

Age and Growth of Black Drum in Louisiana Waters of the Gulf of Mexico

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Abstract.—Morphometric measurements and otoliths (sagittae) were collected from black drums *Pogonias cromis* caught in estuarine and coastal waters off Louisiana. Transverse sections of otoliths had distinct opaque zones that were validated as annual for age determination. One annulus was formed per year during winter and early spring months in all age-classes during each of four years of sampling. There was low variability in age estimates made independently by three readers. Maximum age observed was 43 years. Von Bertalanffy growth models did not describe growth well for all age-classes, perhaps due to an extreme decrease in growth rate at about 4 years of age and continuous, nonasymptotic growth thereafter.

Fishing pressure on black drum *Pogonias cromis* has increased during the mid-1980s in the northern Gulf of Mexico, due in part to mandated state and federal reductions in harvest of red drum *Sciaenops ocellatus*. Black drum landings increased from 1,931 tonnes in 1982 to 4,792 tonnes in 1987 (NMFS 1983, 1988). Catch restrictions on other Gulf species may further increase pressure, yet there are few data on population dynamics for black drum, including age and growth information. Accurate age information is necessary to understand life histories and develop management plans. Such information is used to derive growth models and evaluate variation in year-class strength as affected by the environment and the fishery.

Black drum growth models are available for inshore Texas populations based on tag-recapture (Doerzbacher et al. 1988) and for Virginia waters based on scale analysis (Richards 1973). Studies that have used length-frequency distributions and scales to age black drums have had limited success. When length frequencies were used, only the first two year-classes could be discerned by Pearson (1929) and Simmons and Breuer (1962) because older ages overlapped. Pearson (1929) and Richards (1973) could not read scales from large fish and did not validate age estimates, a prerequisite for fishery management (Beamish and McFarlane 1983).

Otoliths provide accurate, valid age estimates for many long-lived fishes (Beamish and McFarlane 1987). Sagittae have been validated for aging Atlantic croaker *Micropogonias undulatus* (Barger 1985) and red drum (Beckman et al. 1989) from the Gulf of Mexico.

Our study validates age estimates for black drum by following the intrayear progression of annulus formation, determines aging precision by comparing independent estimates of three readers, and derives growth models for black drum from Louisiana Gulf of Mexico and estuarine waters.

Methods

Black drums ($N = 2,259$) were sampled from commercial gill-net ($N = 478$), haul-seine ($N = 319$), purse-seine ($N = 512$), and otter-trawl ($N = 352$) landings and from recreational hook-and-line landings ($N = 58$) from Louisiana estuarine and coastal waters from July 1984 to November 1987 (capture gear was unknown for 540 fish). Haul-seine, gill-net, and hook-and-line samples were predominantly from inshore waters, and purse-seine and trawl samples were from offshore waters. Fork length (FL, mm), weight (W , g), and sex were recorded, and otoliths (sagittae) were removed and stored dry.

Sagittae were embedded in epoxy resin (Spurr 1969) and sectioned (0.7 mm thick) through the core with a Buehler Isomet low-speed saw. Sections were mounted on glass slides with thermoplastic cement, sanded, and polished with alumina micropolish to obtain a smooth surface. Sections were examined with a dissecting microscope and transmitted light at 15–40 \times magnification.

Three readers independently aged 1,080 sections to determine between-reader variability. Two readers read the remaining 1,179 sections. Otoliths were aged without knowing sample source or date of capture. Age was estimated by counting opaque zones from the core to the outer otolith

edge and recording the appearance of the margin as opaque or translucent. An opaque zone inhibits light passage, whereas a translucent zone allows light passage (Wilson et al. 1987). Therefore, in transmitted light, an opaque zone is dark and a translucent zone is light. Time of annulus formation was determined by marginal increment analysis (Barger 1985). Ages were assigned based on a January 1 birth date (Ditty 1986; Beckman et al. 1988).

Precision of age estimates between readers was determined by coefficient of variation and index of precision (Sokal and Rohlf 1981; Chang 1982). Assigned ages were those for which at least two readers agreed on annulus counts. Sections were recounted when initial counts disagreed; sections of the fish's other sagitta were counted when recounts disagreed. Fish were excluded from analyses when ages did not agree.

We included only sexed black drums ($N = 1,823$) to fit growth models so that differences between sexes could be tested. Fork length–weight regressions were fit with the model $W = aFL^b$. Regression for males and females were compared by analysis of covariance (Ott 1977).

Von Bertalanffy growth curves were fit by non-linear regression (SAS 1985) to length-at-age and weight-at-age data. Models were also fit with data weighted by the inverse of sample size for each age-class (SAS 1985) to adjust for unequal sample size by age and to obtain an adequate fit at extreme ages, for which we had few observations. For weighting, ages were rounded to the nearest year to determine sample size in each age-class, and fish older than 36 years ($N = 3$) were deleted so that these few individuals would not affect the curve significantly. The growth equation for length (von Bertalanffy 1938, 1957) was of the form $L_t = L_\infty[1 - e^{-K(t-t_0)}]$, and for weight $W_t = W_\infty[1 - e^{-K(t-t_0)}]^b$; L_t and W_t are the estimated length and weight, L_∞ and W_∞ are the asymptotic length and weight, K is the growth coefficient, t is the age (years), t_0 is the hypothetical age when length or weight would be zero, and b is from the length–weight regression.

Residuals about the regression lines were examined to test the assumption of normality (Sokal and Rohlf 1981). To test differences in von Bertalanffy growth by sex, we compared a full model in which sexes were modeled separately to a reduced model in which sex was not considered. An F -test (Ott 1977) was used to test model differences. Power curves of the form $\text{Length} = a\text{Age}^b$

(Kaufmann 1981) were fit and compared to von Bertalanffy curves.

Results

Black drum otoliths are large and opaque. We could not discern internal structures and estimate age from whole otoliths. Thin sections exposed distinct opaque and translucent zones, which alternated from the core out to the growing edge (Figure 1).

Growth of black drum sagittae does not occur uniformly in all directions throughout life, because annuli were not uniformly apparent around the entire section. Annuli were most consistent and regular in the medial axis. The most distinct and easily counted annuli were ventral to the sulcus, and our analyses were made in this region. Translucent zones were deposited ventral to the sulcus concurrent with deposition of opaque zones dorsal to the sulcus (Figure 1).

Validation that one annulus forms per year in black drum sagittae was based on a single peak each year in plots of marginal increment presence by month (Figure 2A). Samples were pooled over all years to compare annulus formation among age-class groupings (Figure 2B). Plots for each age-class grouping had a single peak, representing yearly annulus formation. Annulus (opaque-zone) deposition generally began between November and January, and was completed between April and June during each year in all age-classes.

Only 5 of 1,080 otoliths were excluded from analyses due to disagreement on age by all three readers. At least two readers agreed on ages for all other fish through initial annulus counts ($N = 1,059$), recounts ($N = 2$), or counts from sections of the other sagitta ($N = 14$). All three readers agreed on 92% of age estimates. Readers 1 and 2, the most experienced, had 98% agreement, whereas reader 3 had 93% agreement with reader 1 and 94% with reader 2. Based on all pairwise comparisons of readers, 6% of counts differed by 1 year, 0.2% by 2 years, and 0.03% by 3 years. Readers had high levels of aging precision, based on a mean coefficient of variation of 0.0051 and a mean index of precision of 0.0030.

Ninety-nine percent of the age estimates of fish (1,167 of 1,179) determined only by readers 1 and 2 were in agreement. When age estimates were not in agreement ($N = 12$), recounts or counts of the matching sagitta resulted in age agreement for all but one fish, for which the matching otolith was unavailable.



FIGURE 1.—Photomicrographs, taken with transmitted light, of transverse sections of black drum sagittae (upper) from a 765-mm (fork length), 6.7-kg female with 17 annuli and (lower) from a 617-mm, 3.5-kg female with 8 annuli. C = core; S = sulcus; M = medial; and V = ventral. Bars = 1 mm. Numbers indicate selected annuli. In the lower panel, arrows indicate numbered annuli on each side of the sulcus. Dorsal to the sulcus, note the opaque zones occurring between annuli. Annulus counts were made in the region immediately ventral to the sulcus.

Length-weight regressions for males and females were not significantly different ($P = 0.897$ for intercepts; $P = 0.248$ for slopes). The regression for combined sexes was

$$W = (1.14 \times 10^{-5})FL^{3.05} \quad (r^2 = 0.97).$$

Maximum ages of black drums sampled were 43 years for a female and 42 years for a male captured by hook-and-line and haul-seine, respectively. These were the only two fish older than 37 years. The distribution of ages cannot be considered representative of the black drum population in the northern Gulf of Mexico due to the nonrandom nature of sampling.

Von Bertalanffy equations fitted to raw data were, for length,

$$L_t = 1,000[1 - e^{-0.0517(t+13.07)}] \quad (r^2 = 0.737),$$

and for weight,

$$W_t = 38,827[1 - e^{-0.0212(t+25.49)}]^{3.05} \quad (r^2 = 0.688).$$

The inclusion of sex in the von Bertalanffy models significantly reduced the model variance ($P < 0.01$). However, there was negligible improvement in fit; r^2 values were 0.741 for length and 0.699 for weight with sex in the model. Separate growth curves for each sex are not presented. They

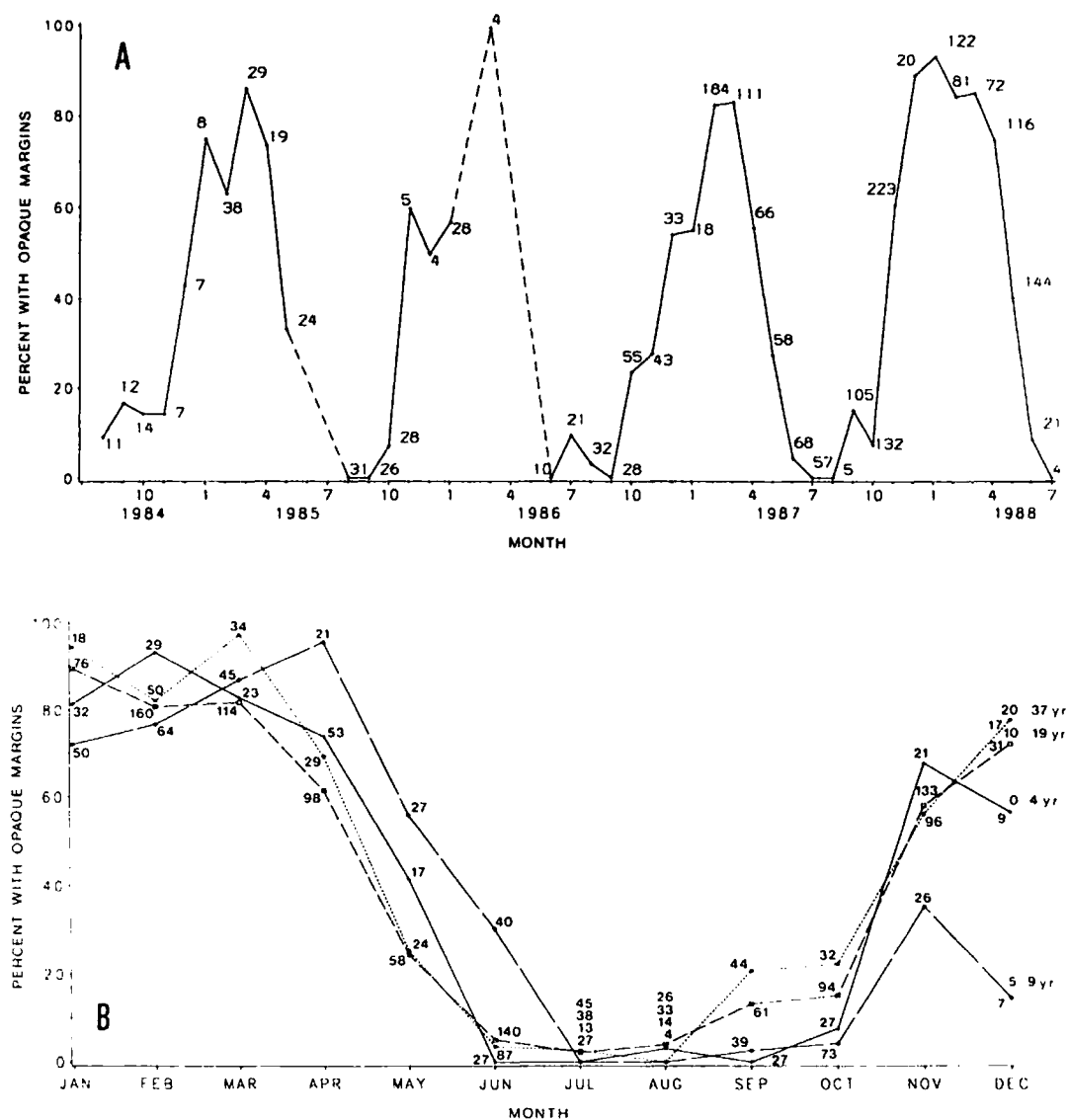


FIGURE 2.—Percent occurrence of opaque margins by month in black drum sagittae: (A) by month and year and (B) for age-groups, years combined. Age groupings are indicated to the right of line plots in B. Sample sizes are indicated next to points in both panels.

diverged only at ages greater than 25 years, for which there were few samples.

Von Bertalanffy equations fitted to weighted data were, for length,

$$L_t = 1,100[1 - e^{-0.0384(t+16.42)}] \quad (r^2 = 0.807),$$

and for weight,

$$W_t = 28,785[1 - e^{-0.0281(t+21.46)}]^{3.05} \quad (r^2 = 0.735).$$

Von Bertalanffy curves for black drums did not fit the data well at the youngest ages (Figure 3).

Similar poor fits, not presented, were obtained for Gompertz (Silliman 1967) and logistic (Kaufmann 1981) models. Power curves fit the data best for younger age-classes, based on residuals about the regression line (Figure 3). However, these models did not fit well the growth of black drums less than 3 years of age. Fitted equations were, for length,

$$FL = 428.1 \text{Age}^{0.215} \quad (r^2 = 0.785),$$

and for weight,

$$W = 1,213 \text{Age}^{0.666} \quad (r^2 = 0.788).$$

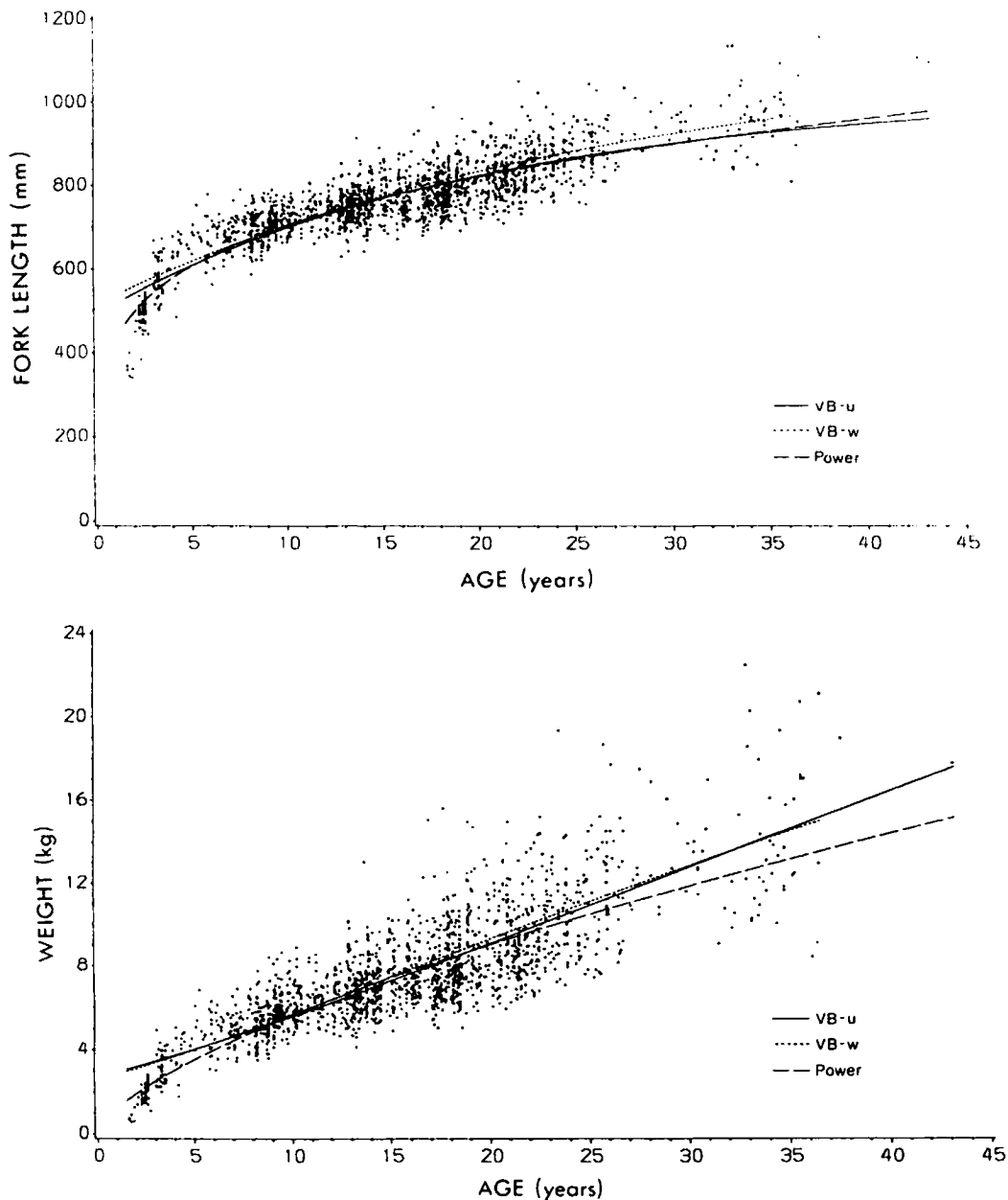


FIGURE 3.—Von Bertalanffy growth curves, unweighted (VB-u) and weighted by the inverse of sample size for each age-class (VB-w), and power growth curves for black drum from Louisiana waters: (upper) by fork length and (lower) by weight.

Discussion

We found black drums to be relatively long-lived. Otolith annuli formed once per year, were easily counted in sections, and provided precise age estimates. The high precision in age estimates is evidence that one reading accurately estimates age of black drums.

In black drum sagittae, annuli are continuous and regularly deposited medially, particularly adjacent to the sulcus. Calcification slows or discontinues in other axes. Counts in some regions underestimated age because all annuli were not visible uniformly throughout transverse sections. Sagittal growth patterns of black drum were similar to those of red drum (Beckman et al. 1989) and of other

species (Blacker 1974; Boehlert and Yoklavich 1984; Kenchington and Augustine 1987). For at least some long-lived fish species, counts near the sulcus may be necessary to discern all annuli.

Descriptions of annulus formation in otoliths have sometimes been confused, particularly concerning timing of formation of opaque and translucent zones (Pannella 1974; Casselman 1982), in part due to ambiguous terminology (Casselman 1987). For example, the type of light source (transmitted versus reflected) affects the appearance of growth zones. Discrepancies in annulus appearance could also reflect inconsistent formation of annuli through the otolith. For example, we observed opaque and translucent zones being deposited concurrently in different regions.

The physiological cause of opaque zones may not be related to spawning. Although annulus deposition coincided with black drum spawning (Beckman et al. 1988), identical annuli were also validated in immature fish. Sagittae of other sciaenids, such as Atlantic croaker (Barger 1985) and red drum (Beckman et al. 1989), exhibit the same seasonal pattern of annulus formation (winter–early spring) as do black drum, though their spawning seasons differ (Simmons and Breuer 1962; White and Chittenden 1977). Annulus deposition is more likely a response to some general exogenous factor, such as seasonal temperature change. Doerzbacher et al. (1988) reported reduced growth of black drums and red drums during the coldest days of the year, which could correspond to annulus deposition.

We found that black drums live at least 43 years. Maximum ages estimated by Pearson (1929) and Richards (1973) for black drums based on scales were 5–7 years, though greater ages were postulated. The scale method has not been validated for black drum and significantly underestimates age in other fish species (Beamish and McFarlane 1987). The longevity we observed for black drum is similar to that of red drum (36 years) from the Gulf of Mexico (Beckman et al. 1989).

Nonlinear curve-fitting procedures minimize the bias introduced when age-classes have unequal sample sizes, although the precision of parameter estimates can be affected (Vaughan and Kanciruk 1982). Weighting of black drum data such that age-classes were equally represented required rounding of age estimates, which reduced precision. However, the resulting von Bertalanffy model for length better described growth of age-classes beyond 25 years. Weighting the data for weight-

at-age models had little effect on the curve within the range of the data.

Our growth models do not describe well the early growth of black drums, and estimates of t_0 (von Bertalanffy model) and intercepts (power model) are biologically unrealistic. Power models best described the growth of black drums younger than age 5; however, none of the models could be used to predict age accurately during this life stage. The sharp decrease in growth rate at 4–5 years of age may reflect reallocation of energy from growth to reproduction, because black drums mature at approximately this age (Beckman et al. 1988; D. Nieland and R. Parker, Louisiana State University, personal communication).

The von Bertalanffy growth coefficient for length (K ; 0.04–0.05) was lower than the value Richards (1973) reported for black drums in Virginia waters (0.158). Our lower values are evidence that growth toward a maximum size occurs at a relatively slow rate for black drums in the Gulf of Mexico. Black drums along the U.S. Mid-Atlantic coast may grow faster than those in the Gulf; however, differences could also be a result of underestimated ages by Richards (1973), as discussed previously. Doerzbacher et al. (1988) reported a K of 0.219 for black drums in Texas, based primarily on fish less than 800 mm in total length (TL). This was during rapid growth stages and excluded winter periods of little or no growth.

Our estimates of L_∞ (1,000–1,100 mm FL) and W_∞ (29–39 kg) for black drums in Louisiana were lower than those Richards (1973) reported for this species in Virginia (L_∞ = 1,474 mm TL, W_∞ = 53 kg). Black drums reach larger sizes in U.S. Atlantic waters than in the Gulf of Mexico. Recreationally caught black drums have been reported to weigh up to 50 kg in Virginia (Richards 1973), but only 35 kg in Louisiana (LOWA 1987). Although L_∞ values are realistic, their biological significance is questionable. Within the size range sampled, an asymptotic size is not attained, and growth is practically linear beyond age 5. Therefore, the concept of asymptotic growth may be unrealistic for black drum. Perhaps L_∞ should not be considered an average maximum size, but simply a mathematical curve-fitting parameter (Knight 1968).

Great variability in size at age makes it difficult to estimate precisely the age of black drum from length or weight; however, age can be estimated precisely by the otolith analysis techniques described in this paper. Further refinements of growth

models will be necessary if growth is to be modeled precisely over all age-classes with a single curve. Additional samples of oldest individuals may improve the fit of growth models and resolve the question of whether growth differs significantly between sexes.

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References

- Barger, L. E. 1985. Age and growth of Atlantic croakers in the northern Gulf of Mexico, based on otolith sections. *Transactions of the American Fisheries Society* 114:847-850.
- Beamish, R. J., and G. A. McFarlane. 1983. The forgotten requirement for age validation in fisheries biology. *Transactions of the American Fisheries Society* 112:735-743.
- Beamish, R. J., and G. A. McFarlane. 1987. Current trends in age determination methodology. Pages 15-42 in R. C. Summerfelt and G. E. Hall, editors. *Age and growth of fish*. Iowa State University Press, Ames.
- Beckman, D. W., C. A. Wilson, R. M. Parker, D. L. Nieland, and A. L. Stanley. 1988. Age structure, growth rates, and reproductive biology of black drum in the northern Gulf of Mexico off Louisiana. Final report to U.S. Department of Commerce, cooperative agreement NA87WC-H-06314, Marine Fisheries Initiative (MARFIN) Program, Washington, D.C.
- Beckman, D. W., C. A. Wilson, and A. L. Stanley. 1989. Age and growth of red drum, *Sciaenops ocellatus*, from offshore waters of the northern Gulf of Mexico. *U.S. National Marine Fisheries Service Fishery Bulletin* 87:17-28.
- Blacker, R. W. 1974. Recent advances in otolith studies. Pages 67-69 in F. R. Harden Jones, editor. *Sea fisheries research*. Wiley, New York.
- Boehlert, G. M., and M. M. Yoklavich. 1984. Variability in age estimates in *Sebastes* as a function of methodology, different readers, and different laboratories. *California Fish and Game* 70:210-224.
- Casselman, J. M. 1982. Age and growth assessment of fish from their calcified structures—techniques and tools. NOAA (National Oceanic and Atmospheric Administration) Technical Report NMFS (National Marine Fisheries Service) 8:1-17.
- Casselman, J. M. 1987. Determination of age and growth. Pages 209-242 in A. H. Weatherly and H. S. Gill. *The biology of fish growth*. Academic Press, New York.
- Chang, W. B. 1982. A statistical method for evaluating the reproducibility of age determination. *Canadian Journal of Fisheries and Aquatic Sciences* 39:1208-1210.
- Ditty, J. G. 1986. Ichthyoplankton in neritic waters of the northern Gulf of Mexico off Louisiana: composition, relative abundance, and seasonality. *U.S. National Marine Fisheries Service Fishery Bulletin* 84:935-946.
- Doerzbacher, J. W., A. W. Green, G. C. Matlock, and H. R. Osborn. 1988. A temperature compensated von Bertalanffy growth model for tagged red drum and black drum in Texas bays. *Fisheries Research (Amsterdam)* 6:135-152.
- Kaufmann, K. W. 1981. Fitting and using growth curves. *Oecologia* 49:293-299.
- Kenchington, T. J., and O. Augustine. 1987. Age and growth of blue grenadier, *Macruronus novaezelandiae* (Hector), in south-eastern Australian waters. *Australian Journal of Marine and Freshwater Research* 38:625-646.
- Knight, W. 1968. Asymptotic growth: an example of nonsense disguised as mathematics. *Journal of the Fisheries Research Board of Canada* 25:1303-1307.
- LOWA (Louisiana Outdoor Writers Association). 1987. Official fish records. The Menhaden Advisory Council for the Gulf of Mexico, New Orleans, Louisiana.
- NMFS (U.S. National Marine Fisheries Service). 1983. Fishery statistics of the United States, 1982. U.S. Department of Commerce, Washington, D.C.
- NMFS (U.S. National Marine Fisheries Service). 1988. Fishery statistics of the United States, 1987. U.S. Department of Commerce, Washington, D.C.
- Ott, L. 1977. An introduction to statistical methods and data analysis. Duxbury, North Scituate, Massachusetts.
- Panella, G. 1974. Otolith growth patterns: an aid in age determination in temperate and tropical fishes. Pages 28-39 in T. B. Bagenal, editor. *The ageing of fish*. Unwin Brothers, London.
- Pearson, J. C. 1929. Natural history and conservation of redfish and other commercial sciaenids on the Texas coast. *Bulletin of the U.S. Bureau of Fisheries* 4:129-214.
- Richards, C. E. 1973. Age, growth, and distribution of

- the black drum (*Pogonias cromis*) in Virginia. Transactions of the American Fisheries Society 102: 584-590.
- SAS (Statistical Analysis System). 1985. SAS user's guide: statistics, version 5 edition. SAS Institute, Cary, North Carolina.
- Silliman, R. P. 1967. Analog computer models of fish populations. U.S. National Marine Fisheries Service Fishery Bulletin 66:31-46.
- Simmons, E. G., and J. P. Breuer. 1962. A study of redfish, *Sciaenops ocellata* Linnaeus, and black drum, *Pogonias cromis* Linnaeus. Contributions in Marine Science 8:184-211.
- Sokal, R. R., and F. J. Rohlf. 1981. Biometry, 2nd edition. Freeman, San Francisco.
- Spurr, A. R. 1969. A low-viscosity epoxy resin embedding medium for electron microscopy. Journal of Ultrastructure Research 26:31-43.
- Vaughan, D. S., and P. Kanciruk. 1982. An empirical comparison of estimation procedures for the von Bertalanffy growth equation. Journal du Conseil Permanent pour l'Exploration de la Mer 40:211-219.
- von Bertalanffy, L. 1938. A quantitative theory of organic growth. II. Inquiries on growth laws. Human Biology 10:181-213.
- von Bertalanffy, L. 1957. Quantitative laws in metabolism and growth. Quarterly Review of Biology 32: 217-231.
- White, M. L., and M. E. Chittenden, Jr. 1977. Age determination, reproduction and population dynamics of the Atlantic croaker, *Micropogonias undulatus*. U.S. National Marine Fisheries Service Fishery Bulletin 75:109-123.
- Wilson, C. A., and eight co-authors. 1987. Glossary. Pages 527-530 in R. C. Summerfelt and G. E. Hall, editors. Age and growth of fish. Iowa State University Press, Ames.

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