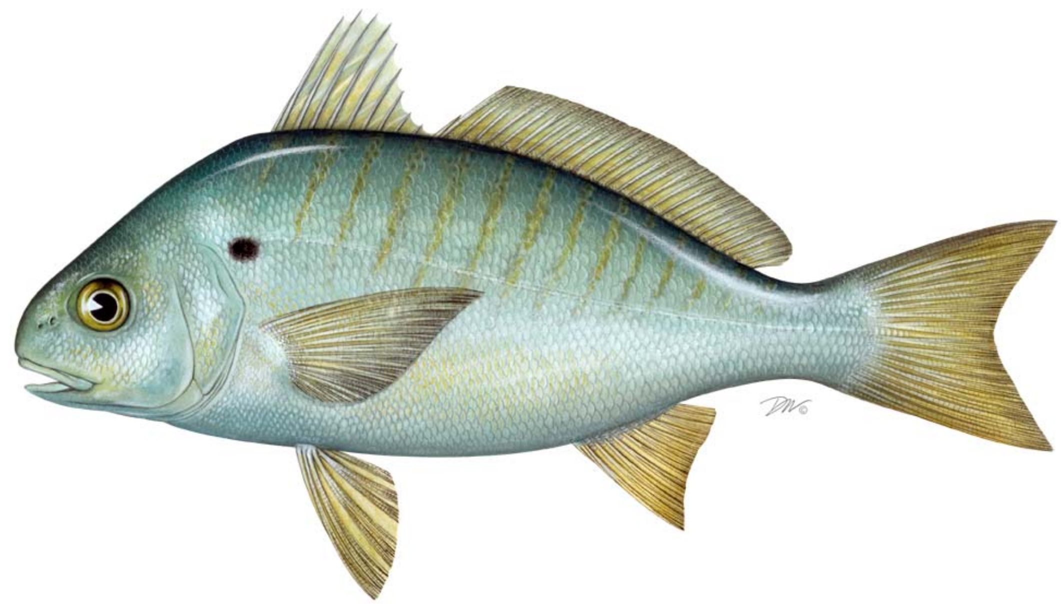
Atlantic States Marine Fisheries Commission

Spot Life History Report

Leiostomus xanthurus



Report to the ASMFC South Atlantic State/Federal Fisheries Management Board

April 2010

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1. Introduction

This report is the result of a Spot Life History Workshop held on March 17-18, 2010, at the Atlantic States Marine Fisheries Commission, Washington, DC. Participants at the workshop included Harry Rickabaugh (Maryland Department of Natural Resources), Joseph Grist (Virginia Marine Resources Commission), Kevin Brown (North Carolina Division of Marine Fisheries), Chris McDonough (South Carolina Department of Natural Resources), and Nichola Meserve (Atlantic States Marine Fisheries Commission). Data and research for the workshop were compiled with the assistance of Laura M. Lee (Virginia Marine Resources Commission), Kristen Corey (Virginia Marine Resources Commission Intern from Christopher Newport University), Dr. Jessica Thompson (Christopher Newport University), James Gartland (Virginia Institute of Marine Science), Randy Gregory (North Carolina Division of Marine Fisheries), Jeanne Boylan (South Carolina Department of Natural Resources), Lauren Dolinger Few (National Marine Fisheries Service), and William Kramer (National Marine Fisheries Service). Extensive analyses were also performed and reported by Laura M. Lee.

2. Stock Description and Definition

Spot (*Leiostomus xanthurus*) range from the Gulf of Maine to the Bay of Campeche, Mexico in estuarine and coastal waters to depths of al least 205 m (Smith and Goffin 1973; Bigelow and Schroeder 1953; Dawson 1958; Springer and Bullis 1958). On the Atlantic coast of the United States, the area of greatest abundance and center of the commercial fishery on the Atlantic Coast extends from Chesapeake Bay to South Carolina. Adult spot within Chesapeake Bay are generally available to commercial and recreational fisheries from April through October, the bulk being taken from August to October when spot are moving out of the bay (Pacheco 1962a). During winter, spot are taken in the winter trawl fishery operating off Cape Hatteras, North Carolina (Pearson 1932).

3. Movements and Migration

Adult spot migrate seasonally between estuarine and coastal waters. They enter bays and sounds during spring, but seldom occur as far up-estuary as do the young. They remain in these areas until late summer or fall before moving offshore to spawn or escape low water temperature (Hildebrand and Schroeder 1928; Roelofs 1951; Dawson 1958; Hoese 1973). A tagging study in Georgia estuaries indicated offshore movement of spot; the longest distance traveled was 118 km (Music and Pafford 1984).

Spot larvae have been collected from within estuaries to the edge of the continental shelf (Hildebrand and Cable 1930; Berrien et al. 1978; Lewis and Judy 1983; Warlen and Chester 1985) from October through May. Larvae were smaller and more numerous offshore (34−128 m) than inshore (17−26 m) (Berrien et al. 1978; Lewis and Judy 1983; Warlen and Chester 1985). Warlen and Chester (1985) reported that spot larvae may be present at any depth but occurred more frequently near the bottom; however, Lewis and Wilkens (1971) found this to be true only at night.

Direct across-shelf transport has been suggested as the major transport mechanism for larvae of sciaenids and other species along the mid-Atlantic coast (Nelson et al. 1976; Norcross and Austin 1981; Miller et al. 1984). Spot larvae emigrate from the offshore spawning area to nursery habitat in winter and early spring. Spot larvae entered a North Carolina estuary at an average age of 59 days (range 40–74 days) and an average size of 13.6 mm (range 11.4 to 15.6 mm) (Warlen and Chester 1985). Larvae entered the estuary segregated by age; significantly younger and smaller larvae immigrated at the beginning and end of the immigration period. Recruitment of the new year class into the Chesapeake Bay occurs in March through May (Norcross 1989). Postlarval spot have been collected in estuarine nursery areas chiefly in April in Delaware Bay (DeSylva et al. 1962), and in January and February in Chesapeake Bay (Welsh and Breder 1923), North Carolina (Hildebrand and Cable 1930; Tagatz and Dudley 1961; Williams and Deubler 1968; Turner and Johnson 1973; Weinstein 1979; Weinstein and Walters 1981; Lewis and Judy 1983; Warlen and Chester 1985), South Carolina (Shenker and Dean 1979; Bozeman and Dean 1980; Beckman and Dean 1984), Georgia (Music 1974; Music and Pafford 1984), and Florida (Welsh and Breder 1923).

The young-of-year spot are largely resident in the nursery habitat for the duration of warm weather, but as temperature drops in the fall, they emigrate to deeper estuarine waters of the ocean (Weinstein and O'Neil 1986). Hildebrand and Schroeder (1928) reported that some young-of-year overwinter in the deeper waters of the Chesapeake Bay although studies only collected spot from April or May through December in the York River and Chesapeake Bay (Pacheco 1962b; Markle 1976).

Juvenile spot are abundant throughout estuarine habitats after recruitment, but densities and estimates of production are typically higher in estuarine creeks and marshes, compared with nearby seagrass meadows or open habitats (Orth and Heck 1980; Weinstein and Brooks 1983; Smith et al. 1984; O'Neil and Weinstein 1987; Szedlmayer and Able 1996). Although densities of spot were twice as high in polyhaline marshes versus oligohaline marshes in the York River (O'Neil and Weinstein 1987), patterns in other systems suggest that the production of spot may be highest in lower salinity, upper estuarine habitats (Brackin 2002; Ross 2003). Spot were found to be a dominant species in the winter (November–June) fish community of eelgrass beds in Bogue Sound and the Newport River, North Carolina (Adams 1976). Young spot (<15 cm) are year-round resident of the inshore waters (rivers, sounds and coastal waters) of South Carolina (Shealy et al. 1974). Spot were trawled in Georgia creeks, sounds and outside waters year-round with largest numbers taken in the creeks during winter (Mahood et al. 1974; Music 1974; Music and Pafford 1984). Spot often segregate by size in estuarine habitats; larger fish are typically found in deeper water (Hales and Van Den Avyle 1989).

4. Life History Data Availability

4.1. Biological Sampling Methods by State

For the life history analyses in this report, useful biological samples include paired length-length, length-weight, and length-age data, and sex data. Three commercial, one recreational, and four fishery-independent sources provided these data (Table 1). Brief descriptions of these sources' sampling and processing methods are provided below.

4.1.1. Commercial Sampling

Maryland

Since 1993, staff from the Maryland Department of Natural Resources (MDDNR) has sampled commercial pound nets during June through September. Spot are measured for total length.

Beginning in 2007, limited age, sex, and weight data have been collected; however, the otoliths have not been processed to date.

Virginia

Since 1989, staff from the Virginia Marine Resources Commission (VMRC) has sampled spot commercial landings from 50-pound boxes of the graded catch obtained at seafood dealers and buyers. Spot are measured for total length in millimeters, weighed to the nearest 0.1 pound, and sexed. Market category, harvest area, gear type, and total catch are noted. Beginning in 1998, samples have been purchased to excise otoliths for age determination. Otoliths are processed and read by Old Dominion University's Center for Quantitative Fisheries Ecology. Maturity data were also collected from purchased samples.

North Carolina

Since 1994, staff from the North Carolina Division of Marine Fisheries (NCDMF) has sampled spot from the major commercial fisheries. Spot are sampled by gear, market category (in culled catches only), and area fished at local fish houses. Fish are measured for total length to the nearest millimeter and sample weights (to the nearest 0.01 kg), as well as total weights, are taken to expand the sample data to the entire landings. Since 1997, subsamples of spot have been purchased from the major commercial fisheries to excise otoliths for age determination. Sex data are also recorded. Otoliths are processed and read at NCDMF. However, only data from 2003 was available at the Spot Life History Workshop.

4.1.2. Recreational Sampling

The Marine Recreational Fishery Statistics Survey (MRFSS) program collects data on marine recreational fishing to estimate statistics characterizing the catch and effort in marine recreational fisheries. Biological samples are available from an angler-intercept survey since 1981 and at-sea sampling of headboat (party boat) fishing trips since 2005. The angler-intercept survey collects data on spot classified as landings (fish brought to the dock in whole form, which are identified and measured by trained interviewers; Type A fish). The at-sea sampling of headboats collects data on spot classified as landings, as well as dead releases (part of Type B1 fish, along with fish that are brought to the dock not in whole form) and alive releases (Type B2 fish). Sampled fish were weighed to the nearest tenth (0.10) of a kilogram from 1981-1993, and to the nearest five one-hundredth (0.05) of a kilogram from 1994 to the present, with very few fish each year being weighted to the nearest 0.025 or 0.01 kg from 2001–2009. Lengths are measured to the nearest millimeter for the length type appropriate to the morphology of the fish (fork length for spot).

4.1.3. Fishery-Independent Sampling

NMFS Bottom Trawl Survey

In 1963, the National Marine Fisheries Service (NMFS) Northeast Fisheries Science Center (NEFSC) implemented a multispecies bottom trawl program, which surveys the Atlantic shelf up to 366m deep between Cape Cod, Massachusetts and Cape Hatteras, North Carolina. The objective of the program is to monitor trends in abundance and distribution, characterize age/length structure, and better understand the biology and ecology of a wide array of finfish and invertebrate species. The survey includes spring and autumn cruise components (the spring cruises began in 1968), and approximately 55 tows are conducted per year. The data analyzed for spot were from the fall cruises only as this is the main time when spot are captured by the survey.

The catch of each tow is identified, counted, and weighed. Individual fish lengths and weights are taken; when the catch of a particular species is large, a subsample of individuals is sampled. Depending on the species, data on sex, maturity, stomach contents, and disease may be recorded. For spot, the following data are available since 1997: fork length to the nearest 10 mm, weight to the nearest thousandth (0.001) of a kilogram, sex, and maturity.

NEAMAP Nearshore Trawl Survey

The first full-scale cruise of the Northeast Area Monitoring and Assessment Program (NEAMAP) Nearshore Trawl Survey occurred in the fall of 2007. The survey is conducted in the nearshore coastal waters (<12 miles) from Cape Cod, Massachusetts to Cape Hatteras, North Carolina (although spot are rarely encountered north of Hudson Canyon, New York). The main objective of the survey is to estimate abundance, biomass, age/length structure, diet composition, and other parameters used in stock assessments for fish and invertebrates of management interest. The survey conducts cruises twice per year, in the spring (April/May) and fall (September/October). A total of 150 sites are sampled per cruise. The catch from each tow is sorted by species and modal size group (i.e., small, medium, and large size) within species. For spot, the aggregate biomass (0.01 kg) and individual length measurements (fork measured in millimeters) are taken. A subsample of three individual spot per length group is sampled for full processing, which includes weighing (individual whole and eviscerated weights to the nearest 0.001 kg), determining macroscopic sex and maturity stage, and removing otoliths for age determination. Spot otoliths collected in this survey have yet to be aged.

ChesMMAP Trawl Survey

The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) Trawl Survey was implemented in 2002 to supplement data needs of single and multispecies stock assessment models. The survey samples the main stem of the Chesapeake Bay for recreationally and commercially important species in the bay. The ChesMMAP survey conducts five cruises per year (March, May, July, September, and November) and samples approximately 80 to 90 sites a year. The catch from each tow is sorted and individual lengths are recorded by species or length class (if distinct classes within a particular species are evident). For spot, fork length (mm) is measured. Stomach contents, ageing structures, weight (to the nearest 0.001 kg), girth, sex, and gonad stage are taken from a subsample of each species or length class. Otoliths are processed and aged at the Virginia Institute of Marine Science (VIMS).

SEAMAP-SA Coastal Survey

The Southeast Area Monitoring and Assessment Program - South Atlantic (SEAMAP-SA) Coastal Survey began in 1989 and is conducted by the South Carolina Department of Natural Resources (SCDNR). This survey has provided long-term, fisheries-independent data characterizing the seasonal abundance and biomass of all finfish, elasmobranchs, decapod and stomatopod crustaceans, sea turtles, horseshoe crabs, and cephalopods that are accessible by high-rise trawls in the 4–10m depth contour. The sampling area extends from the coastal zone of the South Atlantic Bight (SAB) between Cape Hatteras, North Carolina, and Cape Canaveral, Florida. Multi-legged cruises are conducted in the spring (April–May), summer (July), and fall (October) and a total of 102 stations are sampled each season. After each tow, the contents of each net are sorted to species or genus, and the total biomass and number of individuals are recorded (or estimated based on a subsample when large catches occur). In every collection, the catch of spot is weighed collectively and individuals are measured (fork length) to the nearest centimeter and weighted to the nearest gram. When a large number of individuals of any of the priority species are collected in a tow, a random subsample consisting of 30 to 50 individuals is weighed and measured. In 2001, sagittal otoliths and gonadal tissue were taken from spot for age, sex, and maturity assessments. Fork, standard, and total lengths were all measured. Otoliths from the SEAMAP survey are processed and aged at SCDNR.

4.1.4. Ageing Methods

Old Dominion University, Center for Quantitative Fisheries Ecology

Otoliths are received in labeled coin envelopes, sorted and catalogued, and stored dry inside protective Axygen 2.0 ml microtubes within their original coin envelopes. Sagittal otoliths are processed for age determination following a thin-sectioning method. The left or right sagittal otolith is randomly selected and attached to a glass slide with clear Crystalbond™ 509 adhesive. The position of the core is located and marked with pencil. At least one transverse cross-section is removed from each otolith using a Buehler® Isomet™ low-speed saw equipped with a two 3-inch diameter, Norton® diamond grinding wheels. Otolith thin-sections are placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium.

All fish are aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. Two readers must age each otolith independently. When the readers' ages agree, that age is assigned to the fish. When the two readers disagree, both readers must re-age the fish together, again without any knowledge of previously estimated ages or specimen lengths and assign a final age to the fish. When the readers are unable to agree on a final age, the fish is excluded from further analysis.

The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the period when the annulus is deposited (between May and July for spot in Virginia (Piner and Jones 2004)). For spot, the steps include: (1) assume a January 1 birth date; (2) count the number of annuli (opaque bands) in the otolith thin-section, which becomes the initial age assignment; (3) examine the thin-section for translucent growth, keeping the initial age assignment if there is no translucent growth; (4) if there is translucent growth, add one to the initial age if the fish was captured between January 1 and July 31 (and keep the initial age if the fish was captured between August 1 and December 31). Under this method, any growth beyond the last annulus, after its "birthday", but before the end of the annulus deposition period, is interpreted as being towards the next age class.

Virginia Institute of Marine Science

Otolith preparations occur in batches; all otoliths collected from spot in a given year are processed together. The sectioned otolith method is used to prepare the structures. The right otolith is selected and mounted on a piece of 100 weight paper with a layer of Crystal Bond®. A thin transverse section is then cut through the nucleus of the otolith using two Buehler® diamond wafering blades and a low speed Isomet® saw. The resulting section is mounted on a glass slide and covered with Crystal Bond. If necessary, the sample is wet-sanded to an appropriate thickness before being covered. Once prepared, otoliths are viewed using transmitted light under a dissecting microscope, and read independently by each of three readers one time. For each sample, a reader records an age based on the number of annuli present. Final ages are assigned to each specimen as the mode of the three independent readings, one by each of three readers, and are adjusted as necessary to account for the timing of the collection of the sample. Annuli are formed on hard parts in the spring for most fishes, so those collected in April/May are advanced one year if it appears that the annulus for that year had yet to form, and held if the 'mark' has formed recently. Ages of the specimens collected in the fall always corresponded to the number of annuli present on their structures.

North Carolina Division of Marine Fisheries

Spot sagittal otolith samples are collected monthly from the long haul-seine, pound-net, sink-net, recreational hook-and-line fisheries, and NCDMF fisheries-independent programs. Sagittal otoliths have been collected since 1997. Each month, samples (n=10) are distributed across the length range in 20-mm length classes starting at 140 mm total length. Sagittal otoliths are removed, cleaned, and stored dry. Samples are weighed to the nearest 0.01 kg and measured for total length to the nearest millimeter. Date, gear, and water location are also recorded for each sample.

Otoliths are collected and read whole, submersed in water in a black dish and an image is projected on a high resolution monitor from a video camera mounted on a microscope. Ages are assigned based on the number of otolith annuli viewed. The samples are then independently read by the species lead biologist. If any differences are not resolved, the data are omitted.

South Carolina

In the laboratory, the left sagittae are viewed under low magnification with a binocular microscope (10X) and marked with a soft lead pencil on the core. These are then embedded in epoxide resin in silicon molds. After the resin has polymerized, the embedded otoliths are glued to a card held in a jig attached to the arm of a low speed saw. The otolith is positioned so that a transverse section ~0.5-mm thick can be taken through the core. The Isomet Saw is equipped with a pair of diamond-wafering blades, separated by a plastic washer so that the section can be taken with a single cut. The resulting section is mounted on a labeled microscope slide with Cytoseal-XLY. After polymerization of the mounting medium, slides are stored in boxes until viewing. These are examined with a Nikon SMZU microscope equipped with a digital video camera with transmitted light. The video image is analyzed with the Image-Pro image analysis software. The following measurements are taken on each otolith section:

1) radius: distance in millimeters from the center of the core to the edge of the section as measured along the sulcus acousticus
2) a_1: distance in millimeters from the center of the core to the distal edge of the first annulus
3) a_2: distance in millimeters from the center of the core to the distal edge of the second annulus
4) a_3 to a_n: distance from the center of the core to the distal edge of the third annulus and from the core to the distal edge of the nth annulus
5) marginal increment: distance from the distal edge of the last annulus to the edge of the otolith section

Some spot otoliths vary with respect to diffuse, undefined marking near the core of the otolith. These diffuse areas are not interpreted as being a ring. The first annulus is considered the first well-defined, opaque band that can be traced around the entire section.

4.2. Meristics and Conversion Factors

Measurements of spot length are reported in standard length, fork length, and total length (Table 2). Length conversion factors from the literature are reported in Table 3. Additional conversion factors were developed for this report from two sources: Virginia commercial sampling and the SEAMAP survey (Table 3). All length data compiled for this report were converted to total length using the newly developed conversion equations prior to use in additional life history analysis.

5. Age and Growth

5.1. Age

Spot have been aged using scales, otoliths, and length frequency analysis (Table 4). Barger and Johnson (1980) evaluated marks on scales, otoliths, and vertebrae and found that the otoliths possessed the highest potential as age determination structures. Marginal increment analysis indicated that spot annuli on scales were formed in October and November in Chesapeake Bay (Pacheco 1957), from March through May in North Carolina (DeVries 1982), and from late February through early April in Georgia (Music and Pafford 1984). In temperate and subtropical climates, otolith annuli generally form in late spring/early summer including the Atlantic coast/states (Barger 1985; Barbieri et al. 1993; Beckman and Wilson 1995).

The spot is a short-lived species, rarely attaining a maximum age of six years (NCDMF 2005). The maximum lifespan of spot appears to be greater on the Atlantic coast from North Carolina and north. Maximum ages reported in the literature include: age 4.5 (290 mm TL) in New Jersey (Welsh and Breder 1923); age 5 (237.5 mm FL) in Chesapeake Bay (Pacheco 1962b); and age 5 (355–369 mm FL) in North Carolina, although the typical maximum age in the study was about age 3 (DeVries 1981b); and age 3 (210–283 mm TL) in Georgia (Music and Pafford 1984). Age 0–2 spot predominated in populations throughout the range (Pacheco 1962b; Joseph 1972; DeVries 1981a, 1982, Music and Pafford 1984, NCDMF 2005). Otolith ages compiled for the Spot Life History Workshop provided maximum ages as follows: age 6 (340mm TL) from Virginia commercial fisheries; age 4 (319 mm TL) from North Carolina commercial fisheries; age 4 (302 mm TL) from the ChesMMAP Survey; and age 3 (213 mm TL) from the SEAMAP Survey (Table **5**).

5.2. Growth

Growth of spot is very rapid. An average of 84% of the cumulative growth of spot occurs within the first year, and 99% occurs by the end of the second year (Piner and Jones 2004). Reported lengths at age 1 are similar throughout the Atlantic coast with the exception of those reported by Welsh and Breder (1923; Table 4). The smaller size in that study may be because larger fish had left the area. DeVries (1982) reported that back-calculated lengths at the first annulus for North Carolina spot with one annulus were bimodally distributed with modes at 94-134 mm TL and 172–206 mm TL. This bimodality may represent two peaks in spawning as length frequencies of trawled age 0 spot from North Carolina estuaries showed a bimodal distribution from June to September (Ross 1980; Ross and Carpenter 1983; Ross and Epperly 1985).

Spot reach a greater maximum size in the northern part of the range. Estimated relative population growth is smallest in the south and increases with latitude, with the largest growth rates found in the northern latitudes of the Northeast Atlantic (Johnson 1999). Maximum sizes reported in the literature were 330 mm in New Jersey (Welsh and Breder 1923), 345 mm in

Chesapeake Bay (Hildebrand and Schroeder 1928), and 346 mm in Core Sound, NC (DeVries 1982).

5.3. Age-Length Relationship

Identifying an appropriate model describing change in length with age is useful given that many stock assessment models rely on an assumed age-length relationship. Estimates of natural mortality can also be derived from age-length model parameters (see Section 6.). The performance of various age-length models when applied to spot data were evaluated and compared for the Spot Life History Workshop.

Methods

Data

Age-length data were available for varying time-periods from the ChesMMAP and SEAMAP fisheries-independent surveys and from the VMRC and NCDMF commercial fisheries sampling programs (Table 1). The available data report ages as whole years. Fractional ages were calculated based on sampling month and assuming a January 1 birth-date.

Growth Models

Six models that relate change in length with age were fit to the available data to determine what model best characterized spot growth: the von Bertalanffy model, the Ratowsky model, the three-parameter Gompertz model, Richard's growth model, a logistic age-length model, and a two-parameter allometric model (see descriptions in Table 6). Note that parameters of the same name do not necessarily have the same interpretation across different models (for more information, refer to Schnute 1981 and Quinn and Deriso 1999).

Parameter Estimation & Evaluation of Models

The growth models were fit to both whole and fractional ages for each dataset individually, datasets combined by type (i.e., commercial and fisheries-independent), and all data combined. Any outliers observed in the data were removed before fitting. The best-fit parameter values for each dataset configuration were estimated using nonlinear least-squares.

Model fits were first evaluated based on convergence status; models that did not successfully converge were removed from consideration for the associated dataset. The fits of models that successfully converged were compared using the Akaike Information Criterion (AIC) for use with sum of squares (Hongzhi 1989; Hilborn and Mangel 1997). This method takes into account both the goodness-of-fit and the number of parameters estimated. The model fit associated with the smallest AIC value is considered the most likely to be correct among the models considered, given the data. Akaike weights were also calculated to quantify the relative probability that each model is correct, given the data and set of candidate models (Burnham and Anderson 2002). AIC and Akaike weights apply to comparisons of different models fit to the same dataset.

Results

Observed Data

Spot ranging in length from 58 to 362 mm and 0 to 6 in age were observed in the available age data (Figures 1–4). The majority of spot observed in the ChesMMAP (Figure 1) and SEAMAP (Figure 2) surveys were age 0 and 1. Age-1 and age-2 spot were the dominant age groups observed in the VMRC (Figure 3) and NCDMF (Figure 4) commercial fisheries samples. Spot older than age 4 occurred only in the VMRC commercial fisheries samples, which observed age-5 and age-6 spot (Figure 3); note that only three 6-year-olds have been observed in the VMRC samples since they began collecting commercial fisheries age data in 1998. The available age data demonstrate considerable overlap in length distributions between adjacent age classes, especially among the youngest ages (Figures 1–4).

Model Estimates

The parameter values and associated standard errors estimated by the fit of the growth models to whole and fractional ages are shown in Table 7 and Table 8, respectively. Of the models evaluated, the Ratkowsky, Gompertz, and allometric models successfully converged on fits to all dataset configurations for both whole and fractional ages; however, the parameter values estimated from the fit of the Gompertz model to both whole and fractional ages from the SEAMAP data were associated with large standard errors (≥ 30% of estimate) and considered unrealistic. The Richard's model failed to converge or had difficulty converging when fit to most of the datasets for whole and fractional ages. The logistic model failed to converge when fit to fractional age data from both the VMRC commercial fisheries samples and SEAMAP survey (Table 8). The von Bertalanffy growth model did not converge when fit to both whole and fractional age data from the SEAMAP survey (Table 7 and Table 8).

The standard errors of L_∞ and K from the fit of the von Bertalanffy model to whole age data from both the ChesMMAP survey and from the combined fisheries-independent data were large (≥ 30% of estimate; Table 7). The best fit of the Richard's model to whole age data from the ChesMMAP resulted in large standard errors of all model parameters. The logistic model produced large standard errors of t_0 when fit to whole age data from the VMRC and NCDMF commercial fisheries samples, from the ChesMMAP survey, and from the combined fisheries-independent surveys. All parameters of the logistic model had large standard errors when fit to whole age data from the SEAMAP survey. Large standard errors were estimated for t_0 from the fit of the Gompertz model to whole and fractional ages from both the ChesMMAP survey and from the combined fisheries-independent surveys (Table 7 andTable 8). The parameters t_0 and p from the Richard's growth model had large standard errors when fit to whole age data from all data combined and when fit to fractional age data from the VMRC commercial fisheries samples. The standard errors of K and p estimated from the fit of the Richard's model to fractional age data from the ChesMMAP survey were large (Table 8).

Model Comparison

Model fits were compared based on ranking of AIC values among candidate models within each dataset configuration. Only models that successfully converged and/or produced realistic parameter estimates were considered. The calculated AIC values indicated the allometric model was the most likely among the models compared for all dataset configurations when fit to whole age data (Table 9); however, the differences among the AIC values and Akaike weights computed from the model fits to whole age data from the VMRC, NCDMF, combined commercial fisheries data, and all data combined were marginal, suggesting other models considered within each dataset were nearly as likely in being correct as the allometric model. There was no one model that was found to consistently result in the lowest AIC value among the model fits to the fractional age data (Table 10). The comparisons of fit to the fractional age data also indicated all models were near equally as likely in predicting growth in length with age for each dataset configuration (very small differences among AIC values and Akaike weights among models within datasets).

Summary

No one growth model substantially and consistently outperformed other candidate models among the datasets considered here. This is not surprising given the broad overlap in lengths of adjacent age classes observed in the data, which suggests the relationship between age and length in spot is not well defined. Additional age-length models could be evaluated and compared with the models considered in this report; however, given that length appears to be a poor predictor of age for spot, it is not likely that another model will provide a substantial improvement.

Among the models considered here, only the Ratkowsky and allometric models both successfully converged and produced realistic parameter estimates when fit to all dataset configurations. Additionally, the parameters estimated for both of these models were associated with small standard errors in all fits—most standard errors were < 3% of the associated parameter values estimated for the Ratkowsky model and < 2% of the associated parameter values estimated for the allometric model. The allometric model was found to be the most likely among models fit to whole age data for all datasets; though, for most datasets, the allometric and Ratkowsky models had similar calculated probabilities of being correct. The computed AIC values suggested the Ratkowsky model was the most likely among models fit to the fractional age data for two datasets. Again, neither model was found to be substantially more likely than the other for any of the fractional age datasets. The appeal of the Ratkowsky model may be that the L_1 and L_2 parameters are biologically meaningful and can be directly compared to observed data. On the other hand, the allometric model is the more parsimonious (fewer parameters) and so may be preferred. While the results suggest the allometric and Ratkowsky models perform equally well in terms of a quantitative fit, the shapes of the curves from the best-fit parameter estimates of the two models differ. For example, Figure 5 compares the trend in growth predicted by the best-fit of both models when fit to both whole (Figure 5A) and fractional (Figure 5B) age data from all data combined. Selecting an appropriate growth curve should take into account the expected relationship of length with age for the species; that is, it should be biologically meaningful for the species of interest. The growth rate predicted by the Ratkowsky model slows more than that predicted by the allometric model as age increases.

5.4. Length-Weight Relationship

Length-weight relationships for spot reported in the literature were available for North Carolina (Hester and Copeland 1975), South Carolina (Dawson 1958), and Georgia (Music and Pafford 1984) (**Table 11**). For this report, parameters of the length-weight relationship were modeled using a non-linear power regression with length in millimeter and weight in grams (Table 12). There were six data sets with available length-weight data: four fishery-independent (NMFS, NEAMAP, CHESMMAP, and SEAMAP) and two fishery-dependent (combined commercial data from MD, VA, and NC; recreational data from MRFSS (Table 12). All of the data sets demonstrated typical allometric growth patterns with a highly significant relationship between length and weight ($p < 0.001$).

Four of the data sets also provided sex data to review sex-specific differences in growth (NMFS, NEAMAP, SEAMAP, and the combined commercial data). Sex-specific differences in growth are a characteristic of many fish populations; however, only one data set (NMFS) demonstrated a significant difference between male and female spot growth using length and weight (Table **13**). The analysis of the residual sum of squares (ARSS) method was used to compare growth between males and females within each available dataset (Chen et al. 1992). The ARSS method provides a procedure for testing whether two or more nonlinear curves are statistically different. The approach requires that the same model be fit to each dataset being compared.

Daily growth rates for juvenile spot range from 0.02–0.04 g/g/day (Peters et al. 1978; Warlen at al. 1979; Weinstein 1983; Currin et al. 1984).

6. Natural Mortality

For the Spot Life History Workshop, a variety of indirect methods were applied to available data to derive estimates of natural mortality (M). Approaches for computing both an age-constant M and age-varying M values were considered; the methods and resulting estimates are described below.

6.1. Age-Constant *M* Approaches

There are several methods to estimate an age-constant M based on the relationship of natural mortality to various life history characteristics. Hoenig (1983) developed a regression estimator relating natural mortality to maximum age (t_{max}) based on empirical data from a wide variety of taxa. Another method by Hoenig (1983) uses the proportion of individuals that survive to t_{max} to estimate M. Hewitt and Hoenig (2005) revisited that approach and recommended a method that assumes 1.5% of individuals survive to t_{max}. Alverson and Carney's (1975) approach is based on von Bertalanffy growth and requires estimates of the growth coefficient, K, and t_{max} to determine M. Rikhter and Efanov's (1976) approach relates natural mortality to the age at 50% maturity, $t_{mat50\%}$. Pauly's (1980) method is based on an empirical analysis of 175 fish stocks and requires estimates of the von Bertalanffy parameters L_∞ and K as well as water temperature. Using Pauly's (1980) data, Jensen (1996) found a simple relationship between M and the von Bertalanffy K ($M = 1.60 \times K$). Jensen (1996) also derived the simple theoretical relationship: $M = 1.50 \times K$.

The approaches described above were used to calculate age-constant estimates of M. Estimates were computed for individual and combined datasets using the associated life history parameter values estimated in Section 5.3 of this report (Table 14). A value of 23.8 °C was assumed for the water temperature estimate required by Pauly's (1980) method. The only reliable estimate of age at 50% maturity could be derived from the ChesMMAP survey. The estimated value of $t_{mat50\%}$ based on the ChesMMAP survey data was 1.08 years, sexes combined. Applying that value into Rikhter and Efanov's equation for M resulted in an estimate of 1.29 year^{-1} for natural mortality of spot. The estimates of age-constant M based strictly on maximum age ranged from 0.499 to 1.54 year^{-1} (Table 15). Natural mortality estimates based on additional life history parameters ranged from 0.230 to 1.75 year^{-1} (Table 16). Estimates of M based on all available data ranged from 0.230 to 1.75 year^{-1} among all age-constant methods considered (Table 15 and Table 16), with an average value of 0.795 year^{-1} and median value of 0.749 year^{-1}.

6.2. Age-Varying *M* Approaches

A number of approaches have been developed to provide indirect estimates of *M* at age (for example, see Peterson and Wroblewski 1984, Boudreau and Dickie 1989, and Lorenzen 1996, 2005). Lorenzen's (2005) method was used to calculate age-specific *M* values for spot using available data. This approach requires estimates of the von Bertalanffy age-length growth function (to translate length to age) and the range of ages over which *M* will be estimated. The age-specific estimates of *M* are scaled such that the cumulative natural mortality across the selected age range is equal to a "target" *M*.

Lorenzen's method was applied to individual and combined datasets to estimate age-specific natural mortality rates. The required von Bertalanffy parameter values were estimated for each available dataset in Section 5.3 of this report (Table 14). The value for target *M* was determined for each data source using Hoenig's (1983) regression method based on the observed maximum age for each respective dataset.

Estimated natural mortality rates decreased with increasing age (Table 17). Age-specific estimates of *M* based on all available data ranged from 0.468 to 1.31 $year^{-1}$ over the observed age range.

7. Discard Mortality

No studies on spot discard mortality rate were identified. Recent assessments of other sciaenids used the following recreational release mortality rates: red drum – 8% (SEDAR 2009), weakfish – 10% (NEFSC 2009), and Atlantic croaker – 10% (ASMFC 2010). These rates were selected based on available literature (e.g., Duffy 2002; Gearhart 2002; Jordan and Woodward 1992; Malcoff and Heins 1997; Murphy et al. 1995). Overall rates tended to be in the 0–20% range, with factors such as hook type, hooking location, and angler skill level having significant effect. The weakfish and Atlantic croaker assessment referenced above also assumed 100% mortality of discards from commercial gill nets and otter trawls.

8. Reproduction

8.1. Spawning Seasonality

The spot is a late fall to early spring spawner. Time of spawning for spot has been estimated from gonadal development and the appearance of larval and post-larval fish. Spawning off Chesapeake Bay occurs from late fall to early spring from October to March (Welsh and Breder 1923; Hildebrand and Schroeder 1928; Lippson and Moran 1974; Colton et al. 1979). In North Carolina and South Carolina spawning also occurs from October through March (Hildebrand and Cable 1930; Dawson 1958; Berrien et al. 1978; Lewis and Judy 1983; Warlen and Chester 1985; Flores-Coto and Warlen 1993) with peak spawning occurring in December and January (Warlen and Chester 1985) and the bulk of larval and juvenile fish recruiting from January to April (C. McDonough, unpublished data). In Georgia, spot spawn from October to April (Dahlberg 1972; Mahood et al 1974; Music 1974; Setzler 1977).

8.2. Sexual Maturity

Early studies using gross visual assessment estimated that spot mature at the end of their second year or early in their third year of life (Hildebrand and Cable 1930; Dawson 1958). Other studies have supported spot maturity occurring at an age of 2 years for most fish (Hales and Van Den Avyle 1989; Phillips et al. 1989). Recent histological data indicate that spot can begin to mature before reaching one year in age, with 50% maturity for both males and females occurring between age one and two. Males reach 100% maturity by age 2 and females by age 3 (C. McDonough, unpublished data). Reported sizes at maturity have ranged from 166-214 mm TL on the Atlantic coast (Hildebrand and Cable 1930; Dawson 1958; Hales and Van Den Avyle 1989; Phillips et al. 1989; Waggy et al. 2006).

Of the different data sets used during the Spot Life History Workshop, five of the data sets had available information on maturity at size and three had maturity at age (Table 18). The minimum total length at maturity was 110 mm L_T for males and 121 mm L_T for females, with an average size at maturity ranging from 184–273 mm L_T for males and 186–292 mm L_T for females. The lowest values for mean size at maturity occurred in the inshore or nearshore survey data sets (NEAMAP, CHESMMAP, SEAMAP) with higher values occurring in the NMFS offshore survey. The minimum length at 100% maturity for all data sets was 220 mm L_T or greater. All of the data sets had some spot that matured at age zero; however, the majority of spot were considered mature by age two (Table 18, Figure 6). Males generally matured at a smaller size with a significant difference in mean size at maturity between males and females in all of the data sets ($P \leq 0.012$) except NEAMAP ($P = 0.305$) (Figure 7).

8.3. Sex Ratio

Only one study reporting a sex ratio for spot could be found in the current literature. Hata (1985) reported a 1:1 ratio of females to males for spot occurring in the northwestern Gulf of Mexico.

Sex ratios for spot were calculated using the currently available data. Sex ratios were computed for all ages combined and by age for individual datasets. The χ^2 goodness-of-fit test with Yate's correction for continuity was applied to test whether the observed sex ratios departed from a 1:1 ratio (Zar 1999). The heterogeneity chi-square analysis was also applied to combined age data to determine if performing a goodness-of-fit test on pooled data (i.e., all commercial, all fisheries-independent, all combined) would be justified. The null hypothesis of the heterogeneity chi-square analysis is that the individual datasets have the same sex ratios.

The sex ratio (female:male) for spot ranged from 1.11 (52.6% female) to 2.47 (71.2% female) among the individual data sets (Table 19). The highest percentages of females were observed in North Carolina's (71.2%) and Virginia's (68.7%) commercial fisheries data. The χ^2 goodness-of-fit indicated that the sex ratios derived from all datasets significantly deviated from a 1:1 ratio. The results of the heterogeneity chi-square analysis suggest that there are significant differences in the sex ratios among the individual commercial fisheries datasets ($\chi^2 = 21.2$; df = 2; $P < 0.01$) and should not be pooled. The sex ratios of the fisheries-independent datasets were also found to be heterogeneous ($\chi^2 = 438$; df = 3; $P < 0.01$). These results suggest pooling of all data would not be justified. It should be noted that the months sampled and the available years of data varies among the individual datasets; it may be useful to apply the analyses to sex ratios derived from years and/or months shared among the datasets.

The calculated age-specific sex ratios showed no consistent trends across ages among the datasets considered (Table 20). The sex ratios at age indicated a predominance of females at most ages based on the commercial fisheries data. The age-specific sex ratios tended to be higher for the commercial fisheries-dependent data than the fisheries-independent data. The majority of the age-specific sex ratios were found to be significantly different from a 1:1 ratio ($P < 0.05$ or $P < 0.01$; Table 21).

8.4. Spawning Frequency

There are no references in the literature currently that speculate on spawning frequency. While there is some limited information on batch fecundity (see below), the absence of any estimates of spawning frequency preclude any reliable estimates of potential reproductive output for this species.

8.5. Spawning Location

Spot eggs have not been identified in ichthyoplankton collections; however, spawning is believed to occur outside of estuaries based on size distributions of larvae collected along the coast, and infrequent collections of fish in spawning condition from offshore.

Data indicate that spot spawn further offshore and in deeper waters than other sciaenids. Fall migrations of maturing spot to offshore waters were reported from Chesapeake Bay (Hildebrand and Schroeder 1928), North Carolina (Roelofs 1951), and South Carolina estuaries (Dawson 1958). Ripe spot were collected in depths up to 82 m off South Carolina (Dawson 1958) and 8−10 mi off the Georgia coast (Hoese 1973). Smith (1907) stated that in North Carolina spot spawn in the sounds and inlets and Hidebrand and Cable (1930) suggested that spawning occurred in close proximity to passes off North Carolina; however, no evidence was offered to support these statements. Larval distributions of spot also indicate that spawning occurs more heavily offshore (26−128 m) than inshore (14.6–20.1 m; Berrien et al. 1978; Lewis and Judy 1983; Warlen and Chester 1985).

8.6. Fecundity

Spot, like all of the Sciaendae, are batch spawners and there is very limited information on fecundity in this species. Dawson (1958) calculated fecundity gravimetrically for two spot (158−187 mm SL) caught off South Carolina. The calculated number of eggs >200 µm in diameter was 77,730 and 83,900 but it was not known whether these were representative of fully ripe fish. The average size of oocytes undergoing full oocyte maturation (FOM) stage in other Sciaenidae species typically range from 700−900 µm (Roumillat and Brouwer 2004; Overstreet 1983), so the Dawson fecundity levels may be an overestimation due to the inclusion of oocytes that would have been spawned during different batches. Sheridan et al. (1984) listed batch fecundity in spot from the Gulf of Mexico as ranging from 20,900−514,400 oocytes per ovary with relative fecundity relating poorly to both length and weight.

9. Diet

The following is a brief summary from the 1987 ASMFC Fishery Management Plan for Spot (ASMFC 1987), and is included to provide a general description of spot diet. For more a more extensive description, and references, please refer to the 1987 management plan.

Spot are opportunistic bottom feeders that mainly eat polychaetes, small crustaceans and mollusks and detritus. Spot larvae primarily feed upon copepodid and adult copepods, pteropods, and pelecypods. Juvenile spot, 40–99 mm, fed on micro-bottom surface animals such as ostracods, harpacticoid copepods, ispods, amphipods, minute gastropods, and foraminifera. Isopods, amphipods, and mollusks predominate in the diet of larger spot (>100 mm). Small spot tend to be selective; larger spot are more opportunistic.

10. Habitat

Spot are found in estuaries and coastal areas from the Gulf of Maine to the Bay of Campeche, Mexico, and are most commonly found from Chesapeake Bay to South Carolina (Phillips et al. 1989; Chesapeake Bay Program 1991; Murdy et al. 1997; ASMFC 1987). Juvenile spot prefer shallow water areas, less than 8m, over fine sediment and in tidal marshes (Phillips et al. 1989; Stickney and Cuenco 1982; Chesapeake Bay Program 1991). Juvenile spot are found in salinities ranging from 0 to 30 ppt and water temperatures from 5º to 30º C (Stickney and Cuenco 1982; Phillips et al. 1989, ASMFC 1987), and therefore are found from polyhaline to fresh water in nursery areas. Adult spot are tolerant of salinities up to 60 ppt (ASMFC 1987; Phillips et al. 1989) and are more abundant in coastal waters and lower estuaries and less abundant in lower salinity areas, compared to juveniles. Spot can tolerate dissolved oxygen levels as low as 1.3 mg/l, but prefer concentration of 5.0 mg/l or higher (ASMFC 1987; Phillips et al. 1989).

11. Adequacy of Life History Information for Stock Assessment Purposes

The Spot PRT finds there to be inadequate life history data in terms of the spatial and/or temporal availability of spot maturity, fecundity, and age (otolith) information. The limited number of otoliths available from older fish is an additional concern. However, the PRT believes that the life history data currently available may be sufficient for certain assessment models, such as a surplus production model, a length-based assessment model, or a more simple age-based model (e.g., VPA). The PRT recommends the completion of five short-term tasks prior to initiating a stock assessment using one of these model types (see below). The PRT does not believe the data to be currently adequate to support more complex age-based models, such as a statistical catch-at-age model. In addition to the continuation of all ongoing data collection programs, the PRT recommends three additional tasks for completion prior to attempting a more complex assessment model (see below).

12. Life History Research Recommendations

<u>Short-Term Recommendations (i.e., for completion before conducting a stock assessment with a more basic model), in order of priority</u>:

1. Organize an otolith exchange between the major spot ageing labs (ODU/SCDNR/NCDMF). If there are differences in age assignments, hold a spot ageing workshop to establish a coastwide ageing protocol.
2. Add the North Carolina commercial and fishery-independent (gill net survey) data that were unavailable at the data workshop to the life history analyses.
3. Process and read the backlog of otoliths collected from the Maryland and North Carolina commercial fisheries and the NEAMAP Survey.
4. Begin collection of otoliths from NMFS and SEAMAP surveys.

5. Evaluate natural mortality by age once confident that otoliths have been aged consistently between labs.

Long-Term Recommendations (i.e., for completion before conducting a stock assessment with a more advanced model), in order of priority:

6. Continue evaluation of size and age at maturity. (Data available for the analysis in this report was temporally and spatially limited.)
7. Conduct discard mortality studies for gears used in the recreational and commercial fisheries.
8. Define reproductive output based on fecundity and spawning periodicity.
9. Identify stocks and determine coastal movements and the extent of stock mixing via genetic and/or tagging studies.

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14. Tables

Table 1. Data available at the Spot Life History Workshop

Type	Area	Source	Gear	Length-Weight Data	Age (otolith) - Length Data	Sex Data	Maturity Data	Length Measured
Commercial	Maryland Chesapeake Bay	MD DNR	Pound Net	2007–2009 (n=981)		2007–2009 (n=553)		Total
Commercial	Virginia	VMRC	Multiple	1992–2009 (n=106,030)	1998–2009 (n=3,489)	1989–2009 (n=12,910)	1998–2009 (n=7,637)	Total Standard
Commercial	North Carolina	NCDMF	Multiple	2003 (n=358)	2003 (n=351)	2003 (n=302)		Total
Recreational	Atlantic Coast	NMFS (MRFSS)	Hook & line	1981-2009 (n=89,054)				Fork
Survey	Hudson River, New York to Cape Hatteras, NC	NMFS	Trawl	1997–2008 (n=6,112)		1997–2008 (n=6,017)	1997–2008 (n=6,112)	Fork
Survey	Hudson River, New York to Cape Hatteras, NC	NEAMAP	Trawl	2007–2009 (n=661)		2007–2009 (n=611)	2007–2009 (n=610)	Fork
Survey	Maryland and Virginia Chesapeake Bay	ChesMMAP	Trawl	2002–2009 (n=5,283)	2002–2009 (n=5,135)	2002–2009 (n=4,647)	2002–2009 (n=1,062)	Fork
Survey	Cape Hatteras, North Carolina to Cape Canaveral, Florida	SEAMAP	Trawl	1989–2008 (n=745)	2001 (n=746)	2001 (n=290)	2001 (n=290)	Total Fork Standard

Table 2. Descriptions of length measurements used for spot

Measurement	**Description**
Total Length	Measured from the most anterior point of the fish to the farthest tip of the tail with the tail compressed or squeezed together
Fork Length	Measured from the most anterior point of the fish to the rear center edge of the tail
Standard Length	Measured from the most anterior point of the fish to the end of the vertebral column

Table 3. Length relationships for spot, as reported in the literature and developed at the Spot Life History Workshop

Reference	**Location**	**Range (mm TL)**	**N**	**Relationship**	**R^2**
Dawson (1958)	South Carolina		5,162 446 546	SL = 2.000 + 1.2333 TL FL = 8.90 + 1.09 SL FL = 6.170 + 0.893 TL	0.996 0.991 0.997
Jorgenson and Miller (1968)	Georgia	14–11	71 87	TL = -0.606 + 1.2888 SL SL = 0.760 + 0.771 TL	0.910 0.893
Life History Workshop (2010)	Virginia-Florida (VA commercial sampling & SEAMAP Survey)	106–370	65,534 (VA) 65,534 745 (SEAMAP) 745 745 745	TL = -0.554 + 1.268 SL SL = 9.780 + 0.7749 TL TL = 6.411 + 0.904 FL FL = -4.370 + 1.089 TL SL = -7.254 + 0.868 FL FL = 12.967 + 1.117 SL	0.949 0.949 0.984 0.984 0.970 0.970

Table 4. The age-length relationship of Atlantic coast spot, as reported in the literature (modified from Dawson (1958) and Parker (1971)).

			Total length in millimeters at age					
Author	**Area**	**Method**	**1**	**2**	**3**	**4**	**5**	**Other**
Welsh and Breder (1923)	New Jersey	Scales	80–100 median 90	165–220 median 193	240–290 median 275			300 at 4.5 yr
Hildebrand and Schroeder (1928)	Chesapeake Bay	Length frequency	127					
Pacheco (1957)	Chesapeake Bay	Scales	167–224 mean 196	196–269 mean 246				
Hildebrand and Cable (1930)	Beaufort, NC	Length frequency	140 mean					
DeVries (1982)	Core Sound, NC	Scales Scales	143 144	222 219	244 252	321 317	369 355	
Dawson (1958)	South Carolina	Length frequency	144–162	205–218				
Music and Pafford (1984)	Georgia	Scales	128	201	219			
Welsh and Breder (1923)	Fernandina, FL	Length frequency	140					

Table 5. The age-length relationship of Atlantic coast spot, based on otolith ages and total length (mm), as found in data made available for the Spot Life History Workshop

Source		**Total length in millimeters at age**						
		0	**1**	**2**	**3**	**4**	**5**	**6**
VA Commercial (FD)	Size range		135–310	180–340	202–355	260–363	305–355	315–340
	Median		235	260	292	300	330	335
	n		2,316	1,146	331	95	15	3
	Percent by age		59.29%	29.34%	8.47%	2.43%	0.38%	0.08%
NC Commercial (FD)	Size range	104–195	129–268	163–294	230–320	269–319		
	Median	150	217	242	275	287		
	n	52	217	104	33	15		
	Percent by age	12.35%	51.54%	24.70%	7.84%	3.56%		
ChesMMAP Survey (FI)	Size range	58–248	72–273	132–282	219–311	211–302		
	Median	154	187	222	252	274		
	n	2,967	2,008	136	20	4		
	Percent by age	57.78%	39.10%	2.65%	0.39%	0.08%		
SEAMAP Survey (FI)	Size range	106–220	121–271	164–247	213			
	Median	155	183	222	213			
	n	299	425	21	1			
	Percent by age	40.08%	56.97%	2.82%	0.13%			

Table 6. Descriptions of growth models evaluated for spot at the Life History Workshop. Parameters of the same name do not necessarily have the same interpretation across different models.

Growth Model	**Equation**	**Parameters**
von Bertalanffy	$L_t = L_\infty\left[1 - e^{-K(t-t_0)}\right]$	L_t is length at age t, L_∞ is the theoretical asymptotic average length (if $K > 0$), K is growth rate at which the asymptote is approached, and t_0 is the hypothetical age at which length is zero.
Ratkowsky	$L_t = L_1 + (L_2 - L_1)\frac{1-\tilde{p}^{m-1}}{1-\tilde{p}^{n-1}}$ where $\tilde{p} = p^{(t_2-t_1)/(n-1)}$ and $m = 1 + (n-1)\frac{t-t_1}{t_2-t_1}$	L_1 is a parameter defining the length at the youngest age, t_1, and the parameter L_2 represents the length at the oldest age, t_2. The values for t_1 and t_2 are based on the observed data and are entered into the model. n is sample size and the Ford growth parameter p = exp(-K).
Gompertz	$L_t = L_\infty e^{-e^{-K(t-t_0)}}$	L_∞ is the theoretical asymptotic average length (if $K > 0$) and t_0 represents an inflection point on the curve.
Richard's	$L_t = L_\infty\left[1 + \frac{1}{\mathrm{p}}e^{-K(t-t_0)}\right]^{-p}$	L_∞ is the theoretical asymptotic average length (if $K > 0$) and t_0 represents an inflection point on the curve.
Logistic	$L_t = L_\infty\left[1 + e^{-K(t-t_0)}\right]^{-1}$	L_∞ is the theoretical asymptotic average length (if $K > 0$) and t_0 represents an inflection point on the curve
Allometric	$L_t = \alpha t^\beta$	α and β are parameters describing the relationship

Table 7. Parameter estimates (standard error in parentheses) of the age-length growth models fit to whole age data, pooled over years. Values of L_∞, L_1, and L_2 represent total length in millimeters. Note that parameters of the same name do not necessarily have the same interpretation across different models.

Model	Dataset	Parameter					
		L_∞	K	t_0	p	L_1	L_2
von Bertalanffy	ChesMMAP	646 (309)	0.0730 (0.0480)	-3.73 (0.428)			
	SEAMAP	*failed to converge*					
	VMRC	471 (49.3)	0.135 (0.0316)	-4.04 (0.434)			
	NCDMF	309 (10.4)	0.472 (0.0587)	-1.47 (0.145)			
	Fisheries-Independent	890 (691)	0.0464 (0.0450)	-4.08 (0.482)			
	Commercial	370 (12.6)	0.266 (0.0292)	-2.67 (0.198)			
	All	419 (12.4)	0.231 (0.0141)	-1.99 (0.0533)			
Ratkowsky	ChesMMAP				0.930 (0.0447)	153 (0.498)	278 (7.47)
	SEAMAP				1.07 (0.172)	156 (1.31)	243 (13.0)
	VMRC				0.874 (0.0276)	198 (1.86)	350 (5.30)
	NCDMF				0.624 (0.0366)	154 (2.95)	285 (3.95)
	Fisheries-Independent				0.744 (0.0421)	153 (0.470)	244 (5.03)
	Commercial				0.615 (0.0182)	179 (1.98)	307 (2.46)
	All				0.526 (0.0130)	152 (0.569)	278 (2.13)
Gompertz	ChesMMAP	396 (58.7)	0.240 (0.0449)	-0.214 (0.607)			
	SEAMAP	1,038 (3,187)	0.0880 (0.152)	7.26 (30.8)			
	VMRC	409 (24.0)	0.245 (0.0322)	-1.33 (0.133)			
	NCDMF	298 (7.69)	0.650 (0.0629)	-0.662 (0.0644)			
	Fisheries-Independent	429 (74.0)	0.213 (0.0421)	0.123 (0.813)			
	Commercial	351 (8.87)	0.380 (0.0309)	-1.27 (0.0543)			
	All	362 (5.98)	0.435 (0.0142)	-0.368 (0.0321)			

Table 7. *Continued.*

Model	Dataset	Parameter					
		L_∞	K	t_0	p	α	β
Richard's	ChesMMAP	349 (205)	0.362 (0.738)	0.321 (2.21)	1.38 (8.30)		
	SEAMAP	*failed to converge*					
	VMRC	*failed to converge*					
	NCDMF	*failed to converge*					
	Fisheries-Independent	*failed to converge*					
	Commercial	*failed to converge*					
	All	326 (7.48)	0.796 (0.115)	0.510 (0.164)	0.589 (0.182)		
Logistic	ChesMMAP	337 (30.1)	0.409 (0.0424)	0.446 (0.442)			
	SEAMAP	491 (522)	0.245 (0.145)	3.14 (8.19)			
	VMRC	381 (15.8)	0.353 (0.0329)	-0.269 (0.189)			
	NCDMF	291 (6.30)	0.828 (0.0687)	-0.181 (0.0567)			
	Fisheries-Independent	352 (34.8)	0.380 (0.0396)	0.673 (0.528)			
	Commercial	340 (7.05)	0.491 (0.0325)	-0.495 (0.0527)			
	All	337 (3.99)	0.645 (0.0149)	0.256 (0.0370)			
Allometric	ChesMMAP					188 (0.612)	0.243 (0.0127)
	SEAMAP					182 (1.14)	0.231 (0.0335)
	VMRC					232 (0.557)	0.199 (0.00387)
	NCDMF					214 (1.67)	0.211 (0.0111)
	Fisheries-Independent					187 (0.545)	0.244 (0.0118)
	Commercial					230 (0.540)	0.197 (0.00373)
	All					208 (0.477)	0.291 (0.00416)

Table 8. Parameter estimates (standard error in parentheses) of the age-length growth models fit to fractional age data, pooled over years. Values of L_∞, L_1, and L_2 represent total length in millimeters. Note that parameters of the same name do not necessarily have the same interpretation across different models.

Model	Dataset	Parameter					
		L_∞	K	t_0	p	L_1	L_2
von Bertalanffy	ChesMMAP	409 (50.4)	0.194 (0.0428)	-1.62 (0.159)			
	SEAMAP	*failed to converge*					
	VMRC	384 (12.9)	0.275 (0.0287)	-1.71 (0.172)			
	NCDMF	299 (6.70)	0.648 (0.0594)	-0.302 (0.0872)			
	Fisheries-Independent	459 (70.5)	0.156 (0.0395)	-1.81 (0.170)			
	Commercial	349 (6.43)	0.389 (0.0265)	-1.10 (0.101)			
	All	388 (7.00)	0.325 (0.0133)	-0.770 (0.0321)			
Ratkowsky	ChesMMAP				0.824 (0.0352)	133 (0.968)	292 (7.40)
	SEAMAP				1.18 (0.149)	143 (2.03)	266 (11.9)
	VMRC				0.760 (0.0218)	179 (2.21)	344 (4.05)
	NCDMF				0.523 (0.0311)	131 (3.86)	289 (4.02)
	Fisheries-Independent				0.608 (0.0267)	130 (0.990)	247 (3.70)
	Commercial				0.587 (0.0157)	159 (2.30)	315 (2.37)
	All				0.476 (0.0108)	112 (1.15)	286 (2.02)
Gompertz	ChesMMAP	334 (20.7)	0.405 (0.0414)	0.186 (0.135)			
	SEAMAP	4,116 (22,756)	0.0690 (0.121)	18.0 (54.8)			
	VMRC	360 (8.34)	0.411 (0.0302)	-0.336 (0.0432)			
	NCDMF	291 (5.26)	0.865 (0.0650)	0.282 (0.0443)			
	Fisheries-Independent	350 (23.8)	0.368 (0.0381)	0.279 (0.170)			
	Commercial	335 (4.71)	0.538 (0.0286)	-0.146 (0.0394)			
	All	346 (3.77)	0.572 (0.0139)	0.423 (0.0158)			

Table 8. *Continued.*

Model	Dataset	Parameter					
		L_∞	K	t_0	p	α	β
Richard's	ChesMMAP	255 (8.78)	1.93 (0.642)	1.55 (0.187)	0.150 (0.0615)		
	SEAMAP	*problem with model fit*					
	VMRC	340 (12.0)	0.629 (0.181)	0.682 (0.575)	0.610 (0.505)		
	NCDMF	*failed to converge*					
	Fisheries-Independent	*failed to converge*					
	Commercial	*failed to converge*					
	All	309 (3.32)	1.26 (0.113)	1.33 (0.0783)	0.386 (0.0610)		
Logistic	ChesMMAP	304 (13.0)	0.621 (0.0405)	0.777 (0.136)			
	SEAMAP	*failed to converge*					
	VMRC	*failed to converge*					
	NCDMF	286 (4.47)	1.08 (0.0719)	0.647 (0.0371)			
	Fisheries-Independent	312 (14.0)	0.585 (0.0372)	0.863 (0.154)			
	Commercial	327 (3.84)	0.682 (0.0308)	0.407 (0.0271)			
	All	326 (2.64)	0.830 (0.0149)	0.927 (0.0197)			
Allometric	ChesMMAP					164 (0.370)	0.315 (0.00506)
	SEAMAP					166 (0.839)	0.254 (0.0115)
	VMRC					199 (0.777)	0.302 (0.00463)
	NCDMF					176 (1.67)	0.366 (0.0109)
	Fisheries-Independent					165 (0.341)	0.308 (0.00467)
	Commercial					197 (0.730)	0.312 (0.00439)
	All					171 (0.355)	0.423 (0.00295)

Table 9. Calculated AIC values (Akaike weights in parentheses) of growth models fit to whole age data for spot. AIC values in bold indicate the model with the smallest AIC values for the associated dataset.

	Model					
Dataset	**von Bertalanffy**	**Ratkowsky**	**Gompertz**	**Richard's**	**Logistic**	**Allometric**
ChesMMAP	15.2 (0.153)	15.2 (0.153)	15.2 (0.153)	15.2 (0.153)	15.2 (0.153)	**14.3** (0.234)
SEAMAP		12.9 (0.309)			12.9 (0.309)	**12.4** (0.383)
VMRC	14.7 (0.200)	14.7 (0.200)	14.7 (0.200)		14.7 (0.200)	**14.7** (0.201)
NCDMF	12.0 (0.197)	12.0 (0.197)	12.1 (0.196)		12.1 (0.194)	**11.8** (0.217)
Fisheries-Independent	15.2 (0.182)	15.3 (0.181)	15.2 (0.182)		15.2 (0.183)	**14.5** (0.271)
Commercial	14.8 (0.200)	14.8 (0.195)	14.8 (0.200)		14.8 (0.200)	**14.7** (0.205)
All	16.1 (0.164)	16.2 (0.153)	16.1 (0.164)	16.1 (0.164)	16.1 (0.164)	**15.8** (0.192)

Table 10. Calculated AIC values (Akaike weights in parentheses) of growth models fit to fractional age data for spot. AIC values in bold indicate the model with the smallest AIC values for the associated dataset.

	Model					
Dataset	**von Bertalanffy**	**Ratkowsky**	**Gompertz**	**Richard's**	**Logistic**	**Allometric**
ChesMMAP	15.0 (0.167)	15.0 (0.167)	15.0 (0.167)	**15.0** (0.167)	15.0 (0.167)	15.0 (0.166)
SEAMAP		**12.7** (0.504)				12.7 (0.496)
VMRC	14.5 (0.200)	14.5 (0.200)	14.5 (0.200)	**14.5** (0.200)		14.5 (0.199)
NCDMF	**11.8** (0.202)	**11.8** (0.202)	11.8 (0.201)		11.8 (0.199)	11.9 (0.195)
Fisheries-Independent	15.1 (0.201)	15.1 (0.198)	15.1 (0.201)		**15.1** (0.201)	15.1 (0.200)
Commercial	**14.6** (0.201)	14.6 (0.197)	14.6 (0.201)		14.6 (0.201)	14.6 (0.201)
All	15.9 (0.170)	16.1 (0.149)	15.9 (0.170)	**15.9** (0.171)	15.9 (0.171)	15.9 (0.169)

Table 11. Length-weight relationships for Atlantic coast spot (L = total length in mm; W = total weight in grams), as reported in the literature.

Author	**Area**	**N**	**Size Range (mm TL)**	**Equation**
Hester and Copeland (1975)	North Carolina	356	25–195	log W = -5.230 + 3.221 log L
Dawson (1985)*	South Carolina	4,297	45–205	log W = -4.54396 + 2.95831 log L
Music and Pafford (1984)	Georgia	325	120–283	log W = -5.096 + 3.121 log L

*L = standard length

Table 12. Length-weight relationships for Atlantic coast spot, as developed at the Life History Workshop, from different data sets using a non-linear power regression in the form: $W = a(L_T)^b$. L_T = total length (mm); W = weight (g); a = y-intercept; b = slope (regression coefficient).

Data Source	**Number**	**Size Range (L_T mm)**	**a**	**b**	**r^2**
NMFS (FI)	6,112	110–480 mm	6.531×10^{-5}	3.114	0.985
NEAMAP (FI)	661	77–268 mm	6.568×10^{-7}	3.589	0.794
ChesMMAP (FI)	5,283	53–334 mm	3.910×10^{-6}	3.239	0.964
SEAMAP (FI)	745	106–271 mm	2.281×10^{-5}	2.882	0.873
FI Combined	12,806	53–480 mm	4.264×10^{-5}	2.757	0.954
MD/VA/NC commercial (FD)	107,372	95–390 mm	1.319×10^{-5}	3.013	0.823
MRFSS recreational (FD)	50,446*	72–479 mm	1.33×10^{-4}	2.585	0.924

* Samples from 1994-2009 only due to imprecise measurements in earlier years.

Table 13. Results of the ARSS analyses testing for difference in estimated length-weight curves between sexes using available spot data. The "*" indicates a significant difference between males and females.

Type	**Area**	**Gear**	**Source**	**DF-numerator**	**DF-denominator**	***F*-statistic**	***P*-value**
Survey	N. Atlantic	Trawl	NEAMAP	2	605	2.480	0.084
Survey	N. Atlantic	Trawl	NMFS	2	6,012	18.913	< 0.001*
Survey	S. Atlantic	Trawl	SEAMAP	2	284	1.385	0.252
Comm.	MD-NC	Various	MD/VA/NC	2	11,871	2.882	0.056

Table 14. Life history parameter estimates for available datasets used in life history-based approaches for estimating natural mortality. Values of L_∞ represent total length in millimeters.

Type	**Area**	**Gear**	**Source**	**Max Age**	$t_{mat50\%}$	**von Bertalanffy age-length**		
						L_∞	K	t_0
All	U.S. Atlantic Coast	All	All	6		338	0.325	-0.770
Commercial	VA	All	VMRC	6		384	0.275	-1.71
Commercial	NC	All	NCDMF	4		299	0.648	-0.302
Commercial	VA / NC	All	VMRC / NCDMF	6		349	0.389	-1.10
Survey	Ches. Bay	Trawl	ChesMMAP	4	1.08	409	0.194	-1.62
Survey	S. Atlantic	Trawl	SEAMAP	3		*failed to converge*		
Survey	Ches. Bay / S. Atlantic	Trawl	ChesMMAP / SEAMAP	4		459	0.156	-1.81

Table 15. Estimates of age-constant natural mortality for spot using Hoenig's (1983) methods based on maximum age, t_{max}.

Type	**Area**	**Gear**	**Source**	**Max Age**	**Regression Model**	**Proportion Surviving to t_{max}**		
						0.05	**0.01**	**0.015**
All	U.S. Atlantic Coast	All	All	6	0.727	0.499	0.768	0.703
Commercial	VA	All	VMRC	6	0.727	0.499	0.768	0.703
Commercial	NC	All	NCDMF	4	1.08	0.749	1.15	1.06
Commercial	VA / NC	All	VMRC / NCDMF	6	0.727	0.499	0.768	0.703
Survey	Ches. Bay	Trawl	ChesMMAP	4	1.08	0.749	1.15	1.06
Survey	S. Atlantic	Trawl	SEAMAP	3	1.43	0.999	1.54	1.41
Survey	Ches. Bay / S. Atlantic	Trawl	ChesMMAP / SEAMAP	4	1.08	0.749	1.15	1.06

Table 16. Estimates of age-constant natural mortality for spot using life history-based approaches.

Type	Area	Gear	Source	Approach			
				Alverson and Carney 1975	**Jensen 1996 (M = 1.50K)**	**Jensen 1996 (M = 1.60K)**	**Pauly 1980**
All	U.S. Atlantic Coast	All	All	0.888	0.487	0.519	0.388
Commercial	VA	All	VMRC	0.946	0.413	0.440	0.350
Commercial	NC	All	NCDMF	1.16	0.972	1.04	0.656
Commercial	VA / NC	All	VMRC / NCDMF	0.818	0.583	0.622	0.450
Survey	Ches. Bay	Trawl	ChesMMAP	1.70	0.291	0.310	0.273
Survey	Ches. Bay / S. Atlantic	Trawl	ChesMMAP / SEAMAP	1.75	0.234	0.250	0.230

Table 17. Estimates of age-specific natural mortality for spot based on Lorenzen's (2005) method.

Type	Area	Gear	Source	Age						
				0	**1**	**2**	**3**	**4**	**5**	**6**
All	U.S. Atlantic Coast	All	All	1.31	0.822	0.651	0.567	0.518	0.488	0.468
Commercial	VA	All	VMRC	1.07	0.821	0.700	0.630	0.586	0.556	0.535
Commercial	NC	All	NCDMF	1.84	0.971	0.791	0.722	0.690	0.675	0.667
Commercial	VA / NC	All	VMRC / NCDMF	1.13	0.808	0.679	0.613	0.576	0.553	0.538
Survey	Ches. Bay	Trawl	ChesMMAP	1.51	1.11	0.913	0.797	0.721	0.669	0.631
Survey	Ches. Bay / S. Atlantic	Trawl	ChesMMAP / SEAMAP	1.50	1.12	0.917	0.796	0.715	0.658	0.616

Table 18. Maturity schedule for spot based on available datasets, pooled over years, as developed at the Life History Workshop. Length is represented as total length in centimeters.

Type	Area	Gear	Source	n	Min. Size at Maturity		Avg. Size at Maturity		Min. Length at 100% Mature		% Mature at Age 2	
					Males	Females	Males	Females	Males	Females	Males	Females
Survey	North Atlantic	Trawl	NMFS	6,112	14.8	13.7	27.3	29.2	27.0	31.0	-	-
Survey	Mid-Atlantic	Trawl	NEAMAP	610	13.0	15.6	18.4	18.6	23.0	26.0	-	-
Survey	Ches. Bay, VA	Trawl	ChesMMAP	1,062	11.0	12.1	20.9	20.9	27.0		94.2%	
Survey	South Atlantic	Trawl	SEAMAP	290	16.6	17.2	20.1	21.3	22.0	26.0	100%	73.3%
Commercial	VA	Various	VMRC	7,637	17.5	17.0	24.7	24.5	29.0	33.0	94.3%	86.3%

Table 19. Calculated sex ratios (female:male), sample sizes (n), χ^2 values, and probabilities (*P*) that the sex ratio is 1:1 (female:male) for spot based on available datasets, pooled over ages and available years. The χ^2 values were calculated using Yate's correction for continuity. NEAMAP and ChesMMAP expanded sample sizes were used due to the nature of sub-sampling in the surveys.

Type	Area	Gear	Source	n	Sex Ratio	χ^2	*P*
Commercial	MD	Pound Net	MDDNR	553	1.44	17.4	< 0.01
Commercial	VA	All	VMRC	12,696	2.20	1,776	< 0.01
Commercial	NC	All	NCDMF	302	2.47	53.4	< 0.01
Survey	North Atlantic	Trawl	NMFS	6,017	1.18	42.6	< 0.01
Survey	North Atlantic	Trawl	NEAMAP	147,027	1.40	4,053	< 0.01
Survey	Chesapeake Bay	Trawl	ChesMMAP	42,165	1.11	118.4	< 0.01
Survey	South Atlantic	Trawl	SEAMAP	290	1.48	10.4	< 0.01

Table 20. Calculated sex ratios (female:male) at age, pooled over available years. The sample sizes are shown in parentheses.

Type	Area	Gear	Source	Age 0	1	2	3	4	5	6
Comm.	VA	All	VMRC	2.33 (60)	2.15 (1,816)	2.76 (928)	3.66 (303)	1.67 (72)	4.00 (15)	2.00 (3)
Comm.	NC	All	NCDMF	0.636 (18)	3.33 (130)	2.78 (102)	1.54 (33)	2.75 (15)		
Survey	Ches. Bay	Trawl	ChesMMAP	1.02 (21,844)	1.25 (18,323)	0.794 (854)	0.353 (46)	4.00 (5)		
Survey	S. Atlantic	Trawl	SEAMAP	0.786 (75)	0.696 (195)	0.267 (19)	0 (1)			

Table 21. Computed χ^2 values for age-specific sex ratios, pooled over years. The "*" indicates the associated *P*-value is < 0.05. The "**" indicates the associated *P*-value is < 0.01. The χ^2 values were calculated using Yate's correction for continuity.

Type	Area	Gear	Source	Age 0	1	2	3	4	5	6
Commercial	VA	All	VMRC	8.82 **	241 **	202 **	97.6 **	4.01 *	4.27 *	0
Commercial	NC	All	NCDMF	0.500	36.6 **	21.7 **	1.09	2.40		
Survey	Ches. Bay	Trawl	ChesMMAP	2.53	219 **	11.0 **	9.59 **	0.800		
Survey	S. Atlantic	Trawl	SEAMAP	0.853	5.93 *	5.26 *	0			

15. Figures

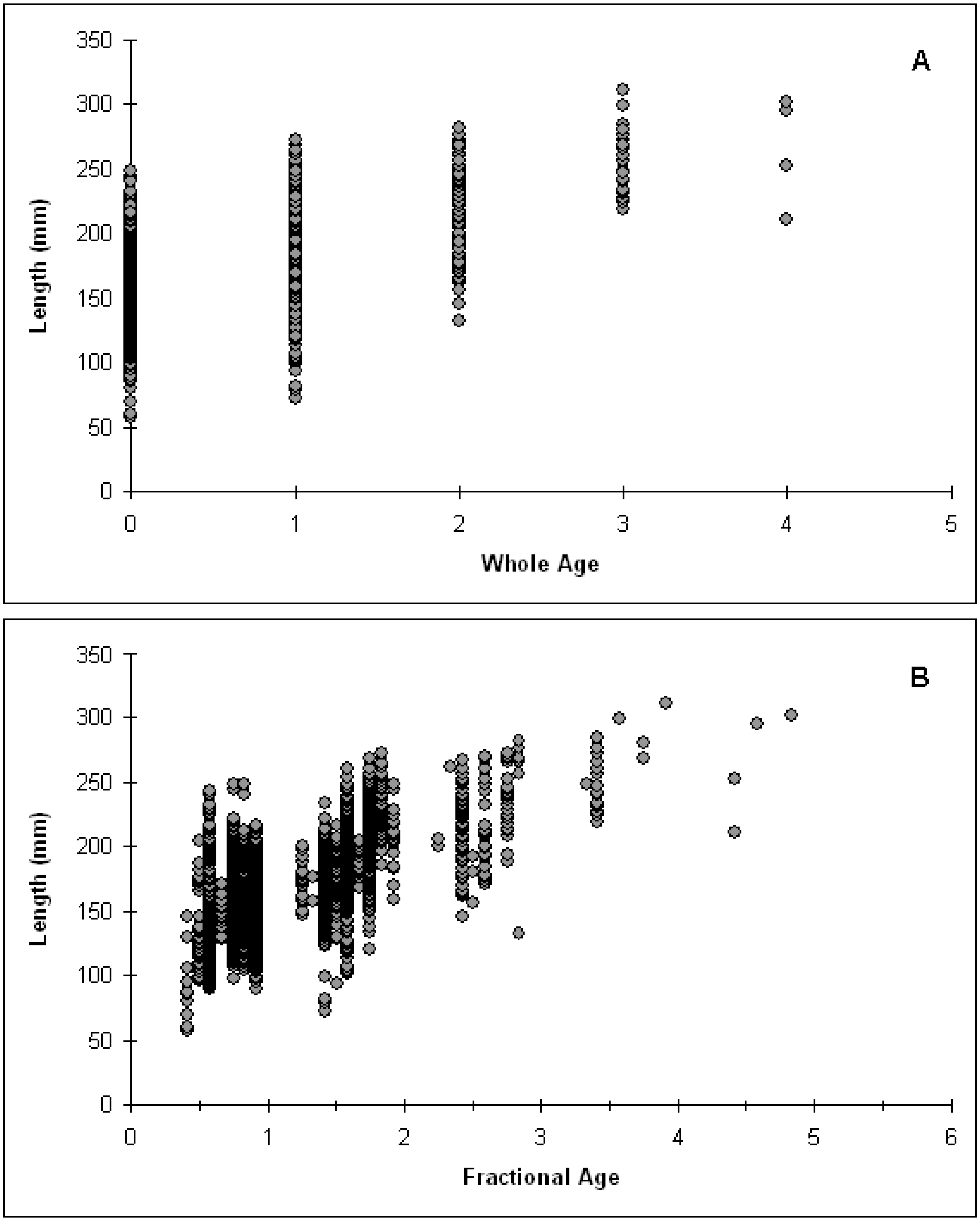

Figure 1. Plot of available age-length data from the ChesMMAP fisheries-independent survey based on whole (A) and fractional (B) ages, pooled over 2002–2009.

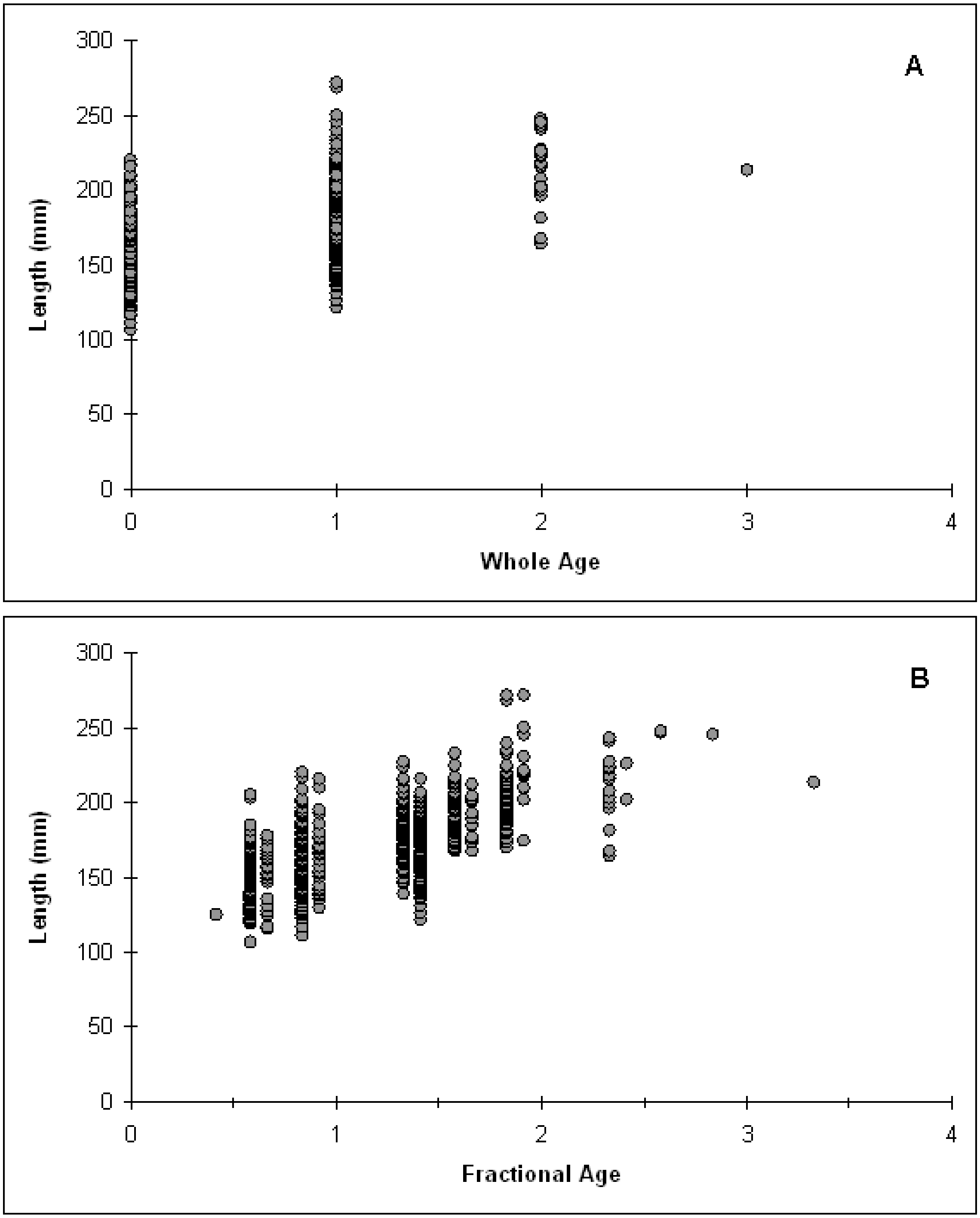

Figure 2. Plot of available age-length data from the SEAMAP fisheries-independent survey based on whole (A) and fractional (B) ages, 2001.

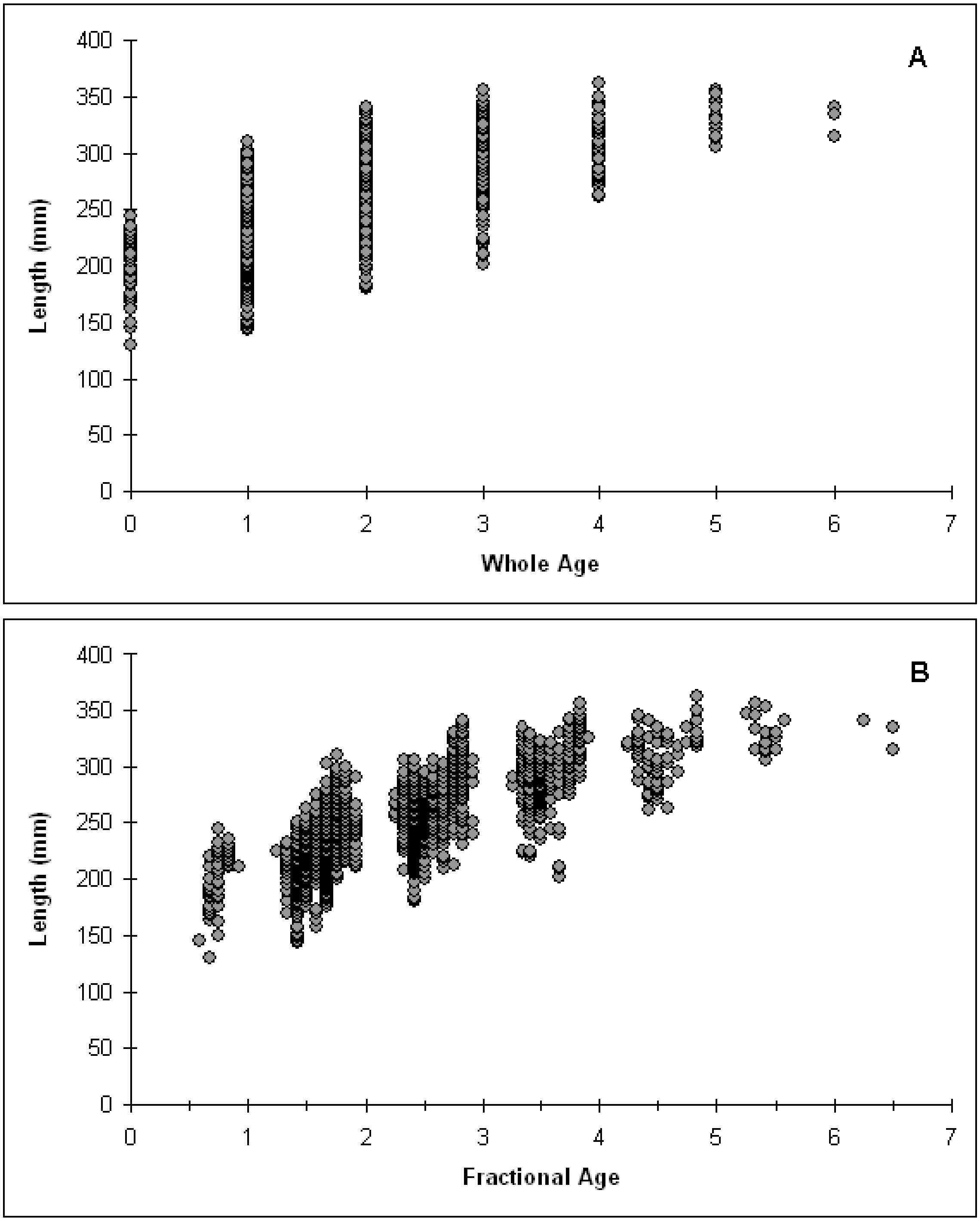

Figure 3. Plot of available age-length data from the VMRC commercial fisheries sampling program based on whole (A) and fractional (B) ages, pooled over 1998–2008.

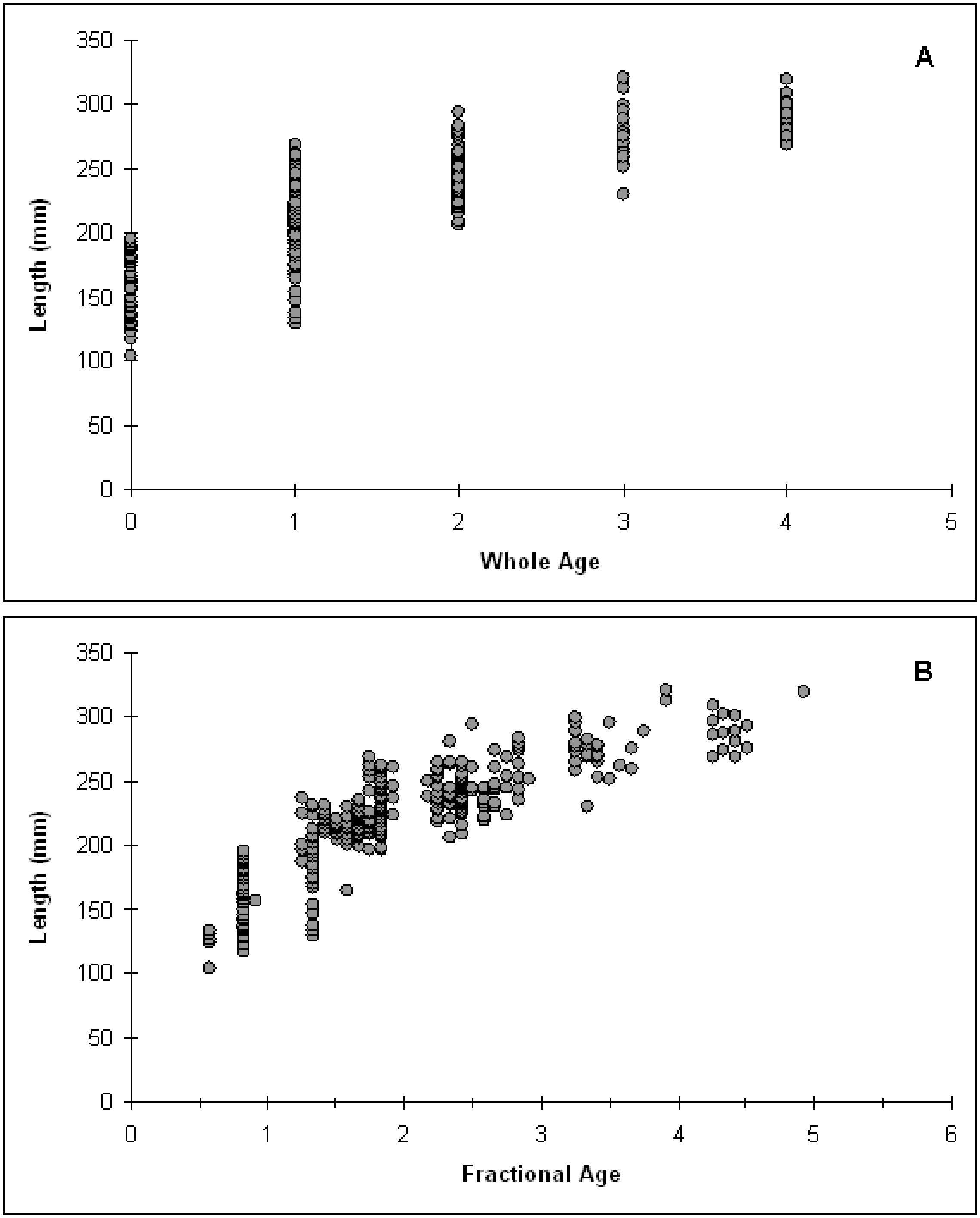

Figure 4. Plot of available age-length data from the NCDMF commercial fisheries sampling program based on whole (A) and fractional (B) ages, 2003.

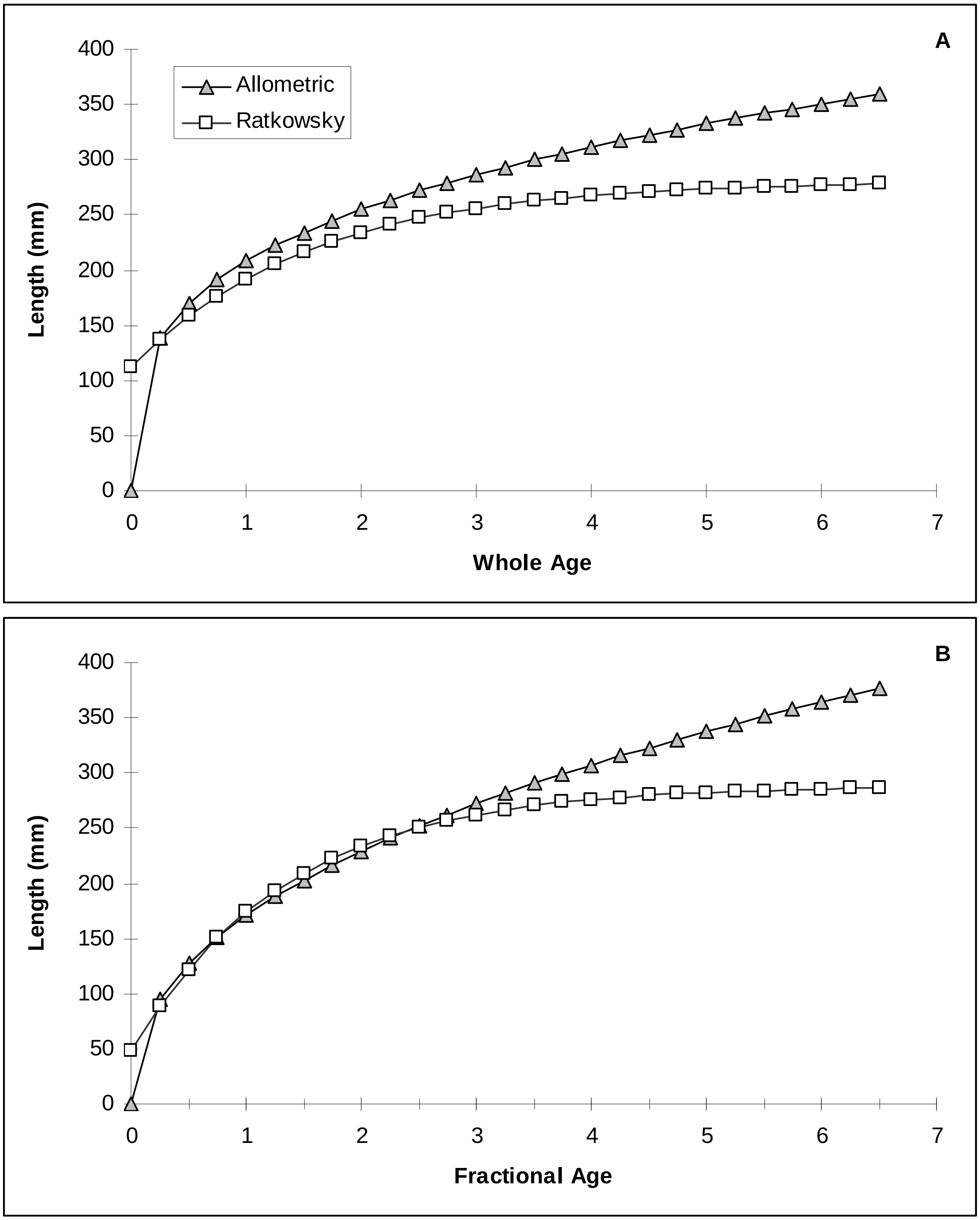

Figure 5. Plot of best-fit curves from allometric and Ratkowsky models fit to whole (A) and fractional (B) age data from all data combined.

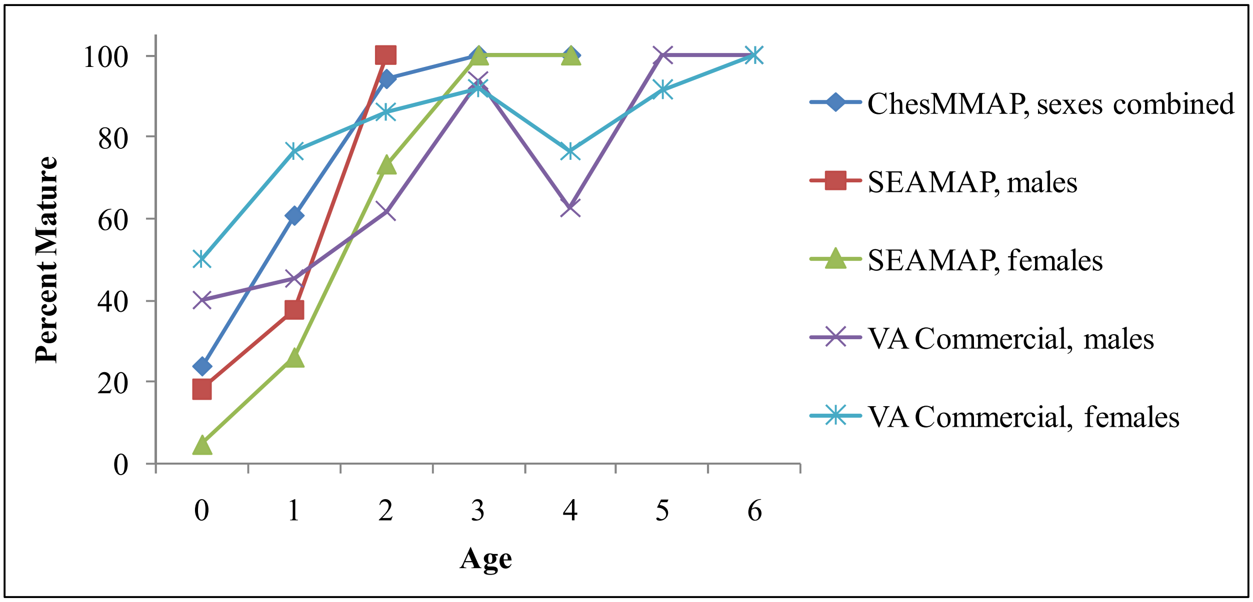

Figure 6. Estimated maturity at age for spot based on available data sets, pooled over years.

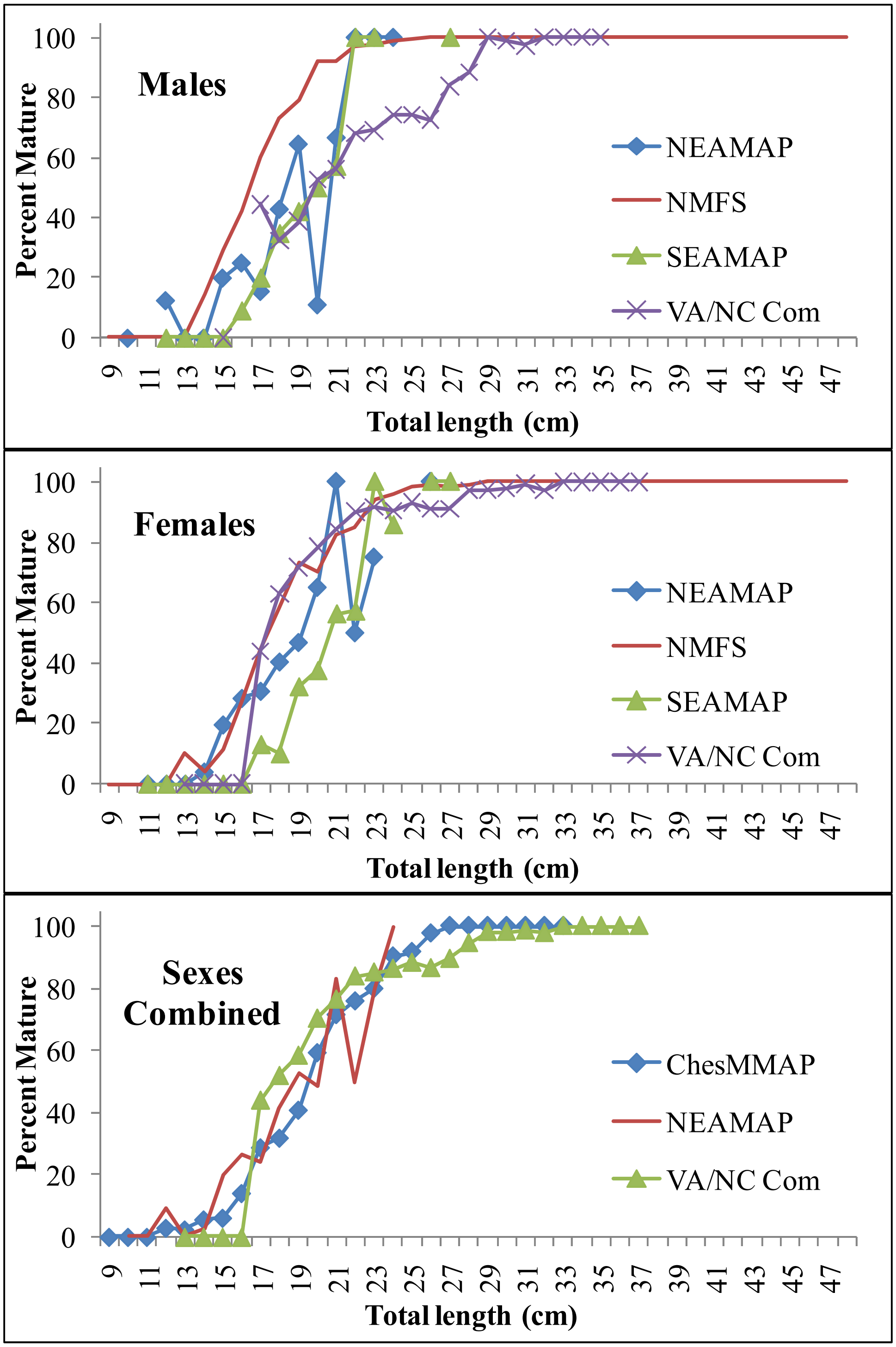

Figure 7. Estimated maturity at length for spot based on available data, pooled across years.