Age Growth and Reproduction of Black Drum, *Pogonias cromis*, in Virginia

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AGE, GROWTH, AND REPRODUCTION OF BLACK DRUM,

POGONIAS CROMIS, IN VIRGINIA

by

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B.S. December 1987, Virginia Commonwealth University

A Thesis Submitted to the Faculty of Old Dominion University in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

BIOLOGY

OLD DOMINION UNIVERSITY
August, 1991

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ABSTRACT

AGE, GROWTH, AND REPRODUCTION OF BLACK DRUM, POGONIAS CROMIS, IN VIRGINIA

The black drum, *Pogonias cromis*, is of great economic importance to the communities of the lower Eastern Shore of Virginia. Fish are sought both commercially and recreationally during their yearly spring spawning run. Although the number of fish caught each year does not rival other exploited species, it is a directed fishery that partially supports many local fishermen, seafood distributors, marinas, motel owners, and restauranteurs.

Black drum were collected during the fall of 1989 and the spring of 1990 to investigate the population dynamics of fish found in Virginia's Chesapeake Bay and surrounding coastal waters. A total of 235 fish was examined for estimation and description of age, growth, mortality, and reproduction.

Observed total lengths for black drum ranged from 229 to 1300 mm. Ages were obtained from otolith sections, with fish ranging in age from 0 to 57 years. Male and female fish did not differ significantly in either size or age composition. Growth was described by the von Bertalanffy growth equation

\[ L_t = 1186 \text{ mm}(1 - e^{-0.0961\text{AGE} + 3.0964}) \]

Black drum exhibited total spawning, which took place during the early spring from late April to May. All fish collected during the spring were mature adults. Total fecundity estimates ranged from \(5.57 \times 10^6\) to \(2.66 \times 10^7\) eggs per female.
DEDICATION

This thesis is dedicated to Marc Zlotkowski and Bob Hendrickson; two friends whose short lives obstructed the fulfillment of all their dreams, but whose memories help to inspire me to continue to strive for mine.
ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to all those who aided in the completion of this project. Much gratitude is due Dr. Cynthia M. Jones for her essential day to day guidance and, of course, for my financial support. Thanks to Dr. Mark E. Chittenden, Jr., for his invaluable advice in the initial stages of project planning and sampling. I would like to thank my graduate committee: Dr. Ray S. Birdsong, Dr. Raymond W. Alden, III, and Dr. Cynthia M. Jones. Each member contributed valuable advise and comments to the writing of this manuscript.

For those who aided in specimen collections, including Wesley Hinkle, Stephen Nixon, Robert Skinner, Sean Priest, and Bill Sharp, I owe much thanks. A special thanks to Hassan Lakkis, who provided statistical help with everything from regression comparisons to calculating sample sizes for fecundity counts. Thanks to Tung Quasch for helping with the seeming endless sectioning of otoliths. And finally, much thanks to my family and friends for their never ceasing question...."How's the research/thesis going? ".

This research was supported by grant # WB F-88-R-2, issued by the United States Fish and Wildlife Service to Dr. Cynthia M. Jones in 1989 and 1990.
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INTRODUCTION

Black drum, *Pogonias cromis*, the largest members of the family Sciaenidae, range along the eastern United States predominantly from Massachusetts to Florida, with an overall distribution ranging from Canada to Argentina (Welsh and Breder 1923; Silverman 1979). Schools of black drum enter Virginia waters during early spring on their yearly spawning migration and continue to congregate until early summer (Richards 1973). During this time, the fish support economically important commercial and recreational fisheries on the Eastern Shore of Virginia. Although the number of pounds of fish caught commercially each year does not rival other exploited species, it is a directed fishery that partially supports many local commercial fishermen, seafood distributors, and restauranteurs. Also, recreational fishermen from outside the state are attracted to the lower Eastern Shore each year in search of trophy fish, possibly providing an influx of money important to the shore’s economy (Jones et al. 1990). After this short spawning period, the schools disband and the fish disperse throughout the Chesapeake Bay and surrounding coastal waters where they remain until their exodus in the fall.

In the past decade several studies have been undertaken with the objective of describing life history parameters of the black drum in the Gulf of Mexico (Fitzhugh and Beckman 1987; Beckman et al. 1990) and in northeast Florida (Murphy and Taylor 1989), while virtually no work has been performed on the stock found in Virginia. Basic life history
parameters and information on population dynamics, including details on
growth, age composition, reproductive biology, and mortality, are
essential to the production of sound management plans. The lack of this
critical information for this species in Virginia places regulating
agencies at a serious disadvantage when developing management
strategies.

Past age and growth estimates of black drum in Virginia have been
made using scales which cannot be accurately read past the tenth ring
(Richards 1973). For example, Desfosse's (1987) oldest fish was aged at
15 years using scales. No validation of black drum age estimates using
scales has been preformed. Murphy and Taylor (1989) and Beckman et al.
(1990) have validated black drum age estimates using sagittal otoliths
through marginal increment analysis in northeast Florida and Louisiana,
respectively. Validated fish ages using otoliths ranged from zero to 43
in Louisiana (Beckman et al. 1990) and zero to four, with a non-
validated maximum age of 58, in northeast Florida (Murphy and Taylor
1989). Age estimates have also been validated for other sciaenids using
marginal increment analysis, including Atlantic croaker (Barger 1985)
and red drum (Beckman et al. 1989).

Because no previous published studies on Virginia's black drum
used otoliths, comparison of age frequencies and age-length
relationships with other stocks has not been possible. This is critical
due to the apparent differences between the stocks from different areas
(Silverman 1979; Beckman et al. 1990). For example, black drum found in
Louisiana's Gulf of Mexico waters had a median total weight of 7.5 Kg
(Fitzhugh and Beckman 1987) as compared to 15.5 Kg in Virginia (Desfosse
1987). Northeast Florida black drum are dominated by smaller fish
ranging from zero to four years old (Murphy and Taylor 1989), while fish this small are not frequently found in Virginia waters. One objective of this study was to produce reliable age determinations comparable to studies of black drum from other localities through investigations of the best way to prepare otoliths to produce the most readable sections with the greatest ease of processing.

While otoliths are the most commonly used structure for aging, many other calcified structures have been used to age fish. Many of these alternate structures, such as scales and fin rays, have provided a means to obtain age without sacrificing the fish. Cass and Beamish (1983) and McFarlane and Beamish (1987) have been able to validate ages using these hard parts. Previous studies on black drum aging concentrated on a single aging structure without considering the use of alternate hard parts. The present study explores other hard structures that could provide precise simple methods for aging fishes, without causing mortality.

Fitzhugh and Beckman (1987) reported that Louisiana black drum exhibited group synchronous oocyte development and observed multiple egg stages throughout the spawning season. Females were reported to spawn every 7 days with batch fecundity estimates ranging from $7.4 \times 10^5$ to $3.8 \times 10^6$ eggs. The annual production of a 7.5 Kg female was estimated to be 18 million eggs (Fitzhugh and Beckman 1987). Pearson (1929) estimated the fecundity of a 100 cm Gulf of Mexico female fish at 5,976,000 eggs.

In northeast Florida 50% of male black drum reached maturity at ages four to five at an approximate size of 590 mm total length, while 50% of female drum reached sexual maturity at five or six years of age
at a length between 650 mm and 699 mm (Murphy and Taylor 1989). 50% of male and female black drum in Louisiana were found to be sexually mature at five to eight years of age at a size between 600 mm and 640 mm fork length (Fitzhugh and Beckman 1987). Only a very small number of fish in these sizes are found in Virginia, with most fish being significantly larger. Consequently, size at maturity for black drum found in Virginia cannot be estimated.

Fitzhugh and Beckman (1987) reported monthly maxima in mean gonadosomatic indices (GSI) during February and March, apparently the peak spawning months in Louisiana waters. In northeast Florida elevated mean and mean-maximum oocyte diameters were found during the peak spawning months of January through March (Murphy and Taylor 1989). Richards (1973) indicated that spawning in the Chesapeake Bay is from April through mid-June based on the presence of ripe adults. Black drum eggs were collected during May 1962 at the mouth of the Chesapeake Bay giving evidence of spawning (Joseph et al. 1964). In 1990, Cowan et al. (1991) found peak black drum egg abundances during the ten day period from 20 to 29 May off Cape Charles, Virginia. Further evidence of a late spring spawning season in the Chesapeake Bay is given by the discovery of larval and juvenile black drum in the late summer and early fall months in the upper parts of the bay (Frisbie 1961). No further published description or estimates of the reproductive biology exist for black drum found in Virginia waters.

This project was undertaken with the following objectives:

1) The development of age determination methods, including hard part comparisons and otolith counting transect analyses.
II) Describing life history and population dynamics information including:

A) Development of age composition data and estimation of growth and mortality parameters.

B) The general description of the reproductive biology of black drum including sex ratios, spawning strategy, maturity schedules, and estimates of total fecundity.
MATERIALS AND METHODS

DATA COLLECTION

From October 1989 to June 1990, black drum were sampled from both the commercial and recreational components of the fishery. Sampling concentrated on the lower Eastern Shore of Virginia, both bayside and seaside, with a few fish also collected from the Lynnhaven area of Virginia Beach (Figure 1). Commercial samples were taken by several different gears, namely gill nets, trot lines, and pound nets. All fish collected from the recreational anglers were caught using rod and reel.

From each specimen, morphometric data were collected including total length (TL) and standard length (SL), two girth measurements, girth 1 (G1) made at the posterior most point of the operculum and girth 2 (G2) made at the point of the greatest girth, approximately at the anterior point of dorsal-fin insertion, total weight (TW), and gonad weight (GW). Lengths and girths were recorded to the nearest 5 mm, total weights to the nearest 0.25 Kg, and gonad weights to the nearest 10 grams. Sexes of fish were recorded, and for females the gonad maturity stages were determined using slight modifications of Kesteven's (1960) system cited in Bagenal and Braum (1971) (Table 1). Subsamples of ovaries from 12 females staged as late developing were weighed, split open, everted, and placed in Gilson's s fluid for estimation of fecundity (Bagenal 1978). Also, throughout the season samples of ovaries were placed in 10% Formalin for one week and later preserved in
70% ethanol for histological confirmation of field assigned maturity stages. Hard parts sampled for aging included otoliths (sagittae), soft pectoral-fin rays and spiny dorsal-fin rays. Entire left pectoral fins and the first six (largest) dorsal-fin spines were taken and stored in labeled whirl packs before freezing. Both sagittal otoliths were removed from each specimen using a hack saw to make a dorsa-ventral cut on top of the fish's head, immediately behind the operculum. Otoliths were cleaned and stored dry in labeled coin envelopes. Scales were not collected due to their history of being unreadable past ten rings (Richards 1973).

DEVELOPMENT OF AGE DETERMINATION METHODS

To prepare otoliths for aging, they were affixed to glass microscope slides with thermoplastic cement, mounted in a chuck and cut with a single thin diamond blade on a Buehler Isomet low-speed saw. At least two serial sections were obtained from randomly selected left or right otoliths from each fish for hard part analyses. Sections were cut between 350-500µ in thickness, as suggested by Beamish (1981). Sectioning was started as close to the nucleus as possible to ensure that at least one section would contain the otolith core. Sections were mounted on labeled microscope slides with Flo-texx clear mounting medium. Otoliths were read under a dissecting microscope at 20-50 X magnification with bright field and transmitted light and opaque marks were interpreted as annular marks.

For aging using fin rays, the largest ray from each selected fin was used (Hill et al. 1989), i.e., the third spine from the spinous
dorsal fin and the fifth ray from the left pectoral fin. The largest fin rays were selected for ease of work after preliminary observations of fin ray sections from different rays showed no within-fin difference in the appearance of annuli. Each soft fin ray or spine was cleaned of all attached epidermal tissues and transversely cut in half. The proximal half was then mounted with thermoplastic cement on a glass slide and serially sectioned with a thin diamond blade using a Buehler Isomet low-speed saw. At least five transverse serial sections 300-500µ thick were made starting at the base of the fin element (Beamish 1981; Cailliet et al. 1986). Sections were mounted on labeled microscope slides with Flo-texx clear mounting medium and opaque marks were read with transmitted light under a dissecting microscope with alternating light and dark field at 50-90 X magnification. Marks were counted as annuli if they had a distinct optical density difference from surrounding areas, if they could be followed around the entire section and if they fell in a discernible sequence.

Two experiments were conducted to develop reliable age determination methods. The first was a counting transect analysis designed to select the best sectioning plane and counting transect for age determinations using otoliths. The second experiment was designed to select the best calcified hard part for determining age. For both, "the best" was evaluated in terms of ease of reading, quality of hard part structure and rings, and the precision of age readings. For each experiment, sample sizes were determined from pre-planned analysis of variance (ANOVA) tables, with a minimum of 25 degrees of freedom for error.
Otolith Counting Transect Analysis

In order to determine the best sectioning plane and transect for otolith annuli readings, 40 fish were randomly selected for analysis. Ten black drum otoliths were sectioned and aged in each of four different counting transects: transverse plane sections read proximally, oblique plane sections read proximally, longitudinal plane sections read rostrally, and longitudinal plane sections read post-rostrally (Figure 2).

A number of criteria for determining the ease and quality of otolith reading were determined and assessed for each otolith section. A score system was established for the experiment with a low score indicating poor reading quality and a high score indicating good reading quality. The criteria for gauging the quality of a section included: 1) the ability to follow rings throughout the entire section, 2) clarity of rings, i.e., are the rings too light or dark, 3) presence of any zones difficult to read, 4) presence of confusing checks or false annuli, 5) distinctiveness of the rings, i.e., are they sharp or fuzzy and broad with some splitting, and 6) agreement or precision of age readings. The qualitative data were analyzed using a Kruskal-Wallis test followed by a distribution-free multiple comparison test (Hollander and Wolfe 1973) to determine if significant differences existed among the four transects.

Comparison Of Hard Parts

The three different hard parts, comprising otoliths, pectoral-fin rays and, dorsal-fin spines, were collected from thirty randomly
selected fish for the analysis of precision of hard parts, with all three aging structures processed and read for each of the 30 fish. All otoliths were serially sectioned only in the transverse plane and read proximally, while the fin rays were processed following the methods as described above.

Quantitative data for the comparison of hard parts experiment consisted of annuli counts. All hard parts were independently read two times by two different readers, with those hard parts where the reader felt that he could not properly assign an age, due to the poor quality of the structure, a value of "NR" was given. Agreement between readers was assessed through two different measures of variation, the Index of Average Percent Error (APE), which is the average error in aging each fish expressed as a fraction of the average of the individual age estimates multiplied by 100 (Beamish and Fournier 1981) and an estimate of the Coefficient of Variation (CV) (Sokal and Rohlf 1981) as suggested by Chang (1982), which is the standard deviation expressed as a percentage of the mean.

Hard part specimens were also evaluated qualitatively following the criteria, methods, and nonparametrical tests explained in the counting transect section of this paper. Additionally, the ease of specimen preparation was assessed.

AGE AND GROWTH ANALYSIS

Left and right otoliths from 30 randomly selected fish were sectioned and aged to determine if differences in ring counts existed between left and right otoliths. All counts were identical for all
thirty otolith pairs. Therefore, for general age analysis only left otoliths were sectioned and read in the transverse-proximal counting transect. Right otoliths were substituted when left otoliths were missing or had been used for the previous aging methods experiments.

All otoliths were independently aged by two different readers following a double blind protocol with precision of age estimates determined from the calculation of the Index of Average Percent Error (Beamish and Fournier 1981). When disagreement occurred between readers (n-2), otoliths were aged a second time. In both cases rereading produced agreement.

Total length-total weight regressions for allometric growth were fit separately for each sex using log-transformed data with the model $TW = aTL^b$. Significant differences between the models were tested for with tests of homogeneity of slopes and intercepts (Rawlings 1988) using SAS's Regression (REG) procedure.

Simple linear regressions were calculated to obtain the relationships between lengths, weights, and girths. Regressions were also calculated to explore relationships between otolith lengths, depths, and weights with recorded body morphometric measurements as well as the ages of the fish. These could potentially provide means to obtain back-calculated length at age for these fish in the future (Casselman 1990).

Separate von Bertalanffy growth functions (VBGF) for males and females were fit to 122 and 93 fish, respectively, using the SAS Nonlinear regression (NLIN) procedure, with the Marquardt option. VBGF models were produced for both total length and total weight. Juvenile fish were included in both female and male data sets. The growth
expressions (von Bertalanffy 1957) used were:

\[ L_t = L_\infty (1-e^{-K(t-t_0)}) \quad \text{and} \quad W_t = W_\infty (1-e^{-K(t-t_0)}) \]

\( L_t \) and \( W_t \) = length and weight at age \( t \) (years)
\( L_\infty \) and \( W_\infty \) = asymptotic length and weight
\( K \) = growth coefficient constant
\( t_0 \) = theoretical age at zero length.

Differences between the sex-specific model parameters for weight and length were calculated using Kimura's (1980) tests, derived through likelihood ratio (LR) methods, for simultaneously testing the equality of von Bertalanffy growth parameters from two samples. Kimura's tests were adapted to be computed by SAS's NLIN procedure.

MORTALITY

Theoretical total annual mortality rates, as defined in Ricker (1975), were calculated using the oldest age fish from the collection following the methods of Hoenig (1983) and Royce (1972). Estimating average annual total mortality rates \((1-S)\), survivorship \((S)\), and instantaneous total mortality rates \((Z)\) for Virginia black drum followed the calculation of \( Z \) from the expression:

\[ Z = -\log_k \frac{t_L}{t_L} \]

\( K \) = Survivorship constant (0.01)
\( t_L \) = Age to which a proportion, \( K \), black drum survive
where $t_L$ can be approximated following Hoenig’s (1983) observation that the maximum age in a sample, $t_{\text{max}}$, can be substituted for $t_L$ and still produce a good estimate of mortality. Average annual total mortality rates ($1-S$) and survivorship ($S$) estimates were calculated from $Z$ using the formulas (Gulland 1983):

\[ 1-S = 1 - e^{-z} \]
\[ S = e^{-z}. \]

REPRODUCTIVE BIOLOGY

Maturity schedules were determined from the field-assigned maturity stages made throughout the sampling season and confirmed through histological procedures. Formalin fixed ovaries were embedded in paraffin, sectioned, and stained with hematoxylin and eosin. All histological processing was completed by the Norfolk General Hospital histology lab. Gross analysis of ovarian stages were based on the oocyte stage composition of the sections following identifying characteristics of oocytes described by Overstreet (1983) for spotted seatrout. In addition to ovary staging, maturity schedules were also developed by following gonadosomatic indices (GSI) for individual male and female fish over the sampling season, calculated as $\text{GSI} = 100 \frac{GW}{TW}$.

Fecundity

The 12 field collected ovary samples remained in Gilson's fluid for three to four months, while manually shaken weekly to help free eggs
from the ovarian tissue. After this period, the samples were rinsed with water using three stainless steel sieves ranging in mesh sizes from 2 mm down to 250 μ to help remove the eggs still attached to the remaining connective tissue while ensuring no loss of eggs. Water was added to each egg sample, bringing the total egg and water mixture to an exact volume of two liters. The egg-water mixture was then stirred with a magnetic stirrer, until the eggs were evenly dispersed throughout the water column. Dense samples were diluted by subsampling with each subsample again combined with water to obtain the 2 liter volume and stirred as above. For each magnetically stirred 2 liter sample, five 5 ml aliquots were taken using a Brinkmann-macro-Transferpettor and preserved with 70 % ethanol. A number of extra "practice" aliquots were obtained from the first few samples processed.

Egg counts were made on a 100 x 100 x 15 mm square gridded petri dish, with 36 individual cells. Eggs were spread uniformly over the entire grid and egg counts were made using the Optimas image analysis system's point object class function. Initial egg counts made on practice aliquots showed that the amount of time necessary to count all 36 cells from every grid was quite excessive. To reduce the total number of counts, one sample was selected and all eggs in each cell for the sample's five aliquots counted. Following the procedure of Hogg and Tanis (1988) for determining sample sizes, the total number of cells required to obtain an estimate of total fecundity with an ± 5 % error was calculated. It was determined that counts from only 30 cells out of the 180 possible cells from all five aliquots of a sample were needed for fecundity estimates to obtain this precision.

An ANOVA of the preliminary counts was calculated and showed that
no significant difference existed between the aliquots (p= 0.131). While there was little variation between sample aliquots, a substantial amount of variation existed within each aliquot (high CV), indicating that it was better to select fewer aliquots, but count more cells from each chosen aliquot. For all remaining fecundity counts, two aliquots from each sample were randomly selected, with 15 cells randomly chosen from each, again with the counts being made using the Optimas image analysis system.

BAYSIDE - SEASIDE COMPARISONS

There has been much speculation that the black drum found on the seaside of the Eastern Shore are fish traveling on their way to the Delaware Bay and do not belong to the Chesapeake Bay stock. Total lengths, total weights, and ages were compared between bay and sea caught fish using simple t-tests to compare means. Differences between seaside and bayside fish were also tested with goodness of fit chi-square tests on age and length distribution frequencies of fish captured with the same type gear.
RESULTS

A total of 235 fish was collected, with 30% of the fish coming from the recreational fishery and 70% coming from commercial catches. Three young-of-the-year black drum were collected from pound net catches made at Lynnhaven Inlet in October and November, 1989. The first adult fish was collected on 02 April 1990 from a pound net catch made in the same location. The last collection was made on 31 May, 1990 from a seaside gill netter.

Total lengths ranged from 229 mm to 1300 mm, with a mean of 1084 mm (Table 2). The total weight mean was 22.5 Kg, with a range from 0.18 Kg to 49.5 Kg. There was no significant difference in total length (t-test; t= 1.93; 1,208 df; p= 0.1664) or total weight (t-test; t= 1.49; 1,159 df; p= 0.2246) between sexes.

DEVELOPMENT OF AGE DETERMINATION METHODS

The black drum otolith is very large, weighing as much as 10 grams with maximum otolith diameters approaching 30 mm. When a section was made in the longitudinal plane (along the maximum diameter) the ends of the otolith in the intended plane could not be cut without first rotating the chuck and otolith rostrally and then post-rostrally to ensure complete cuts. This repositioning for longitudinal sectioning greatly increased the time of processing. This problem did not occur in the transverse or oblique planes. From the qualitative analysis, there
were significant differences among counting transects in ease of reading
(Kruskal-Wallis test, $\chi^2 = 13.43$, 3 df, $p = 0.0038$). The distribution-
free multiple comparisons test based on the Kruskal-Wallis ranked sums
showed significant differences between the transverse-proximal transect
and both the longitudinal post-rostral and longitudinal rostral
transects (Table 3). No other differences were significant. The
transverse-proximal transect was chosen as the "best" due to the ease in
preparation, the shortest time for sectioning, the easiest orientating
on the glass slides, and for their clear and distinct annuli.

Comparison of Hard Parts

There were significant differences among the hard part precision
of age determinations (Figure 3). The APE and CV for otoliths showed no
variation between readers, with 100% of all independent otolith readings
in agreement. The pectoral-fin rays were the next most precise hard
part, with the dorsal-fin spines having the poorest precision. Age
readings were made on 100% of the otoliths selected for this experiment,
while only 63.7% and 36.7% of pectoral-fin rays and dorsal-fin spines
were readable, respectively (Table 4). Fin ray sections that were
deemed readable had 100% agreement between readers for pectoral-fin rays
and 90.9% for dorsal-fin spines when given an error margin of ± 3 rings
(Table 4).

Back drum otoliths were superior to the other hard parts in terms
of ease of reading based on assigned qualitative values (Kruskal-Wallis
test, $\chi^2 = 63.87; 2$ df; $p = 0.0001$). The distribution-free multiple
comparison analysis based on the Kruskal-Wallis scores showed that
otoliths had higher mean scores indicating a greater ease of age reading (Table 5). No significant differences in mean scores existed between the dorsal and pectoral-fin rays.

Paired comparisons were made between otoliths and the two fin rays to determine the relationships between the hard part age estimates (Figure 4). Otolith ages were assumed to indicate true age due to the precision results of this experiment and their history of validation. There was a significant correlation between otolith and dorsal-fin spine determined ages (F= 12.28; 1,9 df; p= 0.007), with dorsal-fin spine ages consistently lower than otolith ages. Variation in otolith counts only explained 53% of the variation in dorsal-spine counts. Pectoral-fin ray age estimates also showed a significant correlation with otolith ages (F= 122.51; 1,17 df; p= 0.0001), with the variation in otolith counts explaining 87.1% of the variation in pectoral-fin ray counts. Figure 4 illustrates that those fin rays, both dorsal and pectoral, capable of being read were predominately from younger fish, with increasingly poor agreement in older fish.

**AGE AND GROWTH ANALYSIS**

A total of 216 fish was usable for age and growth analysis, 120 of which were male, 90 female, 3 immature, and 3 fish with no assigned sexes. Figures 5 and 6 illustrate the similarity in male and female black drum total lengths (t-test; t= -0.359; 92,122 df; p= 0.720) and ages (t-test; t= -0.512; 92,121 df; p= 0.609), respectively. Black drum ages varied from 0 for the three young of the year fish to 57 for the two largest fish. No fish were collected for the ages one through
seven, but all ages between eight and 57 years were represented, excluding ages nine, 43, 44, and 51 through 55.

**Total Length to Total Weight Relation**

Total length-total weight regressions for males and females were not significantly different (F= 0.1314; 1,162 df; p= 0.7175 for difference in slopes, F= 1.606; 1,163 df; p= 0.2068 for difference in y-intercepts). With no differences found between the sexes, the data were pooled, and one length-weight regression was calculated for all fish (Figure 7).

\[
\text{Males: } \quad \text{TW} = (3.79 \times 10^{-6})\text{TL}^{3.216} \quad (n= 90 \quad r^2= 0.90)
\]

\[
\text{Females: } \quad \text{TW} = (1.54 \times 10^{-6})\text{TL}^{3.346} \quad (n= 68 \quad r^2= 0.85)
\]

\[
\text{Combined With Juveniles: } \quad \text{TW} = (1.02 \times 10^{-5})\text{TL}^{3.079} \quad (n= 166 \quad r^2= 0.98)
\]

\[
\text{Combined Without Juveniles: } \quad \text{TW} = (2.27 \times 10^{-6})\text{TL}^{3.291} \quad (n= 163 \quad r^2= 0.88)
\]

A pooled sex model with juvenile fish data included was fit to describe growth for the entire size range observed. A pooled regression was also fit without juveniles to alleviate the significant affect the small number of young fish expressed in curve fitting (Figure 8).

**Weight, Length, Girth, Otolith Morphometrics, and Age Relations**

Total length-standard length, girth-total length, and girth-weight regressions from pooled male, female and juvenile data are presented in
Table 6. Also, regressions calculated to observe relationships between otolith lengths, widths, and weights with fish age, total length, and total weight are found in Table 7.

Von Bertalanffy Growth Function

Growth curves produced for black drum in Virginia indicate that the fish grows very quickly over the first years of life with fish reaching 900 mm total length in only eight years. After this quick growth period, growth slows to a reduced rate for the rest of the fish's life, which evidence shows could span 60 years. The fitted von Bertalanffy growth equations were:

Males:
\[ L_t = 1172(1 - e^{-0.1012(t + 2.614)}) \]
\[ W_t = 37,066(1 - e^{-0.035(t + 1.055)}) \]

Females:
\[ L_t = 1194(1 - e^{-0.0977(t + 2.814)}) \]
\[ W_t = 53,957(1 - e^{-0.0206(t + 2.268)}) \]

Combined:
\[ L_t = 1186(1 - e^{-0.0961(t + 3.096)}) \]
\[ W_t = 48,751(1 - e^{-0.0215(t + 3.664)}) \]

There were no significant differences between the models fitted for separate sexes for length (simultaneous testing of \( L_{m} = L_{f}, K_{m} = K_{f}, \) and \( t_{m} = t_{f} ; \chi^2 = 5.586; 3 \text{ df}; p > 0.10 \)). There was a significant difference between male and female growth models for weight (simultaneous testing of \( W_{m} = W_{f}, K_{m} = K_{f}, \) and \( t_{m} = t_{f}; \chi^2 = 13.415; 3 \text{ df}; p < 0.005 \)). Consequently, the three VBGF parameters for weight
were individually tested for equality between male and female growth models following the procedures of Kimura (1980). The only observed significant difference was between male and female $W_m$ estimates ($\chi^2 = 4.380; 1 \text{ df}; p < 0.05$), which can be attributed to the heavy weight of female ovaries in pre-spawning condition. Pooled data growth curves were produced for length (Figure 9) and weight (Figure 10). Table 8 summarizes the growth parameters and supporting standard errors and coefficients of variation for the individual sex and pooled growth models on length and weight.

MORTALITY

Black drum are large fish with extremely long life spans, which indicates that they have a low annual mortality rate. The two oldest fish among the 216 aged drum were 57 year old females. Using the maximum age observed as an estimate of $t_L$, black drum in Virginia have an estimated average total annual mortality rate of 7.7%. The three theoretical mortality estimates, $Z$, $S$, and $1-S$, are presented in Table 9 with $t_L$ estimates ranging from 50 to 60 years.

REPRODUCTIVE BIOLOGY

Maturity Schedules

Upon arrival to Virginia waters in the early spring, all observed female black drum were in the late developing stage of ovarian maturation. 100% of the observed female fish remained in this stage
until the week of 22 April, 1990 when the first gravid and ripe fish were collected. Actively spawning fish were observed until the week of 13 May, 1990 after which all fish collected were staged as spent (Figure 11).

All histology samples collected confirmed field assigned maturity stages. Only four maturity stages were assigned to female black drum. These included late developing, gravid, ripe/spawning, and spent. Histological sections of the different ovary stages were characterized by the descriptions from Overstreet (1983) for spotted seatrout, adapted for black drum (Table 10).

Male and female gonadosomatic indices (GSI) were tracked over the sampling season through calculated weekly means. During the first four weeks of sampling, male GSI weekly means remained steady with a peak mean value of 2.9 % during the week of 22-28 April. After this period GSI weekly means dropped to approximately 1% where they remained for the rest of the sampling season (Figure 12). Female GSI values followed the a pattern similar to that of the males. During the first few weeks of the spring season weekly means were high, with a season maximum mean value of 13.3% observed during the week of 22-28 April. During the week of 29 April-5 May the GSI mean fell to 10.2%, with the following week’s mean falling to 2.6%. Female GSI means remained below 3.5% for the remainder of season (Figure 13).

Sex Ratios

Male fish made up 56.9% of the overall composition of black drum collected in 1990. Temporal trends of sex ratios were examined by week
of capture (Figure 14). During the early part of the season male and female fish were present in approximately equal numbers, but over the last three weeks of collection male fish began to overwhelmingly dominate catches.

Size at Maturity

All black drum sampled for this study during the spring were sexually mature. Only the young of the year fish collected during the fall of 1989 were immature. All mature fish were either ready to spawn, in the process of spawning, or spent. Sampled fish lacked representation from age groups one through seven, the range historically containing the black drum size and age at first maturity. The smallest fish observed during spring collections was a 875 mm spent female aged at 8 years old. Theories on why these smaller and younger black drum are not found in Virginia will be addressed in the discussion section.

Fecundity

Virginia black drum are very fecund fish, with some ovaries from this study exceeding 4.5 Kg in weight and full of eggs of less than one millimeter in mean diameter when shed (Joseph et al. 1964). Total fecundity estimates ranged from $5.6 \times 10^6$ eggs for a 985 mm, 16.5 Kg fish to $2.7 \times 10^7$ eggs for a 1165 mm, 35 Kg fish (Table 11).

The plot of the fecundity estimates vs. total length (Figure 15) shows that fecundity increased rapidly with size, but slowed as the fish became very large. Regressions of fecundity on total length were
calculated to determine the best model to describe the relationship. A simple linear regression was calculated initially, but produced a poor fit \((r^2 = 0.30)\). A regression was calculated using log-transformed data, but again a poor fit was observed \((r^2 = 0.32)\). The model that best described the relationship between fecundity and total length was a curvilinear quadratic regression \((r^2 = 0.48)\). The quadratic model calculated was the following:

\[
\text{Fecundity} = -7.702 \times 10^{8} + 1.379 \times 10^{6} \text{TL} - 6.008 \times 10^{2} \text{TL}^2
\]

**BAYSIDE - SEASIDE COMPARISONS**

There was no significant difference in mean total lengths \((t\text{-test}; t = -4.450; 128.83 \text{ df}; p = 0.6568)\) or mean age \((t\text{-test}; t = -1.413; 127.83 \text{ df}; p = 0.1589)\) between bayside and seaside fish. There was a significant difference between total weight \((t\text{-test}; t = -3.653; 89.90 \text{ df}; p = 0.0003)\) for the two fish groups, which can be explained by the majority of seaside fish being caught before spawning and having very heavy gonads. Most of the Bayside fish were caught after spawning had taken place. Chi-square tests for goodness of fit were not significantly different for bayside and seaside gill net caught fish for length \((\chi^2 = 30.56; 43 \text{ df}; p = 0.923)\) or age \((\chi^2 = 39.622; 32 \text{ df}; p = 0.206)\) distribution providing further evidence that bayside and seaside fish were from the same stock.
DESCRIPTION OF THE BLACK DRUM FISHERY

The commercial black drum fishery in Virginia is concentrated almost exclusively on the Eastern Shore where fishing takes place both on the seaside and the bayside. Figure 16 illustrates the oscillating pattern of commercial catches of black drum in Virginia over the past 25 years (1991 VMRC Black Drum Advisory Board meeting). Large harvests seen during the late 1960's were succeeded by very low catches in the 1970's and early 1980's. Since 1986 catches have begun to increase with the total commercial harvest of black drum in 1990 being approximately 82,000 pounds.

Since the middle of 1987 the Virginia Marine Resources Commission (VMRC) has required anyone who commercially catches, buys, or sells black drum in Virginia to obtain a Commercial Harvesters Permit and submit weekly catch/purchase reports. A total of 41 harvester permits were issued by VMRC in 1990, with 23 of those permitted fishermen reporting catching black drum (1991 VMRC Black Drum Advisory Board meeting). There were 42 and 23 harvester permits issued in 1988 and 1989, respectively.

Commercial fishermen use 11 to 13 inch mesh gill nets as the primary method of capture and employ a number of different anchored gill net tactics. These range from fishing nets almost in the breakers near the shore to placing nets in deep water over mussel beds. Sometimes when
schools of fish are seen, or even heard through their drumming, fishermen set their nets and then herd the fish into the nets with boats. A smaller number of black drum are caught with trot lines baited with whelks or crabs. Only rarely are black drum caught in pound nets, which the large fish normally appear able to avoid.

Black drum also support a sizable recreational fishery. Since 1988 VMRC has made four aerial recreational boat counts per year during the spring recreational black drum season. Mean daily boat counts were 98 boats for 1988, 137 boats for 1989, and 75 boats per day for 1990. In addition, numerous privately owned boats were observed at the boat ramp at the Cape Charles Marina returning with fish. Recreational charter boat fishing is also quite popular on the lower Eastern Shore. Each year a fleet of charter boats come to King's Creek Marina especially for the spring black drum season. Charter boats are now regulating themselves with a two fish per person per day limit.

AGE DETERMINATION METHODS

Age determination methods analyses indicate that the otolith is the most precise aging structure, of the three, studied for black drum in the Virginia. The best way to prepare an black drum otolith for age determination is by transversely sectioning the otolith and counting rings along the proximal transect. This method provided the best means to determine age, while also providing a distinct reference line, the edge of the sulcus running from the nucleus to the proximal edge of the sections, that functioned as a guide to aid in making ring counts.

While aging with otoliths has been validated for black drum from
northeast Florida (Murphy and Taylor 1989) and the Gulf of Mexico (Beckman et al. 1990), ages obtained in this study were not validated. Aging was performed under the premise that the Virginia population would produce one annulus per year as has been demonstrated for other black drum populations. Age validation using a radiochemical technique that measures the decay of $^{226}$Ra into $^{210}$Pb will be performed on the extra otoliths from each fish pair from this study by the Bedford Institute of Oceanography in Nova Scotia, Canada.

The use of soft pectoral-fin rays to age black drum in the comparison of hard parts experiment was encouraging. Even though pectoral-fin rays tended to underestimate age as fish grew older and were not readable for most of the oldest fish, they were quite precise for younger fish. This hard part provides a means to obtain age without necessitating the sacrifice of the fish, as is necessary for otoliths. Further investigation of this technique should be pursued to better evaluate this structure for aging younger fish.

AGE AND GROWTH

Virginia black drum ages obtained from otoliths in this investigation ranged from zero to 57 years. Previous studies on Virginia fish (Richards 1973; Desfosse 1987) using scales appear to have greatly underestimated fish age, which is due partly to scale growth essentially ceasing in older age fish while body growth continues (Casselman 1990). The maximum reported age for black drum from northeast Florida is 58 (Murphy and Taylor 1989), only one year older than observed in this study. While maximum ages differ only slightly,
there is a strong dissimilarity in age composition. Only 20% of 399 aged fish from the northeast Florida study were older than 4 years, while almost all of the Virginia fish aged were equal to or greater than 8 years old. Beckman et al. (1990) reported that only 3 fish out of the 1,075 sampled from Louisiana waters of the Gulf of Mexico exceeded 36 years in age, with the maximum age being 43 years. It is apparent that black drum from the east coast of Florida and the Gulf of Mexico and are dominated by much younger individuals than those in Virginia.

Size differences of fish parallel the difference in ages between the northeast Florida, Louisiana, and Virginia black drum. Fish observed in this study had overall mean total length of 1084 mm and mean total weight of 22.6 Kg. Desfosse (1987) reported a similar mean total length of 1100 mm, but observed a much lower mean total weight of 19.5 Kg for Virginia, perhaps attributable to his collecting fish from one site over one weekend with most fish staged as spent. In Louisiana Fitzhugh and Beckman (1987) reported that out of a sample size of 1,095 fish collected over three years, the largest fish observed was a 1121 mm fork length, 22.1 Kg male, both of which are very close to the mean size of a Virginia fish. Clearly, the fish in the Gulf of Mexico are much smaller than in Virginia. The mean total length and total weight for fish observed by Murphy and Taylor (1989) in Florida were approximately 523 mm and 4.9 Kg, respectively. Even though the mean sizes are significantly different than those from Virginia, a small number of fish did approach the maximum total lengths observed in this study. The differences in size may be attributable to the fish residing in very different environments. The differences may also be explained by the fish belonging to separate stocks, which is addressed later in this study.
Total Weight to Total Length Relation

Total weight-total length regressions calculated for this study were compared with those from Louisiana (Beckman et al. 1990) and northeast Florida (Murphy and Taylor 1989). Fork length data for the Louisiana population was converted to total length using Murphy and Taylor's (1989) fork length-total length regression equation. Virginia fish weighed more than both Florida and Louisiana black drum at the same length. A 1000 mm total length fish in Virginia has a predicted weight of 17.6 Kg, while fish with the same length from northeast Florida and Louisiana have predicted weights of 15.7 Kg and 14.9 Kg, respectively.

Von Bertalanffy Growth Function

By comparing the von Bertalanffy growth model parameters $K$ and $L_\infty$, black drum from different locations can be compared to determine if the fish have similar growth, which could indicate that the fish belong to the same stock. These estimates have been produced for black drum from northeast Florida (Murphy and Taylor 1989), Louisiana (Beckman et al. 1990), Texas (Doerzbacher et al. 1988), and Virginia (Richards 1973; present study 1990) (Table 12). $K$ is defined as the rate at which fish approach the mean maximum size, $L_\infty$. Fish with higher $K$ values will grow quicker and fish with higher $L_\infty$ values will grow on average to a larger size. Richards (1973) reported a faster growth and a much larger maximum size than reported in the present study. Increased growth can be attributed to the underestimation of ages through the use of scales. The mean maximum size seems unrealistic with no fish approaching a
length of 1474 mm being observed in this study or by Desfosse (1987). Northeast Florida fish appear to grow faster, with a K estimate of 0.124, but the Lₘ estimate of 1172 mm is not notably different from Virginia. Texas and Louisiana black drum reach a much smaller maximum size than those from Virginia. The reported growth rate of fish in Louisiana is low, but in Texas the growth rate is higher than that observed in Virginia. The Texas parameters were calculated from growth information obtained from a tagging study and should be viewed with caution due to the limited size range used for producing the growth model, which was almost entirely composed of smaller fast growing fish.

MORTALITY

Black drum in Virginia have the potential to exceed 55 years in age, which indicates that the fish have a very low natural mortality rate. Black drum have evolved a reproductive strategy that necessitates the production of large numbers of eggs over a long period of time to ensure sufficient offspring production. The major problem for fish of great longevity is that they tend to be highly susceptible to any increase in mortality. A higher rate of exploitation could cause the population to juvenesce to a state of recruitment overfishing where there is not enough egg production to sustain the population. One compounding problem with fishing mortality for Virginia's black drum is that it occurs at the highest rate during the black drum spawning season, which also affects recruitment. These mortality estimates are based on fish with the life span observed in this study. If Virginia black drum belong to a common Atlantic stock and are composed of only
the largest fish residing further north along the east coast, these mortality estimates may not apply to the younger populations found in Florida and the Gulf of Mexico.

REPRODUCTION

Black drum enter Virginia waters during the period from April to May of each year to spawn. Ripe fish were observed by Desfosse (1987) and during this study. Black drum eggs have been collected during the early spring (Joseph et al. 1964; Cowan et al. 1990), with young of the year fish observed moving into shallow areas to reside during the early summer (Frisbie 1961). Murphy and Taylor (1989) reports evidence of black drum spawning from January through April, with March and April the peak months of spawning activity in northeast Florida. Fish in spawning condition were also collected by Murphy and Taylor on the west coast of Florida, around Tampa Bay, during February and March. Spawning in Louisiana waters of the Gulf of Mexico takes place from February through April, with the peak months being February and March (Fitzhugh and Beckman 1987).

GSI and maturity stage data from this study indicate that black drum in Virginia are total spawners. Over a three week period from 22 April to 12 May 1990 female fish progressed from the ovarian development stage of late maturity with high GSI values to the spent maturity stage with low GSI values. Over this short period of time the fish appear to have completely released their eggs and showed no evidence of any further egg development for that year. In Louisiana, Fitzhugh and Beckman (1987) report that black drum exhibited batch spawning with a
female spawning once every seven days. These two very different spawning strategies may be attributable to the difference in the duration of the spawning seasons between the Gulf of Mexico and Virginia black drum. The time period when conditions, such as water temperature, are optimal for spawning is shorter in Virginia as compared to the protracted duration of optimal conditions observed in the Gulf of Mexico.

STOCK CONSIDERATIONS

Black drum, ranging along most of the Eastern United States and all of the Gulf of Mexico states, present problems in stock delineation. Through comparison of size and age compositions, growth parameters, and biological strategies of black drum from different localities, several hypotheses concerning stock membership for Virginia black drum can be formulated.

Hypothesis 1: in the Atlantic there is just one stock ranging from Delaware to Florida, with larger members migrating further north. This would explain the dominance of larger, older individuals in Virginia, with smaller fish found in higher numbers further south. Also, the presence of fish in northeast Florida that have been aged up to 58 years (Murphy and Taylor 1989) and 46 years in Georgia (Music and Pafford 1984, as cited in Murphy and Taylor 1987) tend to support the theory of one Atlantic stock with fish from all portions of the range with similar maximum ages. It is possible that heavier year round fishing pressure producing juvenescence is the cause of smaller fish dominating the southern portion of the range. Although the von
Bertalanffy parameter $K$ differ between northeast Florida black drum and those found in Virginia, they do have very similar $L_{\infty}$ estimates. The difference in $K$ values could be attributed to the application of the VBGF to samples with very different size and age compositions, but drawn from a common stock.

Hypothesis 2: black drum in the Atlantic belong to more than one stock. Virginia fish belong to a northern stock and return each year to their specific spawning grounds, such as the Chesapeake Bay or Delaware Bay, but for the rest of the year they reside elsewhere. Black drum found further south are yearly residents of particular localities where they spawn. Assuming no mixing of stocks, Atlantic black drum would be composed of separate reproductive stocks, each responsible for their own propagation. There is a marked difference in sizes between northern and southern Atlantic fish. Murphy and Taylor (1989) found that only 20% of their sample was made up fish older than age four, while in this study only the juvenile fish collected in the fall of 1989 were younger than eight years. These differences could simply be due to the Virginia and northeast Florida black drum belonging to separate stocks.

Hypothesis 3: Virginia black drum belong to one continuous stock of fish that range from the northern Atlantic down around Florida into the Gulf of Mexico. There are many differences between black drum found in Virginia and those found in the Gulf of Mexico, the most obvious being a difference in size, with the largest fish observed by Fitzhugh and Beckman (1987) only as large as an average fish from Virginia. Spawning strategies also differ. While Virginia and Gulf fish are very fecund, Virginia fish are total spawners while batch spawning has been reported in Louisiana (Fitzhugh and Beckman 1987). Even though there is
mixing within the stock and a constant exchange of genetic information, the fish at the extremes of their range live under very different environmental conditions and consequently employ different strategies.

The determination of black drum stocks is critical to the formulation of any management plan. There is information available on population dynamics and life histories of black drum from most of their range in the United States, but without delineation of stocks and the identification of migration patterns, no appropriate management plan can be implemented. Tagging studies for black drum need to be initiated over their entire range to determine which of the three above proposed hypotheses is valid for Virginia fish stock membership. To ensure the preservation of black drum in Virginia, estimated life history parameters need to be applied to establishing management for the black drum stock to which they are members and in the case of Virginia fish belonging to a stock distributed over a large area, managed in conjunction with all states located along that distribution range.
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von Bertalanffy L.

Welsh, W. W. and C. M. Breder, Jr.
Table 1. Description of field assigned gonad maturity stages for female black drum. Modification of Kesteven's (1960) system cited in Bagenal and Braum (1971).

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Immature</td>
<td>Gonads very small, not yet developing. Young fish that has not yet reproduced.</td>
</tr>
<tr>
<td>2. Early Developing</td>
<td>Ovaries opaque, yellow to orangish. Individual eggs not visible to naked eye.</td>
</tr>
<tr>
<td>3. Late Developing</td>
<td>Ovaries occupy &gt;40% of body cavity, yellow to orangish. All individual eggs opaque, distinguishable to naked eye.</td>
</tr>
<tr>
<td>4. Gravid</td>
<td>Ovaries occupy &gt;50% of body cavity, yellow to orangish; &lt;50% of eggs translucent, most opaque.</td>
</tr>
<tr>
<td>5. Ripe/Spawning</td>
<td>Ovaries at maximum development; spawning; &gt;50% of eggs translucent; translucent eggs may run freely on pressure.</td>
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<tr>
<td>7. Resting</td>
<td>Ovaries very small, fish large enough to have spawned. May still contain left-over eggs.</td>
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</tbody>
</table>
Table 2. Summary of descriptive statistics of total length and total weight for black drum collected in 1989-1990.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Male</th>
<th>Female</th>
<th>Overall</th>
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</thead>
<tbody>
<tr>
<td><strong>Total Length (mm)</strong></td>
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<td></td>
</tr>
<tr>
<td>n</td>
<td>120</td>
<td>90</td>
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</tr>
<tr>
<td>mean</td>
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<tr>
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<td>1,092</td>
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<tr>
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<td>Max.</td>
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<td>1,300</td>
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<td>875</td>
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<td>s²</td>
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<td>s²/n (mean)</td>
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* juvenile - could not determine sex

<table>
<thead>
<tr>
<th>Statistic</th>
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<th>Female</th>
<th>Overall</th>
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<tbody>
<tr>
<td><strong>Total Weight (grams)</strong></td>
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</tr>
<tr>
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<tr>
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<tr>
<td>Max.</td>
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</tr>
<tr>
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<td>11,500</td>
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</tr>
<tr>
<td>s²</td>
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<td>4.2*10⁷</td>
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<tr>
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<tr>
<td>s²/n (mean)</td>
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<td>778.01</td>
<td>474.85</td>
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</table>

* juvenile - could not determine sex
Table 3. Summary of distribution-free multiple comparison test based on Kruskal-Wallis ranked sums of black drum otolith counting transect experiment for qualitatively assigned values. Different letters indicate significant differences. α=0.05 Minimum significant difference in mean scores = 13.43

<table>
<thead>
<tr>
<th>Transect</th>
<th>n</th>
<th>Mean Score</th>
<th>Sum of Scores</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse</td>
<td>10</td>
<td>30.70</td>
<td>307.0</td>
<td>a</td>
</tr>
<tr>
<td>Oblique</td>
<td>10</td>
<td>21.60</td>
<td>216.0</td>
<td>a b</td>
</tr>
<tr>
<td>Rostral</td>
<td>10</td>
<td>13.05</td>
<td>130.5</td>
<td>b</td>
</tr>
<tr>
<td>Post-rostral</td>
<td>10</td>
<td>16.65</td>
<td>166.5</td>
<td>b</td>
</tr>
</tbody>
</table>
Table 4. Summary of specimen readability and agreement between readers for age determinations from the black drum precision of hard parts experiment. (n = 30 fish)

<table>
<thead>
<tr>
<th></th>
<th>Otoliths</th>
<th>Dorsal Fin Rays</th>
<th>Pectoral Fin Rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of Specimens Deemed Readable by Both Readers</td>
<td>100%</td>
<td>36.7%</td>
<td>63.7%</td>
</tr>
<tr>
<td>Percent Total Agreement Between Readers for Readable Specimens</td>
<td>100%</td>
<td>27.3%</td>
<td>47.4%</td>
</tr>
<tr>
<td>Percent Agreement ± 1 Ring Between Readers for Readable Specimens</td>
<td>100%</td>
<td>63.7%</td>
<td>73.7%</td>
</tr>
<tr>
<td>Percent Agreement ± 3 Rings Between Readers for Readable Specimens</td>
<td>100%</td>
<td>90.9%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Table 5. Summary of distribution-free multiple comparison test based on Kruskal-Wallis ranked sums of black drum precision of hard parts experiment for qualitatively assigned values. Different letters indicate significant differences. α=0.05 Minimum significant difference in mean scores = 15.81

<table>
<thead>
<tr>
<th>Hard-Part</th>
<th>n</th>
<th>Mean Score</th>
<th>Sum of Scores</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Otolith</td>
<td>30</td>
<td>74.95</td>
<td>2248.5</td>
<td>a</td>
</tr>
<tr>
<td>Pectoral Rays</td>
<td>30</td>
<td>36.37</td>
<td>1091.0</td>
<td>b</td>
</tr>
<tr>
<td>Dorsal Rays</td>
<td>30</td>
<td>25.18</td>
<td>755.5</td>
<td>b</td>
</tr>
</tbody>
</table>
Table 6. Weight, length, girth, regression equations with supporting statistics for black drum (1990). TL = total length, SL = standard length, TW total weight, G1 = girth at operculum flap, and G2 = maximum girth. Measurements are in grams and millimeters.

<table>
<thead>
<tr>
<th>Equation</th>
<th>Sample Size</th>
<th>TL Range</th>
<th>$r^2$</th>
<th>Corrected Total SSy</th>
<th>Mean Size X</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL = -29.4 + 0.89TL</td>
<td>216</td>
<td>229-1300</td>
<td>0.99</td>
<td>2.67*10^6</td>
<td>1084</td>
<td>940</td>
</tr>
<tr>
<td>TL = 41.1 + 1.11SL</td>
<td>216</td>
<td>229-1300</td>
<td>0.99</td>
<td>3.31*10^6</td>
<td>940</td>
<td>1084</td>
</tr>
<tr>
<td>G1 = -55.2 + 0.74TL</td>
<td>162</td>
<td>875-1265</td>
<td>0.80</td>
<td>6.21*10^5</td>
<td>1089</td>
<td>750</td>
</tr>
<tr>
<td>TL = 274.3 + 1.09G1</td>
<td>162</td>
<td>875-1265</td>
<td>0.80</td>
<td>9.11*10^5</td>
<td>750</td>
<td>1089</td>
</tr>
<tr>
<td>G2 = -53.9 + 0.77TL</td>
<td>162</td>
<td>875-1265</td>
<td>0.78</td>
<td>6.85*10^5</td>
<td>1089</td>
<td>781</td>
</tr>
<tr>
<td>TL = 292.6 + 1.02G2</td>
<td>162</td>
<td>875-1265</td>
<td>0.78</td>
<td>9.11*10^5</td>
<td>781</td>
<td>1089</td>
</tr>
<tr>
<td>G1 = 17.2 + 0.94G2</td>
<td>165</td>
<td>875-1265</td>
<td>0.97</td>
<td>6.29*10^5</td>
<td>751</td>
<td>781</td>
</tr>
<tr>
<td>G2 = 6.04 + 1.03G1</td>
<td>165</td>
<td>875-1265</td>
<td>0.97</td>
<td>6.91*10^5</td>
<td>781</td>
<td>751</td>
</tr>
<tr>
<td>G1 = 507.9 + 0.01TW</td>
<td>165</td>
<td>875-1265</td>
<td>0.90</td>
<td>6.06*10^5</td>
<td>22751</td>
<td>751</td>
</tr>
<tr>
<td>TW = -40894 + 84G1</td>
<td>165</td>
<td>875-1265</td>
<td>0.90</td>
<td>5.01*10^5</td>
<td>751</td>
<td>22751</td>
</tr>
<tr>
<td>G2 = 526.2 + 0.01TW</td>
<td>165</td>
<td>875-1265</td>
<td>0.91</td>
<td>6.91*10^5</td>
<td>22751</td>
<td>781</td>
</tr>
<tr>
<td>TW = -40482 + 81G2</td>
<td>165</td>
<td>875-1265</td>
<td>0.91</td>
<td>5.01*10^5</td>
<td>781</td>
<td>22751</td>
</tr>
</tbody>
</table>
Table 7. Otolith morphometrics, length, and age regression equations with supporting statistics for black drum (1990). TL = total length, OL = maximum otolith length, OH = maximum otolith height, OW = otolith weight, and AGE = fish age in years. Lengths and heights are in millimeters and weights in grams.

<table>
<thead>
<tr>
<th>Equation</th>
<th>Sample Size</th>
<th>TL Range</th>
<th>r²</th>
<th>Corrected Total SSy</th>
<th>Mean x</th>
<th>Mean y</th>
</tr>
</thead>
<tbody>
<tr>
<td>OL = 2.79 + 0.02TL</td>
<td>214</td>
<td>229-1300</td>
<td>0.75</td>
<td>1.85*10^3</td>
<td>1083</td>
<td>24.8</td>
</tr>
<tr>
<td>TL = 165.96 + 36.9OL</td>
<td>214</td>
<td>229-1300</td>
<td>0.75</td>
<td>3.35*10^6</td>
<td>24.8</td>
<td>1083</td>
</tr>
<tr>
<td>OH = 3.08 + 0.01TL</td>
<td>214</td>
<td>229-1300</td>
<td>0.77</td>
<td>8.81*10^2</td>
<td>1083</td>
<td>18.4</td>
</tr>
<tr>
<td>TL = 87.5 + 53.99OH</td>
<td>214</td>
<td>229-1300</td>
<td>0.77</td>
<td>3.35*10^6</td>
<td>18.4</td>
<td>1083</td>
</tr>
<tr>
<td>OW = -5.22 + 0.01TL</td>
<td>214</td>
<td>229-1300</td>
<td>0.53</td>
<td>5.42*10^2</td>
<td>1083</td>
<td>4.82</td>
</tr>
<tr>
<td>TL = 807.5 + 57.25OH</td>
<td>214</td>
<td>229-1300</td>
<td>0.53</td>
<td>3.35*10^6</td>
<td>4.82</td>
<td>1083</td>
</tr>
<tr>
<td>OL = 19.7 + 0.19AGE</td>
<td>214</td>
<td>229-1300</td>
<td>0.49</td>
<td>1.85*10^3</td>
<td>26.4</td>
<td>24.8</td>
</tr>
<tr>
<td>AGE = -37.3 + 2.60OL</td>
<td>214</td>
<td>229-1300</td>
<td>0.49</td>
<td>2.52*10^4</td>
<td>24.8</td>
<td>26.4</td>
</tr>
<tr>
<td>OH = 14.7 + 0.14AGE</td>
<td>214</td>
<td>229-1300</td>
<td>0.54</td>
<td>8.81*10^2</td>
<td>26.4</td>
<td>18.4</td>
</tr>
<tr>
<td>AGE = -45.5 + 3.90OH</td>
<td>214</td>
<td>229-1300</td>
<td>0.54</td>
<td>2.52*10^4</td>
<td>18.4</td>
<td>26.4</td>
</tr>
<tr>
<td>OW = 1.38 + 0.13AGE</td>
<td>214</td>
<td>229-1300</td>
<td>0.75</td>
<td>5.42*10^2</td>
<td>26.4</td>
<td>4.82</td>
</tr>
<tr>
<td>AGE = -1.42 + 5.91OH</td>
<td>214</td>
<td>229-1300</td>
<td>0.75</td>
<td>2.52*10^4</td>
<td>4.82</td>
<td>26.4</td>
</tr>
</tbody>
</table>
Table 8. Estimates of black drum von Bertalanffy growth function parameters for length and weight with standard errors and coefficients of variation. Lengths are in millimeters and weights are in grams.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L_\infty$</td>
<td>1172.23</td>
<td>9.7435</td>
<td>0.83</td>
</tr>
<tr>
<td>$K$</td>
<td>0.10121</td>
<td>0.0049</td>
<td>4.92</td>
</tr>
<tr>
<td>$t_0$</td>
<td>-2.6142</td>
<td>0.3568</td>
<td>13.58</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$W_\infty$</td>
<td>37.066</td>
<td>2914</td>
<td>7.86</td>
</tr>
<tr>
<td>$K$</td>
<td>0.03501</td>
<td>0.0060</td>
<td>17.14</td>
</tr>
<tr>
<td>$t_0$</td>
<td>-1.0553</td>
<td>1.2991</td>
<td>123.1</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>length</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L_\infty$</td>
<td>1193.71</td>
<td>10.5992</td>
<td>0.88</td>
</tr>
<tr>
<td>$K$</td>
<td>0.09770</td>
<td>0.0051</td>
<td>5.16</td>
</tr>
<tr>
<td>$t_0$</td>
<td>-2.8145</td>
<td>0.3579</td>
<td>12.72</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$W_\infty$</td>
<td>53.957</td>
<td>9404</td>
<td>17.43</td>
</tr>
<tr>
<td>$K$</td>
<td>0.02056</td>
<td>0.0061</td>
<td>29.67</td>
</tr>
<tr>
<td>$t_0$</td>
<td>-2.2679</td>
<td>1.9448</td>
<td>85.76</td>
</tr>
<tr>
<td>Combined</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L_\infty$</td>
<td>1186.17</td>
<td>7.4036</td>
<td>0.62</td>
</tr>
<tr>
<td>$K$</td>
<td>0.09612</td>
<td>0.0037</td>
<td>3.85</td>
</tr>
<tr>
<td>$t_0$</td>
<td>-3.0964</td>
<td>0.3758</td>
<td>12.13</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$W_\infty$</td>
<td>48.751</td>
<td>6297</td>
<td>12.91</td>
</tr>
<tr>
<td>$K$</td>
<td>0.02153</td>
<td>0.0051</td>
<td>23.69</td>
</tr>
<tr>
<td>$t_0$</td>
<td>-3.6644</td>
<td>1.9506</td>
<td>53.22</td>
</tr>
</tbody>
</table>
Table 9. Summary of black drum theoretical average total annual mortality (1-S), survivorship (S), and instantaneous total mortality rates (Z) for selected maximum life spans.

<table>
<thead>
<tr>
<th>Maximum Life Span</th>
<th>1-S</th>
<th>S</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>8.8</td>
<td>91.2</td>
<td>0.092</td>
</tr>
<tr>
<td>55</td>
<td>8.1</td>
<td>91.9</td>
<td>0.084</td>
</tr>
<tr>
<td>57</td>
<td>7.7</td>
<td>92.3</td>
<td>0.081</td>
</tr>
<tr>
<td>60</td>
<td>7.4</td>
<td>92.6</td>
<td>0.077</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Immature</td>
<td>Stage observed, but not histologically.</td>
</tr>
<tr>
<td>2. Early Developing</td>
<td>Stage not observed.</td>
</tr>
<tr>
<td>3. Late Developing</td>
<td>Numerous oocytes undergoing vitellogenesis. Yolk vesicle stages and primary oocyte evident.</td>
</tr>
<tr>
<td>4. Gravid</td>
<td>Presence of hydrated oocytes, with late vitellogenic oocytes still dominant.</td>
</tr>
<tr>
<td>5. Ripe/Spawning</td>
<td>Hydrated oocytes more numerous, maturing oocytes becoming irregularly shaped. Presence of postovulatory follicles</td>
</tr>
<tr>
<td>6. Spent</td>
<td>Primary oocytes dominate interspersed with atretic vitellogenic and mature oocytes.</td>
</tr>
<tr>
<td>7. Resting</td>
<td>Stage not observed</td>
</tr>
</tbody>
</table>
Table 11. Total fecundity estimates for 1990 female black drum with supporting statistics.

<table>
<thead>
<tr>
<th>Fish</th>
<th>Total Length (mm)</th>
<th>Total Weight (g)</th>
<th>Age (yrs)</th>
<th>Total Fecundity</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1075</td>
<td>23250</td>
<td>22</td>
<td>2.2181*10^7</td>
<td>1.3305*10^6</td>
</tr>
<tr>
<td>2</td>
<td>1170</td>
<td>34000</td>
<td>32</td>
<td>2.6611*10^7</td>
<td>6.7933*10^5</td>
</tr>
<tr>
<td>3</td>
<td>1180</td>
<td>27500</td>
<td>26</td>
<td>1.3894*10^7</td>
<td>5.7346*10^5</td>
</tr>
<tr>
<td>4</td>
<td>1060</td>
<td>19250</td>
<td>20</td>
<td>1.0379*10^7</td>
<td>5.1495*10^5</td>
</tr>
<tr>
<td>5</td>
<td>1075</td>
<td>22500</td>
<td>22</td>
<td>1.8016*10^7</td>
<td>1.7485*10^5</td>
</tr>
<tr>
<td>6</td>
<td>1085</td>
<td>24750</td>
<td>21</td>
<td>2.0595*10^7</td>
<td>1.4101*10^6</td>
</tr>
<tr>
<td>7</td>
<td>985</td>
<td>16750</td>
<td>19</td>
<td>5.5711*10^6</td>
<td>3.2247*10^5</td>
</tr>
<tr>
<td>8</td>
<td>1210</td>
<td>39000</td>
<td>56</td>
<td>2.1552*10^7</td>
<td>8.4665*10^4</td>
</tr>
<tr>
<td>9</td>
<td>1095</td>
<td>25750</td>
<td>30</td>
<td>2.3880*10^7</td>
<td>3.1525*10^6</td>
</tr>
<tr>
<td>10</td>
<td>1025</td>
<td>19750</td>
<td>20</td>
<td>1.1723*10^7</td>
<td>5.7745*10^5</td>
</tr>
<tr>
<td>11</td>
<td>1085</td>
<td>20500</td>
<td>20</td>
<td>1.2388*10^7</td>
<td>2.4034*10^5</td>
</tr>
<tr>
<td>12</td>
<td>1055</td>
<td>23250</td>
<td>21</td>
<td>2.1259*10^7</td>
<td>1.5104*10^6</td>
</tr>
</tbody>
</table>
Table 12. Estimates of von Bertalanffy growth function parameters from various studies of black drum. Standard errors in parentheses (when available).

<table>
<thead>
<tr>
<th>Study/Area</th>
<th>Growth Parameters</th>
<th>Sample Size</th>
<th>Total Range (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$L_\infty$</td>
<td>$K$</td>
<td>$t_0$</td>
</tr>
<tr>
<td>Richards (1973) Virginia</td>
<td>1474</td>
<td>0.158</td>
<td>-0.04</td>
</tr>
<tr>
<td>Doerzbacher et al. (1988) Texas</td>
<td>798(42)</td>
<td>0.219(0.027)</td>
<td>---</td>
</tr>
<tr>
<td>Murphy and Taylor (1989) Northeast Florida</td>
<td>1172(9)</td>
<td>0.124(0.003)</td>
<td>-1.29(0.08)</td>
</tr>
<tr>
<td>Beckman et al. (1990) Louisiana</td>
<td>1100</td>
<td>0.038</td>
<td>-16.42</td>
</tr>
<tr>
<td>Present Study Virginia</td>
<td>1186(7)</td>
<td>0.096(0.004)</td>
<td>-3.09(0.38)</td>
</tr>
</tbody>
</table>
Figure 1. Study area with locations from which black drum were collected.
Figure 2. Otolith counting transects and sectioning planes evaluated for black drum in the counting transect experiment.
LONGITUDINAL POST-ROSTRAL COUNTING TRANSECT

LONGITUDINAL ROSTRAL COUNTING TRANSECT

TRANSVERSE PROXIMAL COUNTING TRANSECT

OBLIQUE PROXIMAL COUNTING TRANSECT
Figure 3. Precision of age determinations for each hard part, expressed as the average percent error (APE) and coefficient of variation (CV).
DORSAL RAYS  PEOTORAL RAYS  OTOLITHS

HARD PART

PERCENT ERROR

CV  APE
Figure 4. Paired comparisons between alternative hard part age readings with assigned otolith ages for the comparison of hard parts experiment. Solid line indicates complete agreement between hard parts.
Dorsal Spines
Percent Of Spines Readable = 36.7%
\[ r^2 = 0.53 \]

Pectoral Fin Rays
Percent Of Fin Rays Readable = 63.7%
\[ r^2 = 0.87 \]
Figure 5. Total length composition, by sex, for all black drum collected during the 1989-1990 sampling season.
MEAN = 1083.7
n=217

TOTAL LENGTH (mm)
Figure 6. Age composition, by sex, for all black drum collected during the 1989-1990 sampling season.
AGE (years)

NUMBER OF FISH

MALE

FEMALE

JUVENILE

MEAN = 27.1
n = 216
Figure 7. Length to weight relation for male and female black drum collected during the 1989-1990 sampling season in Virginia. Juvenile fish included.
TW = 1.02 \times 10^{-5} TL^{3.079}

n = 166

r^2 = 0.98
Figure 8. Length to weight relation for male and female black drum collected during the 1989-1990 sampling season in Virginia. Juvenile fish excluded.
$TW = 2.27 \times 10^{-6} TL^{3.29}$

$n = 163$

$r^2 = 0.88$

JUVENILES EXCLUDED
Figure 9. Von Bertalanffy growth curve for length for black drum in Virginia, 1989-1990.
$L_t = 1186\{1-e^{-0.09612(t+3.0964)}\}$

$n = 216$
Figure 10. Von Bertalanffy growth curve for weight for black drum in Virginia, 1989-1990.
\[ W_t = 48.751 \left\{ 1 - e^{(-0.02153(t+3.0664))} \right\} \]

\[ n = 165 \]
Figure 11. Percent composition of ovarian maturity stages, by week, for female black drum, 1990.
Figure 12. Gonadosomatic index (GSI) values for male black drum by week of capture (1990).
Figure 13. Gonadosomatic index (GSI) values for female black by week of capture (1990).
Figure 14. Sex ratios, by week of capture, for black drum (1990).
Figure 15. Relation of fecundity estimates to total length for female black drum (1990).
FECUNDITY = \(-7.7 \times 10^8 + 1.4 \times 10^6 + 6.01 \times 10^2 \cdot TL^2\)

\(n = 12\)

\(r^2 = 0.48\)
Figure 16. Black drum commercial landings for years 1965 through 1990 in Virginia. (Data from VMRC Black Drum Advisory Board Meeting, Painter Virginia 18 March 1991)