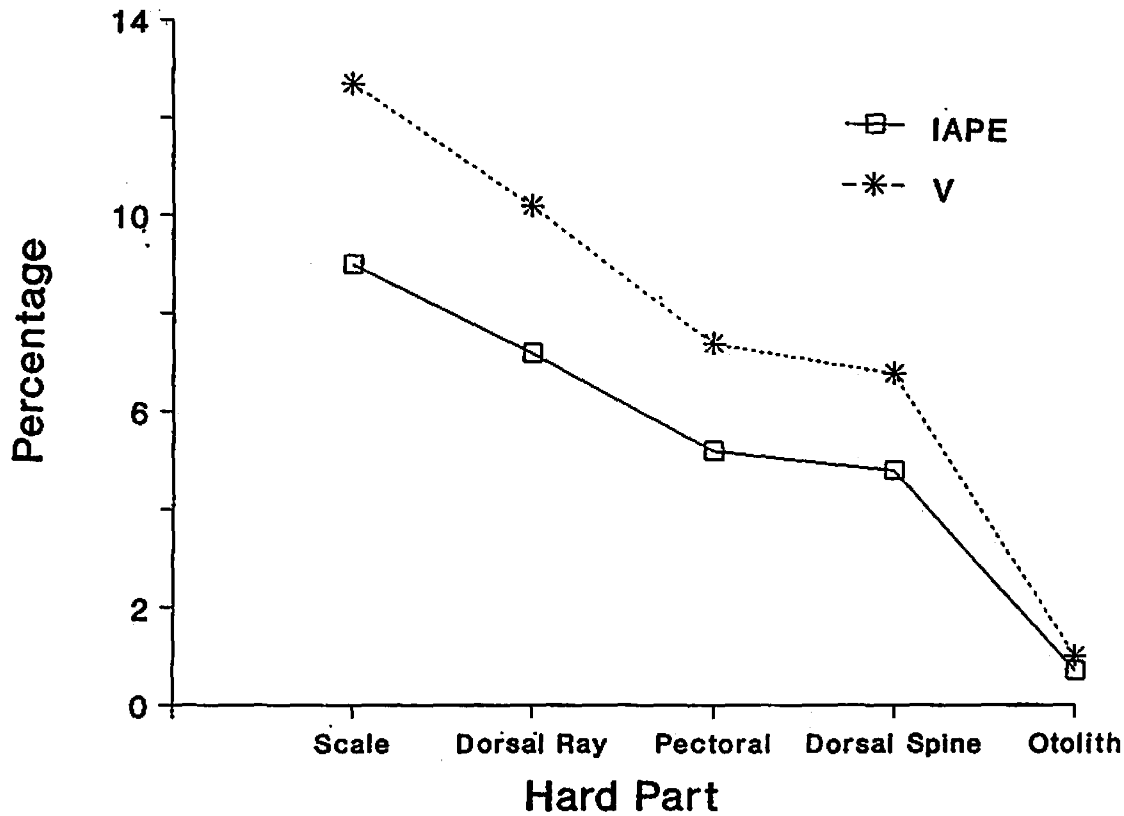

14
10
6
2
0
Percentage
IAPE
V
Scale
Dorsal Ray
Pectoral
Dorsal Spine
Otolith
Hard Part

Figure 19. Hypothetical representation of growth patterns on croaker otoliths. A croaker born in October will overwinter as a juvenile and encounter a slow growth period early in life. The birthdate anniversary falls before re-encountering another slow growth period in the second winter, which results in annulus formation. Hence, a croaker assigned a cohort anniversary date of age I is actually slightly older than one year of age.

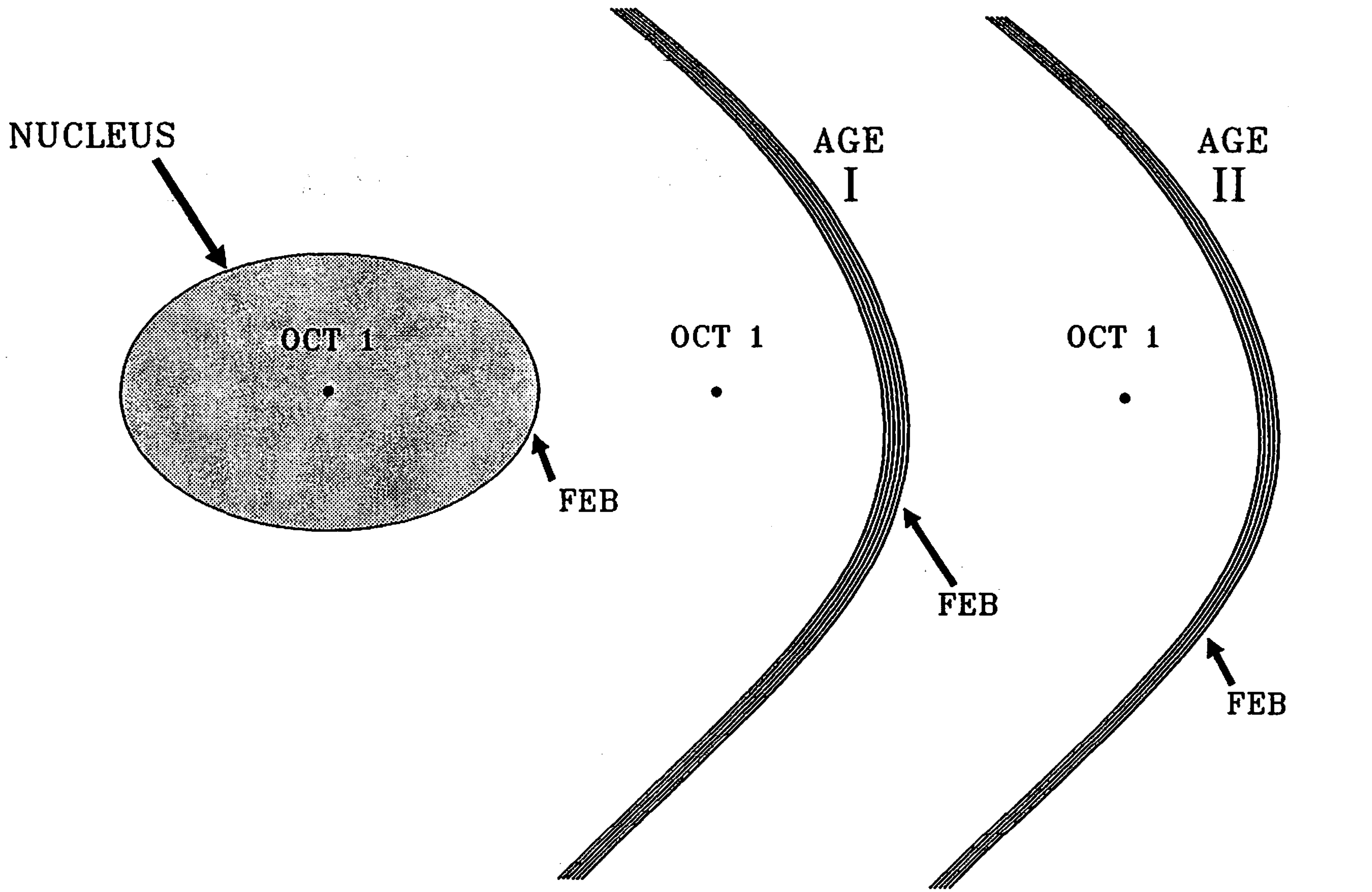
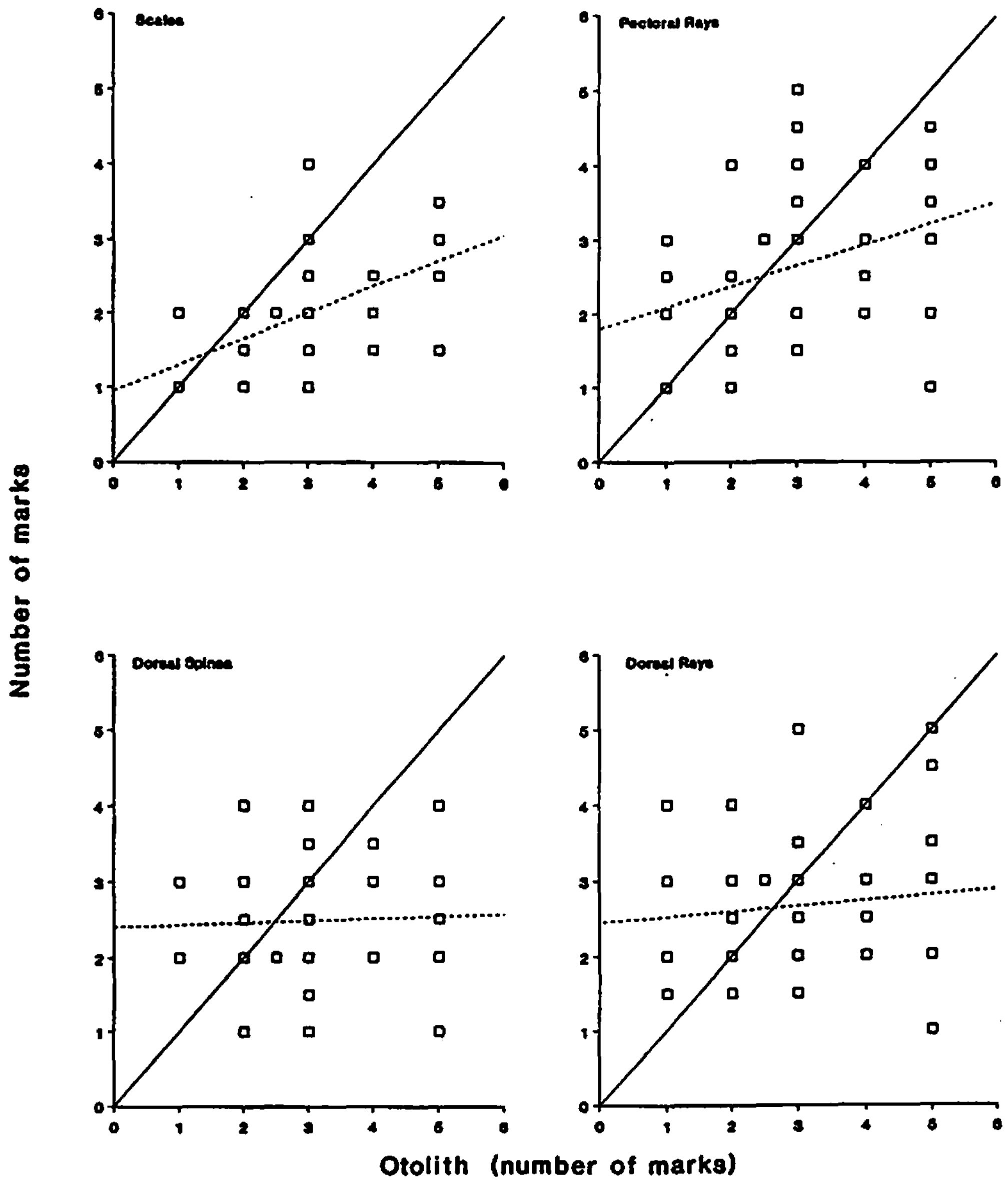

NUCLEUS
OCT 1
FEB
AGE
I
OCT 1
FEB
AGE
II
OCT 1
FEB

Figure 20. Number of marks on indicated hard parts in comparison to marks on otoliths. The 45° diagonals indicate exact agreement between otolith counts and those on other hard parts.


Scales
Pectoral Rays
Dorsal Spines
Dorsal Rays
Number of marks
Otolith (number of marks)

pectoral fin ray age counts. However, variation in otolith counts explained only 13.2% of the variation in pectoral fin ray age counts. Variability in pectoral fin ray age counts was high at each otolith count. For example, pectoral fin ray age counts varied from 1.5-5 for three otolith rings. There was a significant correlation (F=20.33; 1, 46 df; P=0.001) between otolith and scale age counts. However variation in otolith counts explained only 30.7% of the variation in scale age counts. Variability in scale age counts was high at each otolith count. For example, scale age counts varied from 1-4 at three otolith rings. Scales tended to give lower age counts than otoliths did. They did so in 14 of the 19 points and always gave lower counts (7 of 7 points) at older age, eg. four or more otolith marks.

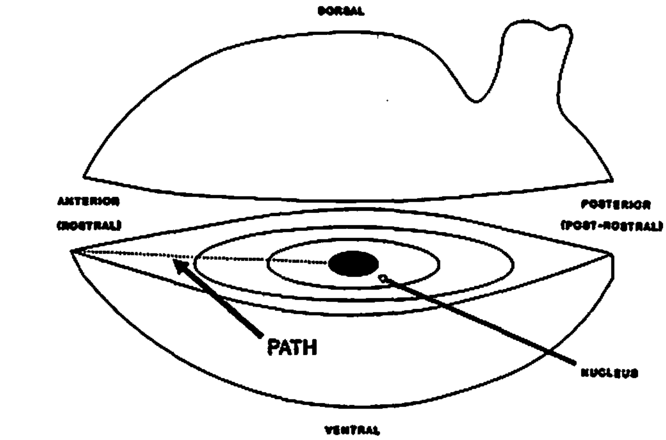
We feel that the best counting path (Fig. 21) for reading otolith annuli is on the proximal side in the transverse - proximal plane. From the counting paths experiment, there were significant differences among counting paths in ease of reading, the qualitative expression (Kruskal-Wallis test, X^2=13.93, df=3, P=0.003). However, there were few or no significant differences in distribution-free multiple comparisons testing (Table 19). The only significant difference was between the transverse-proximal counting path, which had the highest mean score, and the longitudinal-rostral path, which had the lowest mean score.

Otolith growth in croaker, at this point, seems to be isometric with growth in length. With preliminary data from the hard parts experiment, for 56 fish ranging from 225-333 mm TL, there was a significant linear regression of otolith maximum diameter on total length (Fig. 22). That regression explained 66% of the variation in otolith maximum diameter. One observation, however, for a fish 333 mm, may have strongly influenced the regression fit.

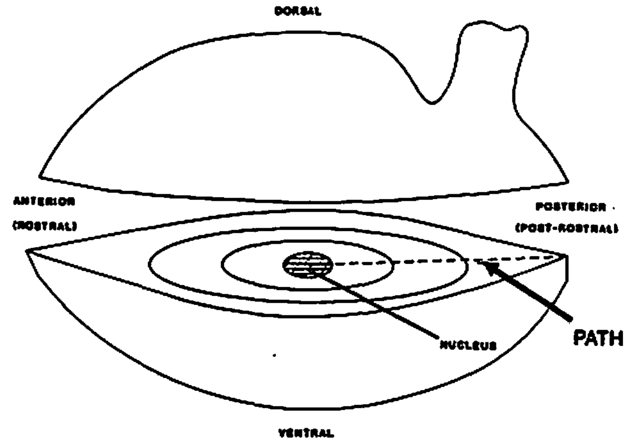
Growth:

Our initial age and growth data indicate that croaker growth is rapid in the first two

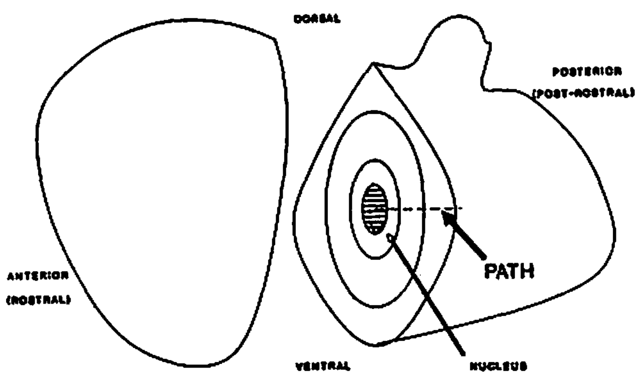
Figure 21. Otolith counting paths and sectioning planes evaluated for Atlantic croaker in the counting path experiment. See Methods for details of the experiment. Dotted lines on each panel indicate the nature of the counting path. The nature of the otolith maximum diameter is also indicated.



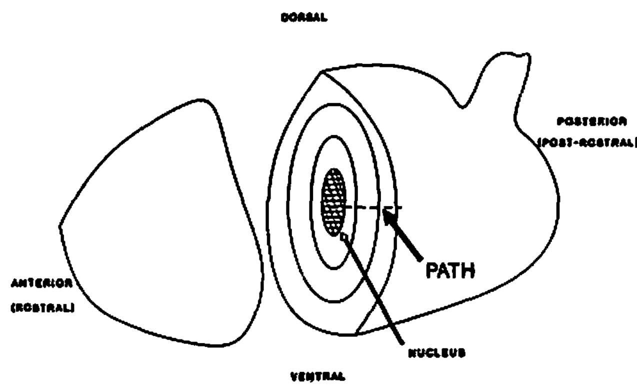
LONGITUDINAL ROSTRAL COUNTING PATH



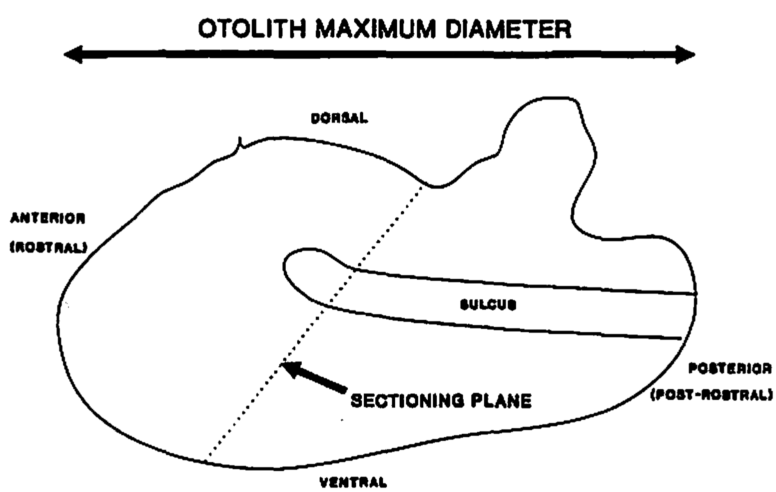
LONGITUDINAL POST-ROSTRAL COUNTING PATH



OBLIQUE PROXIMAL COUNTING PATH



TRANSVERSE PROXIMAL COUNTING PATH



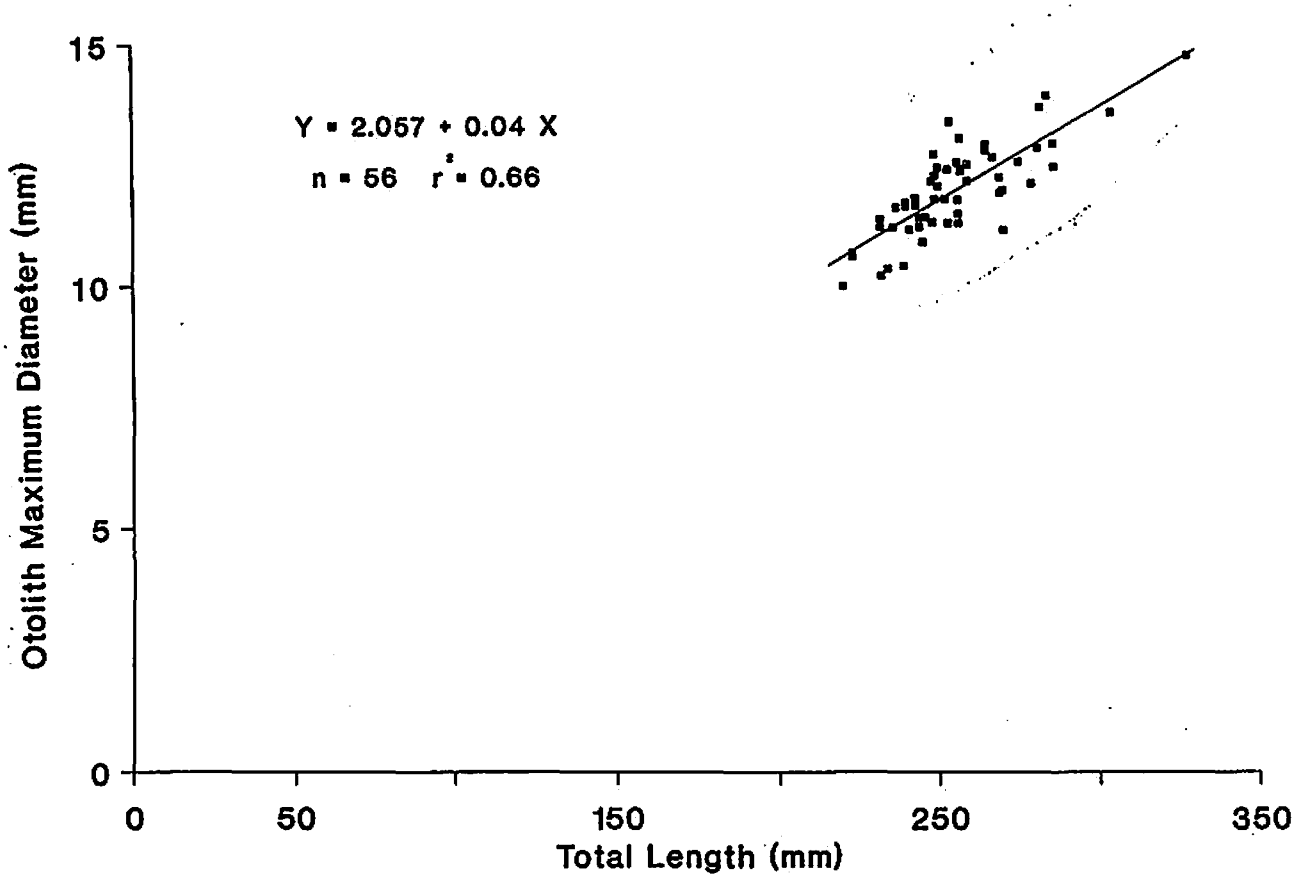
PROXIMAL VIEW

OBLIQUE SECTIONING PLANE

Table 19 . Summary of distribution-free multiple comparison tests based on Kruskal-Wallis ranked sums to qualitatively evaluate otolith counting paths to age Atlantic croaker. Paths are: OP=oblique-proximal; LP=longitudinal-post-rostral; LR=longitudinal-rostral; TP=transverse-proximal. Different letters indicate significant differences at $\alpha=0.05$. n=number of age readings.

Path	n	Mean Score	Sum of Scores	Significance
TP	10	30.5	305	a
LP	10	21.0	210	a b
OP	10	19.2	192	a b
LR	10	11.3	113	b

Figure 22. Regression of otolith maximum diameter on body total length in Atlantic croaker.



Y = 2.057 + 0.04 X
n = 56 r² = 0.66
Otolith Maximum Diameter (mm)
15
10
5
0
0
50
150
250
350
Total Length (mm)

years (Fig. 23), then quickly slows.

The fitted von Bertalanffy growth function (VBGF) was:

$$l_t=267.6(1-e^{-3.61(t-0.29)})$$

Parameter estimates with supporting standard errors and coefficients of variation are summarized in Table 20.

Total Mortality Rates:

The oldest fish among the six largest croaker we collected showed five rings on the otolith section, which we interpret, for now, as an age V or VI fish. In fact, each of these six fish had five rings (Table 21). The oldest fish among the other 96 croaker aged in developing age determination methodology showed 6 rings, which we interpret, for now, as an age VI fish.

Theoretical average total annual mortality rates for fish with a five or six year maximum life span are 53-60%. Table 22 summarizes theoretical rates of average total annual mortality (1-S), survivorship (S), and instantaneous total annual mortality (Z) for preliminary maximum age values of five to ten years. Further work may indicate older ages than the ages V or VI we have encountered so far, so we present mortality rates for a few older ages. Values in Table 22 indicate that total mortality rates are 37-60% for maximum ages between five and ten years.

Weight, Girth, and Length Relationships:

Total weight - total length, girth - total length and standard length - total length regressions, applicable to fish in a 200-400 mm TL range, are presented in Table 23 with

Figure 23. Initial von Bertalanffy growth function for the Atlantic croaker. Preliminary ages are indicated in years.

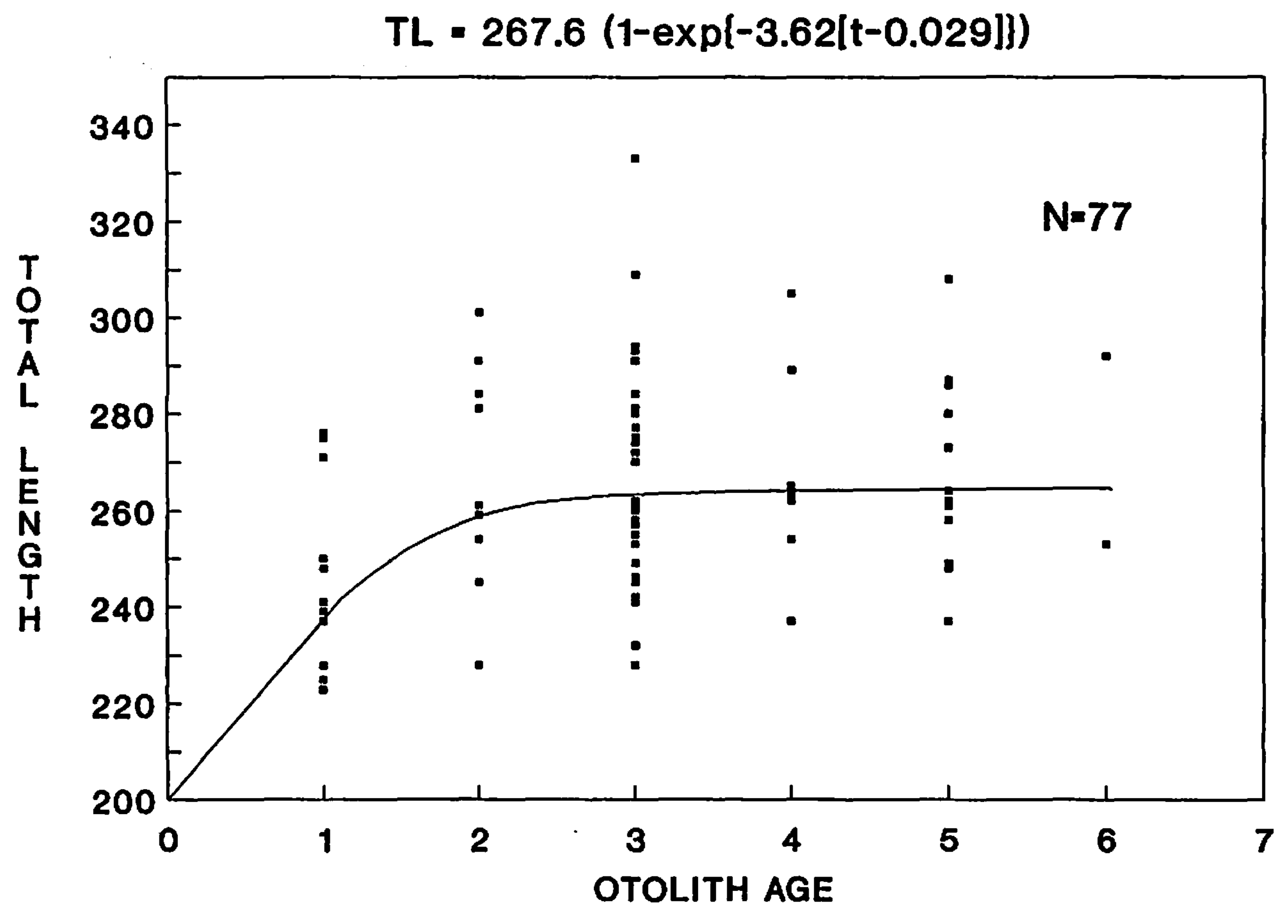

TL = 267.6 (1-exp{-3.62[t-0.029]})
N=77
TOTAL LENGTH
340
320
300
280
260
240
220
200
0
1
2
3
4
5
6
7
OTOLITH AGE

Table 20. Estimates of the von Bertalanffy growth function with standard errors and coefficients of variation (CV).

Parameter	Estimate	Standard Error	CV %
L	267.6	2.99	1.0
K	3.62	14.3	395.4
t_0	0.29	2.78	950.2

Table 21. Summary of total lengths, number of rings on otolith sections, preliminary ages (years), and collection dates for the six largest croaker collected.

Collection Date	Total Length	Number of Rings	Age
Jul 26, 1988	377	5	5
Jul 27, 1988	395	5	5
	375	5	5
Aug 18, 1988	400	5	5
	379	5	5
	386	5	5

Table 22. Summary of theoretical average total annual mortality rates (1-S), survivorship (S), and instantaneous total mortality rates (Z) for listed maximum ages.

Maximum Age (Years)	1-S	S	Z
5	60	40	0.92
6	53	47	0.77
7	48	52	0.66
8	43	57	0.58
9	40	60	0.51
10	37	63	0.46

Table 23. Total weight-total length, girth-total length, and standard length-total length regressions with supporting statistics. All regressions were significant at $\alpha=0.01$. Measures are grams and millimeters.

Equation	n	TL Range	$100r^2$	Residual MS	Corr. Total SS_x	Corr. Total SS_y	$\bar{y}$	$\bar{x}$
TL=15.42 + 1.15 SL	1440	200-400	98.75	11.24	965,707.00	1,295,227.16	267.04	218.63
SL=-10.54 + 0.86 TL	1440	200-400	98.75	8.38	1,295,227.16	965,707.00	218.63	267.04
TL=58.46 + 1.22 G	1280	200-400	90.39	104.37	844,655.06	1,388,370.94	272.57	175.65
G=-26.48 + 0.74 TL	1280	200-400	90.39	63.49	1,388,370.94	844,655.06	175.65	272.57
Log_{10} TW=-5.773 + 3.358 TL (Males)	507	200-400	93.73	0.002	1.20	14.49	2.36	2.42
Log_{10} TW=-5.673 + 3.323 TL (Females)	760	208-386	94.94	0.002	1.96	24.08	2.43	2.44
Log_{10} TW=-5.890 + 3.409 TL (Males and Females Pooled)	1267	200-400	94.56	0.002	3.25	39.95	2.40	2.43

related statistics that can be used to develop standard errors, confidence limits etc. for slopes, means etc. Total weight - total length relationships for males and females were not significantly different in slopes (analysis of covariance, ANCOVA; $F=1.35$, $df=1,263$, $P=0.241$) or intercepts (ANCOVA; $F=1.14$, $df=1,263$, $P=0.280$), so a pooled regression equation is also presented. The calculated slope of the pooled regression significantly exceeded $\beta=3.0$ (t-test; $t=17.81$, $df=1,265$, $P<0.001$), indicating growth was not isometric.

DISCUSSION

Comparative Size Compositions in Trawl and Pound Net Catches:

Length frequency compositions clearly indicate that, as Chittenden (1989) reported for a portion of these data, pound nets capture much larger croaker in the food grades than those observed over a 25-year period of York River trawling. Pound nets capture not only larger maximum sizes. More important, the frequency distributions show little overlap between pound net food grade catches and trawl catches. York River trawl catches apparently have targeted almost exclusively the young-of-the-year croaker, while pound net food grade catches target almost exclusively age I and older specimens and, possibly, some fish approaching age I in late summer. Therefore, it appears for croaker, that York River trawl collections have little importance in evaluating the growth/mortality/maturation/fecundity dynamics that underlie yield and eggs-per-recruit-type models used to evaluate day-to-day fisheries management concerns such as minimum size limits, etc.

Within vs Among Box Variation in Catch Composition:

Present findings on within versus among-box variation in lengths are very similar to what Chittenden (1989) found on weakfish and Atlantic croaker. There was little or no difference in length composition among boxes, the maximum difference in mean length per box being only 8 mm. A regression trend in lengths with the chronology of processing was significant, largely due to a quadratic component. However, in practical terms, this regression effect was not visible in plots of mean lengths on box number in the processing chronology, so the declared significance must largely have reflected a very large sample size (n=2,688). Within-box variation again accounted for more than 98% of the total variation. All in all, therefore, strategy in box selection is not a major problem in estimating mean lengths, because the maximum observed difference in mean length between boxes (8mm) seems quite acceptable.

Present findings on within versus among-box variation in sex ratios are more worrisome. On the good side: 1) among box variation was negligible, as compared to within box variation which accounted for more than 98.5% of the total variation, and 2) confidence limits about the mean percentage male, based on 23 boxes, were pleasantly narrow, 59% $\pm$2. Less good is the significant box-to-box differences and the mild, curvilinear trend in sex ratios with the chronology of processing boxes, both detected, however, using very large sample sizes. We cannot explain the observed differences (ignoring the outlier) or trend, and they may not be biologically real, because croaker show no external sexual dimorphism or dichromatism that might permit recognition of and selection for either sex. Most worrisome is that there was considerable variation in per box percentage male -- 52-67% -- even ignoring a value of 40.74% which was an outlier. Confidence limits for individual per-box percentages about the mean were wide 51-67%, even after deleting the outlier.

The wide variation in per-box sex ratio is the feature which is worrisome. To estimate sex ratios, and other percent composition data, we purchase one box per grade, which, in practice, often becomes only one box per day. Both logistically and financially, it may not be feasible to regularly purchase and process much more than one box/day, numbers that give no estimate of box-to-box variation for that day and/or little variance control. That implies that per-day percentage data, as presently gotten, may be misleading and/or give less confidence than desirable. Given random sampling, mean percentages over the season, or some-such broader base, being based on at least several boxes, would be more satisfactory and, it appears, have acceptably narrow confidence limits.

Sampling Problems in Collecting Data:

Information presented herein should be viewed with varying degrees of reservation, because it is based on non-random sampling in time and space due to difficulties in collecting data. We describe here the nature of these problems and their effects.

We have encountered two major sources of difficulty in collecting biological data: 1) small catches at certain times or areas so that we had no fish to purchase, and 2) poor or erratic cooperation in that some target pound net fisheries refused to sell specimens on which we collect biological data. The problem of small catches hampered our ability to collect biological data at regular intervals, because we simply have not been able to purchase fish at times. Affected data include, primarily, "trend-type data", eg -- indices used to estimate spawning periodicity and hard parts to determine when marginal increments form. Such data are not complete in their periodicity, though their trends are probably reasonable for periods when data exist. The problem of poor cooperation hampers our ability to get randomly-selected, properly-weighted information to estimate overall "composition-type" data. Affected data include, primarily, overall age and size compositions, overall sex ratios, and size and age specific sex ratios, maturity, mortality, and growth. Such data may or may not be misleading.

When catches are small it has proven difficult to purchase specimens. Each fishery has a regular clientele in the general public and commercial seafood buyers upon which it depends for regular sales, in contrast to our small, irregular purchases. Demand by this clientele must be satisfied first when catches are small, and this will be a continuing problem. Small catches can be expected at the beginning and end of the season for each fishery, but also: 1) erratically throughout the season at all fisheries, 2) regularly in certain areas where the fish are apparently not abundant, for croaker, areas such as Reedville or the Eastern Shore till August, and 3) as a general pattern in the summer when the small overall catch causes many fisheries to operate only on an "every-other-day" basis.

The problem of small catches may be viewed as one of random variation in catch size, which does not have much effect on catch size estimates. However, for composition-type data, in contrast, it remains desirable to get data at regular intervals to describe things like spawning periodicity, time trends in sex ratios, periodicity of marginal increment formation, etc. Our back-up action in response to small catches has been to attempt, as feasible, to "come back again the next day" to try and get data. That may not be strictly random, but we feel it does not seriously compromise the reliability of data that describe time trends. The completeness of such data is just not as great as we had hoped.

The problem of non-cooperation in selling specimens or boxes of fish is more serious. It has prevented us from developing strong data that are reasonably random and reasonably properly-weighted. As a result, composition-type data may be non-representative and should be viewed with definite reservations at least, data like overall age and size compositions and many age and size-specific parameters. This will remain so until we get better cooperation and can get randomly-selected data on daily catch sizes and compositions as we had originally intended and attempted. However, we feel some important composition-type data are reasonably sound, or provide boundaries for actual values. This especially includes average estimates for total mortality based on maximum life spans.

Finally, to enhance cooperation when we get it and minimize disruption of commercial operations, we have not attempted to randomly select boxes from the catch on a given day at a given location. From our evaluation of among vs within box variation, such randomization appears unnecessary to get biological data that is reasonably reliable. We have found little box-to-box variation in mean lengths, somewhat more variation in sex ratios. The observed variation in sex ratio seems worrisome, however, only for per/day estimates, or ones with a similarly small data base.

Temporal and Spatial Distribution:

Our present data on temporal/spatial distributions are only catch records. Catch-per-unit-effort is not obtainable, for reasons which follow, though the nominal number of nets fished was given in the Methods. Each net was not always fished each day. When overall catches (all species combined) were large, only some nets -- an unknown number -- were normally fished. In mid summer, the overall catch declined, often to an "unprofitable" daily level, so nets were often emptied every other day. Nets were not fished in windy weather, so some catches pool several fishing days. Despite these problems, we feel the observed temporal and spatial trends, noted below, are realistic, because: 1) the same number of nets generally operated within a fishery after they were first set, and 2) the number of nets probably reflects a long-term evaluation of economics in each fishery. We feel our telephone call evaluations of general catch sizes are also reliable. We had good personal relationships with the fishermen and trust their comments. Some of them feared management regulations, however, and though apologetic about it, would not give detailed catch and effort records.

We have observed that adult croaker occur in the Chesapeake Bay only from early spring through early fall. The observed spatial variation in their temporal distribution suggests adult croaker migrate through the mouth of the Chesapeake Bay primarily in two periods, April, when they enter the Bay, and early August - mid September, when they leave. Adult croaker seemingly enter the Chesapeake primarily along the Western Shore in the spring. Catches were large at Lynnhaven during April, but no croaker were captured along the Eastern Shore until late May. Fishermen on the Eastern Shore, moreover, stated that they normally begin to catch croaker about June. Migration from the bay in late summer seems to occur along both the Western and Eastern Shores, because large catches are regularly made in both areas then.

Details of the summer distribution of adult croaker in the Chesapeake are not clear from the present data. They apparently move upbay from the Bay mouth, because, other than in one episode, no large catches were made near the Bay mouth from early May until early August. Adult croaker seemingly become widely distributed in the mainstem Bay in the summer, though at low levels of abundance. They may become distributed largely in the tributary riverine shallows at that time, but little pound net data now exist for the lower York River in May - June and mid July - late August, periods when they could move into and out from riverine shallows. However, adult croaker are captured in haul seine fisheries in the mid and upper York River in the summer when pound net catches are small in the lower York River.

Spawning Periodicity:

Spawning periodicity is not yet fully clear from data on adult croaker, because we have not been able to obtain in any one year a comprehensive time series of specimens over the April - September period when adult croaker occur in the Chesapeake. It seems clear, however, that adults do not approach spawning condition in the period April-mid July, and that they rapidly mature after mid July. We collected no adult females in the Chesapeake that were ready to spawn. It appears that final maturation and spawning occur outside the Chesapeake, probably about August-September, because maturing adult fish migrate from the Chesapeake in large numbers in August. We were not successful, however, in attempts to purchase croaker from ocean trawlers to compare their reproductive state with fish collected in the Chesapeake.

Size Compositions:

Overall size compositions and maximum sizes observed in the present studies should be viewed with the reservations that they are based on non-random sampling with equally-weighted, pooled collections and could be misleading to an unknown degree. These caveats probably apply to earlier published studies also.

The most important size ranges observed were about 230-330 mm total length in 1988 and about 220-270 mm in 1989. Minimum sizes captured, about 200-210 mm, were similar between years, a phenomenon that probably reflects the commercial grading process.

Maximum sizes observed were 369 and 400 mm, depending on year. Typical maxima, expressed as l_L, were about 340-380 mm, but varied greatly between years. These maxima are somewhat smaller than maximum sizes of 500 mm suggested by White and Chittenden (1977) for cold-temperate waters north of Cape Hatteras based on reports of Hildebrand and Schroeder (1928) and Gunter (1950). However, between year and between study differences in maximum size may reflect passage through the fishery, and unequal weighting of the catch, by different year classes of varying strength. That process would also cause year-to year variation in overall size compositions.

Within grade variation between collections may be an important source of variation in catch compositions. Such variation could reflect growth when manifested as an increase in size over time. However, we also observed erratic patterns and, at times, a seeming decrease in size with time. In these cases, within grade-between collection variation probably reflects market economics and croaker availability: it is probably more profitable, or necessary, to grade the catch using slightly different size standards from day-to-day. Variation within grade-between collections seems to considerably exceed among-box variation. We observed, generally, little among-box variation in the present studies, as Chittenden (1989) also reported, although variation in per day percentage data might be worrisome. There appears to be much overlap between small and medium grades, much less overlap with the large grade. This phenomenon, too, may reflect market economics, because smaller sizes generally sell for less than larger ones.

Sex Ratio:

Overall sex ratios observed in 1988 and 1989 were 42.7% and 37.2% male, respectively. These ratios should be viewed with the reservations that they are derived from non-random sampling and equally-weighted, pooled collections in a situation in which there appear to be distinct time trends in sex ratios.

The seeming between year differences we observed in croaker sex ratio trends in the summer probably reflect, largely, the mid to late summer exodus of croaker from the Bay, and differences in the time when males and females do so. In 1988 there was a clear time trend in sex ratio from a relatively high percentage male in late July-early August -- some 55% -- to a much lower percentage male in late August-mid September -- some 40% male. That pattern indicates male croaker tend to leave the Bay first, so that sex ratios shift toward a greater preponderance of females in late summer. Patterns in 1989 can also be readily interpreted in that way except for one seemingly out-of-line sex ratio, a value of 65% male from one collection along the lower Eastern Shore. That value came from one box, randomly chosen for plotting, from the 24 boxes purchased to evaluate box-to-box variation in sex ratios. Sex ratio values in that experiment were 52-67%, ignoring the outlier of 41% male. These boxes were from a large catch of croaker. Few croaker seem to be caught along the Eastern Shore, however, except in August when they are actively migrating from the Bay. The sex ratios of 52-67% male in that catch probably reflect a catch made from an aggregation of male croaker actively migrating to sea. Subsequent sex ratios in 1989 were low -- only 9.5% male in late August -- the same type of pattern seen in 1988.

Size at Maturity:

The variation in overall maturity stage patterns that we observed for female croaker probably reflects differences in collection periods between years. In 1988, collections were primarily made in late July and August when fish rapidly begin to mature. The late collection period is probably why most females were in advanced stages of maturation that year. In 1989, in contrast, many fish were collected in June and early July, a period when maturation is not far advanced. The collection of many fish in an early period is probably why many fish were only in Immature or Resting stages that year. Fish collected in August of 1989, like in 1988, were primarily in advanced stages of maturation. Finally, relatively many fish collected in 1989 were in the small grade, and it appears that smaller fish tend to mature later in the year than large fish do.

Development of Age Determination Methods

We feel that otoliths offer the best method of annual age determination for Atlantic croaker.

We have suggested the transverse-proximal as the best "path" to use for otolith annual age determination. The proximal side can be accessed by either a transverse or longitudinal section. The transverse section is best, however, because it transects the sulcal groove, on the outer edge of which the annuli seem to be most clear. Another advantage for this path is that the sulcul groove forms a radial line between the focus and the outer edge of otolith. That radial is an excellent linear standard axis to measure, for back-calculation, from the focus to each annulus.

Although staining otolith sections seemed to improve our ability to obtain more accurate growth increment width estimates and to better discern narrow marginal increments, we consider at this point, that the time involved in staining is not worth the results, especially because, as demonstrated above, yearly rings in croaker otoliths are clearly defined and easy to read. Staining would be indicated for more detailed studies, but not for routine croaker aging.

Further work on the otolith-body relationship is needed to better evaluate this relation. Data need to be gathered over a much wider size range to adequately describe the relation, and data are most especially needed for fish <225 mm. When this is done, curvilinear regression and lack of model fit can be better evaluated.

Growth:

We believe our initial VBGF results should be viewed with distinct reservations, and we are not comfortable with them. The asymptotic length we found, 267 mm, falls below the size of many of the croaker that we observed in the large grade. It is well below the 500 mm maximum length suggested for the mid-Atlantic (White and Chittenden, 1976), and it is even further below the maximum of 660 mm reported for the species (Rivas and Roithmayr 1970). It is also well below the L of 419 mm reported by Barger (1985) for Gulf of Mexico croaker. Being inversely related to values of L, the K value we found (3.62) is probably much too high. The data points for the VBGF fitting, however, show distinct curvilinearity and even evidence an asymptote, criteria that Knight (1968) and Gallucci and Quinn (1979) recommend as being needed for a proper fitting. We suspect our randomization procedures, however were not adequate for a proper selection of data.

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